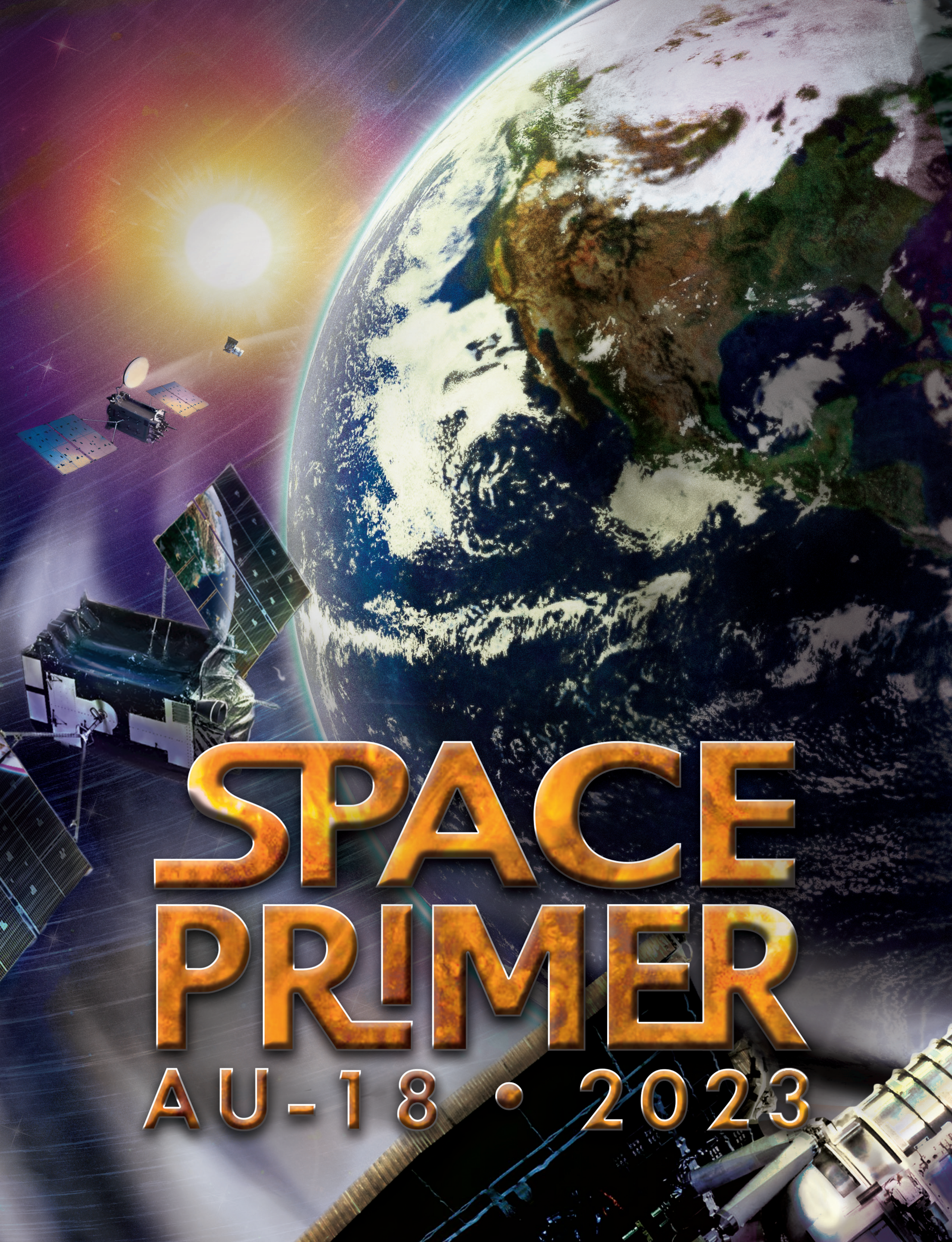
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AU-18 • 2023

AU-18
Space Primer

Prepared by
Air Command and Staff College (ACSC) Schriever Space Scholars
Air War College (AWC) West Space Seminar

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Director
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Dr. Christopher Rein

Design and Production Managing Editor
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Project Editor
Jeanne K. Shamburger

Cover Art, Book Design, and Illustrations
Catherine Smith

Composition and Prepress Production
Nedra Looney

Air University Press
600 Chennault Circle, Building 1405
Maxwell AFB, AL 36112-6026

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Foreword

Space capabilities touch nearly all aspects of our lives. Quietly, from the depths of space, satellites assist us with everything from the timing of global financial transactions and electrical power generation and distribution to television broadcasts and the navigation of vehicles in all domains. The outright loss of those capabilities would have immediate and very real effects experienced in every corner of the globe, both for the everyday American and for the employment of our national instruments of power, including our military forces.

Focusing on the military instrument, space-based capabilities and their support to all domains enable the twenty-first century way of war. They enable modern warfare by providing intelligence, navigation, precision strike ability, weather data, missile warning, post strike assessments, and many other functions. Fighting without space capabilities means reverting to industrial age warfare, like that prior to Desert Storm. The loss of the Global Positioning System (GPS) alone would cause cascading operational and tactical effects on capabilities ranging from navigation to precision strike. The consequence of not accounting for operational considerations in the space domain is simply too high to ignore.

As Guardians, our job is to protect and defend our nation's space capabilities, our way of life, and our way of war. We do that to ensure we can integrate our space capabilities into broader warfighting constructs. The integration of space capabilities is not a simple task, but it is critical to the way we fight as a joint and coalition force.

This space primer is intended as a resource to educate and inform non-space professionals how best to integrate space capabilities into operational planning and warfighting. To that end, it presents space capabilities and operational considerations in a digestible way for leaders and planners alike participating in planning and conducting operations in all domains across the combatant commands. Due to the small size of the Space Force relative to the other services, everyone in the joint force must account for space during planning and execution. This space primer provides a reference that captures the operational considerations specific to the space domain.

I encourage everyone to study this document and learn the knowledge it contains. Semper Supra!

SHAWN N. BRATTON
Major General, USAF
Commander, Space Training and Readiness Command

List of Contributors
Academic Year 2022

Air Command and Staff College Students*
Schriever Space Scholars

Maj Ronald C. Davies, US Space Force
Maj Kara D. Jarvis, US Space Force (Team Lead)
Maj Collin McSorley, US Space Force
Maj Robert J. O'Neil, US Marine Corps

Air War College Students*
West Space Seminar

Lt Col Andrew "Wala" Bogusky, US Air Force
Lt Col Robert "Chopper" McConnell, US Space Force

Faculty Support

Col Kirk W. Johnson, US Space Force, PhD (AWC)
Lt Col Johann Pambianchi, US Space Force (ACSC)
Col Michael V. "Coyote" Smith, US Air Force (Ret), PhD (ACSC)

*Ranks of student and faculty contributors during Academic Year 2022

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List of Contributors (2009 Revision)*

ACSC Academic Year 2008 Students

Maj Burton "Ernie" Catledge, USAF
Maj Edward "Ed" Chatters IV, USAF
Maj Brian "Flash" Crothers, USAF
Maj Bryan "Troll" Eberhardt, USAF
Maj Brian Garino, USAF
Maj Jane Gibson, USAF
MAJ Kenneth "Ken" Kemmerly, USA
Maj Christopher "Chris" King, USAF
Maj Jeffrey "Jefe" Lanphear, USAF
LCDR Jeremy Powell, USN
MAJ Dillard "Wes" Young, USA

Academic Year 2009 Students

Maj Edward Byrne, USAF
Maj Paul "PK" Konyha III, USAF
Maj Jennifer Krolikowski, USAF
Maj Michael Warner, USAF

Faculty Support

Maj Sean "Smokin" Boles, USAF
Lt Col Winston "Pumbaa" Gould, USAF
Lt Col Jonathon "J-Lo" Lowe, USAF
Lt Col Bert Sparrow, USAF
Lt Col Brian Tichenor, USAF
Lt Col Christine Weaver, USAF

List of Contributors (2018 Revision)*

ACSC Academic Year 2015 Students

Maj Nasser Al Badi, Royal Air Force of Oman
Maj Brandon Beers, USAF
MAJ Kris J. Bergemann, USA
Maj Ernie Bice, USAF
Maj Stephen Bichler, USAF
Maj Robert G. Branham, USAF
Maj Aaron M. Croft, USAF
Maj Stephan E. Cummings, USAF
Maj David Davidson, USAF
Maj Carlos Ferrer, USAF
Maj Ricardo Jaime, USAF
Maj Josh A. Klemen, Royal Canadian Air Force
Maj Jeffrey D. Lanphear, USAF
Maj Gabriel A. Medina, Dominican Republic Air Force
LCDR Kyle Moore, USN
MAJ Paul B. Neal, USA
Jason Nelson, Program Manager, AFLCMC
Maj Aaron D. Reid, USAF
MAJ Drew G. Rodgers, USA
LCDR Robert A. Scott, USN
Maj Ingemar "Iggy" Westphall, USAF

Faculty Support

Lt Col Peter Garretson, USAF
Dr. John P. Geis
Dr. Dale L. Hayden

Air University Space Staff Support

Maj Jonathan Burson, USAF

*Ranks of student, faculty, and staff contributors during respective academic years

PART I

SPACEPOWER FOUNDATIONS

Chapter 1

Introduction

Space support to warfighters has become integral to US and allied military successes on the modern battlefield. Space-enabled intelligence, surveillance, and reconnaissance (ISR); satellite communications (SATCOM); positioning, navigation, and timing (PNT); and satellite weather data have given US and allied military forces an asymmetric advantage over their adversaries to date. Warfighters have come to expect space support to operations but may not understand why space support is not instantaneous or persistent. Operational and planning considerations in space, such as orbital constraints and constellation design, can frustrate warfighters during execution. However, access to space information during planning can help reduce such frustrations. Due to their small numbers, military space professionals cannot be everywhere at all times. Therefore, they must find ways to help the joint force obtain space support while maintaining a grasp of space domain limitations and operational considerations.

Why a Space Primer?

The goal of this primer is to integrate spacepower into the thinking of joint planners, joint leaders, and the joint force commander. The Space Force is responsible for presenting highly trained space professionals; enabling capabilities such as ISR, PNT, and SATCOM; offensive space control capabilities and personnel; and defensive capabilities and personnel to the joint force. Additionally, it is charged with developing a space warfighting culture and expanding its capabilities to account for the realities of space as a domain for commerce, exploration, settlement, and, when necessary, warfighting. With a fiscal year (FY) 2022 end strength of 8,400 (FY 23 proposal is 8,600), the Space Force is by far the smallest of the five services' combined 1,348,040 (FY 22) end strength.[1] The nascent Space Force is charged with a multitude of requirements, presenting a prioritization dilemma for the force. Joint leaders and planners can benefit from a document to help them bridge those gaps and seams when space professionals are not available to participate in enduring or emerging planning events and to account for space domain limitations and operational considerations.

Therefore, one purpose of this space primer is to serve as a desktop reference for non-space operational leaders and planners who need to understand space capabilities, space domain limitations, and operational considerations for space support. It seeks to inform leaders and planners while not turning everyone into a space professional. Planners do not need an encyclopedia of all space capabilities, a detailed description of acquisition to end-of-life operations, or an in-depth knowledge of the space domain. However, leaders and planners will benefit from a quick reference to help them incorporate space opportunities and limitations into their operations and planning considerations.

This document also serves as a reference for space and other professionals about operational considerations for space capabilities they may have limited working knowledge of. Service members can use it for exercises and real-world planning events when they are sent forward in support of combatant commands. Space professionals cannot be experts on every space capability and its respective operational considerations. This reference can help them to contribute effectively by providing a quick source of information.

To accomplish these goals, the revised AU-18 endeavors to provide the right balance of information for joint operations and planning and for Guardians, Airmen, Soldiers, Sailors, and Marines. The writing team hopes you find it useful.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Congressional Research Service, *FY2023 NDAA*, 2–3.

Chapter 2

Law, Policy, and Doctrine

Military space operations must function within a legal and policy framework while adhering to doctrinal principles both specific to space and common across all domains. This section briefly discusses the foundations of international law, norms, policy, and doctrine to familiarize the reader with the origin of the existing structure. Having a basic understanding of these areas can inform deeper research and answer questions planners and practitioners might have regarding perceived limitations or restrictions on operations when doctrine is imposed from above. International law defines the interplay of states in space and what is acceptable or unacceptable to the international community. Norms are political commitments that help define behavior but that do not have the force of law as do treaties. National policy, which includes laws and specific policy documents, provides a roadmap to the nation on how it will focus its efforts regarding space. Doctrine provides the guiding principles to shape planning and operations. The interaction of these tools is the bedrock for how the United States will operate and cooperate in space; organize, train, and equip its forces; and plan to defend and secure operations in space or engage in conflict when necessary.

International Law

International law is broadly that which governs relations between states.[1] It has its basis in accepted custom, international treaties, and general principles adhered to by states.[2] Customary international law refers to international obligations based in established international practices and results from the general and consistent practices by states to follow these principles from a sense of legal obligation.[3] Additionally, widely accepted norms that establish consistent state practices over time can become part of customary international law. Treaty law and written conventions are also a basis of international law, but terms are documented and go beyond practice alone to establish the law over time. For treaties and conventions, states do not automatically become party to the measure at question. Rather, they must take concrete action to be bound by the treaty or convention under discussion, as state sovereignty is paramount in the existing international system.[4] The most common ways to consent to be bound are ratification and accession (which are beyond the scope of this document).[5]

The five main treaties that pertain to a state's actions in outer space are the (1) Outer Space Treaty of 1967, (2) Rescue Agreement of 1968, (3) Liability Convention of 1972, (4) Registration Convention of 1975, and (5) Moon Agreement of 1979.[6] The United States is party to the first four of these treaties but has not consented to the Moon Agreement for two reasons. First, the agreement requires signatories to share technology for the extraction of resources and actual resources extracted with developing nations. Second, because the moon is categorized as a "common heritage of all mankind," the United States is not bound by the agreement's provisions.[7] The treaties to which the United States is party provide the basis for everything that it does in space and related to space.

Of particular interest to military professionals, none of these treaties prohibit the placement of "all weapons" in space. The Outer Space Treaty limits only the stationing of *weapons of mass destruction*, with Article IV directing that "States shall not place nuclear weapons or other weapons of mass destruction in orbit or on celestial bodies or station them in outer space in any other manner."[8] Therefore, the common interpretation is that this restriction does not prevent the placement of conventional weapons in space. However, the use of the moon and other celestial bodies is limited to "exclusively peaceful purposes" in Article III, with some clarification of permitted activities provided in the second paragraph of Article IV.[9] For further details on the treaties listed above, refer to the United Nations Office for Outer Space Affairs (UNOOSA) website.

To clarify the application of existing international law to space, two efforts have emerged. They aim to create manuals like those for other domains of warfare, such as the *San Remo Manual* dealing with naval warfare and the *Tallinn Manual* dealing with cyber warfare.[10] The first effort, called the Manual on International Law Applicable to Military Uses of Outer Space (MILAMOS) project, was launched in 2016 by McGill University in Montreal, Canada. The six-year project culminated in the publication of the first volume of MILAMOS on rules in July 2022 with the intention "to develop a widely accepted manual clarifying the fundamental rules applicable to the military use of outer space in time of peace, including challenges to peace."[11] Volume 2, rules with commentaries, is forthcoming.[12] The second effort, led by the University of Adelaide in Australia, branched off from the MILAMOS project and became a more focused look "on the law as it is (*lex lata*), not on the law as we might wish it to be (*lex ferenda*)." Known as the Woomera Manual project, this effort aims to clarify existing law applicable "to military activities associated with the space domain, especially that which is relevant in periods of tension . . . or outright hostilities."[13] These manuals will become integral to understanding the application of international law during conflict that extends into space and should help guide future space planners and practitioners.

Air and Sea Precedents in Developing Space Law

Law has established the basis for air and sea power and is considered foundational in conceiving a spacepower theory. Given the short history of US space activities, author Irvin White offers "a compelling case for the evolution of space law from a basis in international sea and air traditions."[14] Everett Dolman observes in his book *Astropolitik: Classical Geopolitics in the Space Age* that "the bulk of air law, codified in the twentieth century in conjunction with rapid technological developments of the air[plane], then jet plane, has developed primarily through bilateral treaties and multilateral conventions. Law of the sea, on the other hand, developed primarily by codifying existing customary and normative behaviors of seafaring states." He further delineates the major contentious issues regarding air, space, and naval theory as delimitation, sovereignty, registration and liability, and innocent passage.[15]

Delimitation

Delimitation attempts to answer the question of where airspace ends and space begins. According to Dolman, "The two most prevalent approaches for defining outer space have been spatial and functional. The spatial approach explains that space begins just below the lowest point at which an object can be maintained in orbit . . . about 52 miles."[16] The second approach to defining outer space is "the functional approach [that] is based on the propulsion systems of the air/spacecraft and is legally based in 1919 and 1944 International Air Conventions, which defined aircraft as 'any machine that can derive support from reactions of the air.' Under this definition, space begins just beyond the maximum height at which aerodynamic flight is possible."[17] USSPACECOM uses a third approach to define the space domain that combines the above concepts. It defines the *space domain* as "the altitude where atmospheric effects on airborne objects become negligible," making its area of responsibility at "altitudes equal to, or greater than, 100 kilometers above mean sea level."[18]

Sovereignty

In addition to the delineation of space, sovereignty aids in devising a framework for space law. Dolman maintains that the "definition of airspace is acceptable for aircraft, since, due to gravity and the relatively small altitudes concerned, the airspace above the earth can be monitored and controlled. It can be possessed. There is a legally important distinction here: the air is not susceptible to sovereignty, but the airspace is."[19] Dolman states that having sovereignty in space does not mean having control of space due to the rotation of the earth. Therefore, basing space sovereignty on air law is "highly problematic."[20]

Registration and Liability

The third issue regarding air and sea power relevant to spacepower is registration and liability. The United Nations (UN) Convention on the Law of the Sea requires each nation to keep a registry of ships. Individual nations, however, may have their own rules and regulations for registration, safety, and related issues.[21] Dolman notes that "in contrast to sea law, aircraft have the additional requirement of *holding* the nationality of the state in which they are registered" (emphasis in original). He adds, "The requirements for registration of objects in space are stricter than those for sea or air, with the justification that such registration is necessary because of the greater potential for global physical and/or environmental damage. . . . The most compelling reason for registration of spacecraft, according to policymakers, is to enhance national security."[22]

Innocent Passage

The final issue of air and sea law that provides a framework for spacepower theory is that of innocent passage. Dolman states that passage in sea is considered innocent "so long as it is not prejudicial to the peace, good order, or security of the coastal state."[23] Further, "innocent passage on the seas is far less strict than the air regime, and the space regime is the least constrained of all."[24] This circumstance is largely due to the orbital trajectory of space objects and the difficulty involved in changing orbits. In space, it is not feasible to maneuver around another nation's sovereign territory due to the physics of orbital trajectories. Article II of the Outer Space Treaty also provides that there is no sovereignty in space, thereby guaranteeing a right of innocent passage in space.[25] That said, there is no inherent right of innocent passage for spacecraft through the airspace of another state.

Norms

Norms are political commitments that fall short of having the power of laws but can help to define expected behaviors. Policymakers and strategists are seeking to establish norms in space to codify the behaviors of states acting in space, much like those established for the air and maritime domains. Understanding an expected pattern of behavior based on norms can help to identify abnormal, dangerous, and potentially hostile behaviors. To promote norms development, Secretary of Defense (SecDef) Lloyd Austin issued a memo on July 7, 2021, with the subject "Tenets of Responsible Behavior in Space." It lists the five tenets to which all DOD space operations must adhere:

- Operate in, from, to, and through space with due regard to others and in a professional manner.
- Limit the generation of long-lived debris.
- Avoid the creation of harmful interference.
- Maintain safe separation and safe trajectory.
- Communicate and make notifications to enhance the safety and stability of the domain.[26]

The memo further states that the commander, US Space Command, is the collaborating official for DOD stakeholders while the Office of the Under Secretary of Defense for Policy will "advance these tenets, as appropriate, within the US Government and in international relations."[27] The DOD is leading the way by example and actions that will set new norms of behavior for the space domain until diplomatic efforts bear more fruit in this area. For example, the United States announced a unilateral declaration against "destructive, direct-ascent anti-satellite (ASAT) missile testing" on April 18, 2022, rather than waiting on international efforts.[28] The United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) is the lead for the development of cooperation in the space domain and continues to work on norms acceptable to all members.[29]

Policy

Besides international law and norms, US national policy drives how military, civil, and commercial space entities proceed during a given administration and over time. US policy consists of laws formulated by Congress and signed by the president along with documents created primarily by the executive branch as guidance for its actions. Policy documents can be highly prescriptive or general depending on the administration and its focus on and approach to space. Effective policy contributes to and supports a common set of objectives at the national level. Laws should support achievement of such policy objectives.

Legislation such as the annual National Defense Authorization Act (NDAA) and the Goldwater-Nichols Department of Defense Reorganization Act of 1986 sets policy for the national defense enterprise. Congress can use legislation and funding to affect military organization and actions through such legislation. For example, the fiscal year (FY) 2020 NDAA established the United States Space Force (USSF)—enacted on December 20, 2019—thereby codifying the executive branch policy stated in the February 2019 Space Policy Directive-4.[30]

Executive branch policy documents begin with the *National Security Strategy* (*NSS*), identifying "the major national security concerns of the United States and how the administration plans to address them using all instruments of national power."[31] The tenets of all military policy documents are derived from the *NSS*. The executive branch also authors the *National Space Policy of the United States of America* that outlines the nation's approach to operating and engaging in the space enterprise on the national level and drives everything from space exploration to military space policy.

Lastly, the above-stated tenets from the SecDef memo dated July 7, 2021, set a DOD policy on establishing norms of responsible behavior in space. This policy drives all subsequent actions taken by US military space agencies.

Doctrine

The United States Space Force follows joint doctrine as its guiding principles. As such, the principles of joint operations and the joint warfighting functions apply to space operations. Joint Publication (JP) 3-14, *Space Operations*, deals specifically with how the joint force will employ space operations. The commander's overview states that JP 3-14

- provides an overview of the space domain and benefits joint forces derive from access to space,
- discusses space capabilities and provides a common baseline for all elements of the joint force to enable joint planning and facilitate effective joint military operations,
- describes how space operations enable joint functions,
- discusses command and control of joint space operations, and
- describes planning and assessment of joint space operations.[32]

JP 3-14 will require updating once the command relationships and responsibilities become clearer and as the USSF continues to integrate itself into the joint force and establish components across the combatant commands (CCMD). It will also need to describe how the Space Force will execute its own global missions, much like other domains (e.g., JP 3-02, *Amphibious Operations*, or JP 3-12, *Cyberspace Operations*). Additionally, a new joint publication should be created as a peer document to JP 3-30, *Joint Air Operations*; JP 3-31, *Joint Land Operations*; and JP 3-32, *Joint Maritime Operations*. Its focus should be on how space will execute within the existing joint operations establishments and within multi-domain operations. All other joint doctrine as published applies to space operations and will continue to be updated to reflect necessary changes as command structures are developed, defined, or refined to include USSPACECOM and the USSF service component.

The USSF is developing doctrine that will help define the future of space operations and warfare for the service and the joint force. As of this writing, the USSF has several documents that can be considered doctrinal in nature. The first space doctrine is the inaugural Space Capstone Publication *Spacepower: Doctrine for Space Forces*. Signed in 2019 by the first chief of space operations, Gen John "Ray" Raymond, it addresses "why spacepower is vital for our Nation, how military spacepower is employed, who military space forces are, and what military space forces value."[33] The second doctrine document, Space Doctrine Publication 5-0, *Planning*, "describes the Service's current body of knowledge for spacepower planning" and aligns closely with the joint planning process.[34]

Other service branches are forming space doctrine as well. US Army Field Manual (FM) 3-14, *Army Space Operations*, aims to establish "guidance for employing space and space-based systems and capabilities to support US Army land warfighting dominance" while lining up with JP 3-14 and other joint publications.[35] US Air Force Doctrine Publication (AFDP) 3-14, *Counterspace Operations*, will likely be updated since that mission has passed to the USSF.[36] Space doctrine will continue to evolve along with other areas of joint doctrine.

Summary

National and international law, norms, policy, and doctrine help define the operating space within which the military space enterprise must perform. This framework provides the military space planner and practitioner with direction, constraints, restraints, and guidelines for winning a conflict that extends into space. Operating without limits in space and risking the destruction or pollution of key orbital terrain benefits no one. The military space planner and practitioner

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. United Nations (UN), "Understanding International Law."
2. International Court of Justice, "Statute of the International Court of Justice."
3. Cornell Law School, "Customary International Law."
4. UN, "Understanding International Law."
5. UN, "Understanding International Law."
6. United Nations Office for Outer Space Affairs (UNOOSA), "Space Law Treaties and Principles."
7. US Department of State, *Treaties in Force*.
8. UNOOSA, "Exploration and Use of Outer Space," art. IV.
9. UNOOSA, "Space Law Treaties and Principles," arts. III and IV.
10. Schmitt, "Tallinn Manual 2.0"; and International Institute of Humanitarian Law, "San Remo Manual."
11. Boucher, "McGill Publishes Manual on International Law Applicable to Military Uses of Outer Space: Volume I–Rules." For the published manual, see Jakhu and Freeland, *McGill Manual*.
12. McGill University (Montreal), "Manual on International Law Applicable to Military Uses of Outer Space."

13. University of Adelaide (Australia), "Woomera Manual," information pamphlet, 3.
14. Dolman, *Astropolitik*, 113. See also White, *Decision-Making for Space*, 61–88, 187–202.
15. Dolman, 99.
16. Dolman, 118–19.
17. Dolman, 119. For the definition of *aircraft,* see Bloomfield, "Prospects for Law and Order," 156.
18. Joint Publication (JP) 3-14, *Space Operations*, I-2.
19. Dolman, *Astropolitik*, 117.
20. Dolman, 119–20.
21. White, *Decision-Making for Space*, 82.
22. Dolman, *Astropolitik*, 118–19.
23. Dolman, 119.
24. Dolman, 119.
25. UNOOSA, "Space Law Treaties and Principles."
26. Austin to Secretaries of the Military Departments et al., memorandum, subject: Tenets of Responsible Behavior in Space.
27. Austin, memorandum.
28. White House, "Vice President Harris Advances National Security Norms in Space."
29. UNOOSA, "Committee on the Peaceful Uses of Outer Space."
30. White House, Space Policy Directive-4; and Venable, "U.S. Space Force," 455.
31. JP 5-0, *Joint Planning*, II-3.
32. JP3-14, *Counterspace Operations*, vii.
33. US Space Force, Space Capstone Publication, *Spacepower*.
34. Space Doctrine Publication 5-0, *Planning*, 4.
35. Field Manual 3-14, *Army Space Operations*.
36. Air Force Doctrine Publication 3-14, *Counterspace Operations*.

Chapter 3

Spacepower Theory

Military spacepower has deterrent and coercive capacities—it provides independent options for National and Joint leadership but achieves its greatest potential when integrated with other forms of military power. As we grow spacepower theory and doctrine, we must do so in a way that fosters greater integration with the Air Force, Army, Navy, Marine Corps, and Coast Guard. It is only by achieving true integration and interdependence that we can hope to unlock spacepower's full potential.

—Gen John W. Raymond
Chief of Space Operations, US Space Force
Spacepower: Doctrine for Space Forces, 2020

The Soviet Union's launch of *Sputnik I* in 1957 triggered interest in spacepower theory, and international debate immediately emerged on potential applications of an enemy satellite orbiting the earth. Theories ranged from dropping nuclear weapons from space to peacefully overflying countries for treaty verification.[1] Over six decades later, the United States still seeks consensus on the definition of spacepower, while space theorists continue to search for strategies to interpret and employ it.

The connection between space history and spacepower theory is an important evolution and one that this chapter briefly explores. Additionally, it presents six leading spacepower theories and puts them into the context of how space can emerge within joint all-domain operations.

Spacepower Theories

The need to protect US space capabilities has increased with more US national interests in the space domain. However, since space is a unique domain and air and sea models do not adequately transfer, a new strategy is required. With space law codified, the next step in developing a theory is to characterize and define spacepower. Influential space strategists who have shaped the definition and theory of spacepower include David E. Lupton, US Air Force, retired; Everett Dolman, professor, Air Command and Staff College, US Air Force; and John J. Klein, US Navy, retired.

Lupton's Four Schools of Thought

In his seminal 1988 publication, *On Space Warfare: A Space Power Doctrine,* Lupton lays the groundwork for space doctrine. He defines *spacepower* as "*the ability of a nation to exploit the space environment in pursuit of national goals and purposes and includes the entire astronautical capabilities of the nation*. A nation with such capabilities is termed a *spacepower*" (emphasis in original).[2] Having defined spacepower, Lupton further describes four schools of thought about spacepower theory. He particularly explores differences in fundamental beliefs that influence the analysis of the four schools of doctrinal thought concerning the best way to employ space forces.[3] His discussion of the sanctuary, survivability, high-ground, and control concepts establishes a basis for examining the views of the other space theorists addressed in this chapter.

Sanctuary school. The fear that space would be weaponized after the *Sputnik I* launch resulted in a declaration that space must be reserved for peaceful purposes.[4]

Survivability school. The basic tenet of Lupton's survivability school of thought is that "space systems are inherently less survivable than terrestrial forces."[5]

High-ground school. The third concept, known as the high-ground school, is founded on the premise that the military force dominating space will have an asymmetric advantage over its opponent and thus be less vulnerable to attack.[6]

Control school. The final of Lupton's schools of thought is that of control, which argues that the ability to control space enhances the capability to deter war and that, in future wars, space control will be coequal with air and sea control.[7] Of the four schools of thought, Lupton believes that control should be the basis for a spacepower strategy.[8]

Dolman's Spacepower Theory

In his 2002 book, *Astropolitik,* Dolman blends the high-ground and control schools and maintains that a realist approach on developing spacepower theory is necessary. Dolman writes, "Strategy, grand strategy in particular, . . . is ultimately political in nature, that is to say the ends of national strategy are inextricably political, yet the means or dimensions of strategy are not limited."[9] He advocates for the United States to "seize control of outer space and become the shepherd (or perhaps watchdog) for all who would venture there, for if any one state must do so, it is the most likely to establish a benign hegemony."[10]

Dolman's realist view of spacepower discards the notion that a nation should hold to a strategy of hope that one's enemy will not challenge the status quo. Dolman dismisses the sanctuary and survivability schools. He argues for a hybrid high-ground/control spacepower theory. Given the reliance on space and the threats already posed in space, the United States should encourage free passage in space while having the capacity to prevent those who will disrupt this freedom.

Klein's Maritime Model

Klein suggests the use of a maritime model for theorizing spacepower, as maritime theory is broader than naval theory and more relevant to space operations than air theory. His view is that "the term 'maritime,' in contrast to 'naval,' connotes the whole range of activities and interests regarding the seas and oceans of the world, and their interrelationships: science, technology, cartography, industry, economics, trade, politics, international affairs, imperial expansion, communications, migration, international law, social affairs, and leadership."[11]

Klein's extrapolation of maritime power theory into a prospective spacepower theory is one starting point from which the United States can begin a focused push to develop a comprehensive space strategy, even without the weaponization of space. His proposed spacepower theory outlines what space can bring to operations ("in, through, and from" space) and how space is integral to the effective operations of all other domains. It shows the emergence of space within a joint all-domain regime.

Spacepower and Joint All-Domain Command and Control

Regardless of how spacepower theory is developed, its purpose is to inform, predict, and better define the space environment in which warfighting may occur. From spacepower theory comes the development of space strategy and the concept of Joint All-Domain Command and Control (JADC2). The March 2022 JADC2 strategy summary document states that this framework "provides an approach for developing the warfighting capability to sense, make sense, and act at all levels and phases of war, across all domains, and with partners, to deliver information advantage at the speed of relevance."[12] Space bridges the gap between desired and actual effects within any given domain. It synergizes domains within the military instrument of power and augments the military's ability to project power into, from, and to the desired theater and across the full range of operations.

Spacepower is also tied into the National Security Strategy via the National Space Policy. This policy provides the strategic overarching goal of US space objectives and has the means of maintaining superiority in the domain. Space enables JADC2 across the breadth of military operations and conflict continuum so that the United States can maintain its global security and achieve its national objectives.

Summary

As the United States approaches its seventh decade of successful operations in space, experts still disagree on the most appropriate US spacepower theory. This divergence seems to stem from differing opinions on how the space domain should be used. The answer likely lies on a varied spectrum depending on the application of capabilities. Therefore, a comprehensive space strategy is still in development as we confront the potential for competition and conflict in space.

The United States is once again at a critical juncture. As the newest military branch, the US Space Force has the opportunity to shape spacepower theory to develop the space domain into a frontier of the future. The spacepower choices made today will dictate the laws, norms, and assumptions for executing the next era of space exploration and habitation. In developing a comprehensive spacepower strategy, the US must consider current space technologies and opportunities as well as functions and capabilities in past and ongoing operations. This strategy will help to preserve US freedom of access in, from, and to space.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Dolman, *Astropolitik*, 94.
2. Lupton, *On Space Warfare,* 4. A collection of airpower definitions, including those by Gen Billy Mitchell and Gen H. H. Arnold, is found in Cooper*, Explorations in Aerospace Law,* 17–35. Mahan's elements of sea power are contained in his work *Influence of Sea Power,* 22–77. For another comprehensive definition of sea power, see Potter and Nimitz, *Sea Power,* 19.
3. Lupton, 20–21.
4. Lupton, 20.
5. Lupton, 21.
6. Lupton, 21.
7. Lupton, 221.
8. Lupton, 86.
9. Dolman, *Astropolitik*, 144.
10. Dolman, 157.
11. Klein, "Corbett in Orbit." Klein references Hattendorf, "Uses of Maritime History," 19.
12. Department of Defense, *Summary of the Joint All-Domain Command and Control (JADC2) Strategy,* 3.

PART II

OPERATIONAL CONSIDERATIONS

Chapter 4

Basics of Orbital Mechanics

Because space was declared a warfighting domain and US Space Command (USSPACECOM) designated a *geographic* (versus functional) combatant command, an understanding of the spatial and physical properties of space is useful. Orbital mechanics impacts planning factors like mission capabilities, functionality, and coverage. The space environment can be described in several ways. First, the unique environment of space can be explained in terms of physics, which largely speaks to the relationships between the movement of an object and the gravity of celestial bodies—known as orbital mechanics. Second, there is the medium of space or the physical environment, primarily related to hazards from radiation and debris and effects on orbits from atmospheric drag. And third, the space environment can be described in positional terms or regions related to the "geography" of space for lack of a better term. The space geography or environment relates to orbits and physics but speaks more to political considerations and calls to mind terrestrial concepts such as chokepoints, vantage points, and key terrain. It is best to think of these concepts together because they directly influence one another. For example, all satellites in orbit are affected by elements of their physical environment, such as radiation, temperature, third-body effects, orbital characteristics (low Earth orbit [LEO] vice geosynchronous equatorial orbit [GEO]), and perturbations (see chap. 5). These effects are largely a function of certain desirable regions or altitudes that provide the optimal placement and path of satellites depending on their mission.

Orbital Mechanics—the Physics of Spaceflight

Understanding the basics of orbital mechanics is foundational to all other key concepts of the space environment but also—and more importantly—issues like space policy and security. In simple terms, an orbit is the path of an object (e.g., satellite) around a celestial body (e.g., Earth) at a speed that counteracts the force of gravity. An orbit is achieved when an object moves fast enough that the earth's curved surface is "falling" away from it faster than the object itself is pulled to Earth by its gravity.[1] That is, a satellite's velocity must be great enough to overcome the downward acceleration of Earth's gravity: a satellite must "fly" faster than it falls. Theoretically, a baseball could orbit the earth at ground level if it were able to move faster than the horizon was curving away from it (if atmospheric drag were not a factor and the ball was thrown fast enough [~17,600 mph] to "fall" around the earth).

Orbital Factors

Altitude

In terms of distance or altitude, orbits generally fall into four categories: low Earth orbit, medium Earth orbit (MEO), geosynchronous/geostationary, and highly elliptical orbit (HEO). (Parabolic and hyperbolic trajectories are not orbital and will be discussed later.) Velocity in orbit is a function of altitude. For example, the International Space Station in LEO (400 km/250 miles high) travels faster than 17,000 mph, while a weather satellite in GEO (~36,000 km/22,000 miles high) travels at 7,000 mph. This combination of speed and altitude affects the time it takes a satellite to complete one full orbit, called the period. Because it is traveling so fast, a satellite in LEO orbits the earth roughly every 90 minutes. Global Positioning System satellites in MEO have a period of 12 hours (semi-synchronous). A satellite in GEO is "parked" at the precise altitude above the equator that allows it to stay above the same spot on the earth as it orbits Earth every 24 hours, the same rate the earth spins around its axis. Therefore, a geostationary satellite can provide a relatively "unblinking stare" at a certain point or constant uninterrupted data transmission to a stationary satellite receiver (e.g., satellite TV). In contrast, the rapid period of a LEO satellite explains why a constellation of many satellites would be required to maintain a robust communications network in that orbit.

Eccentricity

Another categorization of an orbit is its eccentricity, which can also be thought of as a satellite's variation in altitude or shape, that is, more or less circular or elliptical. The highest point of an orbit about the earth is its apogee, and its lowest point is perigee. A purely circular orbit maintains a constant distance from Earth with no differentiation between apogee and perigee, while an elliptical orbit has varying altitude and eccentricity. Additionally, the satellite in an elliptical orbit is constantly exchanging potential energy and kinetic energy, going from apogee (moving slowest) to perigee (moving fastest) and back. It is worth noting that all natural orbits around Earth will cross or contain the equatorial plane. Thus, it is impossible for an orbit to form a "halo" above any area or "hover" above any spot *not* on the equator (only possible with a geostationary orbit, which matches the equatorial plane).[2]

Inclination

An orbit's inclination—the angle between the orbital and equatorial planes—also provides operationally relevant cues to its characteristics and capabilities. The inclination provides the north and south latitude limits of the orbit. The lowest inclination of 0° matches the equatorial plane (all GEO orbits fall in this category). The highest inclination of 90° is perpendicular to the equatorial plane and describes a polar orbit, one that circles both poles. The inclination of polar orbits makes them ideal for intelligence, surveillance, and reconnaissance (ISR) and mapping operations because as the earth rotates, the satellite can see virtually every point on the planet. A particular type of (near) polar orbit, the sun-synchronous (or heliosynchronous) orbit, uses an inclination and altitude allowing a satellite to visit the same spot over Earth at the same local solar time—for example, overflying New York every day at noon. It is useful for ISR and weather applications because the surface illumination angle stays constant, enabling better detection of changes and patterns over time. Figure 4.1 depicts the concepts of circular and elliptical orbits, apogee and perigee, and inclination.

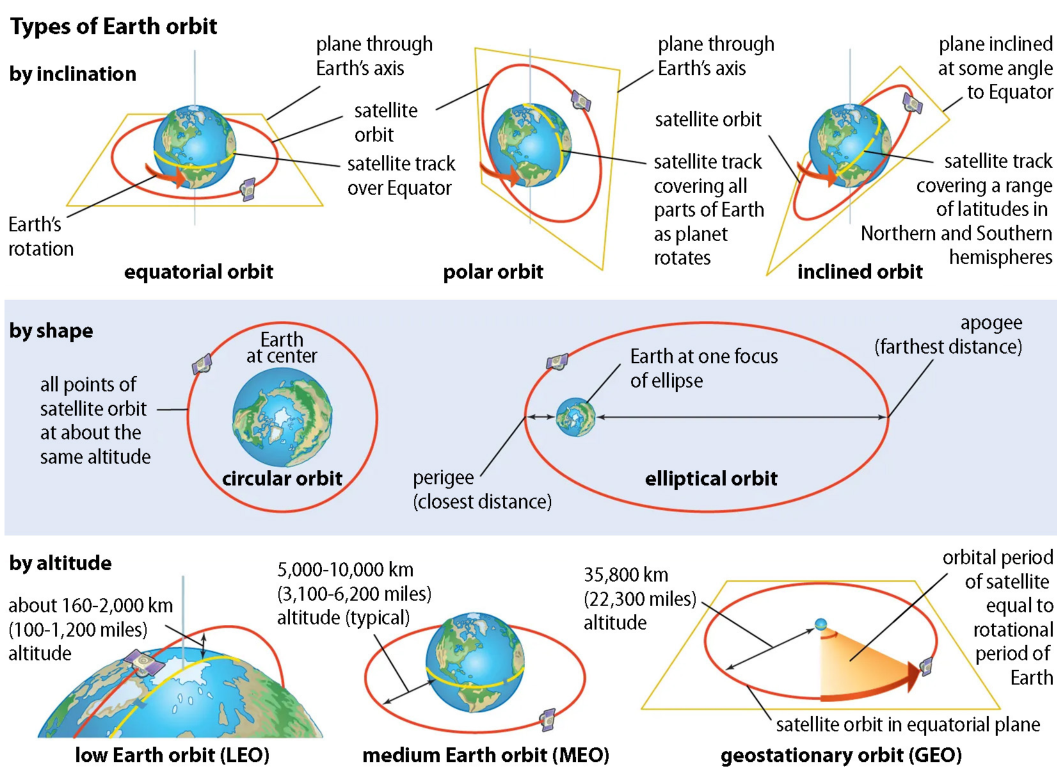


Figure 4.1. Types of Earth orbits. (Reproduced from *Encyclopedia Britannica*, s.v. "Satellite Orbits," accessed September 2, 2022, https://cdn.britannica.com/.)

In addition to Earth orbits, other trajectories traverse space. These include parabolic launches of ballistic missiles, which intersect the earth. Another is the hyperbolic trajectory, an orbit that escapes Earth's gravitational influence and keeps going but is then more subject to third-body effects. It can be used to our advantage as demonstrated by the Voyager missions that used other planets to slingshot and gain velocity. Figure 4.2 shows the concepts of orbits and trajectories in space and their relationship with eccentricity using conic sections.

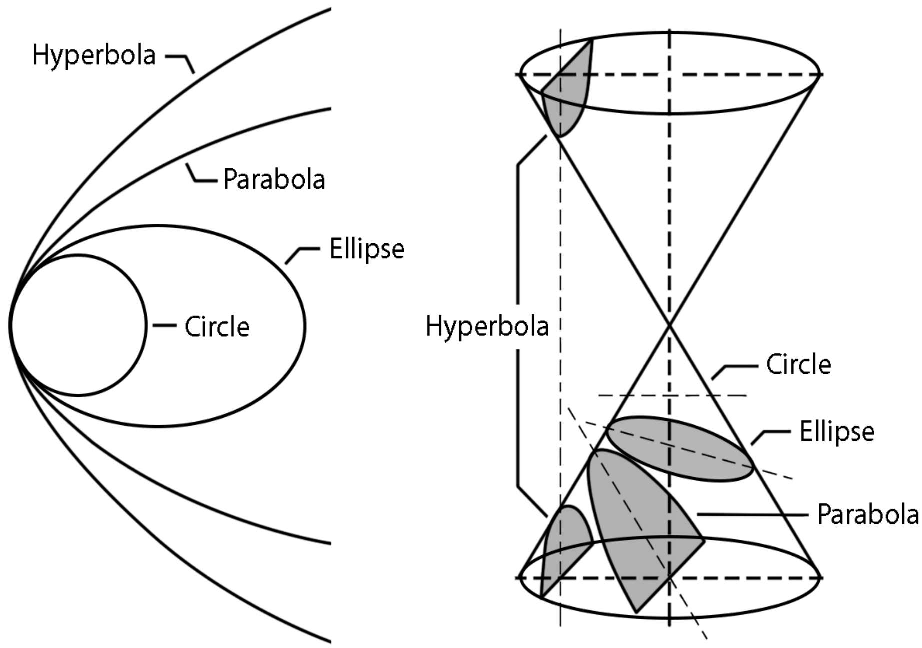


Figure 4.2. Conic sections. (Reproduced from Robert A. Braeunig, "Orbital Mechanics," Rocket and Space Technology website, accessed September 2, 2022, http://www.braeunig.us/space/orbmech.htm.)

Bringing these natural laws and characteristics together, we can begin to generalize and operationalize different orbits for different missions. Higher orbits tend to be more stable (requiring less station-keeping fuel) and slower, while lower orbits are less stable and faster. Higher orbits also provide a larger field of view of an area of the earth but at the tradeoff of less sensor or payload fidelity. Lower orbits are conducive to providing more detail of specific areas on the ground or networked communications links. Circular orbits are used for satellites that need to continuously perform their mission, while eccentric orbits are optimized for missions conducted primarily at apogee or perigee.[3]

Satellites in low, medium, geostationary, and highly elliptical orbits can be generally characterized by their specific missions. LEO satellites are typically used for remote sensing, communications, and weather data while those in MEO orbits are used for collecting and relaying positioning, navigation, and timing information. HEO satellites typically handle missile warning, communications, and remote sensing data while GEO satellites are used for these purposes and for weather monitoring.[4] Figure 4.3 depicts Space Force assets and capabilities in relation to their orbits.

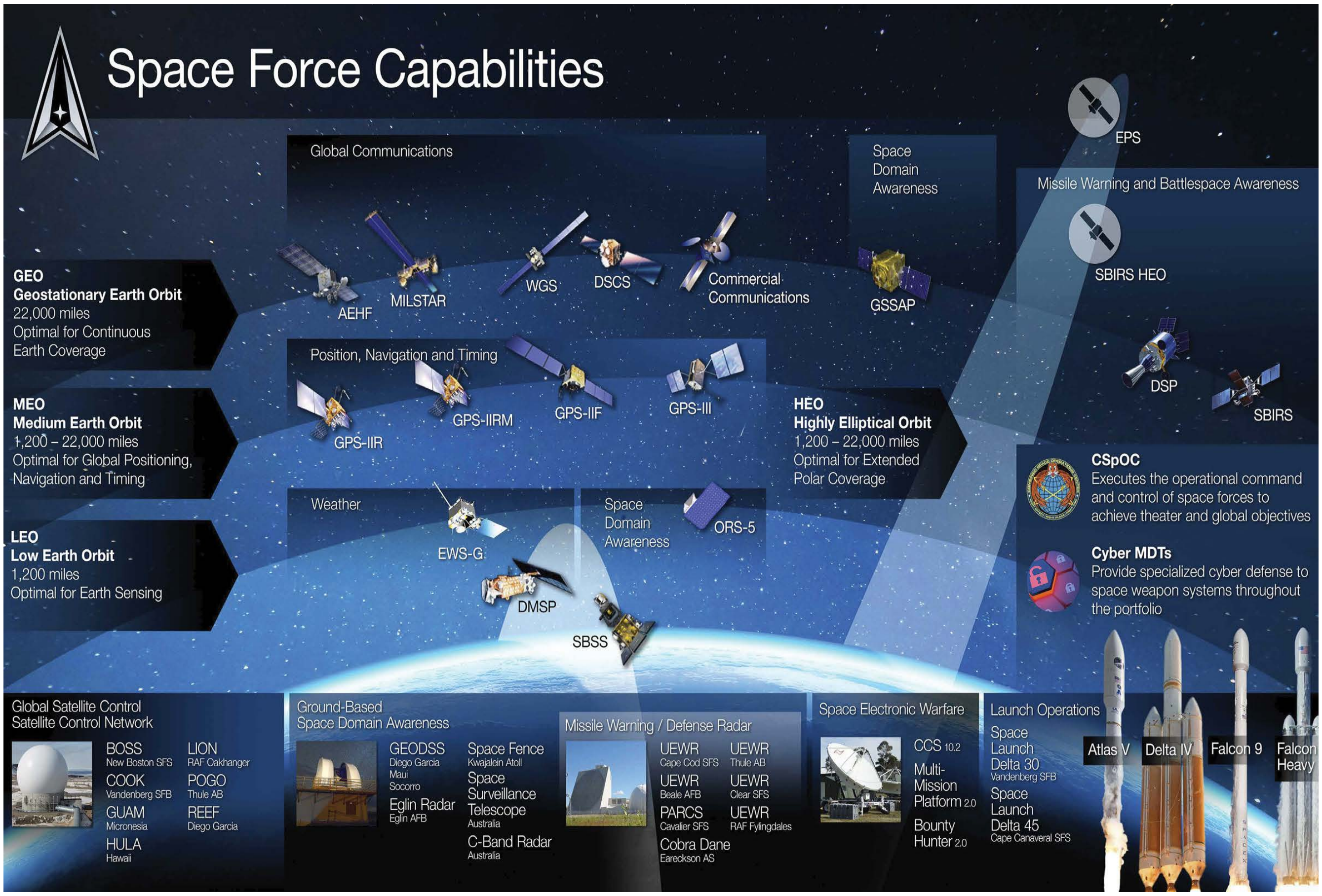


Figure 4.3. Space Force capabilities. (Reproduced from Space Operations Command, "Space Force Capabilities," fact sheet, April 15, 2022, https://www.spoc.spaceforce.mil/.)

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. France and Sellers, "Real Constraints on Spacepower," 62.
2. France and Sellers, 64.
3. Dolman, "Geostrategy in the Space Age," 86.
4. Byrne, Dickey, and Gleason, *Space Policy Primer,* table 2, p. 4.

Chapter 5

The Space Environment

Effects on Satellites in Orbit

The ideal theoretical orbit is stable in that a spacecraft's motion would be self-sustaining and expend no fuel.[1] However, a multitude of forces and factors act on satellites in Earth's orbit. This chapter covers space environment factors that affect objects in space, including forces that impact orbits, the concept of energy as it relates to Earth's "gravity well" (the gravitational pull that a large body exerts in space), and hazards to spacecraft, such as radiation and space debris.

Environmental Factors in Space

It is commonly understood that Earth's atmosphere gets thinner with increasing altitude, but less intuitive is that atmospheric drag still affects objects in "flight" as high as 600 km.[2] Drag is just one of the forces or perturbations that act to change orbital parameters. Others include Earth's oblateness (Earth's "bulge" at the equator as compared to the poles equates to a slightly increased gravitational pull), solar radiation pressure, third-body gravitational effects (moon, sun, planets, etc.), and unexpected thrusting (outgassing or malfunctioning thrusters).[3] In general, these perturbations can change orbital energy and, without active station-keeping, would reduce the altitude and eccentricity of orbits. Therefore, there is no such thing as a perfect orbit, and all satellites must expend fuel to correct back to their "nominal" (effective) orbit. Thus, a spacecraft's useful lifespan is usually a function of its fuel and orbital stability.

Gravity in Space

Gravity has been discussed previously as a function of orbital mechanics. It also provides the context for strategic analogies like key terrain and chokepoints in space and affects space launch and travel limitations.[4] Figure 5.1 shows the effect of Earth's gravity well—a function of an object's mass and distance—with respect to the moon and Mars. A frequently used term in space operations is *Delta-v* or the change in velocity required to get from one point to another. It is primarily a function of the propulsive energy required, also highlighted by the *y* axis of figure 5.1.

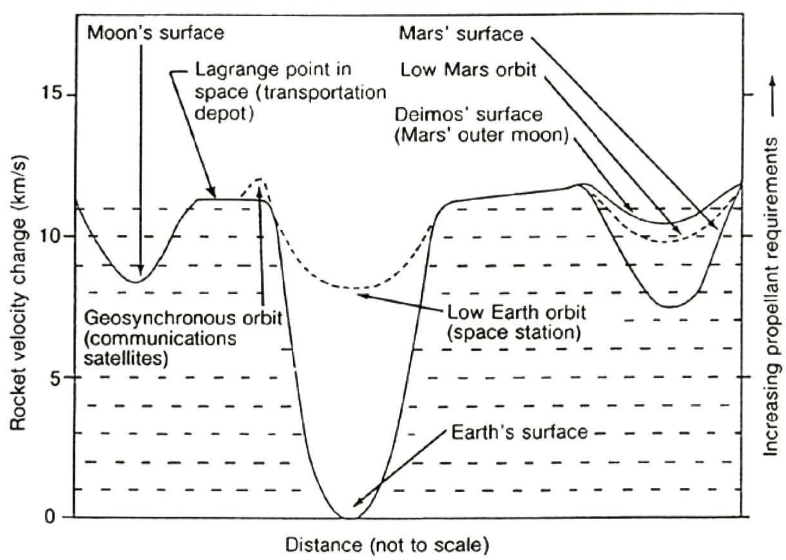


Figure 5.1. Dynamic network modeling for spaceflight logistics with time-expanded networks. (Reproduced from Koki Ho, "Dynamic Network Modeling for Spaceflight Logistics with Time-Expanded Networks" [PhD diss., Massachusetts Institute of Technology, 2015], 25, https://dspace.mit.edu/.)

Delta-v can refer to the energy required to launch an object into space or to move an object from one orbit to another. Figure 5.1 illustrates that the majority of the Delta-v required to escape Earth's gravity well is spent just to get to low Earth orbit (LEO) (100+ km), while only a comparative fraction is required to continue to geosynchronous equatorial orbit (GEO) (~36,000 km). For perspective, to launch a satellite from the earth's surface to a geostationary orbit requires 22 times more effort than to launch a satellite from the moon to a similar distance.[5] Another related concept is the relationship between time, distance, and energy in space: it takes ~5 days to get from LEO to a lunar orbit, less than half the energy required to get from the earth's surface to LEO.[6] Thus, distance, time, and energy (fuel) in space are not based on the familiar linear equations used for terrestrial travel.

Celestial Chokepoints

The terrestrial concepts of chokepoints and lanes of commerce can be applied to regions of space.[7]

Low Earth Orbit

The first strategic stronghold and most heavily populated orbital regime is LEO. Recalling the gravity well discussion, LEO is the (relatively) easiest and cheapest orbit to obtain. It is where most military systems reside and is being rapidly populated by commercial entities (e.g., SpaceX's Starlink communications constellation).

Geosynchronous Equatorial Orbit

The next chokepoint lies in GEO. Recall that the GEO orbit is a narrowly defined belt, confined by the equatorial plane and a singular precise altitude at which a satellite remains fixed over a point on the equator as it follows the earth's rotation. These requirements create a narrow lane, and a finite amount of orbital "slots" exist in GEO, largely due to concerns of signal interference between platforms.[8]

Polar Orbit

Similar to the concept of GEO's slots, another potential chokepoint is found with polar orbits, which have an inclination of 90 degrees. Polar orbits are ideal for ISR and mapping operations because, as the earth rotates, the satellite can see virtually every point on the planet.

Lagrange Points

Strategic vantage points that leverage gravitational relationships are called Lagrange points, locations where the gravity from two celestial bodies is in equilibrium. Orbits near these equilibrium points offer some significant benefits: they tend to require less fuel to maintain, and they can allow spacecraft to maintain nearly fixed positions relative to the two celestial bodies (e.g., Earth and moon). The James Webb Space Telescope, launched December 25, 2021, capitalizes on the L2 Lagrange point. By keeping the earth and moon between the spacecraft and the sun, it provides a clear view of deep space.[9]

Hazards in Space

Besides the effects of gravity on spacecraft, the space environment is subject to both natural and man-made hazards to spacecraft and the use of the electromagnetic spectrum (fig. 5.2).

Space Weather

Because of widespread reliance on space, operations depend not only on terrestrial weather assessments but also on space weather, which refers to the interaction between solar phenomena and Earth's magnetic environment. The effects of magnetic storms extend from the earth's surface to the GEO belt and beyond.

Satellites are constantly buffeted by radiation from the Van Allen radiation belts (bands of charged particles as the earth's magnetic field travels through the solar wind), solar proton events, solar energetic particles, and galactic cosmic rays.

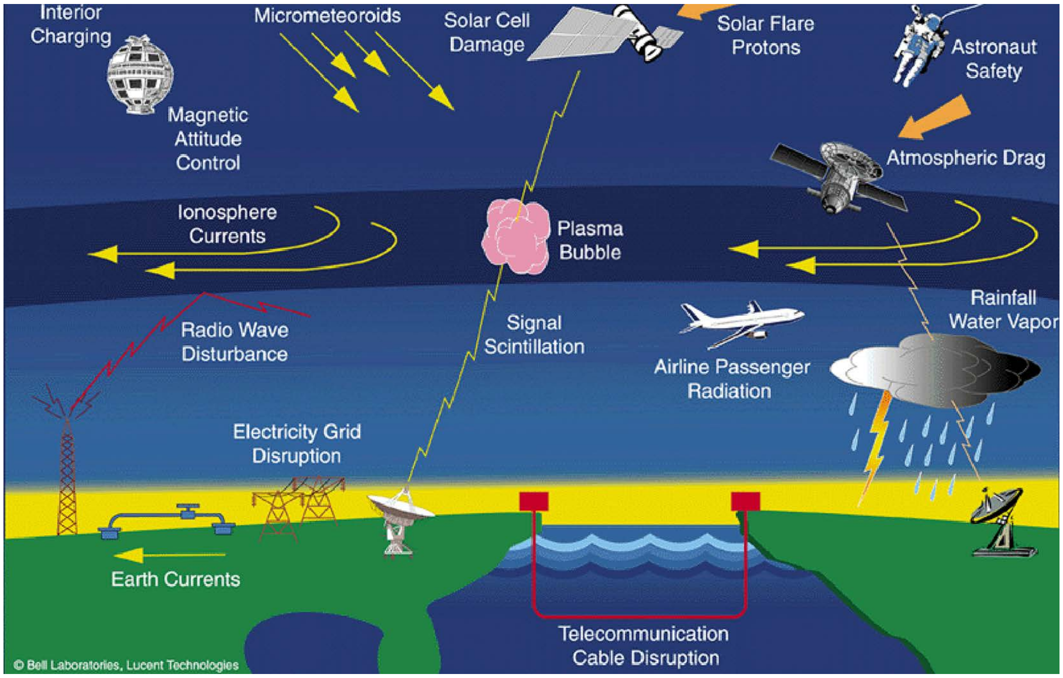


Figure 5.2. Space hazards. (Reprinted from UC Berkeley, "Space Weather Introduction," accessed September 2022, credit/copyright: Alcetel/NJIT), https://multiverse.ssl.berkeley.edu/.)

Orbital Debris

Space is often described as "congested and contested," and while natural micrometeoroids present physical danger to satellites, man-made space debris is becoming increasingly problematic. Of the approximately 500,000 space objects (marble-sized or larger) in Earth's orbit, about 45,000 (up from 27,000 in 2019) are tracked by the Department of Defense's global Space Surveillance Network sensors.[10] Because these pieces of debris are traveling up to 28,000 kilometers per hour (17,500 miles per hour), even a small object can damage or destroy a satellite. Anti-satellite (ASAT) tests, when not performed properly, only contribute to this problem. For example, in 2007 the Chinese ASAT test added more than 3,500 pieces of trackable debris into orbit, many of which will remain in orbit until 2107. More recently, the Russian ASAT test in November 2021 sent more than 1,500 pieces of trackable debris into LEO, at one point forcing the crew of the International Space Station to take shelter.[11] Space debris, unlike shrapnel from a bomb, lingers in orbits long after its creation due to the retention of the velocity and momentum of the two objects that collided. And because the debris is not under any kind of control, it remains a threat to all other objects in its path until it naturally decays due to gravity.

Summary

The space environment is not benign but presents a range of challenges to overcome (gravity) and avoid (radiation, debris). As space activity continues to escalate, the importance of understanding the space environment and its inherent risks will only grow.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Dolman, "Geostrategy in the Space Age," 84.
2. France and Sellers, "Real Constraints on Spacepower," 74.
3. France and Sellers, 74.
4. Dolman, "Geostrategy in the Space Age," 96.
5. Dolman, 94.
6. Dolman, 95.
7. Dolman, 99.
8. Dolman, 97.
9. National Aeronautics and Space Administration, "What Is a LaGrange Point?"
10. Joint Task Force – Space Defense, "18th Space Defense Squadron."
11. Raju, "Russia's Anti-satellite Test."

Chapter 6

Spacecraft

Design, Structure, and Operations

Spacecraft are complex vehicles by nature. Thousands of parts are combined and packed into the nose cone of a rocket and blasted into the cold vacuum of space. Once in orbit, the spacecraft must supply the payload with electrical power, keep it at an acceptable temperature, point its sensors in the right direction, and process its data. This chapter explains how these functions are accomplished.

A typical spacecraft consists of a mission payload (e.g., sensors, transmitters) and the bus (or platform). The bus typically comprises several supporting subsystems: propulsion and thrust, power, guidance and navigation, thermal control, and communications and data handling. Nearly all subsystems have built-in redundancy because hardware can rarely be repaired, and software is limited by what the satellite was programmed to execute prior to launch. Historically, the specific needs of the payload generate the requirements for the bus design. Individually tailored buses are expensive, as each satellite must go through the entire design process. Modular buses are now available to consumers at a more affordable cost. Commercial agencies are also able to build modular satellites for nations without native satellite construction or launch capabilities. This radical approach is reducing the overall fiscal burden in spacecraft design and enabling space novices to put satellites in orbit with moderate investment.

Propulsion and Thrust

A satellite's propulsion system is determined by the orbital position a satellite needs to reach and the type of mission. From launch to station-keeping, a satellite's propulsion system is responsible for delivering a spacecraft to its destination orbit, performing fine orbit adjustments and orbit maintenance. The propulsion system consists of pressurized gas and a nozzle that is opened whenever thrust is required, expelling some of the gas. Normally, satellites are designed with small hydrazine thrusters and/or reaction or momentum wheels to control the satellite's attitude and orbit.[1]

Electrical Power

A successful mission depends on the reliable functioning of the power subsystem. The stringent demands of performance, weight, volume, reliability, and cost make the design of the spacecraft power subsystem a challenging endeavor. Technological advances have enabled the development of more reliable and lightweight power systems. Research continues to develop novel designs that will maximize reliability while further lowering weight.

Every spacecraft electrical power subsystem has four basic components: (1) a source of energy, such as direct solar radiation, nuclear power, or chemical reactions; (2) a device for converting the energy into electricity; (3) a device for storing the electrical energy to meet peak and/or eclipse demands, such as storage batteries; and (4) a system for conditioning, charging, discharging, regulating, and distributing the generated electrical energy at specified voltage levels.

Guidance and Navigation

Attitude control can be defined as the process of achieving and maintaining a desired orientation in space. An attitude control system is both the process and hardware by which the attitude is regulated. In general, an attitude control system consists of three components: navigation sensors, a guidance section, and a control section. A guidance section generates commands to actuators based on inputs from the navigation sensors. A control section then uses actuators to keep the satellite in the correct position.

The attitude control system is required to assess the orientation of the spacecraft and its current state. An attitude maneuver is the process of reorienting the spacecraft from one attitude to another. When conducting an attitude maneuver, a navigation sensor locates known reference targets such as the earth or sun to determine the spacecraft attitude. The guidance section determines when control is required, what torques are needed, and how to generate them. The control section includes hardware and actuators that supply the control torques.[2]

Thermal Control

As previously discussed, space is a harsh environment with extreme hot and cold temperatures. The purpose of a thermal control system is to ensure that the spacecraft maintains a stable temperature so that internal electronics function at optimal temperature ranges without damage. Simply put, the sun heats one side of the spacecraft while the other side is exposed to the cold of space (possibly a difference of hundreds of degrees). Additionally, electrical parts within the spacecraft also generate heat, which can cause unstable spacecraft temperatures. Spacecraft primarily use techniques that employ conduction (moving heat using a substance as the medium) and radiation (releasing heat using electromagnetic radiation). Some of these systems include radiators, surface coatings, multilayer insulation, thermal blankets, and wire heaters.[3]

Communications and Data Handling

One of the most important aspects of the satellite is the communications and data handling subsystem (CDHS) (fig. 6.1). It serves as the ears, brain, and mouth of the satellite. The CDHS gathers raw analog data through one of the satellite's various sensors. That analog data is then processed and translated into digital data by one of the many central processing units onboard the satellite. Finally, this data is modulated onto a carrier signal, amplified, and broadcast through the antenna to a ground station and on to mission control for analysis. Spacecraft health and status information is known as telemetry data.[4]

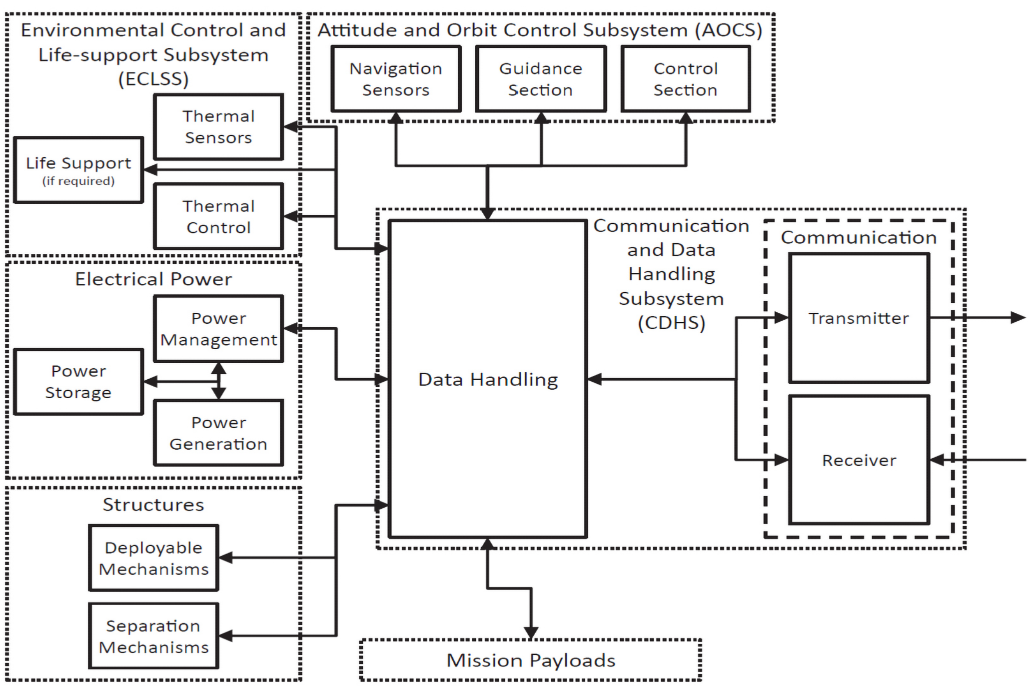


Figure 6.1. Spacecraft subsystem wiring diagram. This wiring diagram shows how the CDHS communicates with satellite subsystems, receives instructions from mission control, and transmits information to ground stations. (Developed by Maj Jonathan Burson, USAF, Air University, Maxwell AFB, AL, 2015.)

Space System Architecture

Space system architectures are composed of several "segments," a collection of components that make a space mission possible. The three primary segments are the satellite, the ground, and communications. The physical satellite is the orbiting element being used or directed to conduct a space mission. The ground segment is the antenna network, the command and control, and the network between them. The ground segment encompasses the personnel, equipment, and procedures required to receive and monitor data on the spacecraft's health and command the spacecraft daily. The communications segment manages the telemetry, tracking, and command between any ground element and the satellite in both uplink and downlink directions.[5]

Concerning military threats, the ground system can be located in any geographic combatant command while the satellite segment is only at USSPACECOM's combatant command. The communication signals are just as subject to jamming as any other signals in any theater. Understanding the segments of a space system is critical for planners when determining supported and supporting responsibilities in theater to protect space assets.

Summary

Spacecraft structures are complicated technological achievements. Their core makeup remains relatively unchanged since the dawn of spaceflight despite decades of technological developments. Satellite manufacture and design will remain costly until standardized spacecraft buses and mass bus-production lines are created. Commercial companies have already achieved this type of production, such as SpaceX's StarLink satellites. Space will always be a harsh environment and require multiple levels of redundancy across spacecraft subsystems. However, as technology advances, the survivability and lifespan of satellites and spacecraft will ultimately improve.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. ESA, "Anatomy of a Spacecraft."
2. Larson and Wertz, *Space Mission Analysis*, 354–55.
3. NASA, "Thermal Systems."
4. Sellers, *Understanding Space*, 449–56.
5. Sellers, 13–21.

Chapter 7

Space Threats

The American way of life and national instruments of power, including most US military operations, are touched in one way or another by space. The United States depends more on space than any other nation.[1] This reliance means that all three space segments—satellite, ground, and communications—are vulnerable to threats. Ground segments are protected under sovereign nation norms, and the telemetry, tracking, and command (TT&C) segment is protected by International Telecommunication Union global norms. However, no global norms of behavior for safety in orbit have been agreed upon for the orbital segment. The US Space Force asserts in its Space Capstone Publication that "military space forces should make every effort to promote responsible norms of behavior that perpetuate space as a safe and open environment in accordance with the Laws of Armed Conflict, the Outer Space Treaty, and international law, as well as U.S. Government and DoD [Department of Defense] policy."[2] This stance will intensify the need for deterrence in and through space, and deterrence increasingly requires counterspace weapons.

Adversaries may use US space system vulnerabilities to remove any advantage the United States may have in space. Planners and practitioners should understand the threats to space operations and support functions and to the capabilities that space operations provide directly to the theater. This chapter breaks counterspace threats to space assets into four categories: kinetic physical, nonkinetic physical, electronic, and cyber.

Kinetic Physical Counterspace Attack

Physical counterspace weapons utilize a direct-kill mechanism resulting in physical damage or destruction to a satellite or ground station.[3] The two types of kinetic counterspace attacks are ground station or ground-segment attacks and anti-satellite (ASAT) weapons.[4] ASATs can be terrestrial-based or co-orbital. Co-orbital ASATs are placed into orbit prior to engaging a target while terrestrially based ASATs are fired from a ground-based system directly at a satellite.[5] Currently, only the United States, China, Russia, and India have successfully tested ASAT weapons against their own assets in space.[6]

Ground Station Threats

The most cost-effective and accessible way to disrupt, deny, degrade, or destroy the utility of space systems is to attack the associated ground segments or terrestrial links due to ease of access compared to a space-based asset. The ground segment is defined by ground station operations, which include TT&C of the space nodes, space launch mission functions, satellite communications (SATCOM) transmission and reception terminals, Global Positioning System (GPS) receivers, and any other user terminal that receives information directly from the satellite.[7]

The ground segment is most vulnerable to physical and cyberattacks. Many contractor research and development facilities and satellite tracking and control stations are lightly guarded. Also, numerous space ground-segment facilities—including SATCOM, launch, data reception, control, research, integration, and testing—are described in open-source materials. These ground facilities house or develop many of the space system life-cycle components necessary to sustain US space systems. One instance of a breach of facilities occurred in 1992, when "two individuals scaled the fence surrounding the Rockwell facility in Seal Beach, California. Using false identifications, the individuals penetrated a clean room where the GPS33 satellite was being assembled and attacked it with axes." The perpetrators caused millions of dollars of damage before they were stopped.[8]

Space Orbital Threats

Spacecraft are complex, expensive, and relatively fragile. They are susceptible to a variety of destructive attacks from kinetic (also known as interceptor systems) and directed-energy weapons (DEW), such as laser and high-powered radio frequencies. From an attacker's perspective, destroying a spacecraft using an ASAT weapon may be desirable because target destruction can be complete and easily verified. Conducting such an attack can have serious political ramifications, however, as was noted after the Chinese performed their first ASAT test in 2007.[9] ASAT attacks require detailed and current positional data for the target satellite to facilitate an engagement. Efforts to gather this data are expensive and easily detectable by dedicated intelligence organizations. Nevertheless, any nation with access to medium-range ballistic missiles and a reasonable space program can develop ASAT weapons.[10] Some of the most common ASAT weapons are described below.

Kinetic-energy or interceptor weapons. Kinetic interceptor systems can be divided into distinct categories: direct-ascent interceptors; low-altitude, short-duration orbital interceptors; high-altitude, short-duration orbital interceptors; and long-duration orbital interceptors. These weapons are typically surface- or air-launched into an intercept trajectory or orbit nearly identical to that of the intended target satellite. Radar or optical systems on board the ASAT guide it into close proximity of the target satellite.[11] These kinetic impact weapons cause structural damage by hitting the target with one or more high-speed masses. Even small pieces of debris travelling at orbital velocities can substantially damage or destroy a satellite.

Direct-ascent interceptors. Direct-ascent interceptors are launched on a booster from the surface or from an aircraft into a suborbital trajectory, typically toward a target in low Earth orbit (LEO), but they can extend to geosynchronous equatorial orbit (GEO). Because these interceptor systems are on a direct suborbital trajectory, their on-orbit lifespan is often measured in minutes (but can exceed one hour if targeting GEO assets)—making them the simplest type of interceptor weapons to design, build, and test.[12] The most famous example of a direct-ascent ASAT occurred in 2007 when China successfully destroyed an inactive Chinese Fengyun-1C (FY-1C) weather satellite, causing a large debris field (fig. 7.1).

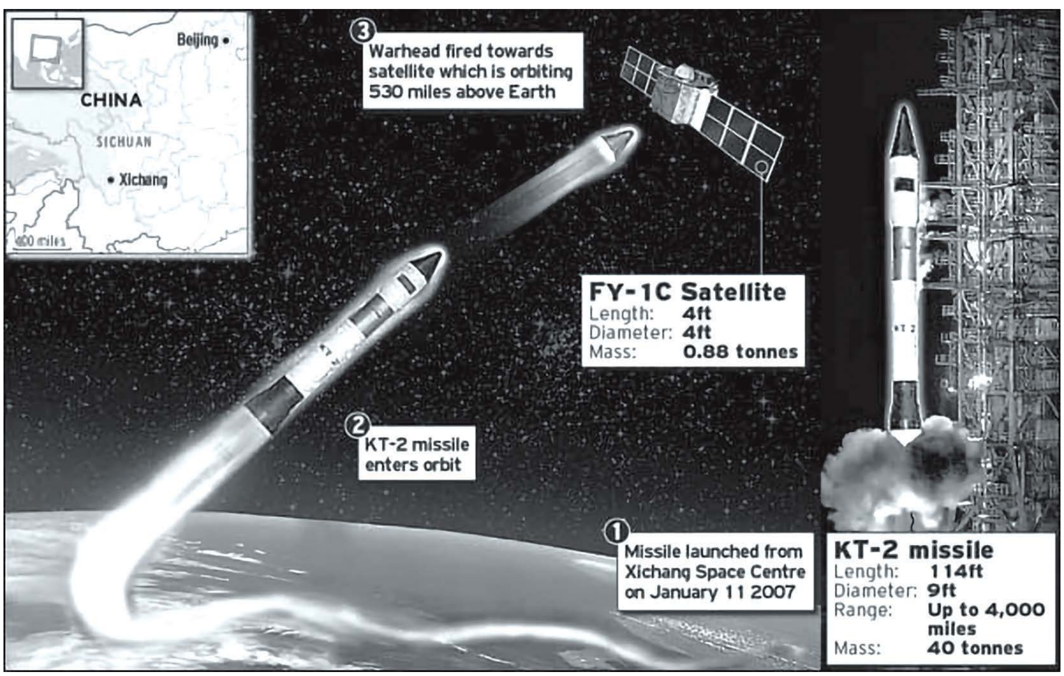


Figure 7.1. Chinese ASAT test. (Reproduced from Embassy of the United States, Addis Ababa, *Weekly Special Report* 9, no. 4 [25 January 2007]: 14.)

Kinetic physical counterspace weapons provide nonreversible effects (fig. 7.2). These weapons can cause second- and third-order effects, such as the creation of space debris or the escalation of conflict. The gravity of these consequences has increased calls for less destructive or more reversable capabilities through the use of nonkinetic counterspace weapons.

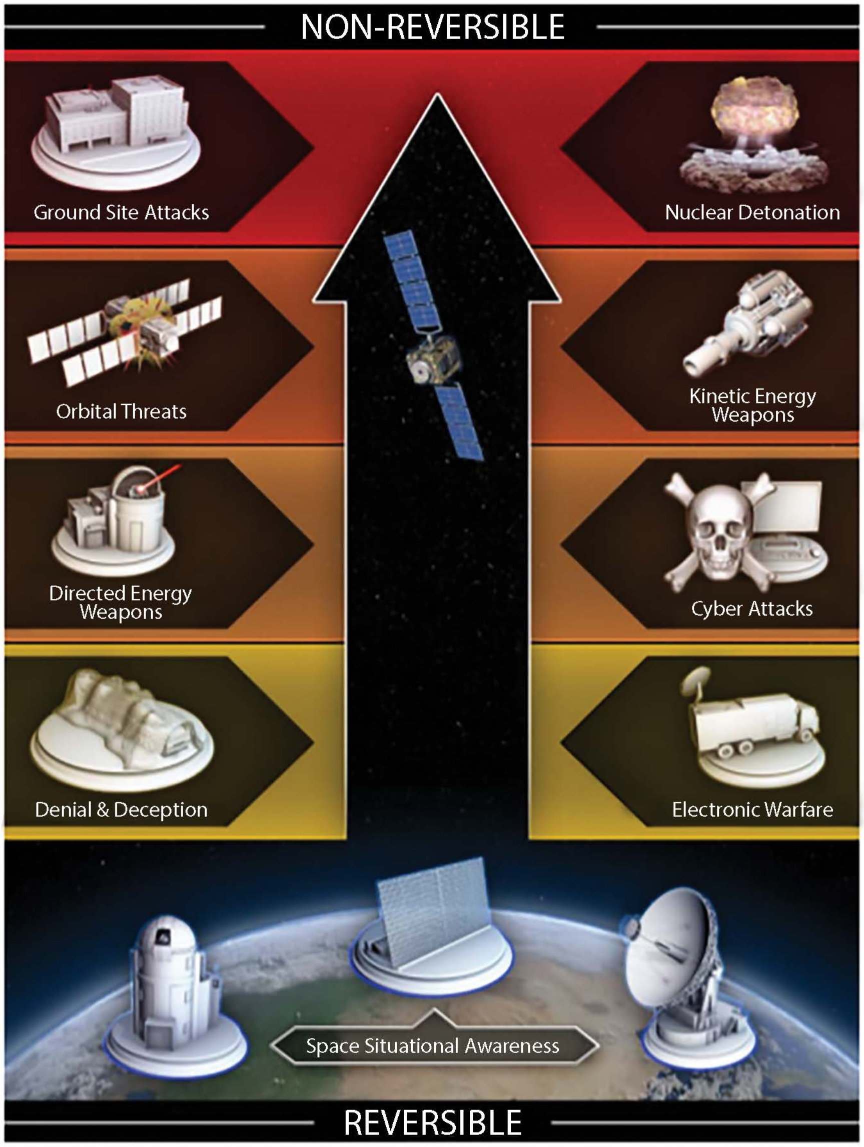


Figure 7.2. Nonreversible versus reversible effects. (Reproduced from National Air and Space Intelligence Center, *Competing in Space* [Wright-Patterson AFB, OH: NASIC, December 2018], 15, https://media.defense.gov/.)

Nonkinetic Physical Counterspace Attack

Nonkinetic counterspace weapons do not make physical contact with a system but cause physical effects. These effects can range from a permanent disability to a temporary degradation of a system. Lasers can be used to disrupt or destroy sensors due to overexposure causing overheating.[13] However, limiting factors such as weather and atmospheric conditions influence the effectiveness of ground-based lasers. There are several categories of nonkinetic weapons, such as directed-energy weapons that come in the form of lasers, radio frequency (RF) weapons, and particle beam weapons.

Directed-Energy Weapons

DEWs emit highly focused energy through lasers, particle beams, or RF waves with the goal of temporarily or permanently incapacitating a target. They can be terrestrial or orbital systems located within line of sight of their targets. The attraction of this technology resides in the capability to rapidly engage multiple targets and be fixed or mobile. DEWs can be reused and rapidly attack new targets, whereas kinetic interceptors tend to be single-shot systems that can be tracked to their target or to reentry if they miss.[14] Research into effective directed-energy weapons continues by friend and foe alike.

Laser Weapons

A laser pointed at a satellite can degrade the electronic components of the satellite's payload, rendering the payload unusable. On imagery satellites, lasers can temporarily blind or permanently disable the satellite's optics.[15] Because even civil lasers can cause damage, the US runs the laser clearinghouse to deconflict laser tests with satellite overflights and ensure awareness for both laser and satellite operators. As a threat, however, laser-based weapon systems demand high levels of power (for systems designed to leave targets permanently inoperative), precision beam quality, a large aperture beam director, and an extremely stable beam pointing system. These characteristics make laser weapons complex but not impossible.[16]

Cyberspace and Electromagnetic Attacks

Both cyber and electromagnetic forms of attack can be difficult to detect or distinguish from accidental interference, making attribution and awareness more difficult.[17] These effects would have serious operational implications if used against the Global Positioning System, Space Force satellite communications system, or other communication systems.[18]

Spoofing

Spoofing is the ability to capture, alter, and retransmit a communication stream in a way that misleads the recipient.[19] Attacking the communication segment via spoofing involves taking over the space system by appearing as an authorized user. Once individuals establish themselves in a system as trusted users, they can insert false commands into a satellite's command receiver and cause the spacecraft to malfunction or fail its mission. Spoofing is one of the most discreet and deniable forms of attacking our space systems.[20]

Electromagnetic Interference

Electromagnetic spectrum jamming uses electromagnetic energy to control the electromagnetic spectrum or to attack an adversary's access to parts or the entirety of the spectrum.[21] The effectiveness of jamming hinges on having detailed information about the target signal and knowing the location of the uplink or downlink source or destination. Open-source intelligence often provides necessary information on transmitter and receiver power and frequencies, while signals intelligence may give greater granularity on the frequency usage and time intervals of any protective measures.

Jammers emit signals that, when matched to the frequency of the signal intended to be interrupted, can mask or obstruct the reception of the desired signal.[22] Thus, all military and commercial communications in theater that use electronic signals are susceptible to jamming. For satellite systems, this includes the TT&C uplink and downlink signals to and from the satellite and the mission data that is widely transmitted to all users within the field of view (e.g., GPS) or relayed by satellites (SATCOM).

Defenses against jamming are also limited. Systems with anti-jamming capability must know the power and direction of the jamming signal. For this reason, most built-in defenses against jamming are confined to known jamming threats. Although tools to combat new threats are added to anti-jamming capabilities as they are exposed, anti-jammers lack the ability to proactively anticipate a jamming signal from an unknown direction or power level.[23]

Uplink jamming. The two types of satellite uplink signals are signals for retransmission (payload signals such as television and communications) and command uplinks to the satellite. Due to the criticality of these links, adversaries may consider jamming the payload and/or the command uplinks. Uplink jamming against a payload signal is an attractive strategy because it affects all recipients of the target communication and may render the satellite unable to perform its primary mission. Since most satellites rely on uplinked command and control information from the ground for station-keeping, payload management, and satellite health and status, attacking a satellite's uplink during critical commanding periods could also seriously degrade mission performance. Although uplink jamming appeals to adversaries because of the potential for global effects, it requires considerable jammer transmitter power to be effective.[24]

Downlink jamming. The two main targets for downlink jamming are SATCOM and positioning, navigation, and timing (PNT) broadcasts. Downlink jamming does not affect the operation of the spacecraft. The objective of downlink jamming is to inhibit the signals of SATCOM or PNT systems, making the signals unusable on the ground.[25] A downlink jamming system broadcasts an RF signal of approximately the same frequency as the targeted downlink signal but with more power. This jamming signal is transmitted toward a terrestrial (ground-based) or airborne satellite downlink reception antenna, where it overpowers the satellite's signal. In an area where many ground-based antennas are using a specific frequency (such as the frequency for GPS in mobile GPS devices), the more output power the jammer provides, the greater the number of affected receivers.[26]

For downlink jamming to be successful, the jammer must be able to operate within the line of sight (LOS) of the ground receiver and in the field of view of the ground receiver's antenna. Some SATCOM or PNT receivers may not be overpowered by the jamming signal despite being in direct LOS of the jammer. For example, airborne electromagnetic warfare platforms defeat LOS restrictions by using altitude to expand coverage and overcome ground-based jamming obstacles.[27]

Jamming technologies. Advances in technology have made equipment for satellite signal jamming smaller and cheaper. For example, the 2001 Space Commission report indicates that Russia marketed a handheld GPS jamming system.[28] It specifies that "a one-watt version of that system, the size of a cigarette pack, is able to deny access to GPS out to 80 kilometers [50 miles]; a slightly larger version can deny access out to 192 kilometers [120 miles]."[29] These jammers have had several high-profile instances of interfering with GPS signals.

Nuclear Weapon Attack: The Ultimate Space Threat

To date, only the USSR and US have detonated a nuclear weapon in space.[30] In 1962 the US conducted a high-altitude nuclear test called Project Starfish Prime, launching a 1.45 megaton atomic weapon from Johnston Atoll to LEO (400 km). When detonated, it fried more than a half-dozen satellites and a large portion of Hawaii's electric grid, besides disabling communications between some of the Hawaiian Islands. This launch and subsequent tests effectively demonstrated that a nuclear explosion can simultaneously affect a space system's ground, communications, and space segments. The Soviets and the US conducted their last high-altitude nuclear tests in November 1962, the same day the Soviets began dismantling their missiles in Cuba. The Limited Nuclear Test Ban Treaty signed on July 1963 ended orbital nuclear tests.

Since the effects of nuclear detonation move out rapidly and permeate all of space, satellites do not need to be directly targeted. The aggressor can simply aim the weapon at a point in space where the adversary has placed critical resources and detonate it—indiscriminately taking out all active satellites in the vicinity and electrical systems directly below. Like kinetic ASATs, an electromagnetic pulse on orbit will equally affect all satellites within range and is therefore an unlikely, but still possible, weapon against space systems.

Summary

As with all complex technologies, space systems have vulnerabilities that provide US adversaries valuable target sets that pose significant risk to national interests. Adversaries exploit these weaknesses to threaten US spacepower via four major areas: kinetic, nonkinetic, electromagnetic, and cyber. The ground segment presents the easiest attack vector because it is the most readily accessible. Adversaries can easily research vulnerabilities and attack multiple locations worldwide. In the electromagnetic and cyber segments, spoofing and jamming may interrupt signals traveling to and from satellites; both are difficult to control and attribute. Finally, a variety of interceptors are proven threats against satellites on orbit, while directed energy provides a glimpse into the future of counterspace operations.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Space Commission, *Report of the Commission to Assess United States National Security*, xiii.
2. US Space Force, Space Capstone Document, *Spacepower,* 43.
3. Harrison et al., *Space Threat Assessment 2021*, 4.
4. Harrison et al., 4.
5. Harrison et al., 4.
6. Weeden and Samson, *Global Counterspace Capabilities,* 1-1, 2-1, 3-1, 3-10, 4-1, 4-3.
7. Wilson, "Threats to United States Space Capabilities."
8. Wilson.
9. Kan, *China's Anti-Satellite Weapon Test*, 1–6.
10. World Economic Forum, "What If Space Was the Next Frontier for War?"
11. Wilson, "Threats to United States Space Capabilities."
12. Wilson.
13. Harrison et al., *Space Threat Assessment 2021*, 4.
14. Wilson, "Threats to United States Space Capabilities."
15. Partlow, "Space System Vulnerabilities and Defenses," 6.
16. Wilson, "Threats to United States Space Capabilities."
17. Harrison et al., *Space Threat Assessment 2021*, 5.
18. Harrison et al., 5.
19. Fritz, "Satellite Hacking," 34, 37.
20. Lee, "Counterspace Operations," 284.
21. Lee, 34.
22. Rendleman, "Lawful Response to Attacks on Space Systems," 6.
23. Partlow, "Space System Vulnerabilities and Defenses," 4, 6–9.
24. Lee, "Counterspace Operations," 281–84.
25. Wilson, "Threats to United States Space Capabilities."
26. Van Niekerk, "Use of Civilian Type GPS Receivers," 2–5.
27. Lee, "Counterspace Operations," 281–84.
28. Space Commission, *Report of the Commission to Assess United States National Security*, 20.
29. Space Commission, 20.
30. King, "Going Nuclear Over the Pacific."

Chapter 8

International Spacepower and Strategic Competition

Space is more crowded than ever before. The major space powers—the United States, Russia, and China—are producing increasingly more space assets while the number of players involved in space continues to grow. Technological advances, economic expansion, and greater competition for prestige and power have directly led to the mounting number of spacefaring nations. Just three nations could launch their own space systems in 1965. As of 2022, thirty-seven sites around the globe have launched to orbit, and 275 nations/consortiums have had satellites on orbit.[1] Space is becoming more accessible and necessary globally.

China

The United States was far ahead of China twenty years ago in economic and military power and in space capabilities. Today, China is a near-peer competitor with greater military power across the board. China possesses significant space capabilities, including an array of space launch vehicles, modern satellites, and antisatellites (ASAT).[2] It has an extensive arsenal of Earth-to-space weapons, including operational communication, radar, and Global Positioning System (GPS) jammers and Earth-to-space direct-ascent, kinetic-kill ASAT missiles to target satellites in low Earth orbit (LEO). Additionally, the 2022 *Annual Threat Assessment* from the Office of the Director of National Intelligence said China was "fielding destructive and nondestructive ground- and space-based . . . ASAT weapons" with the capability of damaging the structural components of LEO satellites.[3]

China has also made strides in other space technologies in the last decade. It returned lunar rocks via the Chang'e 5 probe in December 2000, landed the Yutu 2 rover on the little-explored far side of the moon in 2021, and completed the Tiangong crewed space station in 2022.[4] The Chinese Manned Space Agency (CMSA) hopes to keep Tiangong inhabited continuously by three astronauts for at least a decade. The space station will host many experiments from China and other countries.[5]

Russia

Russia has roots in spacepower dating to the days of the Soviet Union. After the Soviets put the first satellite, *Sputnik I,* in orbit on an R-7 ICBM in the fall of 1957, they established dominance in space through superior rocket technology.[6]

While current Russian capabilities are modest compared to China's, the nation continues to develop high-technology weapons systems under its current leadership. Russia has fielded Earth-to-space weapons (such as communication, radar, and GPS jammers).[7] In April 2020 and November 2021, Russia tested direct-ascent ASATs to enhance its defense and deterrence capabilities and project its power before international mechanisms could enact restrictions. However, the international community has made harsh allegations against Russia, accusing the nation of being irresponsible and endangering active satellites and space stations.[8]

Meanwhile, since the US retired the space shuttle program and joined with Russia to operate and staff the International Space Station (ISS), the US has become moderately dependent upon the Russian space program to ensure staffing and supplies for the ISS are regular and that the Russian escape capsule on the ISS is in good working order.

Today, recent launch failures stem in part from an aging space sector. However, they can also be attributed to the consequences of a toxic leadership culture that leads space officials to avoid declaring launch delays because of negative career implications, even if they deem a system not fit for launch.[9] At the international level, the world has condemned the explosive Russian aggression in Ukraine since 2014, and the resulting economic sanctions placed on the country may have unforeseen impacts on the future of Russian space programs.

Other Spacefaring and Emerging Space Powers

European Space Agency

The ESA is a confederation of twenty-two member countries, eleven cooperative states (though the UK participation is minimal following Brexit), and several other participating nations united around the advancement of space technology, policy, and space exploration.[10] One of the ESA's key ventures is the Galileo satellite constellation, a planned thirty-satellite (twenty-four operational, six spares) navigational network around the earth. When complete, the constellation will consist of eight primary satellites and two backup satellites per orbit in three different orbital axes. This configuration will afford the ESA a robust navigation capability, providing data virtually anywhere on Earth.[11]

India

Born purely out of economic and commercial development intentions, the Indian Space Research Organization (ISRO) developed the largest system of remote sensing satellites and one of the largest communication satellite systems in the world.[12] However, India is now leveraging the dual application of these systems because of the security landscape of the region—especially to maintain a military advantage over its most contentious neighbor, Pakistan, and to try to keep pace with space militarization by its most formidable neighbor, China. As a capable nuclear power and aggressively aspiring space power, India must be monitored.

Japan

Since the beginning of its space program in 1955, Japan has played a key role in international space missions. Japanese astronauts have been passengers on space shuttle launches, and the Japanese built substantial portions of the ISS. They also continue to enhance the technology used in space exploration. Japan's space agency, JAXA, launched the Hayabusa2 spacecraft toward the Ryugu asteroid in 2014, landed sample retrieval rovers in 2018, and returned to Earth with the samples in 2020. The Japanese Quasi-Zenith Satellite System (QZSS) provides positioning, navigation, and timing (PNT) over the Asia Oceania region with a four-satellite constellation.

Australia

Although Australia's space activities are interdependent with those of other nations, the establishment of its own national space agency in 2018 and Defence Space Command in 2022 are steps toward having a greater domestic space capability and capturing a larger share of the global space market. The country's location in the Southern Hemisphere, not far from the equator, makes it a practical choice for space communications relay and launch activities.[13] It must be noted, though, that Australia has been active with rocket testing and launches since WWII.

Iran

In 2013 Iran inaugurated a space tracking center capable of monitoring space objects and equipped with radar, electro-optical, and radio tracking. In 2017 Iran claimed to have launched a satellite into orbit, but the United States deemed the launch a failure.[14] Although the launch was unsuccessful, the aspiration of placing satellites in space and the technological means to achieve it worry the international community, particularly the United States, because of the ongoing Iranian nuclear program and the country's perceived militarized intentions. Theoretically, Iran can apply its space technological gains to develop long-range missiles capable of carrying nuclear warheads thousands of miles away.

Israel

Israel's space industry focuses on high-resolution photographic satellites in LEO and communication satellites in geosynchronous equatorial orbit (GEO). Today, the Israel Space Agency participates in several launch vehicle and satellite system projects with universities and industry partners to compete with other space powers in the field of space research and development.

North Korea

After previous failed attempts to launch a satellite in 1998, 2009, and April 2012, North Korea claimed that it successfully launched an Earth observation satellite in December 2012, indicating to the international community that North Korea might have the capability to launch a satellite into LEO.[15] The strategic ramifications of such tactical technological successes as a component of North Korea's missile ambitions highlight the threat its isolated leader poses to the region and the United States. If North Korea can successfully combine its satellite launch and nuclear weapon capabilities, a dangerous nuclear delivery system may soon be in the hands of the country's leader.[16]

South Korea

On January 30, 2013, South Korea launched its first satellite on the Naro-1 rocket. After two failed attempts, the successful launch demonstrated South Korea's missile capability to its neighbors to the north.[17] Much of South Korea's space program was developed through cooperation with other countries. For example, the launch in 2013 relied on Russian technology for the first stage.[18] In 2015 a South Korean satellite was launched from Russia.[19] South Korea and the United States signed an agreement in 2016 for bilateral cooperation of their space programs. South Korea's space program objectives include a moon landing, satellite development, and deep space exploration.[20]

Strategic Competition

China and Russia present the most immediate and serious threats to US space operations, although the number and quality of threats from North Korea and Iran are increasing.[21] Chinese and Russian strategic intentions and capabilities present urgent and enduring threats to the ability of the Department of Defense to achieve its desired end state in space. In fact, following the 2019 publication of *China's National Defense in a New Era* white paper, China has invested substantially in space and counterspace capabilities that may prove threatening to US space assets and military efficacy.[22] China and Russia have analyzed US dependencies on space and have developed doctrine, organizations, and capabilities specifically designed to contest or deny the US access to and operations in the domain. Concurrently, their use of space is expanding significantly. Both countries consider space access and denial as critical components of their national and military strategies. Specifically, Chinese and Russian military doctrine indicate that they view space as necessary to modern warfare and consider the use of counterspace capabilities as a means to reduce US, allied, and partner military effectiveness and ability to win future wars. China and Russia have weaponized space to deter and counter a possible US intervention during a regional military conflict.[23]

US policymakers and decision-makers will also need to recognize the effects of deploying space weapons on gray zone activities. Gray zone tactics are the use of force or other means to achieve objectives while staying below the threshold of a conventional war.[24] Satellites have long been an integral part of gray zone activities. Fielding space-based weapons would add another dimension of ambiguity to such activities that the United States should consider when making space weapon deployment decisions. As space becomes more congested with a burgeoning number of countries and commercial entities in orbit and dual-use capabilities proliferate, threats increase and space becomes more contested with an expanded gray zone.[25]

Summary

The global economic environment has enabled viable space programs worldwide, creating a competitive, contested, and congested international space setting. Nations with an expanding populace and technology base, such as China and India, have achieved remarkable strides in space exploration. That so many nations have sent their citizens to space is a testament to the cooperative and interdependent nature of space exploration.

Many more states are benefiting from and gaining access to space due to the improvements and proliferation of space technology. The future is bright with challenges and opportunities brought about by innovation, need, and desire. Given the achievements thus far in the space arena, the evolution of space capabilities will be fascinating.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. O'Callaghan, "How Many Countries Have Rockets Capable of Reaching Space?"; and Combined Force Space Component Command, space-track.org.
2. Gleason and Hays, "Roadmap for Assessing Space Weapons."
3. Office of the Director of National Intelligence, *Annual Threat Assessment*, 8.
4. Associated Press, "China Plans Space Station Completion."
5. Jones, "China's Tiangong Space Station."
6. Sagdeev and Eisenhower, "United States–Soviet Space Cooperation during the Cold War."
7. Gleason and Hays, "Roadmap for Assessing Space Weapons."
8. Paikowsky, "Why Russia Tested Its Anti-Satellite Weapon."
9. Zak, "Russian Space Industry in the 2010s."
10. European Space Agency, "What Is ESA?"
11. European Space Agency, "What Is Galileo?"
12. Paracha, "Military Dimensions of the Indian Space Program," 156.
13. Kennedy, "Australia Says It Is Launching Its Own Space Agency."
14. Wisconsin Project on Nuclear Arms Control, "Iran Missile Milestones."
15. Wall, "North Korea Launches Satellite."
16. Taylor and Meko, "North Korea's Weapons Programs."
17. Kwon and Mullen, "South Korean Rocket."
18. Kwon and Mullen.
19. Kang, "South Korea's Quest."
20. Yoon, "Korea, U.S. Agree."
21. Defense Intelligence Agency, *Challenges to Security in Space*, III, 31–32.
22. Stokes et al., *China's Space and Counterspace Capabilities*, 3.
23. Department of Defense, *Defense Space Strategy Summary*, 3.
24. Cohen et al., *Peering into the Crystal Ball*.
25. Gleason and Hays, "Roadmap for Assessing Space Weapons."

Chapter 9

Commercial Space

The commercialization of space began in 1962 with the passing of the Communications Satellite Act. The act provided for foreign participation “in the establishment and use” of a communications satellite system and authorized the corporation formed by that act, Communications Satellite Corporation (COMSAT), to operate the system itself or with foreign governments or businesses.[1] With this act, in 1964 COMSAT helped create the International Telecommunications Satellite Organization (INTELSAT), which operated as an international organization until it went private in 2001 as Intelsat.[2] In 1984 PanAmSat was founded, competing with INTELSAT until it was ultimately sold to Intelsat in 2006 for $4.3B.[3]

Today, NASA fosters the emerging commercial space sector in conjunction with the Federal Aviation Administration’s Office of Commercial Space Transportation and the Department of Commerce’s (DOC) Office of Space Commerce.[4] As of 2022, the DOC’s International Trade Administration website states, “Revenue from global space-based satellite services exceeds $300 billion annually, the majority of which comes from the commercial sector. . . . The increase in private enterprise growth internationally is now significantly larger than government spending on space programs; of the more than 1,300 operational US satellites 70% are for commercial use.”[5] Morgan Stanley stated in July 2020 that the global space economy could exceed $1.1 trillion by 2040.[6] A growing space industrial base poses considerable challenges and opportunities for military space applications. One example is the mega-constellations, such as Starlink, which increase orbital congestion but provide opportunity in their resilient capability through a distributed architecture.

Commercial space capabilities continue to expand and are supported by congressional authority. The 2019 and 2020 National Defense Authorization Acts (NDAA) outline congressional direction to source commercial space capabilities. For example, the 2019 NDAA states that when acquiring commercial imagery, officials should prioritize industry providers that have demonstrated proven capability and are rapidly emerging within the industry.[7] Providers should have a history of global, high-resolution, and cost-effective services; high revisit rates; and reliable performance. The requirements to use expanding commercial capabilities continue across the mission sets of imagery, space situational awareness, launch, and satellite communications.[8] Military and intelligence organizations leverage these companies to expand and enhance capabilities for the warfighter and decision-makers.

With respect to military operations, satellite communications (SATCOM) is a mixture of military satellite communications (MILSATCOM) and commercial satellite communications (COMSATCOM). Operation Desert Storm relied heavily on SATCOM to achieve operational objectives, and the demands increased drastically during Operations Iraqi Freedom and Enduring Freedom. To meet these challenges, the US relied on both military and commercial SATCOM. COMSATCOM usage during Desert Storm was about 20 percent of the total bandwidth, and this ratio grew to approximately 80 percent in Iraqi Freedom.[9] Moving forward, commercial space capabilities will continue to have a key role in supporting joint operational requirements. The Combined Space Operations Center at Vandenberg Space Force Base has a Commercial Integration Cell that allows for integration, planning, and communication between commercial capabilities and the warfighter. Much of the commercial space sector has historically focused on telecommunications; however, spacelift and commercial imagery are burgeoning markets for many space startup companies.

One of the most visible aspects of the commercial space industry is spacelift. The government is not the only US entity pursuing new options for the future of spaceflight. Commercial companies of all sizes are increasingly involved in spacelift and spaceflight capabilities for a range of customers and options. Some are looking to provide commercial spaceflight to take humans to suborbital space and beyond. Others hope to capitalize on emerging technologies to continue to reduce the cost of spacelift.

Summary

The need to access and defend outer space is escalating. Spacelift is only one aspect of a larger industrial base. The US military invests in, relies upon, and must continue to leverage the expanding space industry that will outgrow the military as the primary customer. Commercial innovation across the industry continues to enhance warfighting capabilities through improved communications, imagery, situational awareness, and weather forecasting. In addition, innovations in launch technologies are reducing the cost for space access and broadening the potential for improving space architectures. Understanding and leveraging these capacities in future operations will enable operational and strategic advantage for the United States in warfare and strategic competition.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Galloway, "Originating Communications Satellite Systems."
2. Skybrokers, "Intelsat."
3. Skybrokers, "PanAmSat."
4. Department of Commerce, "Memorandum of Agreement to Advance Coordination in Space"; and Federal Aviation Administration, "Office of Commercial Space Transportation."
5. International Trade Administration, "Commercial Space: Market Overview."
6. Morgan Stanley, "Space: Investing in the Final Frontier."
7. United States Congress, *National Defense Authorization Act for Fiscal Year 2019*, 226.
8. United States Congress, *National Defense Authorization Act for Fiscal Year 2020*.
9. Baghal, "SATCOM Supply Versus Demand."

Chapter 10

Cyber Considerations

As technology advances, the interconnected nature of space and cyber makes distinguishing where one ends and the other begins more difficult. In 2021, US Space Command (USSPACECOM) commander Gen James H. Dickinson said that achieving digital superiority requires a strong relationship between USSPACECOM and US Cyber Command (USCYBERCOM).[1] He also stated that the close alignment of both commanders will strengthen the backbone of the US and its allies.[2] Most US military operations are supported by both space and cyber in one way or another. Increasingly, the United States depends more on space and cyber than other great power nations. This reliance opens critical vulnerabilities in all space system segments—ground, communications or link, user, and space—as highlighted in the "Space Threats" chapter. The development of space capabilities often needs cyber protection to ensure mission success.

Cyberattack

Cyber operations often facilitate the espionage of space technology. Allegedly, a cyber operation conducted from 2003 to 2006 against NASA, the DOD, and defense contractors resulted in the theft of engineering documents and plans for several space systems, including the Mars Reconnaissance Orbiter.[3] Cyberattacks against satellite systems also generate their own additional effects. For example, in 2008, hackers accessed the uplink to the International Space Station, disrupting onboard operations remotely.[4] In 2014, security researchers at a cyber security conference successfully demonstrated the remote compromise of ten SATCOM user terminals, including three variants used by the DOD.[5]

Many nations and non state entities possess a highly developed cyber operations capability because the cyber arena presents a low-cost method for countering high-technology advantages like space. These capabilities make space systems with commercial telecommunications connections vulnerable to cyberattacks. While the DOD and NASA prefer using only secure, private connections for space systems, factors such as technology advancement and cost may make this goal impracticable.[6] Thus, the combination of constantly changing technology and the growth of cyberspace capabilities of unfriendly nations and non state actors means that the threat of cyber operations to space systems will continue to rise.

Space Ground Segment

A command and control (C2) segment or ground control station provides the required commanding and controlling of satellites and includes the data received from the satellite payloads and data provided to the end user. Because of their responsibility to send, collect, and distribute data, ground stations are vulnerable to cyberattacks. This vulnerability requires network hardening to prevent adversarial intrusions.[7]

Gaining access to a ground station's network can allow the adversary to interfere with a satellite's ground data architecture. An attacker could execute a denial-of-service attack limiting the control of the targeted space asset(s). The resulting damage or inability to access satellite capabilities reduces overall mission capacity.[8] USCYBERCOM works through the Joint Force Headquarters DOD Information Network (DODIN) using the Cyberspace Forces Mission Alignment Process (CFMAP) to organize cyber protection teams to harden network defenses, preventing adversaries' access to networks and systems. The CFMAP is discussed in more detail in this chapter.

Space Segment

The space segment consists of the actual satellite. Many legacy satellites in use today were developed before cyberspace was considered a serious threat vector. The lack of cyber consideration, coupled with the challenge that newer constellations are required to work with heritage software, puts these space systems at risk of cyberattacks. With more end users utilizing each space system, the more vulnerable each becomes. Most cyber vulnerabilities come from the ground control station and user interface.[9]

Communications Segment

The link segment is the electromagnetic spectrum telemetry, tracking, and commanding between the C2 segment, ground control station, and satellite(s). These transmissions are susceptible to many threats, such as spoofing and jamming (see chap. 7). The link segment is critical to the survivability of the data provided by spacecraft payloads to the end user and must be protected. Transmission security (TRANSEC) is the protection of the transmission or signal itself, a capability the DOD has relied on for years. However, it must be partnered with communications security (COMSEC) or the protection of the data being transmitted.[10]

Transmission and communications security differ in that TRANSEC prevents the interception, alteration, and denial of a signal being sent while COMSEC protects the data itself.[11] This protection is applied whether the data is being transmitted or stored for later use.[12] Protection of data requires that an encryption method be applied to the system to prevent unwanted access to system data. This encryption process can create latency within a system, causing degradation of some capabilities. USCYBERCOM's partnership in this process will ensure the appropriate level of security is applied with limited impact on operational capability. The COMSEC portion of the link segment further stresses the necessary partnership of USSPACECOM and USCYBERCOM to ensure the space systems required for national security are protected from adversarial attacks.

Cyberspace Forces Mission Alignment Process

USCYBERCOM supports combatant commands (CCMD) through the CFMAP to ensure the appropriate level of support is provided to all CCMDs and Service cyberspace components. This chapter introduces USCYBERCOM's policy, procedures, and responsibilities for implementing its CFMAP in accordance with the Unified Command Plan; Joint Publication (JP) 5-0, *Joint Planning;* and Joint Staff Execute Order (EXORD), EXORD to Implement Cyberspace Operations Command and Control Framework.[13] Table 10.1 outlines the mission alignment process for cyberspace forces.

Table 10.1. Cyberspace Forces Mission Alignment Process overview

OPR	Inputs	Risk Acceptance	Force Management	Tasks	Outputs
J5	• Strategic/national requirements • CCMD inputs	SECDEF	Apportionment (per JP 5-0)	Define • Strategic priorities • Risk informed apportionment • Support plan objectives	• Approved apportionment • Campaign plans (IMOs)
J3	• Prioritized IMOs • CDR's estimates	CDR USCYBERCOM	Allocation (per JP 5-0)	Define • Operational priorities • IMOs	Airspace control orders
JFHQ-C/ DODIN, CNMF	• Orders • Priorities • Tasks		Mission (alignment)	• Mission command	• Troop to task • Assessable tasks

Legend

ACO airspace control order
CNMF Cyber National Mission Force
DODIN Department of Defense Information Network
IMO intermediate military objective
JFHQC Joint Force Headquarters–Cyber (Air Force)

(*Source*: United States Cyber Command Instruction [USCCI] 3000-06, *Cyberspace Forces Mission Alignment Process*, January 8, 2021.)

The CFMAP is a four-step tool used by USCYBERCOM to apportion and assign cyber forces to support CCMD mission requirements. Through the process, CCMDs work with USCYBERCOM to ensure they receive the appropriate level of support for mission success. The CFMAP reviews DOD's cyberspace operations requirements using the following framework: (1) gather/prioritize requirements, (2) recommend force apportionment, (3) task and implement, and (4) assess and adjust. Prior to a CFMAP cycle, USCYBERCOM must obtain the commander's concept approval and prioritization memorandum, force capacity estimates, and assessments of prior cycle activities. Subsequently, USCYBERCOM hosts an operational planning team with stakeholders to outline priorities and key milestones for the current CFMAP year. CFMAP documents are coordinated through USCYBERCOM's cross-functional element, primarily the CFMAP Working Group, Joint Planning Working Group, Joint Planning Board, and Commander's Decision Board.[14]

Summary

USCYBERCOM's cyber operations mission is to protect all DOD network systems from threats. USCYBERCOM counters cyber threats through offensive and defensive measures, but it relies on each stakeholder to provide input for proper cyber force apportionment. The command coordinates with each stakeholder's respective J5 and requires an integrated partnership. Adversaries seek to exploit weaknesses in space through its connectivity to cyberspace. Through the CFMAP, USCYBERCOM can reduce identified gaps and strengthen the DOD's capabilities to meet present and future threats.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Johnson, "USSPACECOM Chief Highlights Link."
2. Johnson.
3. Fritz, "Satellite Hacking," 30–34.
4. Fritz, 33.
5. Santamarta, *SATCOM Terminals*, 3–8.
6. Fritz, "Satellite Hacking," 29–33.
7. Defense Intelligence Agency, *Challenges to Security in Space*, 4.
8. Hutchins, "Cyber Defense of Space Assets."
9. Werner, "Who's Keeping Satellites Safe from Cyberattacks?"
10. Secmation, "Transmission Security."
11. Secmation.
12. Secmation.
13. USCYBERCOM Instruction (USCCI) 3000-06, *Cyberspace Forces Mission Alignment Process.*
14. USCCI 3000-06, 7–8.

PART III

SPACEPOWER ORGANIZATIONS

Chapter 11

United States Space Command

Space is "a vital interest that is integral to the American way of life and national security."[1] The United States Space Command (USSPACECOM) is a unified major command tasked with protecting this increasingly critical domain. It comprises combat-ready forces from each of the services prepared to fight for and preserve US and allied space superiority.[2]

USSPACECOM Organization

The preponderance of space forces and capabilities are presented to USSPACECOM to accomplish its responsibility of planning and executing global space operations and missions. Figure 11.1 depicts the forces dedicated to support the USSPACECOM mission and how they are organized.

USSPACECOM Mission

The president's Unified Command Plan assigns most space capabilities for employment in conflict to the United States Space Command combatant command. A presidential memorandum to the secretary of defense on December 18, 2018, established USSPACECOM as a unified combatant command.[3] USSPACECOM was established as a geographic (not functional) combatant command with a defined area of responsibility (AOR) of 100 km above mean sea level extending into space.[4] Gen John Raymond, the first USSPACECOM commander, explained that this AOR was established "to solidify space as a warfighting domain and to allow us to have a clear, tighter partnership with the other geographic combatant commands and other combatant commands that we have to operate with."[5] The physical parameters define the AOR for USSPACECOM without establishing 100 kilometers as the beginning of space as a matter of policy, over which there is some political debate. With its creation, USSPACECOM now covers the largest AOR in terms of physical space.

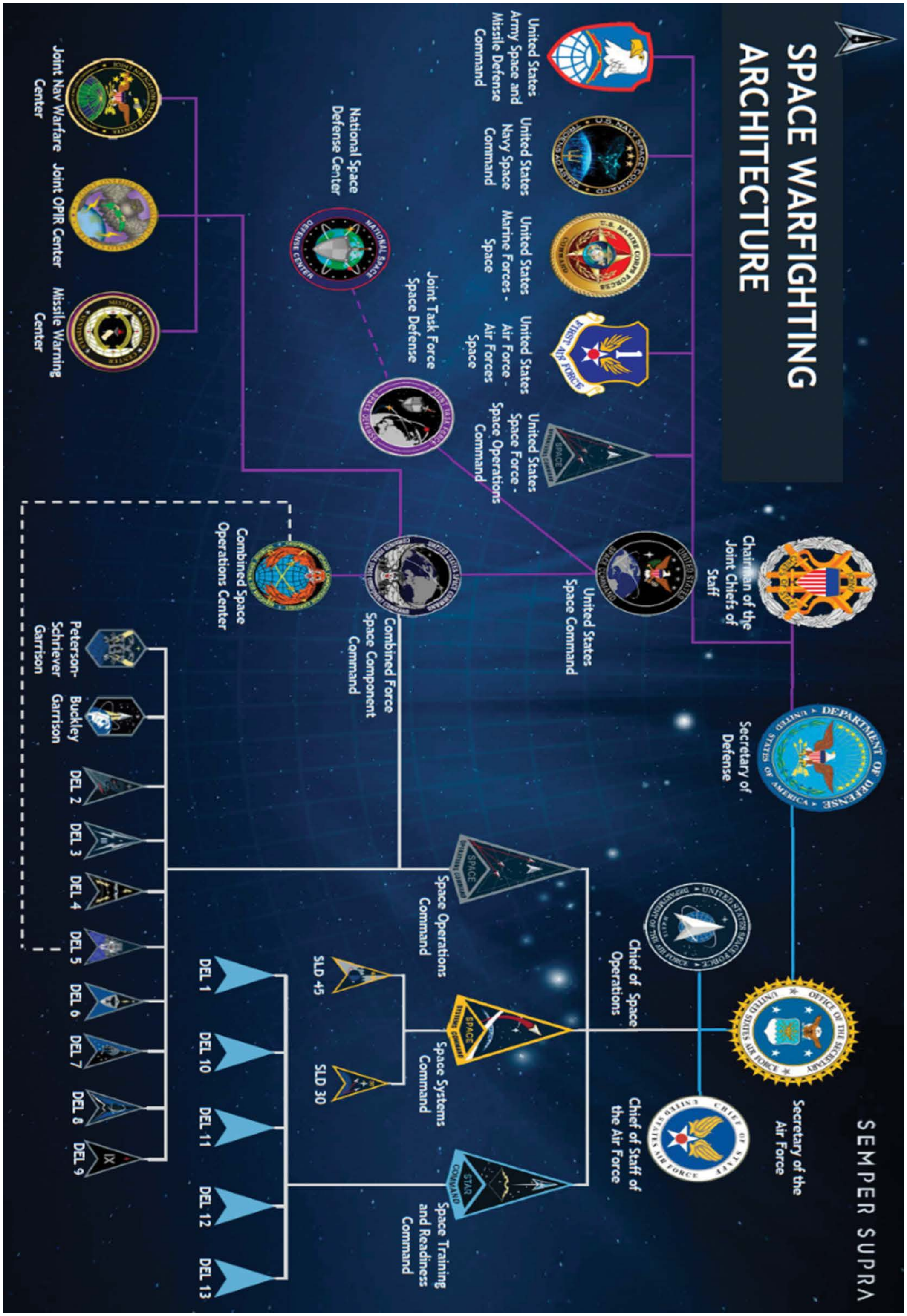
USSPACECOM's mission is to conduct "operations in, from, and to space to deter conflict, and if necessary, defeat aggression, deliver space combat power for the Joint/Combined force, and defend U.S. vital interests with allies and partners."[6] Accomplishing this mission encompasses four focus areas: "deter aggression, defeat our nation's enemies through posture and preparedness, deliver space combat power, and defend U.S., allied and partner interests."[7]

USSPACECOM Subordinate Commands

USSPACECOM's two subordinate commands are the Combined Force Space Component Command (CFSCC) and Joint Task Force–Space Defense (JTF-SD).

Combined Force Space Component Command

The CFSCC provides space effects to the joint warfighter from its headquarters at Vandenberg Space Force Base (SFB), California. It "plans, integrates, conducts, and assesses global space operations in order to deliver combat relevant space capabilities to Combatant Commanders, Coalition partners, the Joint Force, and the Nation."[8] In short, the CFSCC coordinates most space support to the joint warfighter with other combatant commands (COCOM) and air operations centers (AOC).



Legend

DEL – Delta (Space Force mission deltas or units)
SLD – Space Launch Delta

Figure 11.1. Space warfighting architecture. (*Reproduced from* USSF Space Operations Command, "Space Warfighting Architecture," fact sheet, April 15, 2022, https://www.spoc.spaceforce.mil/.)

CFSCC has four operations centers:

- Combined Space Operations Center (CSpOC), Vandenberg SFB, California – Executes operational command and control of space forces and is the lead integrating space operations center.
- Missile Warning Center (MWC), Cheyenne Mountain Space Force Station, Colorado – Provides space- and terrestrial-based missile warning data for the defense of North America.
- Joint Overhead Persistent Infrared Planning Center (JOPC), Buckley SFB, Colorado – Manages and optimizes overhead persistent infrared assets for the intelligence community, the warfighter, and national leadership.
- Joint Navigation Warfare Center (JNWC), Kirtland Air Force Base, New Mexico – Enables positioning, navigation, and timing superiority for the joint warfighter, coalition forces, and interagency partners.[9]

Joint Task Force–Space Defense

Joint Task Force–Space Defense, Schriever SFB, Colorado, ensures space assets are available to the joint warfighter throughout the full range of conflict. In unified action with mission partners, JTF-SD deters aggression, defends capabilities, and defeats adversaries throughout the continuum of conflict.[10] It directs three core functions: space domain awareness, indications and warning, and space superiority. Space domain awareness pertains to identifying and characterizing the physical and electromagnetic spectrum that could affect space operations.[11] Indications and warning is the monitoring of threatening and nonthreatening space activity to provide timely information for commanders to make decisions regarding their assets and missions.[12] Finally, space superiority encompasses activities to protect and defend space assets to maintain freedom of action in space.[13] JTF-SD conducts its mission and core functions through the National Space Defense Center (NSDC). This center provides unity of effort between the DOD, intelligence community, and National Reconnaissance Office against threats to national security interests in the space domain.[14]

USSPACECOM Service Components

As a joint warfighting command, USSPACECOM fields forces and capabilities provided by the military services. The service components to USSPACECOM are the United States Space Operations Command, United States Marine Corps Forces Space Command, United States Navy Space Command, United States Army Space and Missile Defense Command, and Air Forces Space (AFSPACE).

Summary

USSPACECOM is a unified combatant command responsible for military operations in outer space, specifically, all operations 100 km above mean sea level. It is organized into service components and two functional subordinate subcommands to accomplish its mission.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. United States Space Command, "Mission."
2. United States Space Command, "Frequently Asked Questions."
3. Presidential Memorandum for the Secretary of Defense, Establishment of United States Space Command as a Unified Combatant Command.
4. Torkelson, "Defining the Line."
5. Lopez, "SPACECOM Built for Today's Strategic Environment."
6. United States Space Command, "Organizational Fact Sheet."
7. United States Space Command, "Organizational Fact Sheet."
8. United States Space Command, "Organizational Fact Sheet."

9. Vandenberg Space Force Base, “Combined Force Space Component Command.”
10. United States Space Command, “Warfighting Units.”
11. James, “Commander’s Vision.”
12. James.
13. James.
14. James.

United States Space Force Organization

Space Policy Directive-3, National Space Traffic Management Policy, issued June 18, 2018, assigned the Department of Commerce responsibility for all space roles providing services directly to nonmilitary players in space.[1] Space Policy Directive-4, issued February 19, 2019, established the United States Space Force (USSF).[2] While a separate military branch, the USSF remains under the Department of the Air Force and depends on the US Air Force for most support functions and services.[3] The Space Force is one of seven service components under the Department of Defense while US Space Command is one of eleven unified combatant commands. Figure 12.1 depicts the Space Force organizational structure as of late 2022.

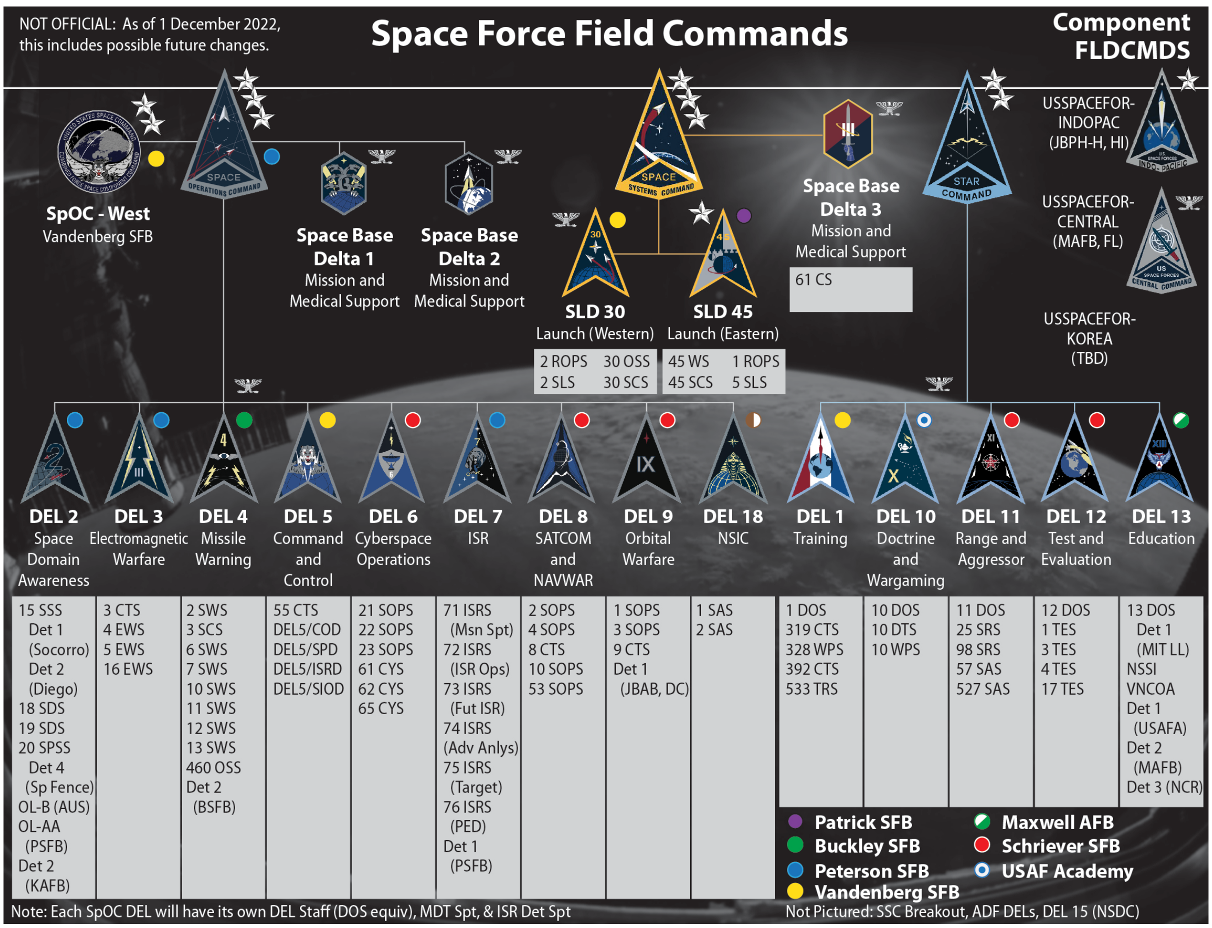


Figure 12.1. Space Force field commands. Unofficial representation of US Space Force organization, current as of December 1, 2022. Reproduced by permission of USSF/1st Delta Operations Squadron.

The chief of space operations (CSO) reports to the secretary of the Air Force in much the same way that the commandant of the Marine Corps reports to the secretary of the Navy. The 2020 National Defense Authorization Act (NDAA) prescribes the composition of the Space Force as the chief of space operations and "the space forces and such assets as may be organic therein."[4] The organization was kept lean and organized in a flattened structure with no more than three command levels between the lowest guardian and the CSO (squadron, delta, field command). Space S-staffs delineate the divisions within each delta in contrast to Air Force A-staffs. The Space Force's new field structure "effectively organizes space forces to fight in place within mission deltas and aligns installation support functions within garrisons."[5] The base operation and combat service support operations now belong to garrison commands associated with each field command. The Air Force implements installation support functions under the direction of the Space Force garrison commanders.

The USSF organizes, trains, and equips Guardians to conduct space operations in support of national objectives.[6] To execute this mission, the service is organized into three field commands below the CSO: Space Operations Command (SpOC), Space Systems Command (SSC), and Space Training and Readiness Command (STARCOM) (fig. 12.1). Beneath each field command is a wing-like equivalent organization called a delta. Space mission deltas are numbered and organized by space capability function and categorized as "operational, support or specialized as determined by the collection of its subordinate units." They are "designed to focus on executing complex missions to empower rapid decision making as an integral part of joint operations."[7]

As depicted in figure 12.1, Space Delta 2 (DEL 2) through DEL 9 are aligned under SpOC—along with Space Delta 18, the National Space Intelligence Center—while Space Delta 1 and Space Deltas 10 through 13 are aligned under STARCOM. SSC comprises Space Launch Deltas (SLD) 30 and 45 and associated acquisition deltas (not depicted). Each delta under the three field commands is tasked with a specific mission. SpOC delta missions include space domain awareness; electronic warfare; missile warning; command and control; cyberspace operations; intelligence, surveillance, and reconnaissance; satellite communications and navigation warfare; and orbital warfare. STARCOM's functions include training, doctrine and wargaming, range and aggressor, test and evaluation, and education. SSC is responsible for developing, acquiring, equipping, fielding, and sustaining space capabilities, and under SSC, Space Launch Delta (SLD) 30 is tasked with launches from the Western Test Range while SLD 45 runs Eastern Test Range launch operations.

Space Operations Command

Headquartered at Peterson SFB, Colorado, Space Operations Command (SpOC) is tasked with "protect[ing] America and our Allies in, from, and to space . . . now and in the future." SpOC also "generates, presents, and sustains combat-ready intelligence, cyber, space and combat support forces and serves as the USSF Service Component to USSPACECOM."[8] Space Force Deltas 2 through 9 and 18 are assigned to Space Operations Command to execute these missions.

Space Delta 2 (Space Domain Awareness)

Space Delta 2 "prepares and presents assigned and attached forces for the purpose of executing combat-ready space domain awareness (SDA) operations to deter aggression and, if necessary, fight to protect and defend the U.S. and our allies from attack in, through, and from space." To maximize mission success, DEL 2 partners with Space Delta 4 (Missile Warning), Space Delta 7 (ISR), and Space Delta 9 (Orbital Warfare) to dynamically integrate cross-functional monitoring and observations to enable space battle management and support multi-domain operations.[9]

Space Delta 3 (Space Electromagnetic Warfare)

Space Delta 3 trains and presents combat-ready space electromagnetic warfare (SEW) forces in support of assigned missions. Headquartered at Peterson SFB, DEL 3 employs SEW capabilities to support full-spectrum national security objectives and provides flexible and responsive space control capabilities to the commander, USSPACECOM, to defend national security space capabilities.[10]

Space Delta 4 (Missile Warning)

Space Delta 4 "operates and supports three constellations of overhead persistent infrared (OPIR) satellites and two types of ground-based radars (GBR)" to conduct "strategic and theater missile warning." DEL 4 provides strategic missile warning and space domain awareness through weapon system architectures that are intelligence-led, cyber-resilient, and driven by innovation. Lastly, DEL 4 provides tipping and cueing to terrestrial missile defense forces, enabling enhanced battlespace awareness to combatant commanders.[11]

Space Delta 5 (Command and Control)

Space Delta 5 is the USSF command and control organization within Space Operations Command that is presented to USSPACECOM to accomplish the Combined Space Operations Center (CSpOC) mission. The CSpOC continuously coordinates, integrates, and executes space operations command and control while providing "tailored space effects on demand to support combatant commanders."[12] Akin to an Air Force air operations center for space operations, the CSpOC uses a multilayered network of joint, agency, and international defense operations centers worldwide to "coordinate, command, and control space effects" ensuring the right effect or capability is available to achieve the theater mission.[13]

Space Delta 6 (Cyber Operations)

Space Delta 6 "provides assured access to space through the $6.8 billion . . . Air Force Satellite Control Network [AFSCN] and defensive cyberspace capabilities" for SpOC space mission systems and architecture. DEL 6 "plans, programs, integrates, operates, and maintains command and control and common-user systems in support of U.S. Space Command, US Air Force Warfare Center, and Missile Defense Agency." DEL 6 schedules "satellite contacts through the AFSCN for more than 190 Department of Defense, Allied, and national agency satellites," manages the USSF Digital Integrated Network communications and global circuit transport system, and safeguards space weapons systems and architecture via cyber defense operations.[14]

Space Delta 7 (Intelligence, Surveillance, and Reconnaissance)

Space Delta 7 is the ISR element of the US Space Force. The ISR delta provides "critical, time-sensitive, and actionable intelligence for space domain operations to allow for the detection, characterization and targeting of adversary space capabilities."[15] DEL 7 is highly integrated with other elements of the ISR community, such as USPACECOM, joint force commanders, research and development entities, and other USSF deltas.[16]

Space Delta 8 (Position, Navigation, Timing, and Communications)

Space Delta 8 provides satellite communications (SATCOM) and the world's gold standard for positioning, navigation, and timing (PNT) signals. It is the "focal point for ensuring US protected and assured military . . . SATCOM to the President, Secretary of Defense, national decision makers, theater commanders, and strategic and tactical forces worldwide." Additionally, DEL 8 provides the "only global utility for PNT signals to both warfighters and civilian users."[17]

Space Delta 9 (Orbital Warfare)

Space Delta 9 prepares, presents, and projects assigned and attached forces to conduct "protect and defend operations and provid[e] national decision authorities with response options to deter and, when necessary, defeat orbital threats." DEL 9 also supports DEL 2 SDA by conducting space-based battlespace characterization operations and on-orbit experimentation.[18]

Space Delta 18 (National Space Intelligence Center)

Space Delta 18 "delivers unparalleled technical expertise and game-changing intelligence—empowering national leaders, joint force warfighters, and acquisition professionals to outwit, outreach, and win in the space domain."[19] DEL 18 is responsible for producing and delivering "foundational intelligence on foreign space capabilities . . . [and] threats to space operations supporting the warfighter, acquisitions and national policy."[20]

Space Systems Command

Headquartered at Los Angeles Air Force Base, Space Systems Command pursues its mission to "pioneer, develop and deliver sustainable joint space warfighting capabilities to defend the nation and its allies and disrupt adversaries in the contested space domain."[21]Acting as the USSF space acquisition arm, this field command is responsible for "developing, acquiring, equipping, fielding, and sustaining lethal and resilient space capabilities for warfighters."[22] It also supports the deltas at Vandenberg Space Force Base (SFB), California, and Cape Canaveral Space Force Station (SFS) and Patrick SFB, Florida. As of December 2022, there are two space launch deltas: Space Launch Delta (SLD) 30 at Vandenberg SFB and SLD 45 at Patrick SFB and Cape Canaveral SFS. They deliver space launch and range operations services for access to space.

Vandenberg Space Force Base – Space Launch Delta 30

SLD 30 "manages all launch and range missions on the Western Range conducted from Vandenberg SFB, including launch activities for the Space Force, Air Force, Department of Defense, NASA, United Launch Alliance, SpaceX, Firefly Aerospace, and other commercial space partner organizations." The Western Range encompasses "99,604 acres of land, operates approximately 16 launch facilities and complexes, and maintains the second largest airfield runway [15,000 feet] in the Department of Defense."[23] SLD 30 provides the "range management architecture and installation services infrastructure that are necessary for the safe placement of satellites into polar Earth orbit, while concurrently retaining the ability to confidence test America's land-based strategic deterrent systems."[24] SLD 30 also supports force development and evaluation of all intercontinental ballistic missiles as well as Missile Defense Agency (MDA) testing and operations.[25]

Patrick Space Force Base – Space Launch Delta 45

SLD 45 provides a "vast network of radar, telemetry, and communications instrumentation support" to facilitate safe Eastern Range launches for DOD National Security Space, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the commercial sector, and the Naval Ordnance Test Unit's support to the Navy's Strategic Systems Programs missions. The Eastern Range extends more than 10,000 miles from the Florida mainland through the South Atlantic and into the Indian Ocean. It includes the launch facilities at Cape Canaveral SFS and a network of instrumentation stations, including Malabar and Jonathan Dickinson tracking annexes and downrange sites.[26]

Four active launch complexes are located at the Eastern Range: Launch Complex 37 (LC-37) for United Launch Alliance (ULA) Delta rockets, LC-40 for SpaceX Falcon 9 rockets, LC-41 for ULA Atlas rockets, and LC-39A owned by NASA. Three inactive launch complexes are also reserved for future missions and mission partners: LC-36 for Blue Origin, which is in a contract with Space Florida; LC-17, reserved for Moon Express; and LC-39B, owned by NASA and undergoing refurbishment.[27]

A unique mission at Patrick SFB is that of Detachment 3, assigned to USAF Air Combat Command, First Air Force. It is the only full-time unit in the Department of Defense that trains for and orchestrates the recovery, retrieval, and rescue of astronauts anywhere around the globe. The Det 3 mission exemplifies how the Air Force supports a USSPACECOM mission set.[28]

Space Training and Readiness Command

The purpose of Space Training and Readiness Command (STARCOM) is "to prepare combat-ready USSF forces to fight and win in a contested, degraded, and operationally-limited (CDO) environment through the deliberate development, education and training of space professionals; development of space warfighting doctrine, tactics, techniques, and procedures; and the test and evaluation of USSF capabilities."[29] STARCOM is organized into five deltas.

Space Delta 1 (Training)

Space Delta 1 at Vandenberg SFB provides initial skills training, specialized warfighter follow-on training, and advanced training events and courses to prepare USSF forces—and designated joint and allied partners—to prevail in a contested, degraded, operationally limited, all-domain environment.[30] Basic Military Training, commissioning sources, and technical schools form the basis of this squadron.

Space Delta 10 (Doctrine and Wargaming)

Space Delta 10 was activated September 30, 2021, at Peterson SFB, Colorado. DEL 10 develops USSF doctrine and tactics and conducts the USSF Lessons Learned Program. It also executes and supports wargames to posture USSF forces and designated joint and allied partners to prevail in a CDO, all-domain environment.[31]

Space Delta 11 (Range and Aggressors)

Space Delta 11 at Schriever SFB, Colorado, delivers realistic, threat-informed test and training environments by providing live, virtual, and constructive range and combat replication capability, preparing USSF, joint, and allied forces to prevail in a CDO environment.[32] The Air Force equivalent is the Red Flag exercises at the Nevada Test and Training Range to hone pilot skills in a contested environment.

Space Delta 12 (Test and Evaluation)

Space Delta 12 prepares USSF forces to prevail in a contested, degraded, and operationally limited environment through the independent test and evaluation of USSF capabilities and delivery of timely, accurate, and expert information in support of weapon system acquisition, operational acceptance, and readiness decisions.[33] Delta 12 also performs the Weapon System Evaluation Program mission to evaluate the effectiveness of fielded systems to perform missions day to day and in a CDO environment.

Space Delta 13 (Education)

Temporarily established at Maxwell AFB, Alabama, in September 2021 until permanent assignment, Space Delta 13 delivers institutional developmental education, develops US Space Force officer accessions, and executes advanced professional military education programs. DEL 13 prepares USSF forces and designated joint, interagency, and allied partners to prevail in a CDO, all-domain environment.[34] USSF is partnering with the Johns Hopkins University School of Advanced International Studies for service-specific, in-residence intermediate and senior developmental education programs. The program is planned for implementation in 2023, and selected Air University faculty will relocate to Washington, DC.[35]

Summary

The establishment of a separate United States Space Force on December 20, 2019, marked 72 years since the last service component—the US Air Force—was formed under the Department of Defense. Built to be lean and rely on the Air Force for most support functions, the USSF organizes, trains, and equips space forces to conduct space operations through the joint force.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. White House, Space Policy Directive-3, National Space Traffic Management Policy
2. White House, Space Policy Directive-4, Establishment of the United States Space Force.
3. US Space Force, "USSF Organization."
4. United States Congress, *National Defense Authorization Act for Fiscal Year 2020.*
5. US Space Force, "Transition into Field Organizational Structure."
6. US Space Force, "USSF Mission."
7. US Space Force, "Transition into Field Organizational Structure."
8. US Space Force, "About Space Operations Command."
9. US Space Force, "Space Delta 2."
10. US Space Force, "Space Delta 3."
11. US Space Force, "Space Delta 4."
12. US Space Force, "Combined Space Operations Center / Space Delta 5 Fact Sheet."
13. US Space Force, "Combined Space Operations Center / Space Delta 5 Fact Sheet."
14. US Space Force, "Space Delta 6."
15. US Space Force, "Space Delta 7."

16. US Space Force, “Space Delta 7.”
17. US Space Force, “Space Delta 8.”
18. US Space Force, “Space Delta 9.”
19. US Space Force, “Space Delta 18.”
20. US Space Force, “Space Delta 18.”
21. DeLaPena, “Military Communications,” slide 4, “Space Systems Command Mission and Vision.”
22. US Space Force, “About Space Systems Command.”
23. Vandenberg Space Force Base, “About Us: History.”
24. Vandenberg Space Force Base.
25. Vandenberg Space Force Base.
26. US Space Force, “Space Launch Delta 45 History.”
27. US Space Force.
28. Continental United States North American Defense Command – First Air Force (AFNORTH and AFSPACE), “First Air Force Takes Command of Det 3 Rescuers.”
29. US Space Force, “Space Training and Readiness Command: Who We Are.”
30. US Space Force, “Space Training and Readiness Command: How We Do It.”
31. US Space Force, “How We Do It.”
32. US Space Force, “How We Do It.”
33. US Space Force, “How We Do It.”
34. Air University Public Affairs, “Space Delta 13 Activates”; and US Space Force, “How We Do It.”
35. US Space Force, “Space Force to Partner with Johns Hopkins University.”

Chapter 13

Presentation of Forces

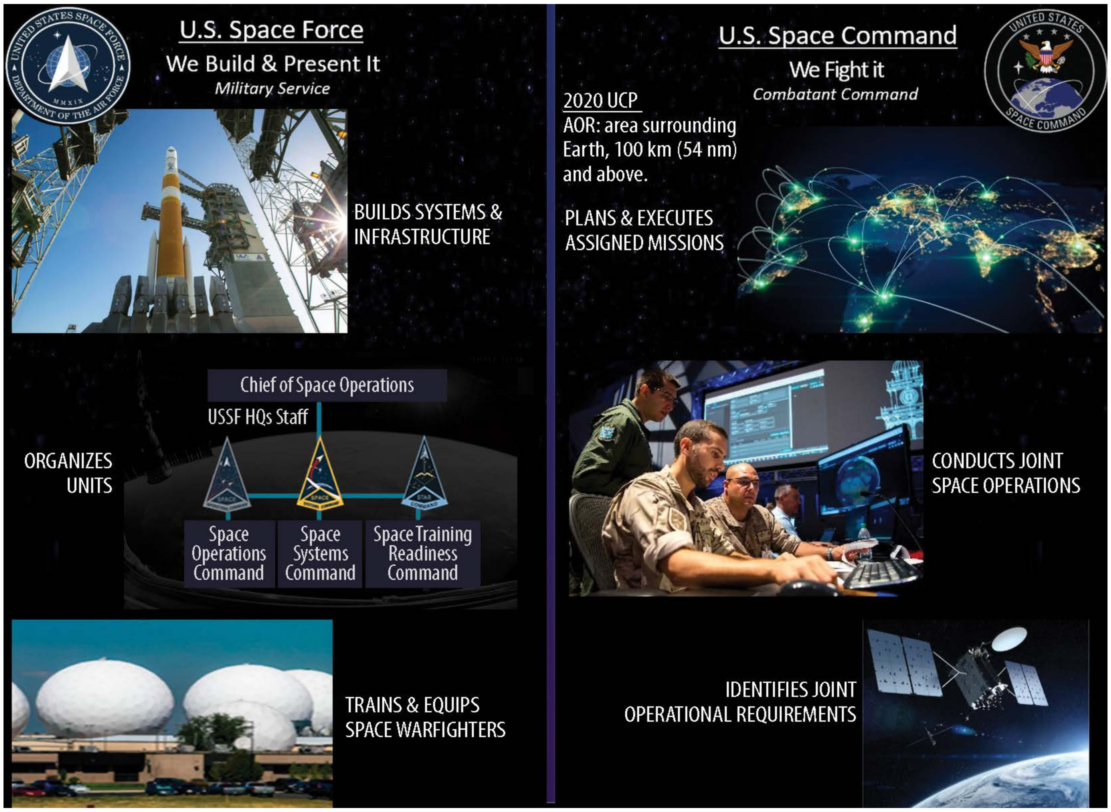


Figure 13.1. US Space Force and US Space Command missions. (Reproduced with permission from US Space Command.)

Space Force Roles and Responsibilities

Per joint doctrine, the United States Space Force (USSF) presents forces to combatant commanders in much the same way as the other military service branches. It establishes a Space Force component in each combatant command (CCMD) to provide an organizational structure for integrating Guardians into the joint force (fig. 13.2). Prior to the standup of the USSF, the joint force commander (JFC) usually designated the senior space professional in a theater as the executive agent of the space coordinating authority (SCA), who was titled the director of space forces (DIRSPACEFOR). Under this legacy construct, the DIRSPACEFOR conducted all planning, coordination, and integration of space activities on behalf of the SCA, usually delegated to the joint force air component commander (JFACC) and typically a non-space professional. USSF will normalize its presentation of forces to incorporate the Space Force component commander (COMSPACEFOR) into combatant commands in the same manner as other services (e.g., commander, Air Force forces [COMAFFOR] and commander, Army forces [COMARFOR]).

The COMSPACEFOR is responsible for all Guardians assigned or attached to the particular joint force, the commander's associated headquarters, assigned or attached Space Force forces, and command and control (C2) capabilities, as required, to which this component belongs. The Space Force intends to have a COMSPACEFOR in any joint force with assigned or attached Space Force forces. Space components will integrate at the component level, providing each combatant commander with a subordinate commander, organic space planning and employment expertise, and C2 focused on the CCMD's warfighting priorities and requirements.[1]

Should the JFC determine to execute command and control of forces through the service component, the COMSPACEFOR must be ready to conduct warfighting operations and C2 of assigned and attached forces. The JFC can further designate the COMPSPACEFOR as the Joint Force Space Component commander (JFSCC), effectively dual-hatting the senior Space Force commander in the theater. These two types of command are not mutually exclusive and may be used concurrently as has been demonstrated many times across numerous theaters.[2] For more detail on joint force organization, see Joint Publication 1 (JP-1), *Doctrine for the Armed Forces of the United States.*[3]

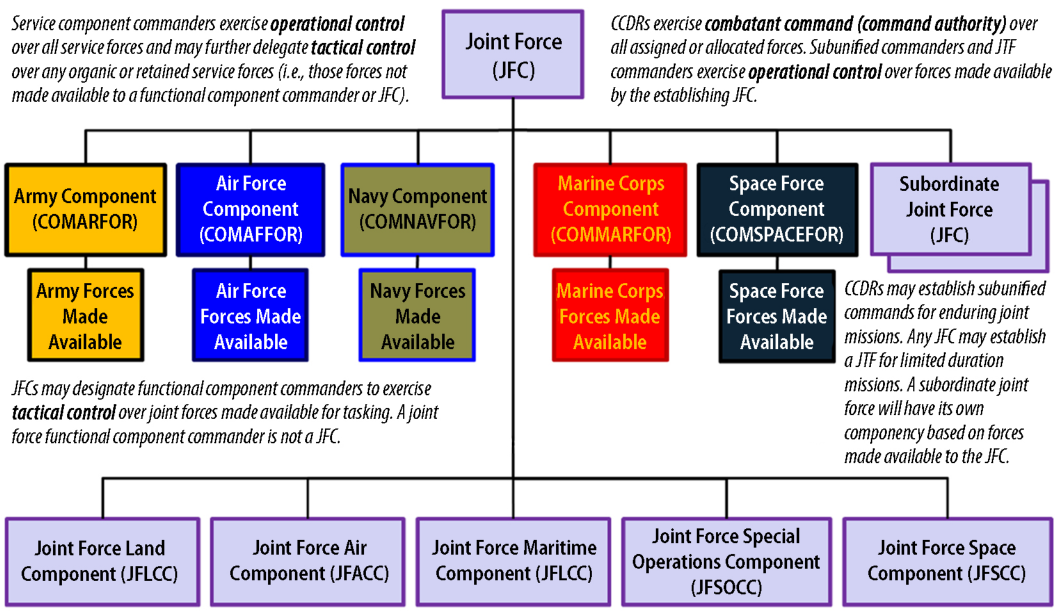


Figure 13.2. Joint force structures. (USSF/COO, Apsides #6, "Space Force Component Primer," November 19, 2021, 10. Reproduced by permission from USSF/Office of the Chief of Space Operations.)

Space Force Command and Control

Most space forces execute their wartime mission from their day-to-day locations, and US Space Command (USSPACECOM) will provide command and control in support of the other combatant commands as necessary and requested. For the few space forces and capabilities that might be assigned or attached directly to theater CCMDs, C2 will be accomplished through the COMSPACEFOR and/or the JFSCC, if so designated. This component commander should have the preponderance of space forces and the ability to command and control those forces as prescribed in joint doctrine. Actions taken by theater assigned and attached space forces that might affect operations beyond the theater and potentially reach global effects will remain under USSPACECOM for C2 and execution. However, the timing and tempo of these effects will be coordinated with theater operations and deconflicted globally. For planning and execution, contact the COMSPACEFOR/JFSCC and their associated staffs for space forces available for tasking.

Joint Integrated Space Teams

The bulk of space forces and capabilities are presented to USSPACECOM to accomplish its assigned mission of planning and executing global space operations and missions. With USSPACECOM responsible for most space operations supporting other CCMD operations globally, it must stay integrated with all CCMDs and be prepared to act as the supporting and supported command throughout global operations. To effectively do so, USSPACECOM assimilates into other CCMDs through the placement of joint integrated space teams (JIST) at the CCMD headquarters level. JISTs are small teams that facilitate coordination between USSPACECOM and other CCMD staffs for global space requirements and activities.

Component Field Commands

Additionally, like every other military service, the Space Force is responsible for presenting forces to the CCMDs through a service component organizational structure. The Space Force uses component field commands (C-FLDCOM) to integrate space operations at the component level while conducting military operations under the delegated authorities of the combatant commander. Space Force components play an "important role [in] integrating space capabilities into joint operations in every domain and every area of responsibility."[4]

Summary

USSPACECOM will command and control the majority of space forces during conflict as the supported or supporting command. The COMSPACEFOR will be responsible for assigned and attached forces to each theater CCMD and may be designated JFSCC by the JFC. The JFSCC will coordinate, synchronize, and deconflict its effects with the other components to maximize the effectiveness of fires and effects provided by all components. The COMSPACEFOR and/or JFSCC will be responsible for ensuring space forces are accounted for in the theater's time-phased force and deployment data (TPFDD) projections for level 3 plans to ensure timely arrival and effectiveness of space forces in the theater, as necessary.[5]

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Joint Publication (JP) 5-0, *Joint Planning;* and US Space Force, Apsides #6, "Space Force Component Primer," 3, 8.
2. JP 5-0; and US Space Force, 4.
3. JP-1, *Doctrine for the Armed Forces of the United States.*
4. Space Doctrine Publication 1-0, *Personnel*, 9.
5. JP 5-0, *Joint Planning, I-12*; and US Space Force, Apsides #6, "Space Force Component Primer," 7.

Chapter 14

US Government Space Organizations

As space has become a more congested, contested, and competitive domain laden with threats from near–peer adversaries, the United States government has emphasized the importance of developing space capabilities. Over a dozen government agencies are tasked with national security space responsibilities to secure space assets and prepare for future conflicts. This chapter outlines some of the key federal organizations that contribute to supporting the warfighter directly.[1]

Space-Related Intelligence Organizations

National Reconnaissance Office

The National Reconnaissance Office (NRO) develops and operates overhead reconnaissance systems and conducts intelligence-related activities for US national security. Headquartered in Chantilly, Virginia, it maintains ground stations across the United States and at joint facilities worldwide. The NRO launches space vehicles from the Eastern and Western Ranges and operates as a hybrid organization, with members from US intelligence organizations, the armed services, and the DOD civilian sector.[2]

The NRO started as a classified agency in the Department of Defense after its official establishment in 1961 and was declassified in 1992.[3] It is charged with developing, acquiring, launching, and operating America's intelligence satellites.[4] The NRO supports the United States by providing satellite communications, navigation capabilities, early missile warning, signals intelligence (SIGINT), and actionable imagery. The NRO's roles include the following: "(1) monitoring the proliferation of weapons of mass destruction; (2) tracking international terrorists, drug traffickers, and criminal organizations; (3) developing highly accurate military targeting data and bomb damage assessments; (4) supporting international peacekeeping and humanitarian relief operations; and (5) assessing the impact of natural disasters, such as earthquakes, tsunamis, floods, and fires."[5]

National Geospatial-Intelligence Agency

The National Geospatial-Intelligence Agency (NGA) is a member of the intelligence community and the Department of Defense. It is tasked with the "exploitation and analysis of imagery and geospatial information," making it the nation's primary source of geospatial intelligence (GEOINT)—information having a geographic component.[6] Data can include imagery (from visible and invisible wavelengths), maps, satellite photography, Global Positioning System (GPS) coordinates, and historical patterns. This information allows analysts to evaluate topological aspects (e.g., terrain, elevation) and detect changes in human activity to determine what and how events are happening at locations around the world, why those events matter, and what events are likely to occur next. This assessment generates timely, relevant, and accurate intelligence supporting national security and emergency response to natural or man-made disasters.[7]

The military and intelligence communities and civilian authorities use intelligence generated by the NGA. The NGA cooperates with international partners and commercial imagery providers to develop the products its users require.[8]

National Security Agency

The National Security Agency (NSA) is part of the DOD, serving as a combat support agency. The NSA supports military operations through its signals intelligence and cybersecurity activities. It exploits SIGINT data collected by satellite systems and other sources to produce intelligence products to enhance military operations, while cybersecurity protocols help ensure the security of military communications.[9]

Although the NSA works on many issues, its Defense Special Missile and Astronautics Center (DEFSMAC) focuses on space-related intelligence gathering. The DEFSMAC coordinates intelligence collection on foreign satellites and space platforms and is also responsible for providing early warning services for space and missile launches in countries at war or experiencing a crisis.[10]

National Space Intelligence Center

The National Space Intelligence Center (NSIC), also known as Space Delta 18, is headquartered and co-located with the National Air and Space Intelligence Center (NASIC) at Wright-Patterson Air Force Base, Ohio. This delta comprises Space Delta 18 headquarters staff and two squadrons, the 1st Space Analysis Squadron and the 2nd Space Analysis Squadron. Delta 18 supports the US Space Force's ability to fulfill its service responsibilities by providing foundational and science and technology intelligence for the space domain.

Other Associated Government Space Organizations

National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) is a federal agency in the Department of Commerce. NOAA's mission is to "understand and predict our changing environment, from the deep sea to outer space, and to manage and conserve America's coastal and marine resources."[11] NOAA uses a variety of assets, including advanced weather satellites, to collect the data it studies.

National Aeronautics and Space Administration

According to the 2022 National Space Strategy, the vision of the National Aeronautics and Space Administration (NASA)—"exploring the secrets of the universe for the benefit of all"—is built upon over six decades of leadership in the space arena.[12] Its associated mission is to "lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and bring new knowledge and opportunities back to Earth." This vision and mission underlie the efforts of over 18,000 team members in NASA's ten field centers, numerous installations, and Washington, DC, headquarters.[13] Although the DOD provides candidates for NASA's astronaut training program, NASA is the sole owner and facilitator of the US government's human spaceflight program.

Missile Defense Agency

The Missile Defense Agency (MDA) is a research, development, and acquisition agency within the DOD.[14] Its mission is to "develop, test, and field an integrated, layered Ballistic Missile Defense System (BMDS) to defend the United States, its deployed forces, allies, and friends against all ranges of enemy ballistic missiles in all phases of flight."[15]

The MDA uses a variety of networked space- and terrestrial-based sensors and radars to detect and track missile threats worldwide. The information from these sensors is communicated to ground- and sea-based interceptors via a sophisticated C2 network.[16]

Defense Advanced Research Projects Agency

The Defense Advanced Research Projects Agency (DARPA) dates back to the launch of *Sputnik I* in 1957. Since then, it has held to a singular and enduring mission: to make pivotal investments in breakthrough technologies for national security. Departing from the typical mold of incremental advances, DARPA seeks to achieve transformational changes in technology.[17] Toward this end, it develops revolutionary technology and proof-of-concept systems that may lead to future acquisition programs.[18]

Summary

These organizations are major contributors to US government space activities, and each organization has a specific role in supporting the warfighter. The integrated efforts of military, civilian, and commercial space organizations ensure that US national spacepower is safely developed, operated, and protected within the space domain.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Richardson, "National Security Space Organizations 101."
2. NRO, "Who We Are."
3. NRO, "Who We Are."
4. NRO, "About NRO."
5. NRO, "What We Do."
6. National Geospatial-Intelligence Agency (NGA), "NGA's Mission."
7. NGA and National System for Geospatial Intelligence (NSG), *Geospatial Intelligence*, 3.
8. NSG, 29–30.
9. National Security Agency/Central Security Service (NSA/CSS), "Mission and Combat Support."
10. NSA/CSS, "Profiling DEFSMAC."
11. NOAA, "Our Mission and Vision."
12. NASA, *NASA Strategic Plan 2022*, 6.
13. NASA, "Our Mission and Values"; NASA, "NASA Centers and Facilities"; and NASA, "Who Works Where."
14. MDA, "Agency in Brief."
15. MDA, "Our Mission."
16. MDA, "Ballistic Missile Defense System."
17. Federal Communications Commission, "What We Do."
18. Defense Advanced Research Project Agency, "About DARPA."

Chapter 15

Space Acquisition Organizations

Space acquisition is a tough business. Warfighters want the maximum capability they can get; they want it now and within budget. To satisfy the warfighter's needs, the Space Force, Air Force, Navy, and Army employ their own space acquisition organizations. In many ways, space acquisition executes similarly to non-space acquisition, using the same processes, regulations, and policies. However, space systems are low quantity, high-cost assets with unique requirements. They must endure the harsh environment of space, have minimal component failure due to lack of on-orbit maintenance, and provide critical capabilities to warfighters in the ultimate high ground.

The organizations described in this chapter use the defense acquisition system process to identify existing or developing technologies to meet user needs. Acquisition organizations then work closely with key agencies—relying heavily on universities for basic research, national labs for application, and industry for advanced technology development. In addition, system program offices (SPO) ensure that contractors manufacture each end item according to specifications. SPOs also work with an independent test organization to validate that operational system requirements have been met. During the acquisition process, planners for new space programs must consider the physical limitations of the intended operating environment and inherent differences in space systems procurement.

DOD acquisition of space systems is more complex and expensive, involves more advanced technology, and has a different life-cycle cost than other types of systems. This chapter outlines the major DOD and associated space acquisition organizations and explains why the characteristics of space result in acquisition quandaries.

Key DOD Space Acquisition Organizations

Space Systems Command

Headquartered at Los Angeles Space Force Base, California, Space Systems Command (SSC) is responsible for developing, acquiring, equipping, fielding, and sustaining lethal and resilient space capabilities for warfighters. As part of fielding, the command is responsible for launch operations, on-orbit checkout, developmental testing, sustainment, and maintenance of military satellite constellations and other Department of Defense space systems. SSC manages a portfolio that includes satellite communications (SATCOM), global positioning, infrared, space superiority, weather, and responsive space systems. The United States Space Force (USSF) space launch mission and launch bases are aligned under SSC, which acts as the Space Force's lead interface with the Air Force Research Laboratory (AFRL).[1]

Space Rapid Capabilities Office

Headquartered at Kirtland AFB in Albuquerque, New Mexico, the Space Rapid Capabilities Office (SpRCO) is a direct reporting unit of the US Space Force and has a specialized, restricted, and unique mission. The SpRCO was created in response to the National Defense Strategy calling for improvements to defense acquisition. It is a small, streamlined organization with dedicated acquisition support functions. These include contracting, financial management, human resources, security, program management, and technical engineering support critical in enabling the rapid response required for unique missions. SpRCO expedites delivery and deployment of space capabilities in response to the requirements of the commander, US Space Command.[2]

Space Development Agency

Headquartered in Washington, DC, the Space Development Agency (SDA) aims to provide responsive and resilient space capabilities and support of the joint force and as part of Joint All-Domain Command and Control (JADC2)—increasing warfighters' lethality, maneuverability, and survivability. The SDA delivers capabilities to joint warfighting forces in two-year tranches to develop and field capabilities more quickly.[3]

National Reconnaissance Office

Refer to chapter 14, "US Government Space Organizations," for more information on the National Reconnaissance Office (NRO) as an acquisition organization.

Laboratories and Universities

In addition to the Space Force, Air Force, Army, and Navy space acquisition units, various laboratories, universities, and industry partners assist in the research portion of the acquisition process of DOD space systems to meet the national security objectives of the United States. While these partners are too numerous to list here, those described below provide an idea of the organizations that affect space acquisition. The United States relies on universities, nonprofit institutions, and its own in-house laboratories to continue to improve its capabilities tied to long-term national security needs. Universities are used heavily for basic research, national labs and industry share most of the application research, and industry is also the primary contributor of advanced development.[4]

Department of Defense Laboratories

The Air Force, Navy, and Army have their own labs to assist in developing their required capabilities to meet specific operational requirements. The organizations tie to the acquisition program offices in a supporting role for developing innovative technologies and systems.

Air Force Research Laboratory. Headquartered at Wright-Patterson AFB, Ohio, the AFRL supports the science and technology needs of the Air Force and the Space Force. The Space Vehicles Directorate "develops and transitions technologies for more effective and affordable space missions" in support of US defense. SpaceWERX is the US Space Force branch of the AFWERX team, focused on advancing space technology innovation and expanding the space industrial base. It accomplishes these goals by "guiding additional partners, leveraging commercial investment, and rapidly pursuing innovative technologies while closely aligning its efforts with Space Force operators and acquisition professionals."[5]

US Naval Research Laboratory. Located in Washington, DC, the Naval Research Laboratory conducts multidisciplinary program research and technology development for maritime applications. It also serves as the Navy's lead for space technology, development, and support.[6]

US Army Space and Missile Defense Command Technical Center. The US Army Space and Missile Defense Command (USASMDC) Technical Center is located at Redstone Arsenal, Alabama. Its purpose is to research, develop, test, and integrate new solutions. The Space and Strategic Systems Directorate is the primary division responsible for researching space capabilities for the Army.[7]

Federally Funded Research and Development Centers

The DOD partners with and funds numerous commercial and academic institutions to advance the science and technology vital to national security interests. Federally funded research and development centers (FFRDC) assist the government with research and analysis, systems development, and acquisition in an advisor or supporting role to the government. FFRDCs are nonprofit, independent organizations and do not manufacture for, compete with, or work for commercial companies. The following are some examples of FFRDCs and their focus areas.

The Aerospace Corporation. Aerospace is headquartered in El Segundo, California, and performs objective technical analyses and assessments for government, civil, and commercial customers. It was created in 1960 in response to a period of rapid growth in space technologies, when advances in space defined the cutting edge. Aerospace provides levels of support to the immediate and long-term requirements of military and intelligence space programs and other programs of national significance.[8]

The MITRE Corporation. MITRE works in the public interest across federal, state, and local governments as well as industry and academia. It brings "innovative ideas into existence in areas as varied as artificial intelligence, intuitive data science, quantum information science, health informatics, space security, economic and public policy, trustworthy autonomy, cyber threat sharing, and cyber resilience."[9]

Sandia National Laboratories. Sandia National Laboratories (SNL) is headquartered in Albuquerque, New Mexico, with a second lab in Livermore, California, and other offices across the United States. SNL is operated and managed by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc.[10] Sandia has contributed to the overall use of space for national interests through improving satellite capabilities, developing radiation hardening of electronics in space, testing space materials, and innovating engineering solutions for space challenges.[11]

Massachusetts Institute of Technology's Lincoln Laboratory. MIT's Lincoln Laboratory has several mission areas, including space systems and technology. In this role, the laboratory's focus is on developing technology to help achieve space domain awareness. It works with various space systems to improve man-made satellite detection, tracking, and identification; space flight safety; mission assessments; and technology for space environment monitoring.[12]

Brookhaven National Laboratory. Brookhaven is located in Upton, New York, and funded by the Department of Energy's Office of Science. One of the facilities at Brookhaven is the NASA Space Radiation Laboratory. The radiation lab simulates space radiation and analyzes its effects on biological specimens and industrial materials.[13] This analysis is critical to ensuring the safety of astronauts and the survivability of satellite materials to avert premature system failure.

Lawrence Livermore National Laboratory. Located in Livermore, California, the lab is funded by the Department of Energy's National Nuclear Security Administration. Its mission is to provide science and technology to enhance national defense, reduce the global threat of terrorism and weapons of mass destruction, and respond to scientific issues of national importance.[14]

Summary

Space is an unforgiving environment where systems must survive extreme cold and hot temperatures and are subject to space debris, cosmic rays, radiation belt particles, energetic plasma, and solar flare particles. These conditions can cause interference, punctures to the spacecraft, radiation damage, particle charging, leakage, and erosion.[15] Space systems are often required to subsist for a decade or longer in this punishing atmosphere without the opportunity for maintenance or overhauls. Mission assurance planning includes activities for checking that space systems operate properly once launched into orbit since retrieval for repair is impractical.[16] Space acquisition programs are typically always in development due to the physical limitations and uniqueness of space. As with all DOD acquisition programs, tradeoffs occur between cost, schedule, and performance in the space sector. If a program requires something to be acquired faster or to get back on schedule, more money can be inserted into the program or performance reduced.

Characteristically, increases in the capability of a program cause its cost to rise and its schedule to lengthen. Since satellites are often designed to last for long durations without maintenance, any change to schedule or performance generally results in a significant cost increase. Acquisition programs cannot reduce schedules or change requirements without affecting costs, just as they cannot obtain a cheaper product on a faster timeline with more advanced technology. There is an art to balancing the tradeoffs among cost, schedule, and performance to get a system fielded on time, within budget, and in compliance with all laws, policies, and regulations.[17]

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. US Space Force, "Space Systems Command."
2. US Space Force, "Space Rapid Capabilities Office."
3. Space Development Agency, "Who We Are."
4. Department of Defense Research and Engineering Enterprise, "About Us."
5. US Air Force, "Air Force Research Laboratory."
6. US Naval Research Laboratory, "About Us."
7. USASMDC, "Technical Center."

8. The Aerospace Corporation, "Dedicated Space Enterprise."
9. MITRE Corporation, "Center for Data-Driven Policy: Tangible, Measurable, and Innovative Ideas."
10. Sandia National Laboratories, "About Sandia."
11. Sandia National Laboratories, "Sandia Technology in Space."
12. Massachusetts Institute of Technology, Lincoln Laboratory, "Space Systems and Technology."
13. Brookhaven National Laboratory, "Research Facilities."
14. Lawrence Livermore National Laboratory, "TESSA [Testbed Environment for Space Situational Awareness]."
15. Finckenor and de Groh, S*pace Environmental Effects*.
16. Defense Acquisition University, "Space Acq RDT," slide 3, notes.
17. Hitchens, "How Space Force Acquisition Works."

PART IV

MISSION SETS AND OPERATIONS

Chapter 16

Positioning, Navigation, and Timing

Although positioning, navigation, and timing (PNT) have become synonymous with the Global Positioning System (GPS), this capability is only one system of what is known globally as the Global Navigation Satellite System (GNSS). This chapter's focus is GPS missions, segments, capabilities, and limitations and future concepts in development. The GPS's primary mission is to give users navigation information no matter where they are—on land, at sea, in the air, and even in space.[1] The civilian population and military personnel alike incorporate GPS-provided PNT services into everyday life. PNT is used in mobile phones, computers, cars, ships, aircraft, spacecraft, missiles, bombs, and artillery, as a few examples. It is a critical part of the modern technological infrastructure and a backbone of civil, economic, and defense activities globally.[2]

Global Positioning System Missions

Military and civilian users worldwide use GPS positioning and timing data for navigation. Additionally, GPS performs a tertiary nuclear detonation detection mission.

Navigation

The mission most commonly associated with GPS is navigation. GPS offers highly accurate position, velocity, date, and time information anywhere in the world through a technique called trilateration. A minimum of four GPS satellites—the number required to perform trilateration—is guaranteed anywhere on the earth between the 70° north and 70° south latitudes—making GPS a relatively global system. GPS capability is limited closer to the North and South poles due to lack of constellation coverage over the poles.[3]

Another benefit of GPS is its operability in all weather conditions. Unlike laser-guided munitions, GPS-aided bombs work anytime—rain, snow, fog, day, or night. This all-weather, worldwide capability has driven the development of numerous positioning, targeting, and mapping applications useful to many commercial industry sectors. These include surveying, energy exploration, transportation, construction, and farming.

Time Transfer

The second mission of GPS is time transfer. The time standard that the DOD uses is Coordinated Universal Time or UTC. This is the time maintained by the US Naval Observatory (USNO) and the de facto standard of timekeeping worldwide. Typically, it is not practical to call the USNO whenever a time update is needed. Because GPS is widely available at all times and places, it has become the DOD's primary relay for timing information from the USNO. GPS time never deviates more than 20 nanoseconds from USNO time.

One application of the time transfer mission is synchronizing digital communications. GPS timing allows satellites and communication terminals to transfer simultaneously to the new frequency during frequency-hopping operations.[4] Time transfer also affects communications outside of GPS—including the internet, financial and banking systems, and mobile phones—by providing a highly accurate time stamp for each packet of information sent over those networks.[5]

Nuclear Detonation Detection System

GPS satellites carry an additional payload suite to support the Nuclear Detonation (NUDET) Detection System (NDS). The sensor array includes optical, X-ray, dosimeter, and electromagnetic pulse (EMP) sensors. The sensors detect and measure light, X-ray, subatomic particles, and EMP characteristics to pinpoint the location and yield of a surface or an airborne nuclear detonation. The information sensed on the GPS NDS system is relayed to the ground-based Integrated Correlation and Display System (ICADS).[6] Among the tasks that the NDS supports are treaty monitoring and nuclear force management.

Global Positioning System Segments

Space (or satellites), control, and user equipment are the three elements of GPS. Every space architecture is built of "segments," common elements required to make a space system fully functional. GPS is no different and must be understood as a whole system when planning in contested situations. The link can be considered a fourth element; it includes the electromagnetic spectrum used to carry the information to users and command and control of the constellation. For GPS, the S-band is used for command and control while the L-band delivers user data.

Space Segment (Satellites)

At a minimum, the GPS constellation needs twenty-four satellites in six orbital planes to ensure that the user has at least four satellites in view at all times. Although more GPS satellites are in orbit than can be operationally employed at one time, the current operational constellation consists of thirty-one Block IIR, IIR-M, IIF, and Block III satellites in a semi-synchronous orbit, or medium Earth orbit (MEO), at approximately 20,000 km from the earth.[7] Figure 16.1 overviews the evolution of GPS and inherent capabilities.

Figure 16.1. GPS block capabilities. (Reproduced from Alan Cameron, "Benefits Coming from the GPS III Constellation," *GPS World*, April 1, 2019, https://www.gpsworld.com/. Graphic sourced from Lockheed Martin and Boeing Co.)

GPS offers three types of services to its user base: Standard Positioning Service (SPS), Precise Positioning Service (PPS), and the Safety-of-Life (SoL) frequency. SPS is available for anyone's use—military or civil. SPS accuracy is within 3 to 5 meters. Only authorized personnel can access PPS—those with the correct decryption keys, such as the US military and its allies. PPS accuracy is within 2 to 4 meters. The SoL signal is a designated civil aviation frequency for protected aeronautical radio navigation services that provide higher power and greater reliability.[8] Several signals and codes comprise each of the GPS services. Civilian and military GPS receivers are built and coded to receive the appropriate service and data necessary for mission execution.

Control Segment (Commanding)

The control segment commands GPS satellites to ensure that they remain in the proper course with the correct navigational data to provide the available signals. This section covers how the control segment works and what the GPS Operations Center (GPSOC) offers military and civilian users.

The headquarters for the control segment is the master control station (MCS) at Schriever SFB. It is operated by the 2nd Space Operations Squadron (SOPS) with support from 19 SOPS, an Air Force Reserve unit. An alternate master control station (AMCS) at Vandenberg SFB became operational in 2007 when the Air Force implemented the GPS architecture evolution plan (AEP). The AEP enabled the Air Force to replace "its original, mainframe-based GPS master control station with an entirely new one built on modern . . . [information] technologies."[9]

As a part of the MCS team, the GPSOC is the one-stop shop for accuracy models, constellation health, and GPS service questions. It operates 24/7 and provides assistance at any time. The ops center supports the military and civil community. The Federal Aviation Administration (FAA) or Coast Guard can use the GPSOC to answer civil-related GPS questions.

The MCS provides command and control of the GPS satellites via monitor stations and ground antennas. High-quality GPS receivers are placed globally at precise locations (see fig. 16.2). These receivers track satellites just as any other ground receiver would—they obtain the satellite's ephemeris data used to calculate its position in orbit.[10] Information is then transferred to the MCS and processed through a Kalman filter. This filter is an algorithm that determines how the satellite has deviated from where it should be. The MCS transmits that data back to the satellite via the ground antenna to update the satellite with its true location and time.

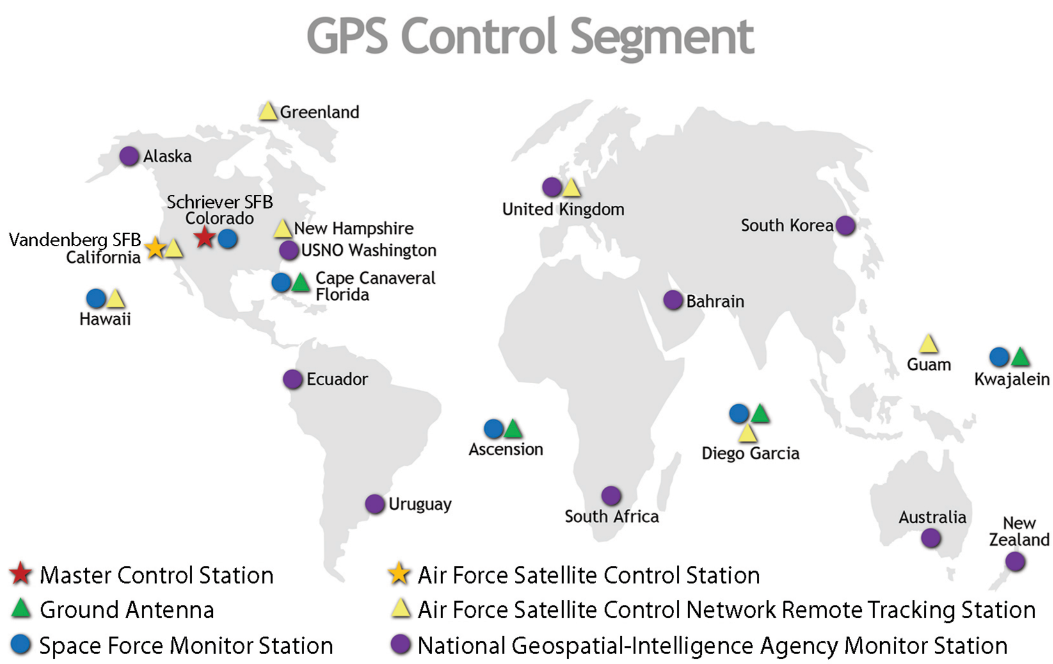


Figure 16.2. GPS control segment. (Adapted from National Coordination Office for Space-Based Positioning, Navigation, and Timing, "Control Segment," GPS.gov, accessed March 22, 2022, https://www.gps.gov/.)

User Segment (User Equipment)

Millions of users, civilian and military, employ GPS in countless ways. Its widespread availability is possible through the third GPS segment—user equipment. Receivers today are easily obtained and come in many shapes and forms with ever-increasing capabilities. However, they all work essentially the same way.

Each receiver acquires an almanac from a GPS satellite. The almanac tells the receiver the location and state of health of all GPS satellites so it can start acquiring their signals. The entire almanac updates in about eleven minutes, and data is refreshed in navigation devices receiving the signal. This almanac changes when the satellites are updated and if any changes are made to the constellation. This process is reflected, for example, in using a GPS watch to start a run. For instance, if the receiver is in Colorado Springs at 0800, the almanac tells it to find space vehicles 4, 17, 23, and so forth. The receiver acquires the signal from the satellites and compares the receiver's internally generated code (specific for each satellite) to the code it is obtaining from the satellites. It also begins to look at each satellite's navigation data to see where the satellite thinks its position is and how far the clock has drifted while getting corrections about atmospheric delay.

The time it takes for the signal to travel from the satellite to the receiver is known as time offset. The receiver then shifts its internally generated code to align with the code received from the satellite and records that time offset. Based on this time offset, the distance between the satellite and the receiver is determined. This process is repeated with four or more satellites. The cumulative information is entered into the position equations and calculated. As a result, users know their position in the world and can navigate from there.

GPS Capabilities/Limitations

GPS has many features enabling it to function and mitigate limitations. Those covered in this chapter primarily relate to the accuracy of location services, consistency of service, and mitigation of jamming.

Accuracy

It is impossible to be 100 percent accurate because several sources introduce errors into the navigation solution. The most common contributing factors are the atmosphere, multipath errors, satellite clock errors, satellite ephemeris/datums errors, and dilution of precision.

Atmospheric errors. All signals degrade as they pass through the atmosphere. The same is true for the GPS. The troposphere and ionosphere can introduce errors into the GPS signal. Some error is created when the GPS signal goes through the troposphere (the atmosphere extending from Earth's surface up to about nine miles), but fortunately, the troposphere is not a significant source of error.

However, the ionosphere (60–300 kilometers or 37–190 miles above Earth depending on fluctuation) can produce widespread sources of error, especially at the poles. The error will affect the position indication when a single-frequency receiver is used. Military users can access a dual-frequency receiver to compare more than one signal from each satellite. The receiver then compares the positions and subtracts the values to determine the true position, mitigating the effects of ionosphere error (fig. 16.3). Many civil receivers can now use multiple frequencies on the GPS IIF and III along with a dual-frequency receiver to increase their positional accuracy.

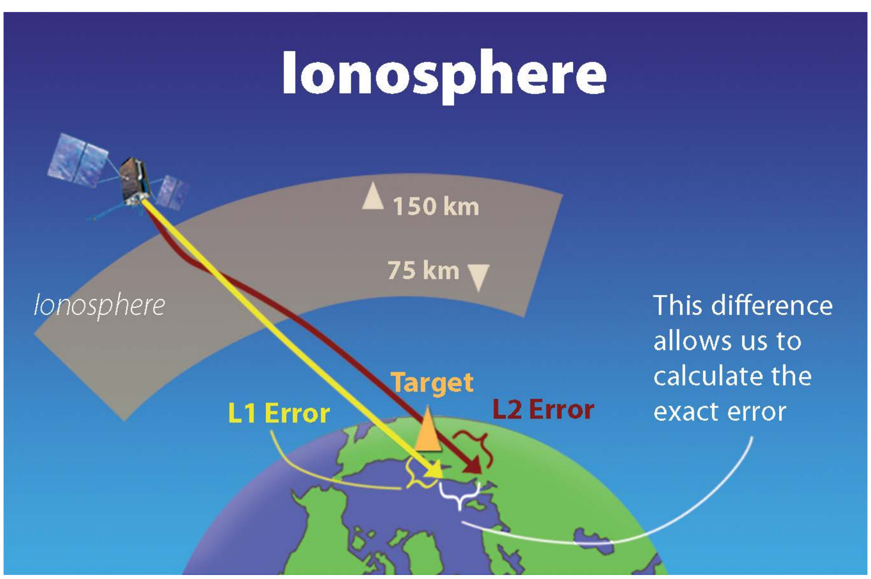


Figure 16.3. Error induced on L2 by the ionosphere. (Developed by Maj Jonathan Burson, Air Force Research Institute, Maxwell AFB, AL, 2015.)

Multipath errors. Multipath errors occur when the signal bounces off objects before the user equipment receives it. This phenomenon is most prevalent in urban canyons. As the signal bounces around, it takes longer to reach the receiver, thereby increasing the time offset. Accordingly, the calculated distance to the satellite is longer, and the position is less accurate. There are a couple of ways to mitigate these effects. First, the signal structure is known as right-hand circularized. When it bounces off a building, it becomes left-hand circularized and appears as noise to the receiver. Second, the receiver knows it should be obtaining the signal in a certain amount of time. If a signal breaks an established threshold, the receiver will disregard that signal.[11]

Additionally, one of the factors that 2 SOPS works to control is the error generated by inaccurate satellite clocks and ephemeris data. The daily uploads keep the satellite information as precise as possible (discussed in the "Control Segment" section above).

Dilution of precision. The final source of error is generated through the geometry of the constellation with respect to the user—known as the dilution of precision (DOP). The user cannot affect DOP, but mission planning with the GPSOC and air operations center can mitigate scenarios where high dilution of precision exists.

GPS Interference and Navigation Tool (GIANT) software is used in the GPSOC and air and space operations centers to generate a variety of products for mission planning and prediction. GIANT simulates GPS interference for a given region over a 24-hour period and projects the navigational accuracy a GPS user can expect during that time. It also produces a chart that depicts the dilution of precision for an area of interest.[12] This information is useful when determining if a GPS-aided munition will be effective or if mission planners should strike a target at another time or use a different platform if it is a time-sensitive target. DOP is unitless and *does not equate* to the accuracy for that area. A DOP of two does not mean that the accuracy is two meters, but rather that the constellation geometry is well positioned. Typically, a DOP greater than six means the accuracies will not be good. Military planners may have to consider waiting for the constellation geometry to become more favorable if reliance on GPS is an operational necessity.

GIANT also maps what the jamming environment looks like. By modeling a known jammer location and the power it is emitting, GIANT relays how effective the jammer is for various platforms and altitudes. GIANT products can also aid in developing a flight plan that would avoid jammers altogether.

Jamming. The GPS signal is highly susceptible to jamming. Four parameters need to occur to be able to jam: a higher transmitted power, transmitting at the correct frequency, alignment with the antenna, and line of sight (LOS) to the antenna.

First, the GPS signal is extremely weak and operates below the natural noise threshold of Earth. The GPS signal is equivalent to shining a 25-watt lightbulb from 20,000 km away. In terms of power, the GPS signal is 10 to 16 watts. Because the signal has little power and travels a long distance, it is remarkably easy to make a jammer that transmits higher power levels.[13] Second, because the frequencies on which GPS transmits are available open source, it is not difficult to program a jammer to these frequencies. Third, since most receiver antennas are omnidirectional, alignment is not an issue for a jammer. The final parameter, LOS, depends on the location of the user relative to the receiver. A jammer must be able to see the receiver to impede the signal going to it. Consequently, the user must place the jammer in the correct location to disrupt the signal.[14] For this reason, an operator can mitigate the effects of jamming by placing the receiver away from the source of jamming and impeding LOS to the receiver itself.

Upgrades on the GPS IIR-M/F and GPS III incorporate multiple codes on each frequency that enable many possibilities to achieve two clear frequencies and help prevent GPS jamming. These satellites also include higher-output transmitters and "flex power" (newer user equipment will make flex power obsolete and unnecessary) to ensure that the receiver sees a stronger signal and can fight through GPS jamming.

Associated Systems

Blue Force Tracking

Blue Force Tracking (BFT) is a system that uses GPS to give friendly forces a picture of the area of operations with locations of friendly forces as well as known hostile and noncombatant forces. The system displays location of forces overlaid on a map. Thus, the commander has an enhanced situational awareness through the ability to track troops in real time.

Distress Alerting Satellite System

In 1997, the Distress Alerting Satellite System (DASS) established the updated search and rescue satellite-aided tracking system (SARSAT).[15] The SARSAT uses the GPS constellation to get location information to assist in finding missing people and vehicles that have disappeared or have been involved in a mishap. Employing GPS satellites in medium Earth orbit improves location services over low Earth orbit satellites due to the slower relative speed they move across the ground; thus, the satellite has a longer time to send a signal to a given receiver. The DASS updates use the L5 signal on the GPS IIF and GPS III. Figure 16.4 shows how the GPS is incorporated into the COSPAS-SARSAT system (Russian Cosmicheskaya Sistyema Poiska Avariynich Sudov [space system for search of distressed vessels]). and how the DASS is structured.

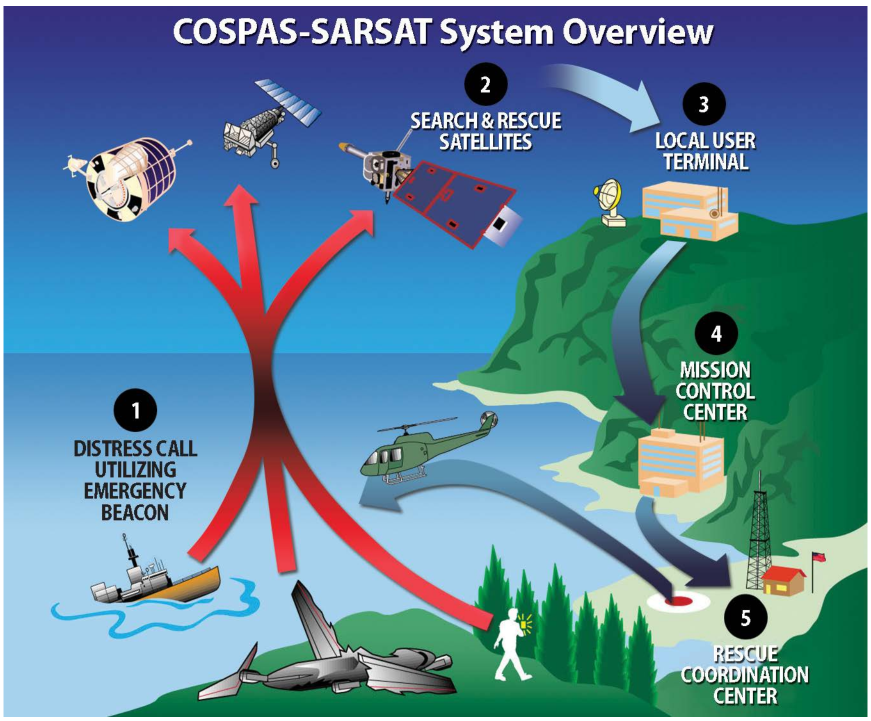


Figure 16.4. COSPAS-SARSAT system (artist rendition). (Courtesy of National Oceanic and Atmospheric Administration [NOAA], accessed September 21, 2022, https://www.nasa.gov/.)

Future Concepts

The Defense Advanced Research Projects Agency (DARPA) continues its modernization efforts in the space, control, and user segments to fortify the system and address user needs. The Quantum Apertures (QA) program endeavors to develop new ways of receiving radio frequency waveforms.[16] Scheduled for 2023, DARPA's H6 program "seeks to develop ultra-small, low-power, fieldable clocks that can maintain their microsecond timing precision for one week over an operating range of -40 to 85 Celsius without GPS fixes."[17] The Robust Optical Clock Network (ROCkN) program aims "to create optical atomic clocks with low size, weight, and power (SWaP) that yield timing accuracy and holdover better than GPS atomic clocks."[18]

Current research builds on DARPA's contributions in recent successful programs. These include Adaptable Navigation Systems (ANS); Microtechnology for Positioning, Navigation, and Timing (Micro-PNT);

Quantum-Assisted Sensing and Readout (QuASAR); the Program in Ultrafast Laser Science and Engineering (PULSE); and Spatial Temporal and Orientation Information in Contested Environments (STOIC).[19]

Summary

Positioning, navigation, and timing have been essential to the success of military commanders since the beginning of warfare. The launch of the initial GPS satellites in 1978 did not change that, but it did change the ease of access to accurate PNT and expanded this access to the masses. Satellite-based PNT is used around the world for private use, throughout numerous industries, and across government sectors. GPS is the gold standard for PNT.

GPS and other satellite-based PNT systems are not without problems. Whether they come from errors induced by the atmosphere or through intentional jamming of the GPS signal, the capabilities provided by GPS are challenged in the space, ground, and control segments. Thus, researchers continue to develop new methods to provide PNT—space-based and otherwise—so the warfighter always has dependable, accurate PNT functionality anywhere on Earth.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. US Space Force, "Global Positioning System."
2. Space and Missile Systems Center, "GPS Modernization."
3. Andersen et al., "Accuracy Assessment of Positions," 129.
4. GPS Information.net, "Simplified Tutorial."
5. Leveson, "Economic Benefits of GPS."
6. Bell, "Analysis of GPS Satellite Allocation," 11–13, 18–19.
7. National Coordination Office (NCO) for Space-Based PNT, "Space Segment."
8. NCO for Space-Based PNT, "New Civil Signals."
9. NCO for Space-Based PNT, "Control Segment"; and NCO for Space-Based PNT, "Architecture Evolution Plan."
10. An *ephemeris* is "simply a table giving the coordinates of a celestial body at specific times during a given period." GPS satellites (and other navigational constellations—such as the European Union's Galileo, Russia's GLONASS, and China's BeiDou) transmit ephemeris data in the form of "parameters that can be used to accurately calculate the location of a satellite at a specific moment in time." The data relays a satellite's path as it orbits Earth but is valid for just a short period of a few hours or less. Thus, operators require current ephemeris data to "minimize errors that result from minor variations in a satellite's orbit." Spirent, "What Is an Ephemeris?"
11. US Coast Guard, *NAVSTAR GPS User Equipment Introduction*, D-1–D-3.
12. Bowman, "GIANT."
13. Anthony, "Our Terrifying Reliance on GPS."
14. National PNT Advisory Board, "Jamming the Global Positioning System."
15. Affens et al., "Taking the Search out of Search and Rescue."
16. DARPA, "Quantum Shift in Spectrum Sensing."
17. DARPA, "Tactical-Grade Clock."
18. DARPA, "GPS-Quality Timing Accuracy."
19. DARPA, "Adaptable Navigation Systems"; DARPA, "Micro-Technology for Positioning, Navigation and Timing"; DARPA, "Quantum Shift Sensing"; DARPA, "Program in Ultrafast Laser Science and Engineering"; and Waterston, "Spatial, Temporal, and Orientation Information."

Chapter 17

Satellite Communications

This is the President of the United States speaking. Through the marvels of scientific advance, my voice is coming to you from a satellite circling in outer space. My message is a simple one. Through this unique means, I convey to you and all mankind America's wish for peace on Earth and goodwill toward men everywhere.

—Pres. Dwight D. Eisenhower
December 19, 1958

This chapter gives warfighters and their staffs a basic understanding of the capabilities of military and commercial satellite communications (COMSATCOM) systems. Military dependency on SATCOM bandwidth grew exponentially in the thirteen years between Operations Desert Storm and Iraqi Freedom (OIF). The bandwidth available to the operational area in OIF was 30 times that provided in Desert Storm.[1] Further, COMSATCOM companies supplied the military only 20 percent of the bandwidth to conduct operations during Desert Storm versus over 80 percent in Operations Iraqi and Enduring Freedom (OEF). United States Space Command (USSPACECOM) forwards bandwidth requirements to the Defense Information Systems Agency (DISA), which then determines COMSATCOM requirements. As the DOD-designated contracting authority, DISA obtains commercial services via an existing contract vehicle or generates new contracts as necessary.[2]

Military SATCOM (MILSATCOM) affords minimum essential warfighting connectivity, including systems designed to provide anti jamming capabilities and survivable nuclear command and control. Future MILSATCOM systems are unlikely to fully meet the rapidly expanding capacity requirements and would also be cost prohibitive to meet the full demand. Commercial SATCOM is therefore needed to fill the gap.

Military reliance on radio repeaters in space (i.e., satellites) will only increase in the future because satellites are a key method of connecting the isolated warfighter to the Department of Defense Information Network (DODIN), ultimately enabling network-centric warfare. The DODIN is defined as "the set of information capabilities and associated processes to collect, process, store, disseminate, and manage information on demand to warfighters, policy makers, and support personnel, whether interconnected or stand-alone, including owned and leased communications and computing systems and services, software (including applications), data, security services, other associated services, and national security systems."[3] This network brings information superiority to decision makers in the field by providing commanders with real-time or near real-time information. It ties together all the functions of joint operations to facilitate timely execution of operations and reaction to ongoing events.[4]

Satellite Communications Basics

In conventional terrestrial radio communications, a large radio repeater or relay is situated on high ground to transmit a radio signal from one location to another. SATCOM is similar, but with SATCOM the high ground is space and the radio repeater is a communications satellite. Earth-based satellite terminals transmit signals to and receive signals from the satellite using specific frequencies. The frequency from a SATCOM terminal to the satellite is the uplink frequency, and the frequency from the satellite to the SATCOM terminal is the downlink frequency. A SATCOM terminal is any terminal used to connect a user to a satellite through the electromagnetic spectrum. The terminal may be an airborne, a naval, or a ground facility and can be fixed or mobile.

The purpose of the space-based radio relay is to provide "over the horizon" communications by overcoming the challenges of distance or obstructions inherent to terrestrial-based systems that require line of sight. However, the great distances involved in SATCOM pose two disadvantages: signal attenuation and communications delay. The first, signal attenuation, is the loss of some signal strength over distance, requiring space-based communications to have much greater transmit power and receiver sensitivity than terrestrial-based communications. The second disadvantage, communications delay, affects all current satellite systems. The delay time in voice and video communications is most noticeable to field operators because system processors compensate for the data delays and can take nearly 240 milliseconds due to the required propagation time.[5]

Communications Satellite Modules

A major module of a communications satellite is the communications payload. The payload has the transponders, antennas, and—for some communications satellites—crosslinks. A transponder provides the capability to amplify received radio signals from the uplink antennas. It also sorts the input signals and directs the output signals to the proper downlink antennas. The antennas receive radio signals from and transmit to SATCOM terminals. Crosslink payloads furnish connectivity directly from one satellite to another without going through a SATCOM ground terminal.

Radio Spectrum

Where communications wires cannot be laid or when terrain and other line-of-sight radio frequency limitations hamper terrestrial-based communications, satellite communications keep forward-based ground units and rear echelons in contact.[6] SATCOM systems have several components that enable effective worldwide communications. These include the frequencies available for use within the electromagnetic spectrum through which SATCOM systems operate. The SATCOM systems used today typically operate in one of three frequency bands: ultrahigh frequency (UHF), super-high frequency (SHF), or extremely high frequency (EHF). Figure 17.1 depicts some of the systems operating in these frequency ranges, the radio spectrum or bands used by respective satellites, and the corresponding use of those bands.

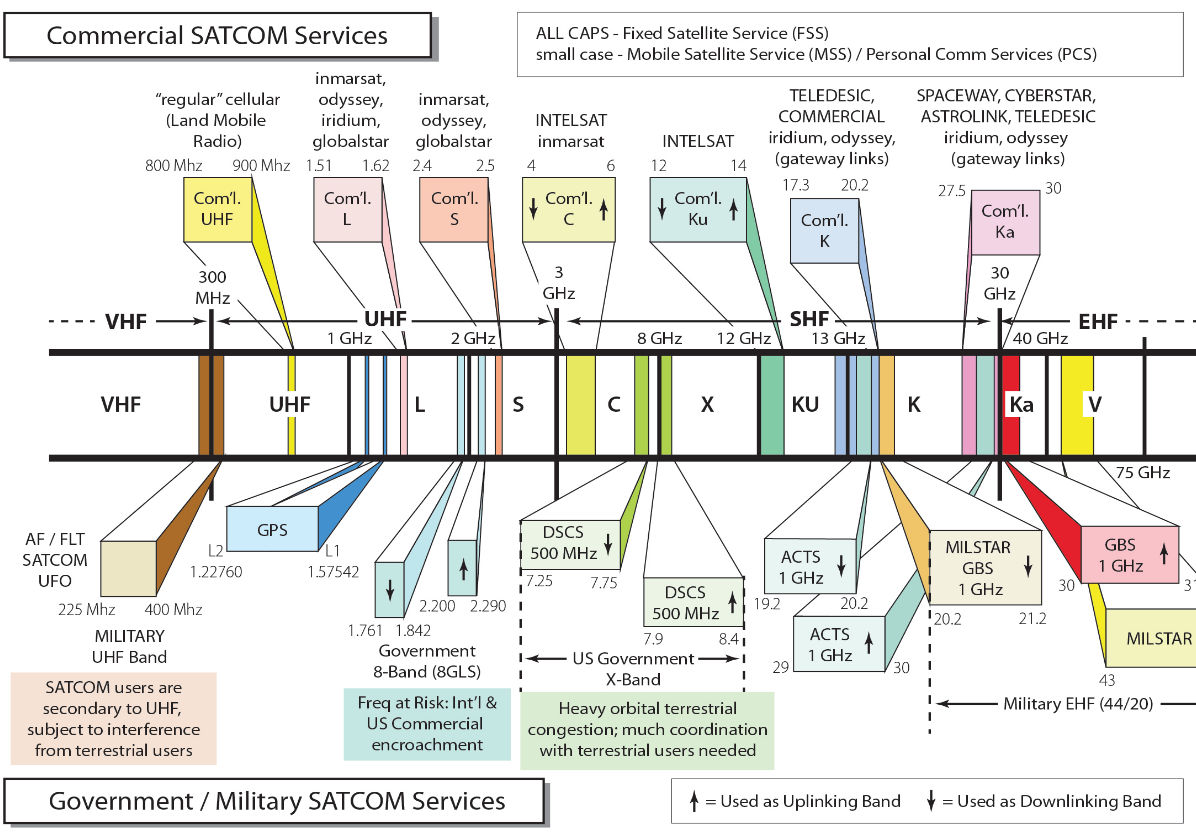


Figure 17.1. SATCOM bands. (Source: Vikas Samyal, "Sat Comm in Transition," *Geospatial World*, February 22, 2012, https://www.geospatialworld.net/.)

Current Military Satellite Communications Enterprise

The MILSATCOM enterprise as it stands today consists of four elements: protected, wideband, wideband broadcast, and narrowband. A fifth area, COMSATCOM systems, also integrates with MILSATCOM services to give warfighters additional capacity and greater flexibility through redundancy. Table 17.1 shows the capabilities inherent in each of them.

Table 17.1. DOD SATCOM systems overview

Protected	Wideband	Wideband Broadcast	Narrowband	Commercial
EHF Q/Ka-Band	SHF-X/Ka-Band	Ka-Band	UHF P/L-Band	L, S, C, X, Ku, Ka Bands
Milstar I/II • Survivable/protected communications for national leaders and joint force (AJ, LPI, LPD, EMP hardened) • Crosslinks (no ground relay required) • Polar • Protected communications for north polar region (LPI, LPD) *AEHF/Milstar Follow-on* • Greater throughput • International partners	• High data rates for deployed forces and enterprise users • DISN enterprise extensions and reach-back for deployed forces *DSCS* • X-band only • Airborne and maritime COTM capability • Some AJ *WGS* • DSCS follow-on • X and Ka-bands • COTM with Ka-band (airborne and maritime) • Greater throughput • International partners	*UFO* • GBS Ka payload on UFO satellites • High throughput • Small antennas • Smart push-pull data broadcasts *WGS* • X- and Ka- bands • Return channel capability with 2-way Ka-band • Airborne and maritime COTM capability	*UFO* • Lightweight, mobile terminals, COTM • Low data rates/space segment limited • Supports joint force, INTEL LOG nets • DAMA/IW increases user accesses • No AJ *MUOS* • UFO Follow-On 6–10x legacy capacity • Global cellular service • On-demand use • Supports legacy UHF transition • Greater number of accesses	• Growing capability • Augment MILSATCOM • Mobile and fixed satellite services • High throughput ◦ Telemedicine ◦ CSS ◦ Split-based operations ◦ Video • Less protection • Pay for services

Source: Adapted from Joint Publication 3-14, *Space Operations*, May 29, 2013, D-2, https://nsarchive.gwu.edu/. (Note: The latest JP 3-14 version, April 10, 2018 [incorporating change 1, October 26, 2020], does not include the above table, but the information is current.) For illustrations overviewing SATCOM systems, see Cordell A. DeLaPena, SES, Program Executive Officer for MilComm & PNT, "Military Communications and Positioning, Navigation, and Timing [PNT] Overview with GPS Update," briefing to PNT Advisory Board, May 4, 2022, slides 6 and 9, https://www.gps.gov/.

Legend

AEHF	advanced extremely high frequency
AJ	anti jam
C	C-band, 3.74.2 GHz
COTM	communications on the move
CSS	commercial satellite services
DAMA	demand assigned multiple access
DISN	Defense Information System Network
DSCS	Defense Satellite Communications System
EHF	extremely high frequency
EMP	electromagnetic pulse
GBS	Global Broadcast Service
GHz	gigahertz
INTEL	intelligence
IW	integrated waveband
Ka	Kurtz-above band, 27–40 GHz
Ku	Kurtz-under band, 12–18 GHz
L	L-band, 1–2 GHz
LOG	logistics
LPD	low probability of detection
LPI	low probability of intercept
MHz	megahertz
MILSATCOM	military satellite communications
MUOS	Mobile User Objective System
P	P-band, 250–500 MHz
Q	Q-band, 33–50 GHz
S	S-band, 2–4 GHz
SHF	super-high frequency
UFO	Ultrahigh-Frequency (UHF) Follow-On system
WGS	Wideband Global Satellite Communications

Each system in these five areas offers unique advantages that makes it particularly suitable to fulfill specific warfighting needs. Together, these systems comprise a robust, cost-effective integrated MILSATCOM architecture that satisfies critical DOD requirements.

Today, the DOD SATCOM enterprise architecture includes seven primary systems (all in geosynchronous orbits) operating in UHF, SHF, and EHF ranges: (1) UHF Follow-On (UFO), (2) Mobile User Objective System (MUOS), (3) Defense Satellite Communications System (DSCS), (4) Wideband Global SATCOM (WGS), (5) Milstar, (6) Advanced EHF, and (7) Enhanced Polar System (EPS).

Ultrahigh-Frequency Follow-On

After replacing the Navy's Fleet SATCOM (FLTSAT) system, the Ultrahigh-Freqency Follow-on constellation became the primary DOD system for tactical mobile communications providing UHF, EHF, and Global Broadcast Service (GBS) capabilities worldwide (see fig. 17.1 above). Although the UFO satellite system plays a vital role in meeting DOD's voice, data, and video transmission needs, it is now considered a legacy system since the final UFO satellite, Flight 11 (F11), was launched December 17, 2003. UFO satellites supply tactical narrowband communications supporting air and ground operations, "the Navy's global communications network, serving ships at sea," and other government entities, including the White House, State Department, and Department of Homeland Security.[7]

Mobile User Objective System

The US Space Force's Mobile User Objective System is the current narrowband tactical satellite communications system, delivering far better data and voice service to mobilized US forces than legacy systems. The 10th Space Operations Squadron (10 SOPS), Space Delta 8, operates UFO and MUOS narrowband communications. The MUOS gives military users improved voice quality and an upgraded communications payload with ten times the transmission throughput over the legacy UFO satellite system. MUOS satellites also have an additional communications payload compatible with the UFO system.[8]

Consumers of MUOS capabilities use UHF terminals to access the system's network. These end-user terminals or antennas are typically "small and portable enough to be carried deep into military theaters of operation." The UHF frequency also "offers the capability of penetrating jungle foliage and inclement weather as well as urban canyons."[9]

Defense Satellite Communications System

The Defense Satellite Communications System is the legacy SHF MILSATCOM workhorse. It is a worldwide military satellite network managed under USSPACECOM by DISA.[10] It consists of space segments along with ground terminals that operate in the SHF band to provide long-haul multichannel communications connectivity.[11] The system is an important part of the comprehensive plan to support globally distributed military users on the ground, at sea, in the air, and in cyberspace.

Additionally, each satellite has six SHF transponder channels (one with limited anti jam capability) capable of providing worldwide secure-voice and high-data-rate communications.[12] A single steerable dish antenna provides an increased power spot beam that is flexible to suit the needs of different sizes of user terminals.[13]

Although DISA manages DSCS for USSPACECOM, the US Space Force (USSF) operates and maintains the system. Space Operations Command's (SpOC) 4 SOPS (a Space Delta 8 unit at Schriever Space Force Base, Colorado), is responsible for DSCS on-orbit operations (station-keeping), telemetry analysis, tracking data for orbit determination, and commanding of onboard subsystems.[14] The USSF's 53 SOPS operates the DSCS payload. The 53 SOPS is headquartered in Colorado Springs, Colorado, but the payloads are operated by units dispersed around the globe.[15]

Wideband Global Satellite Communications

The Wideband Global SATCOM constellation provides "worldwide flexible, high data rate and long haul communications for the Department of Defense, governmental organizations, and international partners."[16] WGS replaced the DSCS constellation, providing a "quantum leap in communications bandwidth" over the legacy system.[17] The "revolutionary" WGS-11+ satellite currently in development "will have more communications flexibility than the entire existing WGS constellation" and give combatant commanders "twice the mission capability in contested environments."[18]

WGS satellites operate within the SHF spectrum using X- and Ka-band bandwidth and can crossband between the X and Ka bands.[19] The system includes eight X-band phased-array antennas, ten Ka-band gimbaled-dish antennas, and one X-band Earth coverage antenna.[20]

Milstar Satellites

Although the term "Milstar" was originally based on the Military Strategic and Tactical Relay acronym, government sources no longer refer to it as an acronym but as a system (i.e., Milstar vice MILSTAR). Milstar furnishes highly robust, secure, and survivable communications to fixed-site and mobile terminals. Its unique capabilities enable US forces to maintain information superiority throughout all levels of conflict and ensure that warfighters retain freedom of action through continuous, secure, jam-resistant communication.[21]

Milstar has several features that distinguish it from earlier satellite communication systems. Milstar's flexible capabilities allow the use of crossbanding (similar to WGS's crossbanding capability) and processed UHF-to-UHF communications. The crossbanding on Milstar enables EHF terminals to communicate with SHF or UHF terminals.[22] Its payload contains onboard computers that perform resource monitoring and control functions supporting worldwide voice, data, and video communications.[23] Milstar II satellites also have nulling antennas to overcome enemy jamming attempts.[24]

The 4th Space Operations Squadron is responsible for overall command and control and payload management of the Milstar constellation.[25] The squadron operates the combined Milstar/Advanced Extremely High Frequency (AEHF) system with the AEHF mission control segment (MCS), which performs satellite command and control, communications resource management, systems engineering support, mission planning, user support, and anomaly resolution.[26] Day-to-day commanding for the Milstar/AEHF constellation of satellites is accomplished through the Command and Control System–Consolidated (CCS-C) Assurance and Capability Enhancement (CACE) system, which also supports the DSCS/WGS constellation.[27] The 4 SOPS dispersed mobile sites provide continuing operations during higher states of readiness.[28]

Advanced Extremely High Frequency

The AEHF system is the replacement for the Milstar system. It is a "joint service satellite communications system delivering survivable, global, secure, protected, and jam-resistant communications for high-priority military ground, sea, and air assets." AEHF allows the "Department of Defense to control tactical and strategic forces through all levels of conflict and supports the attainment of space superiority for the joint force."[29]

AEHF satellites respond to service requests from operational commanders and user terminals, providing real-time, point-to-point connectivity and priority network services.[30] Each military service has its own ground terminal for AEHF communications. The Navy's primary terminal to access AEHF and Milstar satellites is the Navy Multiband Terminal (NMT). The NMT is also capable of connecting to DSCS, WGS, and the Enhanced Polar System.[31] The Army has upgraded its Secure Mobile Anti-jam Reliable Tactical Terminal (SMART-T) that was originally used for Milstar to be compatible with AEHF.[32] Air Force components that employ AEHF services use Family of Advanced Beyond Line-of-Sight Terminals (FAB-T) to do so. FAB-T consists of ground and airborne terminals for command posts and force elements.[33]

Enhanced Polar System

The Enhanced Polar System is to the North Polar Region what AEHF is to the rest of the world; it provides continuous secure communications capability above 65° north latitude. By delivering many of the same capabilities as AEHF to the extreme northern region of the earth, EPS enables a trusted communications link for Navy, Coast Guard, Air Force, and other missions in the area.[34] The ability to communicate in this region is critical as the military expands Arctic operations over the next several years.[35]

Future Concepts

With data and communication being a cornerstone of operations, the military is continually innovating and working with industry to develop the communication architectures within the military. The DOD utilizes a worldwide network mesh architecture that enables mission command, network operations between the home station and dispersed units, and high-capacity data exchange. To keep pace with enemy threats, the network systems are being updated and fielded regularly to maintain multi-domain superiority.[36]

Additionally, to bolster the current communication architecture, the DOD is working with industry on a proliferated LEO communication architecture. As evidenced by capabilities like SpaceX's Starlink, communication networks can be distributed in LEO at a reduced launch cost and footprint. A proliferated constellation offers the resiliency needed to provide effects in a contested and congested environment and delivers data at decreased latency to the warfighter.[37]

Summary

The DOD is producing more-capable satellite communication systems in response to the warfighters' requirements for bandwidth. Systems like Blue Force Tracking (BFT) continue to proliferate, and the demand for real-time live feeds to military forces on the ground continues to grow. Consequently, the US military is saturating its current communication systems. Satellite communication is integral to supplying information—a critical element to all military operations—to commanders and key decision-makers. To help meet military SATCOM requirements, the United States has upgraded its MILSATCOM capabilities—from UFO to MUOS, from DSCS to WGS, and from Milstar to AEHF. Nonetheless, these improvements are not commensurate with the increasing demand.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Joe and Porche, *Future Army Bandwidth,* 11.
2. Snodgrass, "Commercial SATCOM Support."
3. Joint Publication (JP) 6-0, *Joint Communications System,* I-1.
4. JP 6-0, I-1.
5. Prasad, *Principles of Digital Communication Systems,* 38.
6. "Space Support to Operations," in Air Force Doctrine Publication 3-14, *Counterspace Operations*, 13–15.
7. National Telecommunications and Information Administration, "225–328.6 MHz"; and US Navy, "UHF Follow-On Program."
8. Director, Operational Test and Evaluation, *Mobile User Objective System*, 2.
9. US Navy, "UHF Follow-On Program."
10. Defense Information Systems Agency, "Our History."
11. US Space Force, "Defense Satellite Communications System."
12. US Space Force, "Defense Satellite Communications System."
13. Liopiros and Lam, "Extremely High Frequency Satellites," 77.
14. US Space Force, "4th Space Operations Squadron."
15. Hahn, Kellar, and Stubblefield, "Satellite Communications," 26; and White, "53rd Signal Battalion."
16. US Space Force, "Wideband Global SATCOM Satellite."
17. Space War staff writers, "Boeing Completes On-Orbit Handover."
18. Space Systems Command Public Affairs, "WGS-11+ Satellite and Ground System."
19. US Space Force, "Wideband Global SATCOM Satellite."
20. Ray, "Highest Capacity Military Communications Satellite."
21. US Space Force, "Milstar Satellite Communications System."
22. US Space Force, "Milstar Satellite Communications System."
23. Northrop Grumman, "Milstar Payloads."
24. Northrop Grumman, "Milstar Payloads."
25. US Space Force, "4th Space Operations Squadron."
26. US Space Force, "Advanced Extremely High Frequency System."
27. US Space Force, "CCS-C Assurance and Capacity Enhancement (CACE)," slide 42.
28. US Space Force, "4th Space Operations Squadron."
29. US Space Force, "Advanced Extremely High Frequency System."
30. US Space Force, "Advanced Extremely High Frequency System."
31. Assistant Secretary of the Navy for Research, Development, and Acquisition, "NMT Navy."
32. US Army Acquisition Support Center, "Secure Mobile Anti-jam."
33. Department of Defense, *Fiscal Year (FY) 2023 Budget Estimates*, vol. 1, 19–22.
34. Luckenbaugh, "Space Force Partners with Norway."
35. Harris, "White House Arctic Strategy."
36. Walker, "Global Network Design."
37. Machi, "US Military Places a Bet on LEO."

Chapter 18

Space-Based Intelligence, Surveillance, and Reconnaissance

Military reconnaissance was one of the first applications of space technology in the United States. The Soviet Union's 1957 launch of *Sputnik I*, the world's first orbiting artificial satellite, induced the United States to explore the concept of a space-based reconnaissance program. Today, space-based intelligence, surveillance, and reconnaissance (ISR) capabilities give commanders and policymakers information to aid in establishing national policy and in planning and executing military operations.[1] Space-based ISR systems exploit the electromagnetic spectrum (EMS) to bring the capability of collecting against a multitude of targets, which can range from disaster relief missions and targeting analysis to characterization of the operational environment, indications and warnings of a ballistic missile attack, and battle damage assessment (BDA) (see fig. 18.1).

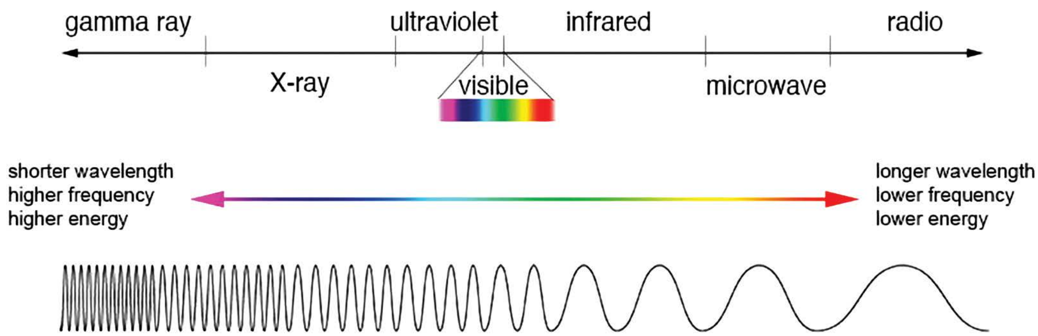


Figure 18.1. The electromagnetic spectrum. (Reproduced from "The Electromagnetic Spectrum," Imagine the Universe! NASA, March 2013, https://imagine.gsfc.nasa.gov/.)

Space-Based ISR Fundamentals

Space-based ISR capabilities and products are requested in the same way as other forms of ISR—through the collections requirements and priorities process managed by the A2 shop (Intelligence, Surveillance and Reconnaissance and Cyber Effects Operations). Most space ISR satellites are not necessarily continuously gathering data. Rather, satellites that provide snapshots in time can be augmented by additional assets collecting in the same or even different areas of the EMS. While there may be short gaps in collection (minutes to a few hours), capabilities can be concentrated on a priority target, which, over time, constitutes surveillance. These "following" systems effectively provide continuous collection on a target as the previous satellite moves out of view in its orbit.[2]

The coverage a satellite provides over a target depends on its orbit and priority. Because satellites in geosynchronous equatorial orbit maintain a relatively stable position over the earth, they provide constant surveillance for large portions of the globe. Satellites in low Earth orbit (LEO) and medium Earth orbit (MEO) surveil much smaller areas in greater detail, but their faster orbit cycles allow just a few minutes' coverage at a time. Thus, the tasking of satellites to collect data on a target area must be prioritized based on the specific EMS data needed and the satellite assets available to collect that information. Information from satellites is usually combined with data from other surveillance methods to give the intelligence community as much coverage as a target may require.[3]

The signals intelligence satellites of today are developed and launched jointly by the United States Space Force (USSF) and National Reconnaissance Office (NRO) with support from the National Security Agency (NSA). Intelligence collections are delivered for processing to the USSF and their process owners—for example, the National Geospatial-Intelligence Agency (NGA) and NSA for imagery intelligence (IMINT) and signals intelligence (SIGINT), respectively, for processing, analysis, dissemination, and exploitation.[4] Additionally, both organizations are responsible for the operations and maintenance of national-level databases and furnish intelligence products to commanders and policymakers. Data collected at the theater and tactical levels by airborne collection systems and other methods are managed by the military services. The services are responsible for providing this data to national-level databases. The NGA has the overall responsibility for managing, disseminating, and archiving imagery intelligence data.

Commercial and civil entities also contribute appreciably to these databases.[5] Today, more than three dozen countries and multinational organizations operate space-based imaging platforms.[6] The NGA is the executive agent for the purchase of commercial satellite imagery in the DOD and has the capability to buy rights in two distinct forms. It can purchase imagery for immediate use, or it can purchase the rights to selected imagery for future distribution, depending on specific requirements.[7]

Types of data collected from space typically fall into three categories: IMINT, SIGINT, and measurement and signature intelligence (MASINT).

Imagery Intelligence

The detail discernible in an image depends on the sensor's spatial resolution, or the size of the smallest possible feature that it can detect. In other words, spatial resolution is the smallest separation between two objects where the objects are still distinguishable. This type of resolution is related to the ground sample distance (GSD) of a system. GSD is defined as the distance between centers of pixels or the centers of areas sampled on the ground.

Images where only large features are visible are said to have coarse or low resolution. In fine- or high-resolution images, small objects can be detected. Military sensors, for example, are designed to view much greater detail and therefore have very fine resolution. With current systems, resolution is usually referred to in meters or centimeters, and each pixel will sample a square area on the ground in those terms. Generally speaking, the finer the resolution, the less total ground area can be seen. The images in figure 18.2, below, depict GSDs in inches versus meters as captured by the Itek optical reconnaissance camera system developed for the CORONA program during the Cold War.

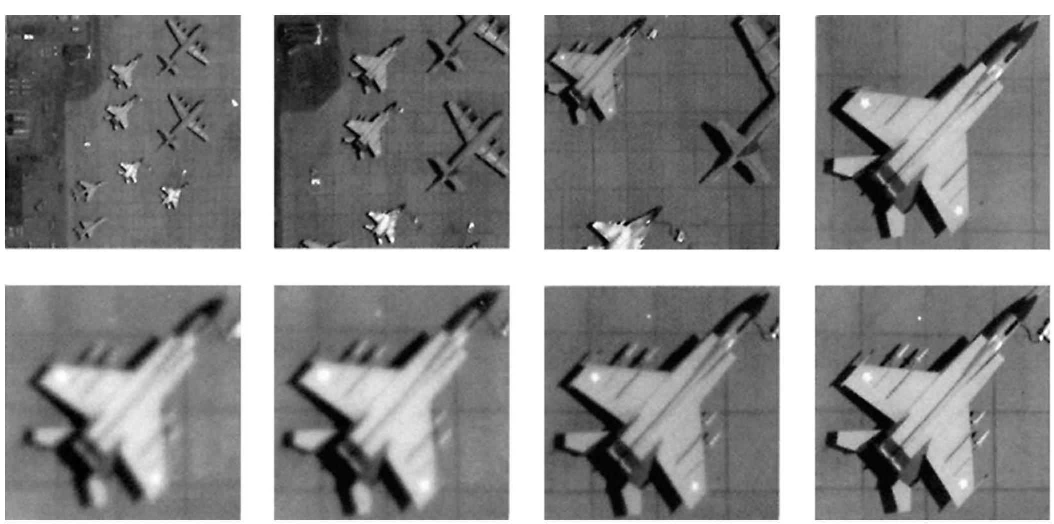


Figure 18.2. Ground sample distances. *Left to right*: *first column*, 48-inch GSD; *second column*, 24-inch GSD; *third column*, 12-inch GSD; *fourth column*, 6-inch GSD. (Adapted from Federation of American Scientists, "Coverage – Resolution and Swath ITEK Optical Systems," accessed November 22, 2022, https://irp.fas.org/.)

An array of methods is used to collect imagery intelligence, including electro-optical, space-based radar, infrared, and multispectral.

Electro-Optical Imagery

Electro-optical imagery is collected from the portion of the electromagnetic spectrum visible to the human eye. Images can be transmitted to Earth electromagnetically whenever in view of a downlink ground station. Those images can then be processed and distributed almost instantly.

Space-Based Radar Imagery

Space-based radar systems rely on synthetic aperture radar (SAR) systems (fig. 18.3). Using SAR, a space-based radar sends out a pulse of radio waves that bounces off the object to be depicted. The scattered pulses then return to the radar and are captured by the receiving antenna, which acts as the radar's aperture.

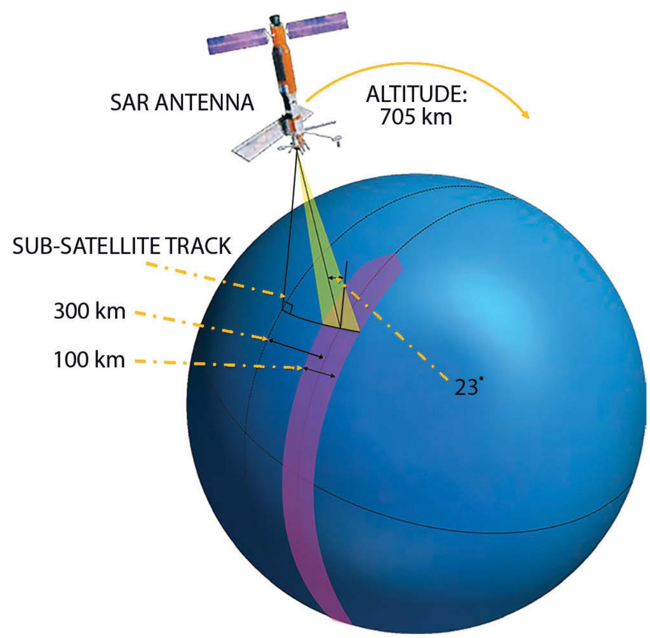


Figure 18.3. SAR concept. (Adapted from NASA, Jet Propulsion Laboratory, "What Is SAR, Anyway?," Internet Archive Wayback Machine, accessed October 11, 2022, https://web.archive.org/.)

Resembling photographs, SAR images are actually maps in which the image is a measure of the radar energy reflected back to the antenna. Water droplets in fog and clouds are transparent to radio waves of the proper frequency, just as window glass is to light waves of the visible frequency. Hence, a SAR instrument can gather data in meteorological conditions where optical sensors would be rendered useless, as it can provide excellent images even in fog, clouds, or darkness.[8]

Infrared Imagery

Some IMINT satellites collect images in the infrared (IR) portion of the EMS, which lies between the visible and microwave wavelengths. Infrared has a range of wavelengths, just like visible light. IR sensors on satellites are used to determine temperature variations of the object being imaged, which is useful for many applications and can be used day and night. For example, it is possible to determine if oil is running through a pipeline, if a nuclear reactor is active, or if a vehicle is operating. A more common use for IR sensors on a satellite is weather monitoring. Many weather satellites have IR sensors to monitor temperature differences on Earth. Some of these sensors can be extremely sensitive to temperature variations.

Multispectral Imagery

Multispectral imagery (MSI) fuses images across the EMS and provides a digital means for a variety of important taskings, including mission planning, thermal signature detection, and terrain analysis. It is frequently used as a map substitute when standard mapping, charting, and geodesy products are outdated or inadequate. MSI's main attribute is the ability to record spectral reflectance in different portions of the electromagnetic spectrum. This imaging typically provides such things as terrain information over broad areas in an unclassified format. Thus, MSI can be shared with personnel and organizations not usually privileged to access controlled information from national assets. Multinational forces, news media, and civil authorities can all reap the benefits of MSI.

Signals Intelligence

The United States deploys SIGINT spacecraft in all orbits: geosynchronous equatorial orbit to acquire ultrahigh and very high frequency communications and LEO and MEO to collect signals from air defense and early warning radars. Highly elliptical orbits (HEO) give satellites both long dwell times at high latitudes and short dwell times at low latitudes, maximizing signals collection over multiple regions for specific and repeating durations or frequencies. The type of SIGINT collected often dictates which orbit will be used for a particular satellite.

Targets for SIGINT collection include space system components emitting electromagnetic waves such as uplink, downlink, or cross-link transmitters. Such emitters may be located at ground facilities and/or on satellites. In some situations, SIGINT collection satellites may also be able to acquire signals of interest as they are reflected off another object. Another potential target would be communications intelligence (COMINT) emitters that, although not directly tied to an operational space system, are conveying information associated with it. One example is the communications at a launch range that occur before, during, and after a new satellite launch.

Timeliness is an important quality of any intelligence operation. Trained personnel can conduct electronic intelligence (ELINT) and COMINT (for relatively simple unencrypted systems) in real time. Foreign instrumentation signals intelligence (FISINT), however, requires significant amounts of time. For instance, an intelligence analyst might gain a limited understanding of what is in a telemetry signal in days or weeks. But the ability to thoroughly assess what each telemetry channel represents (there may be hundreds) may take years and would likely involve fusion of data from other types of intelligence. In all cases, the amount of time required to answer a specific intelligence question is a function of the skill and experience of the analysts involved as well as access to the appropriate tools (e.g., big data or large and/or complex datasets and artificial intelligence).

A major goal of any SIGINT operation is to precisely locate the source of a signal, known as geolocation. Such data can be used to target weapons against the emitter and the platform to which it is attached (either a ground facility or a satellite). SIGINT systems can generally provide only bearing information (based on the direction of arrival of the intercepted signal), not the range to the emitter (bearing and range together would uniquely locate the emitter). However, by combining a single bearing fix with location data from SIGINT systems situated elsewhere, analysts may be able to triangulate the emitter location.

SIGINT can contribute considerably to an overall understanding of the configuration, capabilities, and characteristics of the emitter and the emitter platform. All SIGINT subdivisions can assist with this analysis. ELINT can determine overall emitter characteristics and power requirements while COMINT can add detailed emitter characteristics. COMINT might also provide, indirectly, a number of other system details. FISINT is probably the most useful technique, especially the analysis of unencrypted telemetry signals. Weapon system operators often rely on telemetry to monitor many aspects of their operation. SIGINT analysts use that telemetry signal to determine characteristics of system components and sensors. These characteristics include sensor event timing and parameters; status, health, or criticality of individual components; and the interconnections among various components.

SIGINT is also crucial to the success of any electromagnetic attack (EA). SIGINT pinpoints radio frequency (RF) characteristics of the target link so the military can select or develop EA systems. SIGINT may also be used to monitor the effects of an attack while it is occurring (as in a counterspace operation).

Signals intelligence is produced by exploiting foreign communication systems and noncommunication emitters. The SIGINT discipline is subdivided into three subareas: ELINT, COMINT, and FISINT. They are differentiated based on the type of analysis to be performed and the nature of the emitter.[9]

Electronic Intelligence

JP 2-0, *Joint Intelligence,* defines ELINT as "intelligence derived from the interception and analysis of noncommunication emitters" such as radar.[10] ELINT exploits signal "externals" or the characteristics of the actual transmitted signal (including frequency of carriers and subcarriers, modulation, bandwidth, and power level), beam footprint parameters, and emitter location and motion. A collection signal parameter can be used to obtain an RF fingerprint for each emitter/emitter platform, which can then be used to locate and rapidly identify the specific emitter or emitter type in subsequent intercepts. ELINT usually requires the least amount of analysis of the three SIGINT subareas. Typically, systems designed for ELINT collection may also be capable of performing COMINT and/or FISINT activities.

Communications Intelligence

According to JP 2-0, COMINT is "intelligence and technical information derived from collecting and processing intercepted foreign communications passed by radio, wire, or other electromagnetic means."[11] Generally, the intercepted signal is demodulated, and the original data streams are extracted (e.g., voice, electronic messages, and computer data), which can then be processed by computer or analyzed by human analysts. While extracting the original data streams may not be possible for encrypted communication systems, traffic analysis techniques can still be used to get some useful intelligence data. COMINT also involves the exploitation of signal "internals" or the actual data contained in the signal. These include embedded imagery, when pictures or diagrams are encoded by a computer network or radio frequency for storage and/or transmission.[12]

However, COMINT analysis is more apt to provide information about the users of the communication link and their activities versus the communication system itself. COMINT is routinely used to meet other intelligence requirements and normally requires more analytical effort than ELINT but less than FISINT. Systems designed for COMINT collection may also be capable of ELINT and/or FISINT activities. COMINT exploitation of signals transmitted by a communication satellite can be used to identify a communication system's users (e.g., by the association of call signs). Also, based on the identity of the users or by looking at the data itself, analysts can assess the criticality of a communication system to a country's overall military activities.

Foreign Instrumentation Signals Intelligence

FISINT is a specific area of SIGINT that exploits intelligence collected on foreign equipment and control systems. Intelligence analysts gather signals from video data links, telemetry systems, and firing command systems and conduct technical analysis of the signals.[13] Generally, the intercepted signal is demodulated, and the original data streams are extracted. Traffic analysis techniques can provide useful intelligence data for encrypted communication systems even when the original data stream(s) cannot be retrieved. Similar to COMINT, FISINT also involves signal internals. However, unlike COMINT, FISINT can be used to determine the configuration, characteristics, and capabilities of the emitter and, more importantly, the overall system of which the emitter is a part. Of the three SIGINT subareas, FISINT generally requires the most analytical effort. Typically, satellite systems designed for FISINT collection may also be capable of performing COMINT and/or ELINT activities.

Measurement and Signature Intelligence

JP 2-0 defines MASINT as "information produced by quantitative and qualitative analysis of physical attributes of targets and events to characterize, locate, and identify them." One aspect of MASINT looks at the parameters of an event or object such as the flight profile and range of a cruise missile.[14] In contrast, data for signatures—the other aspect of MASINT—is collected over time and used to create target profiles and algorithms for surveillance or weapons systems.[15] By processing and comparing various measurements and signature data, analysts can glean additional complementary information beyond the capability of IMINT and SIGINT sensors. For example, a simple visual-spectrum image can reveal the external characteristics of an adversary weapon system. But MASINT sensors could use the raw visible-light data along with other sensor data to reveal the material composition of the weapon (e.g., metal or composite material).

MASINT is subdivided into six disciplines: radar, radio frequency, geophysical, nuclear radiation, materials, and electro-optical. These subdivisions were created to bring structure to the broad range of capabilities.[16] Space-based MASINT abilities, from a technical perspective, are any space-based remote sensing capacity other than IMINT and SIGINT that can be employed individually or collectively to derive technical intelligence on an adversary capability or intent.

Block IIR GPS systems employing nuclear detonation (NUDET) capability can detect, locate, and report nuclear detonation events by measuring light, infrared, gamma, atomic, and electromagnetic signatures (see chap. 16).[17] This system is a collection of sensors analyzing phenomena or signatures for the common purpose of providing the location and yield of a nuclear detonation. This function is categorically a MASINT operation.

Similarly, the legacy Defense Support Program (DSP) satellites—now part of the Space-Based Infrared System (SBIRS) satellite constellation—also perform MASINT-like functions. DSP satellites are equipped with two types of infrared sensors as well as nuclear signature sensors. The infrared sensors measure changes and characteristics in infrared signatures and can determine if a ballistic missile has been launched and its probable impact point. The nuclear detonation sensors on DSP satellites—like those on the GPS/NDS system—are designed to give the location and yield of a nuclear detonation.[18] These platforms look for distinguishing features—not necessarily externals or signal internals—to determine action or intent, making them inherently MASINT.

In short, MASINT is an ISR discipline but not necessarily an ISR platform. Space-based remote sensing systems can derive MASINT by measuring and analyzing various phenomena or signatures to extract distinguishing characteristics. These sensors can reside on single or multiple space platforms. They need only be employed for a common purpose of deriving additional technical intelligence beyond traditional SIGINT and IMINT capabilities.

Summary

Space-based ISR capabilities give commanders and policymakers information to aid in establishing national policy and in planning and executing military operations. The ability to use space assets to find, fix, track, target, and assess targets is critical to the combat kill chain. IMINT, SIGINT, and MASINT assets bring the capability of collecting against a multitude of targets. Targets can range from BDA to indications and warnings of a ballistic missile attack. These collections are delivered for processing to their process owners—the NGA for IMINT and the NSA for SIGINT, respectively, and the USSF. Additionally, these organizations are responsible for the operations and maintenance of national-level databases and furnish intelligence products to commanders and policymakers to act upon.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Joint Publication (JP) 3-14, *Space Operations,* A-1.
2. JP 3-14, A-1.
3. JP 3-14, A-1.
4. Hays et al., *Spacepower for a New Millennium,* 119.
5. National System for Geospatial Intelligence, *Geospatial Intelligence (GEOINT) Basic Doctrine*, 18.

6. Union of Concerned Scientists (UCS), "UCS Satellite Database."
7. Department of Defense Directive 5105.60, *National Geospatial-Intelligence Agency,* 4.
8. NASA, "What Is Synthetic Aperture Radar?"
9. JP 2-0, *Joint Intelligence*, B-5.
10. JP 2-0, B-6.
11. JP 2-0, B-6.
12. JP 2-0, B-6.
13. JP 2-0, B-6.
14. JP 2-0, B-6.
15. JP 2-0, B-6.
16. Lowenthal and Clark, *Five Disciplines.*
17. DOD, *Global Positioning System (GPS) 2008,* 2, 6.
18. Sweetman and Ebner, *Jane's Space Systems,* 244–45.

Chapter 19

Space Domain Awareness

The Space Surveillance Network (SSN) employs a combination of optical and radar sensors to support the Combined Space Operations Center's (CSpOC) mission to detect, track, identify, and catalog all man-made objects orbiting the earth. Space surveillance supports the CSpOC mission but also is a critical part of space domain awareness. This chapter discusses the concept of space domain awareness (SDA), types of space events that require SDA, and some possible responses to these events. It also describes the components of the SSN, its sites, and how they combine to support the space surveillance mission. Finally, this chapter concludes with an overview of SSN future systems and command and control upgrades.

Space Domain Awareness Overview

The Space Capstone Publication, *Spacepower: Doctrine for Space Forces,* defines *space domain awareness* as "the effective identification, characterization, and understanding of any factor associated with the space domain that could affect space operations and thereby impact the security, safety, economy, or environment of our Nation."[1] According to the Space Foundation, *space situational awareness* (SSA) "refers to keeping track of objects in orbit and predicting where they will be at any given time."[2] Space domain awareness takes space situational awareness to the next level by involving "all factors, activities, and events of all entities conducting, or preparing to conduct, space operations."[3]

Space domain awareness is intrinsic to the battlespace awareness necessary to protect space assets and plan and execute operations. It is accomplished by analyzing—as thoroughly as current technology allows—space capabilities on and orbiting the earth. This analysis gives commanders, space operators, and mission planners the information required to conduct space operations effectively. Thus, while SDA supports all space operations activities, it is an integral component of space control.[4]

SDA monitors and assesses human-made and natural objects and events in space. For example, knowledge of satellites' orbits allows operators to predict potential collisions between satellites and act to prevent them. SDA also allows operators to take precautionary measures to protect satellites in the event of space activities such as meteor showers and solar flares.[5] Figure 19.1, an overview of the components of SDA, shows how SDA relies on several factors to provide actionable information to command and control elements.

Although SDA is foundational to all space activities, the SSN cannot track every satellite continuously because of the limited number of sensors and their geographical distribution (fig. 19.2). To mitigate this inability to constantly track every space object, the 18th Space Defense Squadron (18 SDS) maintains a database of all man-made and natural objects in Earth orbit using a tracking cycle that starts with a prediction.[6] The 18 SDS projects where a newly launched object will be and then sends out the prediction in the form of a nominal element set (ELSET) to the space surveillance sensors. An ELSET is a collection of parameters used to predict the motion of a satellite and consists of identification data, the classical orbital elements, and drag parameters.[7] These sensors use the nominal ELSET to search for the object. If the assumption is close, the sensor will detect and track the object. The sensor then collects observations from the space track and transmits the data back to the CSpOC for processing and analysis.[8]

Another tool the CSpOC uses to distribute the limited tracking capabilities of the SSN efficiently is prioritized sensor tracking. A USSPACECOM regulation defines categories of priority assigned according to each satellite's type and orbit and prescribes specific data-collection instructions for each category. For instance, data collection requirements for satellites with high-interest missions or unstable orbits (objects about to decay) will have priority over other satellites.[9]

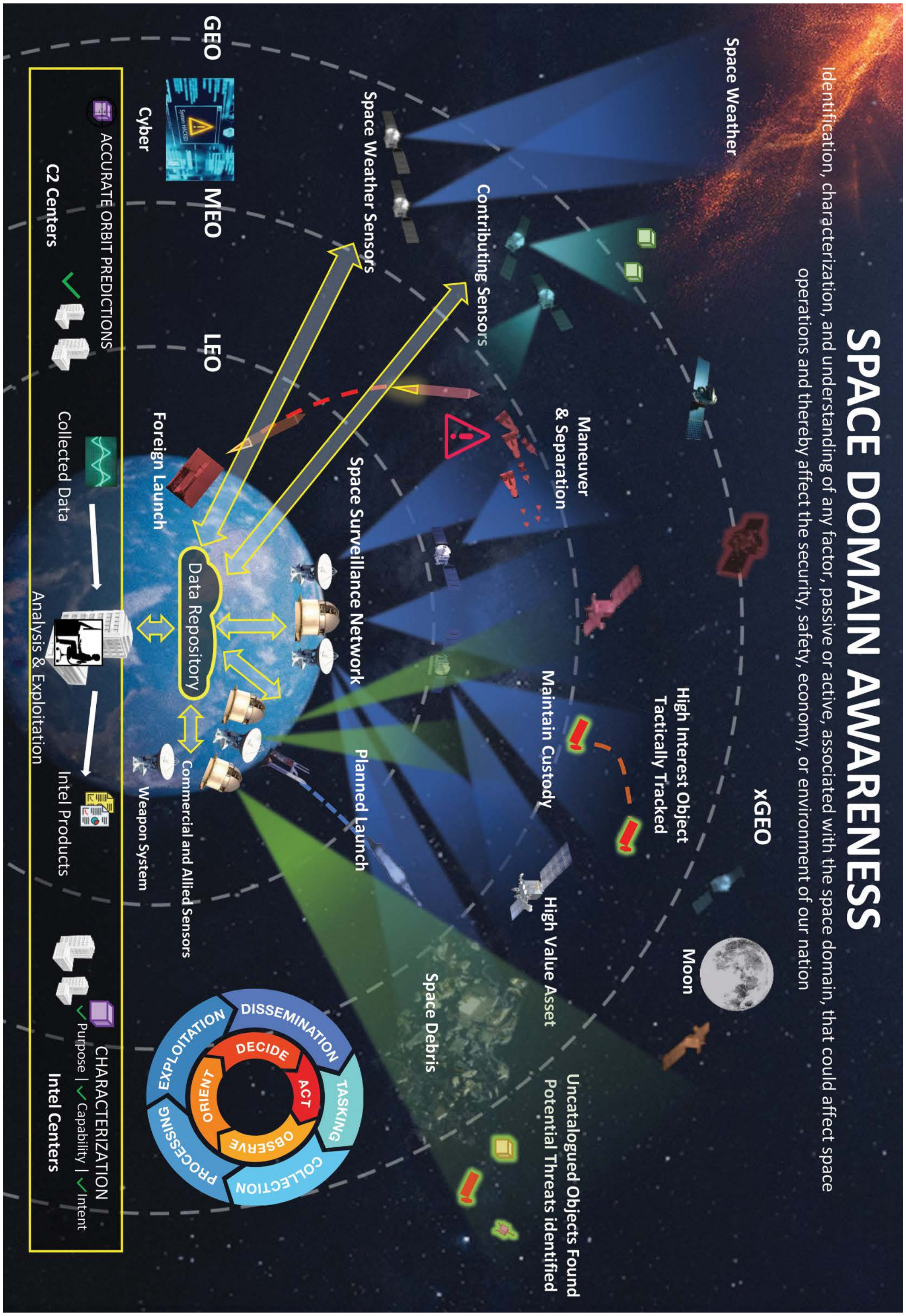


Figure 19.1. Space domain awareness. (Reproduced by permission of United States Space Command/J5, December 2022.)

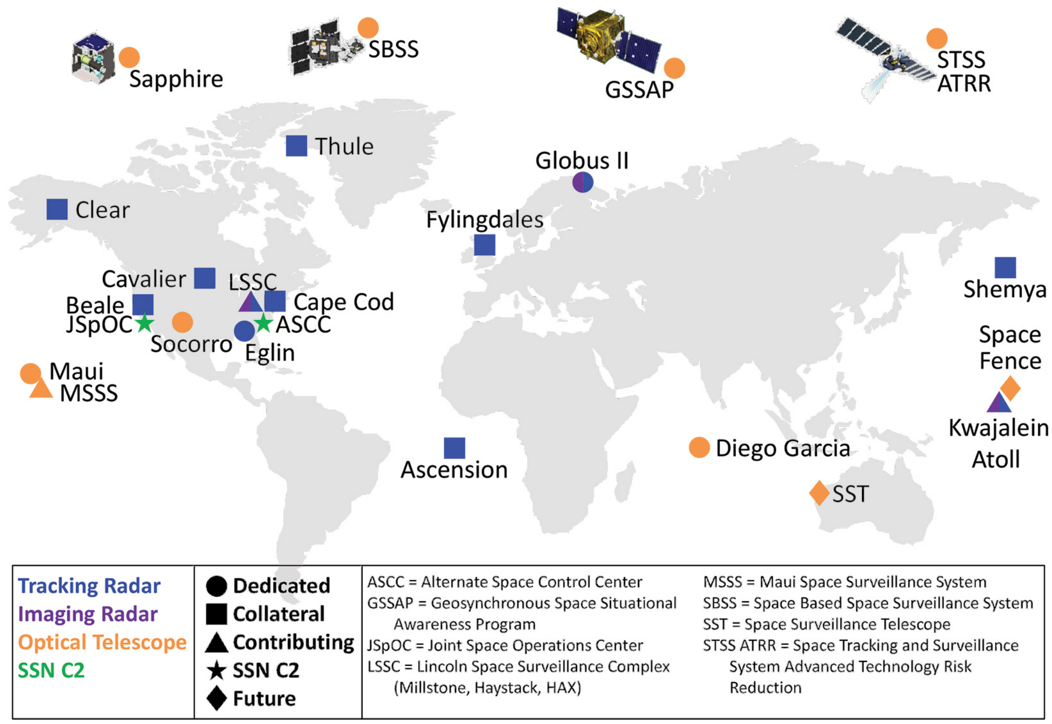


Figure 19.2. Space Surveillance Network. (Adapted from "Control Segment," GPS.gov, accessed October 13, 2022, https://www.gps.gov/.)

Space Events

An activity affecting space assets of the United States or any other nation is considered a space event. Possible space events tracked and identified by the SSN and cataloged for SDA include new foreign launches (NFL), anti-satellite (ASAT) launches, preplanned launches (PPL), maneuvers, separations, reentries, and breakups.[10]

A *new foreign launch* is the launch of a satellite by a foreign country or agency without prior coordination with USSPACECOM.[11] An *anti satellite launch* is a specific type of NFL designed to destroy or degrade a satellite in orbit, which could be perceived as an act of war.

A *preplanned launch* is a space launch for which USSPACECOM has received advance notification and launch information from the launching agency and/or payload owner(s) about the payload mission, launch profile, and parameters. The two types of PPLs are domestic and cooperative. A *domestic launch* refers to a PPL from the United States or a US platform. A *cooperative launch* is a PPL from a nation other than the United States but that has prior coordination with USSPACECOM.[12]

A *maneuver* is simply a change in the orbit of a satellite. This change can occur with the satellite orbit's size (shape), inclination (orbital plane), or both.[13] Most satellite maneuvers are considered station-keeping, meaning that the satellite is being moved slightly to keep it in a particular orbit around the earth. However, there are cases where maneuvering is for satellite repositioning, end-of-life preparations, or other reasons. In such events, the 18 SDS will coordinate with intelligence sources to determine the purpose of these maneuvers and send warnings to forward users if necessary.[14]

A *separation* is "the intentional disconnection of one or more parts or contents of a satellite from the main body."[15] Certain satellites are specifically designed to perform separation missions. Intelligence sources usually confirm satellite separations.[16]

Reentry refers to a near-Earth (NE) space object that, due to the drag force of the atmosphere and gravitational effects, can no longer remain in orbit and falls back to Earth. Objects that survive reentry may generate false indications of a missile threat to US or Russian missile warning systems. As a result, the CSpOC manages a reentry assessment program that predicts atmospheric reentry times for space objects and notifies the National Military Command Center (NMCC).[17]

A satellite *breakup* is the unintentional separation of multiple objects from the main body of a payload, rocket body, or other orbiting object. Most breakups are caused by propulsion-related events or accidental detonations; however, the causes of others are simply unknown. The number of new objects detected because of a breakup will vary greatly. Detection depends on factors such as the satellite's orbital parameters, collision variants, and the availability of space surveillance sites with coverage of the event.[18]

Responding to Space Events

When a space event occurs, the 18 SDS at Vandenberg SFB, California, is responsible for determining if the event is accidental, incidental, or the result of a hostile action directed against the United States and then forwarding its assessment to USSPACECOM. The CSpOC gathers information from a variety of sources—especially its Combat Operations Division's Space Domain Awareness Operations Cell—to make this determination.

Once the USSPACECOM commander receives the CSpOC's report, the commander may request a space event conference from the NMCC. During the space event conference, USSPACECOM describes the activity and provides one of the following assessments:

- **No** – An attack against a space system has neither occurred nor is in progress.
- **Concern** – Events are occurring that have raised the level of concern. Further assessment is necessary to determine the nature of the activity involved. Pending completion of the ongoing assessment, precautionary measures to enhance responsiveness or survivability are suggested.
- **Yes** – A verified attack against a space system has occurred. This assessment means that all source data confirms that the hostile event has occurred or is occurring.

USSPACECOM's assessment of a space event will determine what courses of action the United States will take in response to it.

SSN Radar Sensor Systems

Radar sensors used by the SSN are divided into two categories: (1) mechanical (the oldest type of radar used by the SSN) and (2) the newer phased array radars (PAR).

Space Object Identification

Space object identification (SOI) analyzes signature data to determine and fully understand satellite characteristics such as origin, capabilities, vulnerabilities, size, shape, motion, and orientation. SOI information is used to determine the operational status of payloads and may forecast maneuvers or deorbits. The process of using SOI data—in conjunction with other intelligence resources—to determine the nature of unidentified payloads is called mission payload assessment.

There are four categories of sensor SOI: wideband, narrowband, photometric, and optical imaging. Wideband SOI provides a detailed radar picture of the satellite. Haystack (the Advanced Research Project Agency [ARPA] Lincoln C-Band Observable Rader [ALCOR] owned by the Defense Advanced Research Projects Agency [DARPA]) and Globus II (operated by Norway, owned by US) have the capability of providing wideband SOI.[19] Narrowband SOI provides a two-dimensional depiction of the radar energy charted on a graph as amplitude versus time.[20] Narrowband SOI sensors are located at Ascension Island; Beale AFB, California; Cavalier AFS, North Dakota; Clear Space Force Station (SFS), Alaska; Cape Cod, Massachusetts; Shemya, Alaska; Eglin AFB, Florida; Royal Air Force (RAF) Fylingdales, England; and the Lincoln Space Surveillance Complex (LSSC) in Massachusetts. Photometric SOI is the analysis of the intensity, luminance, and illuminance from systems like the Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) system. Finally, optical-imaging

SOI refers to object identification obtained using optical telescopes augmented with Advanced Electro-Optical System (AEOS) long-wave infrared (LWIR) (AEOS-L) and AEOS adaptive optics sensors.[21]

Protecting the Space Surveillance Network

The ground SSN sensor sites are positioned around the world. While USSPACECOM owns the SSN ground sensor facilities, they are located in other combatant commanders' areas of responsibility (AOR). As a result, when a verified attack occurs or is in progress, USSPACECOM relies on the other unified commanders to protect US assets. Thus, combatant commanders play a key role in defending not only their AORs but also the US homeland.

Space Surveillance Network Sensor Missions

All sensors in the SSN are responsible for providing space surveillance data to the CSpOC at Vandenberg SFB and to the Alternate Space Control Center (ASCC) at Dahlgren, Virginia. The sensors in the network are categorized mainly by their availability to support the CSpOC. This availability is based on the primary mission of each sensor. The SSN sensor missions are divided into three categories—dedicated, collateral, and contributing—and can change from one category to another depending on the needs of the nation and the military. The sensors are listed below according to each category at the time of publication.

Dedicated Sensors

A dedicated sensor is a USSPACECOM operationally controlled sensor with a primary mission of space surveillance support.

GEODSS. GEODSS is an electro-optical telescope with the mission to detect, track, and collect SOI on deep-space satellites in support of the CSpOC. Each GEODSS site is controlled and operated by units of Space Delta 2, headquartered at Peterson SFB, Colorado. Currently three detachments operate GEODSS sensors: Detachment 1, Socorro, New Mexico; Detachment 2, Diego Garcia, British Indian Ocean Territories; and Detachment 3, Maui, Hawaii.[22] The GEODSS sites provide near real-time DS surveillance capability. The system operates only at night when the telescopes are able to detect objects 10,000 times dimmer than the human eye can perceive. Since it is an optical system, cloud cover and local weather conditions influence its effectiveness.[23] The telescopes scan across the sky at the same rate as the stars appear to move. Doing so keeps the distant stars in the same positions in the field of view. As the telescopes slowly move, the GEODSS cameras take rapid electronic snapshots of the field of view. Computers then take these snapshots and overlay them on each other. Star images, which remain fixed, are electronically erased. However, man-made space objects do not remain fixed, and their movements show up as tiny streaks that can be viewed on a console screen. Computers measure these streaks and use the data to calculate the positions of objects.

AN/FPS-85 PAR. Located at Eglin AFB, Florida, the AN/FPS-85 PAR is operated by the 20th Space Surveillance Squadron (20 SPSS), another unit of Space Delta 2. The 20 SPSS operates and maintains the only dedicated NE/DS, high-capacity PAR in the SSN. It is also the only SSN phased array sensor specifically designed and optimized for space surveillance. Its capabilities, location, and orientation give it the capacity and coverage to potentially track all LEO objects once per day.

Globus II. Globus II is an AN/FPS-129 mechanical X-band radar used for tracking and wideband imaging of NE and DS objects. Its location in Norway improves coverage capability of high-interest objects and provides significant mission payload assessment support. The radar system, developed by Raytheon, was originally installed at Vandenberg. While Globus II is US owned, Norway controls and operates it.

Space-Based Space Surveillance (SBSS) System. The SBSS Block 10 satellite conducts electro-optical surveillance of space objects as it travels around Earth in a sun-synchronous orbit. Operated by the 1st Space Operations Squadron (1 SOPS) at Schriever SFB, Colorado, the SBSS system searches for, detects, and tracks man-made space objects in deep space. It collects metric observations and photometric SOI data. The SBSS provides much-needed capability to the existing ground-based SSN sensors because it is unaffected by the limitations of weather, foreign basing, and sunlight or moonlight effects.[24]

Geosynchronous Space Situational Awareness Program (GSSAP). Operated by 1 SOPS, the GSSAP system is the newest space-based addition to the SSN. The first two GSSAP satellites launched on July 28, 2014, with GSSAP-5 and GSSAP-6 launched in January 2022.[25] Orbiting in the GEO belt, these satellites are able to accomplish rendezvous and proximity operations (RPO). RPOs allow the GSSAP satellites to maneuver near a space object of interest, enabling characterization for anomaly resolution and enhanced surveillance while maintaining flight safety. Because GSSAP satellites are in the GEO belt, the data they collect uniquely contributes to timely and accurate orbital predictions, enhances information about the geosynchronous orbit environment, and further augments space flight safety—specifically satellite collision avoidance.[26]

Sapphire. The Sapphire satellite is the only dedicated SSN sensor not owned by the United States. Sapphire is Canada's first dedicated operational military satellite and was developed for the SSN as a partnership between Canada and the United States. This small space surveillance satellite uses an electro-optical sensor to observe objects orbiting the earth at altitudes of 6,000–40,000 km.[27]

Collateral Sensors

A collateral sensor is a USSPACECOM operationally controlled sensor with a primary mission other than space surveillance (usually, the sensor's secondary mission is to provide surveillance support).

Upgraded Early BMEWS Warning Radars (UEWR). The UEWRs are five ground-based radars (GBR) that, in conjunction with the Perimeter Acquisition Radar Attack Characterization System (PARCS), provide ground-based missile warning coverage for North America. Three UEWR sites were part of the legacy Ballistic Missile Early Warning System (BMEWS), and two were part of the Precision Acquisition Vehicle Entry Phased Array Warning System (PAVE PAWS). The UEWRs are continually upgraded with new hardware and software to make them more effective and efficient at accomplishing their primary mission of missile warning (including support for missile defense) and a secondary mission of space surveillance. The Space Operations Command (SpOC) squadrons that report to Space Delta 4, Peterson SFB, operate the sites at Clear SFS, Thule Air Base, and Beale AFB. The Royal Air Force operates the RAF Fylingdales site in the UK.[28]

Clear SFS began operations in 1961 as a BMEWS site with three defense radars (AN/FPS-50s), each 400 feet long and 165 feet high, and a mechanical tracking radar (AN/FPS-92) 84 feet in diameter. Operated by the 13 SWS, the radar system has two faces that together form a coverage area 240 degrees wide and about 3,000 nautical miles into space. The coverage extends from the Arctic Ocean to the West Coast of the lower forty-eight states.[29]

Thule Air Base has a UEWR-modified BMEWS site operated by the 12 SWS. The two faces at the Thule AB radar site cover an area 240 degrees wide and about 3,000 nautical miles into space.[30] RAF Fylingdales operates the only three-faced PAR in the Space Surveillance Network. Because Fylingdales has three faces, its radar provides full 360-degree coverage of the sky. Fylingdales' primary mission is warning of an intermediate-range (IRBM), medium-range (MRBM), or submarine-launched (SLBM) ballistic missile attack against the United Kingdom and Western Europe. Its secondary mission is to warn of an intercontinental ballistic missile (ICBM)/SLBM attack against the CONUS. Fylingdales' tertiary mission is to furnish space surveillance data on orbiting objects to the CSpOC Space Domain Awareness Operations Cell and Alternate Space Control Center.[31]

Beale AFB is a UEWR-updated PAVE PAWS site operated by the 7th Space Warning Squadron (SWS). The Cape Cod SFS, constructed in 1978 and the first US PAVE PAWS station, is operated by the 6 SWS. The 6 SWS is a geographically separated unit of Space Delta 4, Buckley Space Force Base, Colorado.[32]

Perimeter Acquisition Radar Attack Characterization System (PARCS). The 10 SWS operates PARCS, located 15 miles south of the Canadian border at Cavalier SFS, North Dakota. The PARCS mission is to provide warning and attack characterization of SLBM and ICBM attacks against the CONUS and southern Canada. Along with the AN/FPS-85 PAR at Eglin, it is one of the workhorses of the SSN, providing surveillance, tracking, reporting, and SOI data on highly inclined and polar-orbiting objects. Because of its unique origin, PARCS can track hundreds of objects simultaneously. PARCS is a single-faced phased array radar (AN/FPQ-16) that uses traveling wave tubes similar to Cobra Dane.

Cobra Dane. Cobra Dane is situated at Eareckson Air Station on the island of Shemya in the Alaskan Aleutian Islands. It is a US Space Force (USSF) radar system operated by Raytheon under the functional control of 13 SWS, Space Delta 4, for missile defense, space surveillance, and SOI.[33] Built in 1977, Cobra Dane is the most accurate PAR currently in the SSN.[34] Because of its location and radar capabilities, Cobra Dane provides a significant portion of SOI to the SSN, operating in the L-band frequency and detecting objects out to 2,000 miles.[35]

Ascension radar. Since becoming operational in 1957, the tracking station on Ascension Island has undergone numerous replacements and upgrades. Today, the Ascension radar—a mechanical tracking radar—primarily provides radar tracking data to support test and evaluation of ballistic missiles launches, space launch vehicles, and aeronautical development programs within the Eastern Range portion of the Launch and Test Range System (LTRS). When not supporting its primary mission, Ascension's radar has the secondary mission of space surveillance in support of the USSPACECOM Space Surveillance Network.[36]

Contributing Sensors

Contributing sensors are those owned and operated by other agencies that provide space surveillance support upon request from the CSpOC.

Lincoln Space Surveillance Complex (LSSC). The LSSC is owned and operated by the Lincoln Laboratory of the Massachusetts Institute of Technology (MIT). The radars at Millstone Hill and Haystack in Tyngsborough, Massachusetts, are part of the complex and an important part of the SSN. The Millstone radars provide data to the SSN, contributing 60 to 80 hours of space surveillance per week to the CSpOC. The Haystack Ultrawideband Satellite Imaging Radar (HUSIR) is an imaging radar that provides wideband SOI data to the CSpOC. HUSIR supports the CSpOC one week out of every six. USSPACECOM has limited recall of the HUSIR sensor outside of scheduled times.[37]

Kwajalein Space Surveillance Center (KSSC). Located at the Reagan Test Site (RTS) on the Kwajalein Atoll in the western Pacific Ocean, the KSSC acts as the interface between the CSpOC and the RTS radar antennas. Operated by the Army, the RTS's primary mission is to support test and evaluation of developmental and operational ICBMs, space launch vehicles, and aeronautical development programs within the Western Range portion of the LTRS. When they are not supporting this primary mission, four separate radars at the RTS contribute space surveillance data to the SSN through the KSSC. Due to its proximity to the equator, the KSSC alone can track one-third of the geosynchronous belt.[38]

Maui Space Surveillance System (MSSS). The MSSS is collocated with the Maui GEODSS telescope on the summit of the 10,000-foot Mount Haleakala on the island of Maui, Hawaii. These two SSN assets form the Maui Space Surveillance Complex (MSSC). The MSSS is a national resource supporting various government agencies and the scientific community. It is operated by the 15 SPSS, Delta 2.[39]

The 15 SPSS employs several telescopes to conduct its primary mission of research and development; three contribute image and photometric space surveillance data to the SSN as a secondary mission. Although the site has been operational for over fifty years, numerous and ongoing equipment updates make it a world-class observation site with cutting-edge technology providing some of the most accurate optical and metric data to the SSN.[40]

Space Surveillance Telescope (SST). The SST, located in Western Australia, is a DARPA-sponsored initiative developed by MIT Lincoln Laboratory to improve cataloging of deep space and geosynchronous space objects through enhanced telescopic detection capabilities. The Royal Australian Air Force will operate the SST jointly with the USSF's Space Delta 2.[41]

Space Fence. The Space Fence increases timeliness, accuracy, detection, and tracking.[42] One of the two ground-based PARS is in the Kwajalein Atoll and the other in Western Australia. The Space Fence is an S-Band radar system integrated into the SSN that detects, tracks, identifies, and characterizes man-made and naturally occurring space objects (fig. 19.3). It is used primarily to observe low Earth objects but is able to detect and track objects in medium and geosynchronous equatorial orbits.[43] The 20th Space Surveillance Squadron, Space Delta 2, conducts Space Fence operations.[44]

Legend

CSpOC	Combined Space Operations Center	LEO	low Earth orbit
DOD	Department of Defense	MEO	medium Earth orbit
DODIN	Department of Defense Information Network	SOC	Space Fence Operation Center
ISS	International Space Station	SSN	Space Surveillance Network

Figure 19.3. **Space Fence (artist rendition)**. (Reproduced from "Space Fence [SF]," in Robert F. Behler, FY 2020 Annual Report [Washington, DC: Office of the Director, Operational Test and Evaluation, 2021], 205, https://www.dote.osd.mil/.)

Command and Control Systems

The 18 SDS uses the Space Defense Operations Center (SPADOC) and parts of the Correlation, Analysis, and Verification of Ephemerides Network (CAVENet) systems to command and control the SSN. These systems enable the 18 SDS to update the surveillance catalog and contribute to conjunction assessment for collision avoidance.[45] The Advanced Tracking and Launch Analysis System (ATLAS) is the follow-on to the SPADOC and CAVENet systems. ATLAS enables the background processing of SSN observations to correlate, retag, or detag objects to keep pace with the emerging involvement in the space domain. To improve satellite catalog maintenance, the manual differential correction refines the iterating process of space object prediction. The improvements brought by ATLAS allow the 18 SDS to stay current with emerging launches and activities within the space domain. The US Space Force plans to replace SPADOC, fielded in 1979, with the Space Command-and-Control (Space C2) system that will merge operational-level C2 capabilities into one integrated system. Space C2 "will deliver applications to decision-making hubs—like the National Space Defense Center, Combined Space Operations Center and the 18th Space Control Squadron—that will help process data from ground- and space-based sensors."[46]

In September 2015, the DOD established the National Space Defense Center (NSDC), located at Schriever SFB, as the subordinate center of USSPACECOM's Joint Task Force–Space Defense. The NSDC coordinates intelligence, civil, military, and commercial space for unified space defense operations.

Summary

The Space Surveillance Network is essential to the United States and its goal of maintaining space superiority and SDA. The 18 SDS and CSpOC use information from the SSN in operational and tactical planning for all DOD space capabilities. The synergistic effects of the sensor sites described have allowed the CSpOC to maintain a robust satellite catalog of around 30,000 objects currently orbiting the earth.[47] The SSN also allows the CSpOC, along with other DOD and intelligence community agencies, to give unified commanders the data necessary to avert or mitigate threats from space events to space systems and their associated ground-support systems.

This chapter discussed sensor technologies used to track objects orbiting Earth. It also highlighted features of the sensor sites that constitute the SSN and described the CSpOC process of tasking sensor sites and analyzing space track data. As the technology of spaceborne platforms improves and the population of objects orbiting Earth increases, SSN sensor sites will continue to require modifications and enhancements in the evolving space environment.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. US Space Force, Space Capstone Publication, *Spacepower*, 34.
2. Space Foundation, *Space Briefing Book*, 19.
3. Air Force Doctrine Publication 3-14, *Counterspace Operations*, 9.
4. US Space Force, Space Capstone Publication, *Spacepower*, 38–39.
5. US Space Force, 38–39.
6. Joint Task Force–Space Defense, "18th Space Defense Squadron."
7. National Coordination Office for Space-Based Positioning, Navigation, and Timing, "Control Segment."
8. NASA, *Small Spacecraft Technology State of the Art Report*, 337–38.
9. USSTRATCOM Directive 505-1, vol. 2 (SD 505-1 V2), *Space Surveillance Operations*, 11.
10. SD 505-1 V2, 11.
11. SD 505-1 V2, 24.
12. SD 505-1 V2, 38.
13. Wright, Grego, and Gronlund, *Physics of Space Security*, 49.
14. Bonnette, "18 SOS Activates New Detachment."
15. SD 505-1 V2, *Space Surveillance Operations*, 50.
16. SD 505-1 V2, 50.
17. SD 505-1 V2, 53.
18. SD 505-1 V2, 57.
19. Camp, Mayhan, and O'Donnell, "Wideband Radar," 267–80; and Cooper, "Engineers Demonstrate Pulsed Thermography."
20. Solodyna and Banner, "Narrowband and Wideband Radar," 15–17.
21. Foley, "Nanosat Employment," 8–9.
22. US Space Force, "Ground-Based Electro-Optical."
23. US Space Force, "Ground-Based Electro-Optical."
24. US Space Force, "Space Based Space Surveillance."
25. Prince, "GSSAP 5 and 6 Join the Fleet."
26. Prince; and US Space Force, "Geosynchronous Space Situational Awareness."
27. Government of Canada, "Space Situational Awareness and the Sapphire Satellite."
28. US Space Force, "Space Delta 4"; US Space Force, "Perimeter Acquisition Radar Attack Characterization System"; and Boyer, "Cavalier Space Force Station."
29. US Space Force, "Space Delta 4"; and Tarantola, "There Isn't an ICBM."
30. Buckley SFB, "12th Space Warning Squadron"; and Missile Defense Advocacy Alliance, "Upgraded Early Warning Radars."
31. Royal Air Force, "RAF Fylingdales."
32. Buckley SFB, "6th Space Warning Squadron"; and Crossman, "6th Space Warning Squadron."
33. Buckley SFB, "Space Delta 4–Missile Warning."
34. US Space Force, "Cobra Dane Radar."
35. US Space Force, "Cobra Dane Radar"; and Missile Defense Agency, "Cobra Dane."
36. NASA, "What Is the 'Range'?"; and Williams, "Small Island, Big Mission."
37. MIT, Lincoln Laboratory, "Haystack Ultrawideband Satellite."
38. MIT, Lincoln Laboratory, "Reagan Test Site."
39. US Space Force, "15th Space Surveillance Squadron."
40. US Space Force, "15th Space Surveillance Squadron."
41. Ryan, "Space Surveillance Telescope in Western Australia."
42. Lockheed Martin, "Space Fence."
43. Lockheed Martin; and Hitchens, "Second Space Fence."
44. Eglin AFB, "20th Space Surveillance Squadron."
45. Joint Task Force–Space Defense, "18th Space Defense Squadron."
46. Albon, "Legacy Command and Control System."
47. European Space Agency, "ESA's Space Environment Report 2022."

Chapter 20

Meteorological/Environmental Satellites

Timely knowledge of weather conditions is integral to the planning and execution of military operations. Real-time night and day observations of weather conditions give operational commanders greater flexibility in the use of resources for imminent or ongoing military operations and in the planning of future operations. Current weather observation data in a specific region connects the data gaps for commanders in assessing impacts on people and resources. Weather observations are accomplished using remote sensing—the "process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance."[1]

The military has validated the merit of meteorological data through its consistent use of satellite imagery in the effective and efficient conduct of military operations. Satellite-based remote sensors allow situational awareness of environmental conditions in areas that otherwise would not be accessible via aircraft or other terrestrial means, such as human weather observers or weather observing systems. For weather forecasters, this data is essential in the process of accurately characterizing the current state of the atmosphere and building forecasts of potential mission impacts.

This chapter first describes the present fleet of Defense Meteorological Satellite Program (DMSP) satellites, NASA's meteorological satellites, and the National Oceanic Atmospheric Administration's (NOAA) civil weather satellites. NOAA is the primary agency that the DOD meteorological community uses in support of operations. Next, this chapter summarizes other US civil weather satellites as well as foreign satellite programs. Finally, it discusses the future of the US meteorological satellite program and our international cooperation with other nations as a part of the Coordination Group for Meteorological Satellites (CGMS).

Operational Demand for Meteorological/Environmental Satellites

Weather and environmental satellites give commanders essential data for accurate, dependable weather forecasting in support of air, land, and maritime operations. Cloud-cover data products are needed to determine weather conditions in data-denied and data-sparse regions and to forecast weather in all phases and types of operations. Commanders require timely weather data for in-theater operations, including en route (e.g., refueling), target area, and recovery operations. Meticulous analysis of surface and upper-level wind data supports all aspects of military operations. Such data ranges from the assessment of nuclear, biological, and chemical weapon effects (e.g., radioactive fallout conditions) to the prediction of weather system movement for proper weapons delivery, including missile launches.

Precipitation information (type and rate) is required to forecast soil moisture, soil trafficability, river stages, and flooding conditions that could affect land-based force deployment/employment. Ocean tidal information is vital to naval operations for safe passage in and out of ports and river entrances and for landing amphibious craft. Sea ice conditions significantly impact surface/subsurface ship operations. Data on the location of areas of open water or thin ice is crucial to submarine surfacing and missile launch operations. It is also needed for deploying air-dropped sonobuoys used for detecting submarines. Knowledge of the location and size of icebergs is imperative for the safe navigation of surface ships and submarines. These types of data could offer a vital advantage over adversaries in submarine and antisubmarine warfare. Most of this critical information is acquired through the DMSP. However, as NOAA and the international meteorological community continue to improve their capabilities, a combination of satellite platforms appears to be the method for future operations.

Defense Meteorological Satellite Program

The DMSP mission is to provide an enduring and survivable capability to collect and disseminate global visible and infrared cloud data and other specialized meteorological, oceanographic, and solar-geophysical data in support of worldwide DOD operations.[2] The DOD's only operational weather satellite system, the DMSP is now in its seventh decade of service—the longest-running satellite production satellite program to date.[3] It was designed primarily to give the military a dedicated remote weather observing system in space. Under peacetime conditions, weather data is also available from civil weather satellites, such as geostationary operational environmental satellites (GOES) and polar operational environmental satellites (POES). Through DMSP satellites, military weather forecasters can more effectively detect developing patterns of weather and track existing weather systems over remote areas.

NOAA assumed all functions related to command and control of the DMSP constellation in May 1998 at its Satellite Operations Control Center (SOCC) in Suitland, Maryland.[4] The Remote Sensing Systems Directorate of the Space Systems Command at Los Angeles AFB is responsible for managing the Defense Meteorological Satellite Program.[5] Activated at Schriever SFB on October 1, 1998, the 6th Space Operations Squadron (6 SOPS) is an Air Force Reserve unit providing a "hot backup" capability for the SOCC.[6]

User Segment

While the command, control, and communications (C3) segment meets the ongoing needs of DMSP satellites, the DMSP user community is serviced by centralized and tactical components of the user segment. The user segment consists of Earth-based processing and communications functions for receiving, preparing, and distributing global weather data to support Air Force, Space Force, Army, Navy, Coast Guard, and Marine Corps requirements. Specialized vans and shipboard terminals, using direct readout of real-time infrared and visible spectrum images from the DMSP satellites, also form part of this segment.

The 557th Weather Wing (557 WW) at Offutt AFB, Nebraska, and the Fleet Numerical Meteorology and Oceanography Center (FNMOC) at Monterey, California, are the centralized components of the user segment. The 557 WW's products and services include aviation, terminal, and target forecasts; weather warnings and advisories; automated flight plans; and exercise/special mission support. The wing also recovers and processes stored mission data from the C3 segment and then integrates data from other sources (e.g., GOES, POES), generates weather and space environmental products, and offers operational support to its respective customers. The 557 WW is the lead DOD organization for the overall processing and distribution of centralized meteorological mission sensor data in support of worldwide military activity. Its mission includes weather forecast support to the US Army, which does not have a meteorological component.[7]

The FNMOC receives DMSP data to provide operational products and forecasts to the Navy. Specifically, the FNMOC furnishes naval forces with analyses and forecasts of oceanographic and marine weather parameters for any global location, to include ocean surface and subsurface temperatures and other meteorological conditions. The 557 WW and FNMOC also support many other DOD and government agencies.[8]

The tactical components of the DMSP user segment are the fixed and mobile land- and ship-based tactical terminals operated by the US Space Force, Air Force, Navy, and Marine Corps. These terminals directly downlink readouts of real-time visible and infrared cloud-cover data and data from the DMSP satellites.[9]

Other Military Weather Satellites

In 2020 the USSF declared initial operational capability (IOC) of the Electro-optical Infrared Weather System Geostationary (EWS-G1) spacecraft, the first geostationary weather satellite owned by the DOD.[10] It utilizes a repurposed NOAA GOES satellite positioned over the Indian Ocean region to provide continuous, timely weather data for the Indo-Pacific Command (INDOPACOM) theater.[11] The initial space vehicle of the Weather System Follow-on – Microwave (WSF-M) is projected to be launched in fiscal year 2024 and a second in 2028.[12] With these solutions, the DOD should have uninterrupted weather satellite coverage for many years into the future.

Civil and Foreign Weather Satellites

Polar-Orbiting Programs: Joint Polar Satellite System (JPSS)

JPSS is a collaborative program between NASA's Goddard Space Flight Center, which manages the JPSS system, and NOAA, which owns and operates the spacecraft in support of civil meteorological operations. As part of this program, NOAA (through NASA as its acquisition agent) provides the afternoon orbits that support its civil (National Weather Service) weather and climate requirements while the European Organization for the Exploitation of Meteorological Satellites' (EUMETSAT) meteorological operational (MetOp) satellites cover midmorning orbits.[13] The constellation concept for JPSS, developed in 2010 in coordination with EUMETSAT and the DOD, exemplifies how the polar-orbiting weather satellites work in concert.[14] Through this concept, JPSS provides most of the data that "informs numerical weather forecasting in the U.S. and delivers critical observations during severe weather events."[15] The JPSS will continue the development of critical Earth-observing analyses required for improving weather forecasts, climate monitoring, and warning lead times of severe storms.[16]

Geostationary Programs

A DMSP product can be relayed to its user in 15 to 45 minutes, depending on the satellite's overpass times and the tasking's priority. Civilian polar-orbiting satellites are also affected by a lag in data transmission. Using civilian and foreign geostationary satellites helps offset the time delay. Geostationary satellite systems such as NOAA's GOES and EUMETSAT's meteorological satellites (Meteosat) offer a rapid refresh rate of cloud/weather data every 30 minutes. These satellites also offer a constant look angle resulting in high-quality pictures. Currently, NOAA operates two GOES satellites and one on-orbit spare over the United States.

Polar versus Geostationary Programs

Geostationary satellites have the best temporal (time) resolution, recording images over the same area roughly every 30 minutes. Polar-orbiting satellites have the worst temporal resolution, recording images over the same area roughly twice a day per satellite. However, because polar-orbiting satellites are closer to the earth (~500 miles altitude compared to ~22,500 miles for geostationary satellites), they provide more fidelity than geostationary satellites. Their better spatial (horizontal) and radiometric (temperature) resolution allows more accurate determination of cloud type (figs. 20.1 and 20.2).

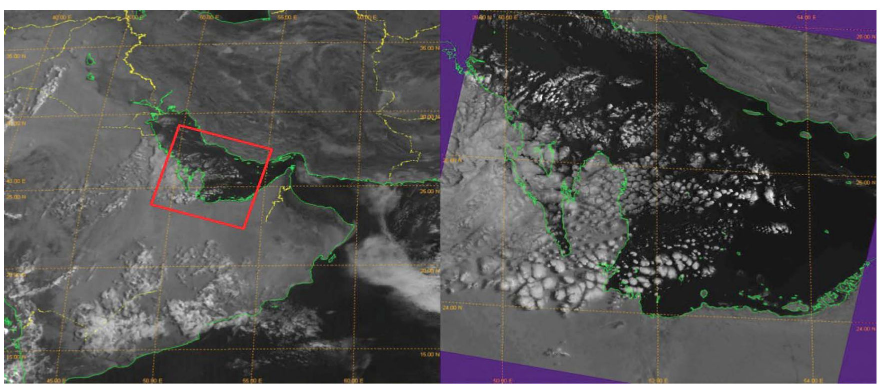


Figure 20.1. (*Left*) **GOES versus** (*right*) **DMSP coverage**. (Courtesy of 557th Weather Wing.)

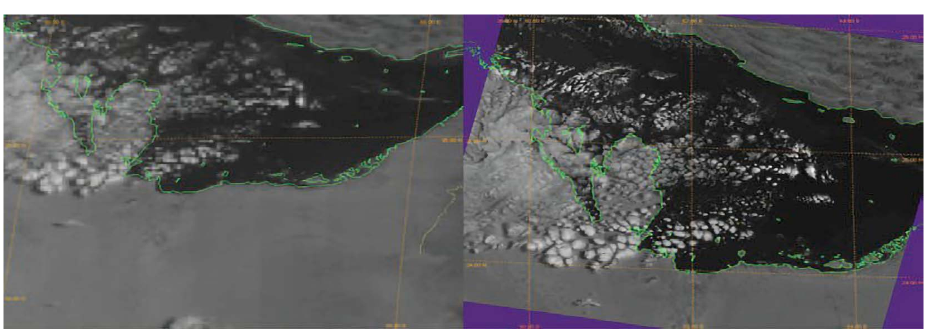


Figure 20.2. (*Left*) **GOES versus** (*right*) **DMSP resolution**. (Courtesy of 557th Weather Wing.)

International Cooperation

International cooperation for the employment of meteorological satellites must continue to grow to help save financial resources and improve unity of effort by sharing capabilities and technology. However, such collaboration is challenging because many countries focus on information protection and the realist approach of national interests first.

The Coordination Group for Meteorological Satellites (CGMS), of which NASA and NOAA are members, is presently the most effective forum for attracting other nations into cooperative agreements. Other members include China, France, Germany, India, Japan, Korea, and Russia.[17] The CGMS must continue to expand its boundaries to other nations, especially in data-sparse regions around the world. The potential for growth increases as the cost of weather satellites also increases.

Summary

Whether military members realize it or not, data collected by weather satellites is critical to military operations worldwide. Without the capability these satellites provide, access to relevant weather data for Soldiers, Sailors, Airmen, Guardians, and Marines would be limited—particularly in areas where access to terrestrial meteorological equipment is unavailable. Thus, preserving and extending our space-based environmental monitoring capability are essential to effective military operations now and in the future.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. US Geological Survey, "What Is Remote Sensing?"
2. US Space Force, "Defense Meteorological Satellite Program."
3. Erwin and Berger, "Race against Time"; and Erwin, "Space Force Orders New Weather Satellite."
4. National Environmental Satellite, Data, and In+formation Service, "History of NOAA Satellites"; and "DMSP – Block 5D-3," Spaceflight101.
5. US Space Force, "Defense Meteorological Satellite Program."
6. 310th Space Wing, "310th Operations Group."
7. 557th Weather Wing, Fact Sheet.
8. Fleet Numerical Meteorology and Oceanography Center, "Overview"; and Naval Meteorology and Oceanography Command, "Fleet Numerical Meteorology and Oceanography Center."
9. US Space Force, "Defense Meteorological Satellite Program."
10. "US Space Force Declares IOC."
11. "US Space Force Declares IOC"; "and Erwin, "NOAA's Former Satellite."
12. Erwin, "Space Force Orders New Weather Satellite"; and Ball Aerospace, "Weather System Follow-On – Microwave."
13. NOAA, "Joint Polar Satellite System"; and Klaes and Holmlund, "EPS/METOP System."
14. NOAA, "History of NOAA Satellites."
15. NOAA, "Joint Polar Satellite System."
16. NOAA, "NOAA's Newest Satellite."
17. World Meteorological Association, "International Space Agencies."

Chapter 21

Missile Warning Systems

This chapter addresses the missile warning systems assigned to USSPACECOM in support of the North American Aerospace Defense Command (NORAD) agreement to protect the continental United States and Canada from ballistic missile attack.[1] Also discussed are the fundamental aspects of infrared (IR) sensors as they apply to missile warning. Finally, it covers systems developed for theater-level missile defense for the protection of forward-deployed allies and US forces.[2]

Missile Warning Overview

Missile warning provides missile attack notification(s) to national leaders, combatant commands, multinational partners, and forward-deployed personnel. A well-organized missile warning system structure allows commanders to maximize detection and warning of inbound ballistic and nonballistic missiles, thereby ensuring effective passive defense, active defense, and attack operations. For terrestrial sensors, that data comes in the form of radar information. Space-based assets provide missile warning data gathered by sensors from the IR spectrum, discussed next.[3]

Infrared Sensors

Used extensively in military applications, IR sensors detect energy emitted in the form of heat from objects. Applications for ground-based and aerial IR sensors include target acquisition, surveillance, night vision, homing, and tracking.[4] On spacecraft, IR sensors can detect heat from events such as large forest fires, volcanic eruptions and geothermal activity, and space and missile launches. Technological improvements have increased the sensitivity of IR sensors to object signatures and location accuracy without registering such false targets as sun reflections. The ability of space-based sensors to detect IR events through all stages of missile flight allows for accurate and timely warning of missile launch and ballistic impact locations and times.[5] The United States Space Force operates two space-based infrared sensor constellations: the Defense Support Program (DSP) and the Space-Based Infrared System (SBIRS).

Defense Support Program

Consisting of ground and satellite segments, the DSP was the stalwart of missile warning from its first launch in the early 1970s. Since then, DSP satellites have provided uninterrupted early warning capability—with 23 satellites launched in the program.

In 2001, the DSP ground system was replaced by the Space-Based Infrared System ground construct, though DSP satellites continue to operate as part of the newer SBIRS architecture.[6] The final DSP satellite went to orbit in 2007.[7] As the DSP satellite constellation reaches its end of life, it is being replaced with a constellation of SBIRS geosynchronous equatorial orbit satellites.

In addition to launch detections, DSP satellites have numerous sensors on board to detect nuclear detonations.[8] Each satellite in the DSP constellation spins around its Earth-pointing axis, allowing the IR sensor to sweep across the earth like a second hand sweeping across the face of a clock collecting mission data.

Figure 21.1. Defense Support Program satellite (artist concept). (Courtesy of US Air Force.)

Space-Based Infrared System

The DSP system proved its worth to missile warning during Desert Shield/Desert Storm, but that conflict also highlighted the need for an even more capable missile warning system. Thus, in 1995 the Air Force announced that SBIRS would be the follow-on program to DSP, incorporating lessons learned using twenty-first-century technology.[9]

SBIRS is designed to accomplish four main goals. First, like the DSP before it, it provides missile warning whenever missiles are launched. SBIRS contributes to missile warning by supplying timely and accurate data to the combatant commanders and other users regarding detection, identification, and predicted impact-point location of ballistic missile launches. Second, it is integrated into the Ballistic Missile Defense System (BMDS). SBIRS supports the missile defense mission by providing timely, accurate, and reliable transmission of missile launch and in-flight data to missile defense assets in-theater—allowing those systems to respond to an enemy attack. Third, it contributes to technical intelligence about missile launches. SBIRS performs the technical intelligence mission by providing expeditious relaying of IR target signatures and threat performance data to the intelligence community for analysis. Finally, it supplies battlespace awareness to personnel on the front lines. Battlespace awareness refers to the provision of data used to enhance the overall situational awareness of decision makers, support battle damage assessments, and aid in intelligence preparation of the operational environment.[10]

SBIRS is an integrated "system of systems" with space and ground components. The space component consists of legacy DSP satellites, SBIRS geosynchronous equatorial orbit (GEO) satellites, and SBIRS payloads hosted on satellites in highly elliptical orbits—known as SBIRS HEO.[11]

The SBIRS ground components include the Mission Control Station (MCS) at Buckley SFB, Colorado, and MCS Backup (MCSB) at Schriever SFB, Colorado. Ground components also include mobile/deployable ground stations and upgraded dispersed relay ground stations (RGS) originally used for the DSP program.[12] MCS crew members control the SBIRS and DSP satellites and process the data collected for the missile warning mission. RGSs receive missile warning data from the satellites and forward the data via secure communications links to control stations for processing. Crew members verify these reports and send them to the NORAD operations centers at Cheyenne Mountain SFS, Colorado; Alternate Missile Warning Center at Offutt AFB, Nebraska; the theater event system (TES); and other command centers providing strategic and tactical missile warning.

Operating SBIRS is a group effort conducted by units from Space Delta 4 at Buckley SFB.[13] The 2nd Space Warning Squadron (2 SWS) at Buckley provides operational control from the MCS of all satellites in the SBIRS constellation—DSP and SBIRS GEO satellites and SBIRS HEO payloads—and processes the data.[14] The 11th Space Warning Squadron (SWS) performs the battlespace awareness and technical analysis missions using data from DSP, SBIRS, and other IR sensors.[15] The 3rd Space Communications Squadron (3 SCS) operates and maintains satellite communications architecture, ensuring the missile warning/launch data gets to SBIRS operators as well as combatant commands and allies.[16]

Figure 21.2. SBIRS geosynchronous equatorial orbit satellite (artist concept). (Courtesy of US Air Force.)

Upgraded Early Warning Radars

The Upgraded Early Warning Radars (UEWR) are five ground-based radars (GBR) that, in conjunction with the Perimeter Acquisition Radar Attack Characterization System (PARCS), provide ground-based missile warning coverage for North America. Three UEWR sites were part of the legacy Ballistic Missile Early Warning System (BMEWS), and two were part of the Precision Acquisition Vehicle Entry Phased Array Warning System

(PAVE PAWS). The UEWRs are continually upgraded with new hardware and software to make them more effective and efficient at accomplishing their primary mission of missile warning (including support for missile defense) and a secondary mission of space surveillance. All the sites, with the exception of RAF Fylingdales, are operated by SpOC squadrons that report to Space Delta 4, Peterson SFB.[17]

Missile Warning Center

The Missile Warning Center (MWC) at Cheyenne Mountain SFS is operated by the Combined Force Space Component Command (CFSCC). The MWC fulfills USSPACECOM's responsibility to NORAD by providing unambiguous, timely, accurate, and continuous integrated tactical warning and attack assessment (ITW/AA) data. The center receives event data from the missile warning sensors, analyzes the data to develop a site report, and disseminates the data and report. This information is passed to senior authorities in the National Military Command Center, Canadian Forces Integrated Command Centre, United Kingdom Space Operations Coordination Centre, combatant commands, and other key agencies. The data collected by missile warning sensors and analyzed by the MWC is critical to NORAD's timely attack assessment mission for North America.[18]

Theater Missile Warning

While the USSPACECOM MWC meets the need for strategic missile warning by disseminating data to NORAD, it also oversees the tactical-level missile warning required by combat forces in a theater. The theater event system was designed to meet the warfighter's growing demand for situational awareness of theater-class ballistic missiles.[19]

Theater Event System

The theater event system elements receive data from space-based sensors and process ballistic missile warning information to disseminate to joint forces and units. While the missile warning sensors may be hosted on platforms on orbit, in the air, and/or on the ground, the purpose of the system is to provide decision makers with pertinent information to enable battlespace awareness. Using IR sensors, missile tracking includes launch detection, mid-course tracking, terminal phase re-entry, impact prediction, nuclear detonations detection, and follow-on decision-making.[20]

For the space-based missile warning component, the SBIRS and DSP satellites host sensors that detect IR energy (heat) from sources such as booster exhaust. The SBIRS MCS receives transmitted data from the various elements of the theater event system and supports identification of missile type, predicted impact point and time, and estimated launch point. Combined, the theater event system warning elements directly support command and control, fires, intelligence, and maneuver operations.[21]

Theater Event System Data Reporting

The primary mission of the theater event system is to report theater/tactical threats. For theater warning, the theater event system elements (SBIRS, joint tactical ground stations [JTAGS], and tactical detection and reporting [TACDAR]) relay the in-theater launch via voice over secure phone networks. The TES relays launch warning data via a satellite broadcast network called the Integrated Broadcast Service (IBS) using the Common Interactive Broadcast (CIB). IBS is the worldwide standard network used by the DOD for transmitting time-sensitive strategic and tactical data to all echelons of joint service operational users. CIB is an approved message format standard that allows near real-time sharing of intelligence and information over the IBS network.[22]

When a missile warning event occurs, it is likely that more than one of the TES elements—possibly all three—will process and report the event. To help control and deconflict multiple reports of the same event, "first detect–first report" (FDFR) procedures are used. The first TES element that processes the event initiates a missile warning conference call and relays the missile warning information by voice. If any of the other TES elements are processing the same event, they will share the information they have on that event. Similarly, tactical display processors in the field correlate missile tracks received by different TES elements. This identification of corresponding missile tracks ensures that duplicate tracks from the same event do not appear as multiple launches in-theater.[23]

Summary

Space-based IR sensors and missile warning radar sites around the globe provide the world's most sophisticated missile warning system for the president, secretary of defense, geographic and functional combatant commanders, and the entire joint military community. The robustness of US missile warning systems and their inherent redundancy enable the United States to promptly respond to any attack on its sovereignty or national interests. The US missile warning posture will continue to be enhanced as additional components of SBIRS and other missile warning follow-on systems attain full operational capability.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Agreement between the Government of Canada and the Government of the United States of America on the North American Aerospace Defense Command.
2. Joint Publication (JP) 3-14, *Space Operations*, II-7.
3. JP 3-14, II-7.
4. Joint Ballistic Missile Defense (BMD) Training and Education Center (JBTEC), "Student Reference Supplement," 51–52.
5. JBTEC, 52.
6. US Space Force, "Space Based Infrared System."
7. US Space Force, "Defense Support Program."
8. US Space Force, "Defense Support Program."
9. Richelson, "Space-Based Early Warning."
10. Missile Defense Advocacy Alliance, "Space-Based Infrared System."
11. US Space Force, "Space Based Infrared System."
12. Buckley SFB, "2d Space Warning Squadron"; Missile Defense Advocacy Alliance, "Space-Based Infrared System"; and DOD, *Space Based Infrared System High*, 8.
13. US Space Force, "Space Delta 4"; and Defense Visual Information Distribution Service (DVIDS), "Space Delta 4 Detachment 1 Deactivates."
14. Buckley SFB, "2d Space Warning Squadron."
15. Kirchner, "11th Space Warning Squadron."
16. USSF, "Space Delta 4"; and DVIDS, "Space Delta 4 Detachment 1 Deactivates.
17. Missile Defense Advocacy Alliance, "Upgraded Early Warning Radars."
18. Vandenberg SFB, "Missile Warning Center Fact Sheet."
19. Field Manual (FM) 3-14, *Army Space Operations*, 3-14–3-16.
20. FM 3-14, 3-15.
21. FM 3-14, 3-16.
22. USSTRATCOM Directive 523-2, *Theater Event Systems*, 6; DOD, *Fiscal Year (FY) 2022 Budget Estimates*, Justification Book, Vol. 3b of 3, 237; and JBTEC, "Student Reference Supplement," 171.
23. US Strategic Command Directive 523-2, *Theater Event Systems*, 23.

Chapter 22

Space Control

Space remains a congested, competitive, and contested operating domain with many threats. The United States uses the space control and orbital warfare missions within the US Space Force (USSF) as a means for meeting the challenges of the space domain. While space control focuses on ensuring freedom of action in space for the United States and its allies, orbital warfare focuses on preserving freedom of access to the domain from space. This chapter discusses the space control and orbital warfare missions and adversary threats to US space systems.

Space Control Fundamentals

Space control is the use of combat forces, support elements, and combat service support to ensure freedom of action in space for the United States and its allies while denying or reducing the adversary's ability to act.[1] Space professionals exploit the operational concepts of the space domain to achieve an asymmetrical advantage over the enemy and establish space superiority. The space control mission area comprises offensive and defensive space control (OSC and DSC), both highly dependent on space domain awareness (SDA).

Countering space system threats is the US Space Force's space control mission. The USSF conducts space control on behalf of the United States Space Command (USSPACECOM).[2] Offensive and defensive space control require SDA for surveillance, intelligence, and analysis of the space environment.[3] Many of the specific actions and programs of space control are classified.

Space Delta 3 conducts the Space Force's space control mission through four operational squadrons that provide SDA and accomplish DSC and OSC in coordination with the Combined Space Operations Center (CSpOC).[4]

Space Domain Awareness

SDA is foundational to the space control mission area as part of the targeting and effect process. A significant part of SDA is space surveillance. Several squadrons in Space Delta 2 and Space Delta 4 conduct the space surveillance mission for the Space Force. The information gathered feeds the CSpOC decision-making process.

Defensive Space Control

Joint space operations doctrine states that DSC operations "consist of all active and passive measures taken to protect friendly space capabilities from attack, interference, or hazards."[5] Space Force operators employ these passive and active measures in distinctive ways. The 16th Space Electromagnetic Warfare Squadron (16 EWS), a unit of Space Delta 3 at Peterson SFB, Colorado, conducts DSC for the Space Force and nation.[6]

Passive DSC mechanisms reduce vulnerabilities while increasing the survivability of US space assets.[7] Many activities associated with passive space control are executed throughout military operations. Operations security (OPSEC) protects critical unclassified information about space systems and capabilities from reaching the enemy through unintended or unauthorized disclosures. Information assurance and system hardening measures safeguard networked information within space systems from cyberattack. Concealment and dispersal of ground systems reduce the likelihood of adversaries identifying all necessary targets for hampering US space-based capabilities while ensuring redundancy in space operations. The detection and characterization of adversary intentions by SDA analysts is passive assessment.[8]

The most comprehensive of the passive DSC measures are the vulnerability and survivability assessments. These periodic examinations determine if the space system and its operators properly mitigate possible weaknesses and evaluate the likelihood of maintaining operations during an attack.[9]

In contrast to passive DSC, active DSC involves avoiding and removing hostile space threats in various segments of space operations. The maneuver of a satellite in orbit away from an anti satellite threat represents one type of active defensive measure against a physical or kinetic space segment threat. Configuration changes to the radio frequency or RF amplitude may abate an active threat against a communications segment. The addition of complicating factors like encryption or a new frequency-hopping scheme could also serve as active defensive measures.[10]

Within the range of space control operations—as active DSC transitions into the OSC realm—Air Force doctrine discusses the concept of suppression of adversary counterspace capabilities (SACC). SACC targets adversary counterspace technologies with a US response. SACC responses may involve space or ground-based kinetic attack, information operations, or any other response deemed appropriate in countering the adversary threat.[11] The Counter Communications System (CCS) is an example of an active DSC program with offensive capabilities. The CCS negates adversary counterspace actions and supports offensive actions with the ability to interrupt adversary space communications.[12]

Offensive Space Control

The objective of OSC is to prevent the enemy from using space capabilities to its advantage. OSC includes countering the adversary's ability to use or access space systems or services for purposes hostile to US national interests.[13] Some of the effects-based operations achieved through OSC are interdiction, deception, and suppression of the enemy's space capabilities—including ISR, C2, and navigation. OSC may even include the isolation of the enemy's political leadership.[14] The 4th Space Electromagnetic Warfare Squadron (4 EWS), under Space Delta 3 at Peterson SFB, accomplishes the OSC mission for the Space Force. The 4 EWS operates the CCS and "trains, equips, and mobilizes to employ space electromagnetic warfare capabilities in order to support full spectrum national security objectives."[15]

Orbital Warfare

The Space Force's orbital warfare discipline is "the knowledge of orbital maneuver as well as offensive and defensive fires to preserve freedom of access to the domain."[16] Orbital warfare ensures the United States and coalition space forces can "continue to provide capability to the Joint Force while denying that same advantage to the adversary." [17] Through offensive and defensive measures, the USSF counters threats to US space systems.

Space Delta 9 represents the USSF in-domain maneuver and fires element. Being in the space domain ensures freedom of action throughout the domain by projecting combat power through space security and combat power projection. Space security establishes and promotes safe conditions in the domain. Combat power projection integrates offensive and defensive operations to maintain the desired level of freedom of action relative to an adversary. The 1st Space Operations Squadron (1 SOPS) and 3rd Space Operations Squadrons (3 SOPS) are the units presented to USSPACECOM to conduct operations in the domain. Space Delta 9 is at the forefront as new forces are developed and integrated to conduct orbital warfare operations in the space domain.[18]

Summary

The Space Force's space control mission is to protect DOD space systems from threats. USSPACECOM counters threats to US space systems using offensive and defensive measures. Adversaries exploit weaknesses in space systems to threaten the three major segments of a space system: ground, communications, and space. The ground segment presents the easiest attack vector because it is the most readily accessible, vulnerabilities are easily discovered via the Internet, and multiple locations around the world can be attacked. In the communications segment, spoofing and jamming may interrupt signals traveling to and from satellites while the problem of bandwidth piracy is difficult to control. Finally, in the space segment, various types of interceptors threaten satellites on orbit, while directed energy provides a glimpse into the future of counterspace operations. The space control mission addresses the threats at each segment to ensure continuity of space operations.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Joint Publication (JP) 3-14, *Space Operations,* II-8.
2. Congressional Research Service, "United States Space Force."
3. JP 3-14, *Space Operations*, II-12.
4. US Space Force, "Space Delta 3 – Space Electronic Warfare"; and Defense Visual Information Distribution Service (DVIDS), "4th, 5th and 16th SPCS Re-designation."
5. JP 3-14, *Space Operations*, II-2. See also US Space Force, Space Capstone Publication, *Spacepower*, 36.
6. US Space Force, "Space Delta 3 – Space Electronic Warfare"; and DVIDS, "4th, 5th and 16th SPCS Re-designation."
7. JP 3-14, *Space Operations*, II-2–II-3.
8. JP 3-14, II-2–II-3.
9. JP 3-14, II-2–II-3.
10. JP 3-14, II-2–II-3.
11. LeMay Center, Air Force Doctrine Publication 3-14, *Counterspace Operations*, 1, 5.
12. DOD, *(FY) 2018 Budget Estimates,* Justification Book Vol. 3b of 3, 699; and JP 3-14, *Space Operations*, II-2–II-3.
13. JP 3-14, II-2–II-3.
14. JP 3-14, II-2–II-3.
15. US Space Force, "Space Delta 3 – Space Electronic Warfare"; and DVIDS, "4th, 5th and 16th SPCS Re-designation."
16. US Space Force, Space Capstone Publication, *Spacepower, 51.*
17. US Space Force, Space Capstone Publication, 51.
18. US Space Force, "Space Delta 9."

Chapter 23

Spacelift

Spacelift provides access to space—key to any activity in space. Historically, this access was primarily a function of national governments. Today, the commercial enterprise overwhelmingly dominates space launch. In 2022 commercial space activities comprised 77 percent of the global space economy, totaling $362 billion.[1] In the past, specific payloads flew on specific boosters due to limited options for launch. For example, from 1989 until 2009, GPS satellites launched from Delta II launch vehicles.[2] Today, payloads can fly on many types of boosters; since 2010 Global Positioning System (GPS) satellites have launched on Delta IV and Atlas V launch vehicles and commercial Falcon 9 rockets.[3]

The landscape of spacelift capabilities has changed drastically since the beginning of the space race. More countries can access space launch through commercial contracts. Even more extraordinary is the shift from governments as the only spacelift providers to commercial and private industries also providing this function. While countries and companies worldwide have or are developing spacelift capabilities, this chapter focuses on US launch vehicles. It discusses the current inventory of unmanned boosters, the near future of government and commercial systems, and US launch sites. In the United States, spacelift systems are divided into the following general categories:

- Suborbital - reach an altitude of 100 km (62 miles) or higher but do not have the trajectory and velocity to maintain Earth orbit. Currently, most of these launch vehicles are sounding rockets for scientific research, but as the future of commercial crewed spaceflight grows, more suborbital launches are likely to become crewed adventures.
- Small - place payloads that weigh less than 2 metric tons (mt) (up to 2,000 kg or 4,410 lb.) into low Earth orbits (LEO).
- Medium - place payloads of 2–20 mt (up to 20,000 kg or 44,100 lb.) into LEO.
- Heavy - place payloads of 20–50 mt (up to 50,000 kg or 110,000 lb.) into LEO.
- Super heavy - place payloads of more than 50 mt into LEO.[4]

These divisions offer a helpful comparison of spacelift capabilities when considering launch vehicles. While LEO is used here for categorization, many spacelift systems can launch to various orbits and altitudes. Crewed space systems capable of reaching the International Space Station (ISS) are in the medium or heavy classes, while crewed missions to the moon were in the super-heavy class. Uncrewed space missions fall into all five categories of spacelift systems. This chapter covers the systems most commonly used.

Operational Uncrewed Spacelift Systems

Uncrewed systems in the current US inventory include the evolved expendable launch vehicles (Delta IV and Atlas V) and the Falcon family vehicles, discussed below. Other uncrewed systems are the Delta II, Pegasus, and Minotaur rockets.

Delta IV

Today, United Launch Alliance builds the Delta IV vehicles in Decatur, Alabama. There are five vehicle configurations: the Delta IV Medium (Delta-IVM), three variants of Delta IV Medium-Plus (Delta-IVM+), and the Delta IV Heavy (Delta-IVH). With the exception of the Delta-IVH, the Delta IV is in the medium-lift class.[5] A single common booster core is used for medium-lift applications, but the Delta IV can be configured with up to four strap-on solid-rocket boosters to lift from 9,200 to 14,500 pounds to a geosynchronous transfer orbit (GTO).[6] The Delta IV launches from SLC-37 at Cape Canaveral Space Force Station (SFS) and from SLC-6 at Vandenberg Space Force Base (SFB). Limited Delta IV inventory remains as of 2022.

Atlas V

The Atlas V comes from a family of launch vehicles that made its debut in 1957 as America's first operational intercontinental ballistic missile.[7] The Atlas, Atlas II, and Atlas III launch vehicles have logged nearly 600 launches for US government and commercial missions.[8] The Atlas V also uses the common core booster with up to five strap-on solid-rocket boosters.[9] Like the Delta IV, the Atlas V is a medium-lift launch vehicle. The Atlas V will phase out and be replaced by the Vulcan system.[10]

Falcon

The Falcon family of launch vehicles is produced by Space Exploration Technologies (SpaceX). Established in 2002, SpaceX set out with the goal of revolutionizing space technology by manufacturing reusable rockets and enabling people to inhabit other planets.[11] As of December 14, 2022, SpaceX completed 192 successful Falcon family launches, with 153 total landings and 127 relaunched rockets.[12]

Falcon 9. Falcon 9 is a reusable, two-stage rocket designed and manufactured by SpaceX for the reliable and safe transport of people and payloads into Earth orbit and beyond. Falcon 9 is the world's first orbital-class reusable rocket. Reusability allows SpaceX to relaunch the most expensive parts of the rocket, driving down the cost of space access.[13]

Falcon Heavy. The Falcon Heavy builds on the Falcon 9 by adding two additional Falcon 9 first-stage engines used as strap-on boosters. The engines produce a thrust of nearly 5 million pounds at liftoff, enabling the Falcon Heavy to place nearly 141,000 pounds of mass into LEO and nearly 60,000 pounds into GTO. It is also capable of sending a 37,000-pound payload on a mission to Mars. These capabilities place the Falcon Heavy into the super heavy–lift class, and until NASA's Space Launch System, was the world's most powerful rocket. Before Falcon Heavy, only the Saturn V rocket—used to fly to the moon and last flown in 1973—had the capacity to deliver a larger payload to orbit.[14]

Crewed Spacelift Systems

United Launch Alliance (ULA), Orbital ATK, SpaceX, and Northrop Grumman produce spacelift vehicles capable of delivering payloads to the ISS and beyond. The Space Transportation System—more commonly called the space shuttle—was retired permanently in 2011 after 30 years of service.[15] While the shuttle offered super heavy–lift capability and easy, reusable crewed access to space while pushing space technology development to new heights, the president decided in 2004 to retire the program after the Columbia Accident Investigation Board report. It stated that it was "in the nation's interest to replace the Shuttle as soon as possible as the primary means for transporting humans to and from Earth orbit" because of its obsolete technologies and aging system.[16] Today, NASA and private companies, such as SpaceX and Blue Origin, have developed new capabilities to conduct crewed space transport.

Space Launch System

NASA's Space Launch System (SLS) was conceived as the next generation of spacecraft for human exploration into deep space. Weighing 5.75 million pounds and standing 322 feet high—taller than the Statue of Liberty—it has a super heavy–lift payload capacity of 154,000 pounds, allowing it to carry more payload to deep space than any other vehicle.[17] Its inaugural payload, the *Orion* capsule, is similar in shape to the Apollo spacecraft but significantly larger. It can transport "four crewmembers for lunar missions and later support missions" and "up to six crewmembers to and from the International Space Station."[18] In a historic return to building a long-term presence on the moon, the first uncrewed SLS and *Orion* (named Artemis I) launched on November 16, 2022, from Cape Canaveral, Florida. It splashed down in the Pacific Ocean west of Baja, California, on December 11, 2022, after a 25.5 day mission to the moon. The Artemis I mission demonstrated *Orion*'s systems in a spaceflight environment and the spacecraft's safe reentry, descent, splashdown, and recovery prior to the first crewed mission on Artemis II and beyond.[19] Artemis missions will "pav[e] the way for a long-term lunar presence and serv[e] as a steppingstone for astronauts on the way to Mars."[20]

SpaceX Dragon

In 2020, SpaceX returned America's ability to fly astronauts and cargo into space for the first time since 2011. The Dragon capsule is capable of carrying up to seven passengers or 6,000 kg (13,228 lb.) of cargo to the ISS and returning 3,000 kg (6,614 lb.) of cargo back to Earth. As of December 1, 2022, Dragon made thirty-two trips to the orbiting laboratory.[21] The concept of the Dragon and Falcon space systems emphasizes the feasibility of reusable rockets and capsules for maximum accessibility to space.

Blue Origin

Founded in 2000, Blue Origin is pursuing space tourism. The Blue Origin suborbital New Shepard vertical takeoff, vertical landing (VTVL) spaceship is designed to take three to six people on a round trip into suborbital space. The goal is to have a reusable launch vehicle that can quickly be refueled for another trip.[22] In July 2021, New Shepard became the first commercial vehicle under a reusable launch vehicle license to fly paying customers, both payloads and astronauts, to space and back.[23]

Space Launch Sites and Facilities

NASA and the DOD determine which launch site to use based on the type of orbit a mission requires. These sites include the following:

- Cape Canaveral SFS and Spaceport Florida: provide access to low inclination and polar orbits in addition to test range activities
- Vandenberg SFB and the California Spaceport: provide access to polar orbits in addition to test range activities
- Wallops Island Flight Facility and the Mid-Atlantic Regional Spaceport: often used for testing first-time launch vehicles in support of commercial development and STEM education
- Reagan Test Site, Kwajalein Atoll: test site for ballistic missiles, interceptors, and spacelift vehicles
- Pacific Spaceport Complex, Kodiak Island, Alaska: the only high-latitude, full-service spaceport in the United States, it is specifically designed for space launches to LEO, sun-synchronous orbit, and highly elliptical orbit.[24]

In addition to the sites the US government primarily uses, commercial vendors also provide services. They include SpaceX, developing a commercial spaceport in Boca Chica Village in South Texas; Blue Origin, with a private launch site in West Texas; and Virgin Galactic, basing its space tourism venture at Spaceport America near White Sands Missile Range, New Mexico. The Mojave Air and Space Port near Edwards AFB, California, was home to the Ansari XPRIZE–winning launches and continues to be a major player in the commercial spacelift arena, supporting more than 60 companies.[25]

Summary

The demand to access outer space is growing, and spacelift is essential to access it. Whether for tourism, scientific discovery, Earth-orbiting satellites, or journeying to other planets, the US government and commercial industry are providing current spacelift capabilities and developing future ones to fulfill the growing requirements. Modern space missions are continuing to innovate so that future crewed and uncrewed spacelift capabilities will be increasingly reliable, efficient, and effective.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Space Foundation, "Space Report 2022."
2. NASA, "Space Launch Report: Delta II."

3. Erwin, "Falcon 9 Launches GPS Satellite."
4. McConnaughey et al., "Draft Launch Propulsion Systems Roadmap," 1-7.
5. Berglund and Wilkins, "Boeing Delta IV," 1.
6. Baker, *Jane's Space Directory*, 284.
7. Lockheed Martin, "On Atlas' Shoulders."
8. United Launch Alliance, "Atlas V."
9. United Launch Alliance.
10. ULA, "Inaugural Vulcan Flight."
11. SpaceX, "Mission."
12. SpaceX, "Mission."
13. SpaceX, "Falcon 9."
14. SpaceX, "Falcon Heavy"; and Lethbridge, "Falcon Heavy Fact Sheet."
15. NASA, "Space Shuttle Era."
16. Smith, "NASA's Space Shuttle Columbia," CRS-3.
17. NASA, "NASA's Space Launch System."
18. NASA, "Orion Crew Exploration Vehicle."
19. NASA, "Artemis I."
20. NASA, "Splashdown."
21. SpaceX, "Transporting Humans to the Orbiting Laboratory."
22. Wall, "Lifelong Dream"; and Blue Origin, "New Shepard."
23. Cowing, "Commercial Astronauts to Space and Back."
24. NASA, "Launching from Both U.S. Coasts."
25. Mojave Air and Space Port, "Discover"; and Federal Aviation Administration, "Spaceports by State."

Acronyms

AEHF	Advanced Extremely High Frequency (system)
AEOS	Advanced Electro-Optical System
AEOS-L	Advanced Electro-Optical System (AEOS) long-wave infrared
AEP	architecture evolution plan
AFDP	Air Force doctrine publication
AFRL	Air Force Research Laboratory
AFSPACE	Air Forces Space
ALCOR	ARPA (Advanced Research Project Agency) Lincoln C-Band Observable Radar
AMCS	alternate master control station
ANS	Adaptable Navigation Systems
AOC	air operations center
AOR	area of responsibility
ASAT	anti-satellite (weapon)
ASCC	Alternate Space Control Center
ATLAS	Advanced Tracking and Launch Analysis System
BDA	battle damage assessment
BFT	Blue Force Tracking
BMDS	Ballistic Missile Defense System
BMEWS	Ballistic Missile Early Warning System
CACE	Command and Control System–Consolidated (CCS-C) Assurance and Capability Enhancement
CAVENet	Correlation, Analysis, and Verification of Ephemerides Network
CCMD	combatant command
CCS	Counter Communications System
CCS-C	Command and Control System–Consolidated
CDHS	communications and data handling subsystem
CDO	contested, degraded, and operationally limited (environment)
CFMAP	Cyberspace Forces Mission Alignment Process
CFSCC	Combined Force Space Component Command
CGMS	Coordination Group for Meteorological Satellites
CIB	Common Interactive Broadcast
CMSA	Chinese Manned Space Agency
COCOM	combatant command
COMAFFOR	commander, Air Force forces
COMARFOR	commander, Army forces
COMINT	communications intelligence
COMSAT	Communications Satellite Corporation
COMSATCOM	commercial satellite communications
COMSEC	communications security
COMSPACEFOR	Space Force component commander
COSPAS	Cosmicheskaya Sistyema Poiska Avariynich Sudov (space system for search of distressed vessels)
CSO	chief of space operations
CSpOC	Combined Space Operations Center
C3	command, control, and communications
C2	command and control

DARPA	Defense Advanced Research Projects Agency
DASS	Distress Alerting Satellite System
DEFSMAC	Defense Special Missile and Astronautics Center
DEW	directed energy weapon
DIRSPACEFOR	director of space forces
DISA	Defense Information Systems Agency
DMSP	Defense Meteorological Satellite Program
DOC	Department of Commerce
DOD	Department of Defense
DODIN	Department of Defense Information Network
DOP	dilution of precision
DSC	defensive space control
DSCS	Defense Satellite Communications System
DSP	Defense Support Program
EHF	extremely high frequency
ELINT	electronic intelligence
ELSET	element set
EMP	electromagnetic pulse
EMS	electromagnetic spectrum
EPS	Enhanced Polar System
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EWS	electromagnetic warfare squadron
EWS-G1	Electro-optical Infrared Weather System Geostationary
EXORD	execute order
FAA	Federal Aviation Administration
FAB-T	Family of Advanced Beyond Line-of-Sight Terminals
FDFR	first detect–first report
FISINT	foreign instrumentation signals intelligence
FLTSAT	Navy Fleet SATCOM
FM	field manual
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FRDC	federally funded research and development center
FY	fiscal year
GBR	ground-based radar
GBS	Global Broadcast Service
GEO	geosynchronous equatorial orbit
GEODSS	Ground-Based Electro-Optical Deep Space Surveillance
GEOINT	geospatial intelligence
GIANT	GPS Interference and Navigation Tool
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GPSOC	GPS Operation Center
GSD	ground sample distance
GSSAP	Geosynchronous Space Situational Awareness Program
GTO	geosynchronous transfer orbit

HEO	highly elliptical orbit
HUSIR	Haystack Ultrawideband Satellite Imaging Radar
ICADS	Integrated Correlation and Display System
ICBM	intercontinental ballistic missile
IMINT	imagery intelligence
INDOPACOM	Indo-Pacific Command
INTELSAT	International Telecommunications Satellite Organization
IOC	initial operational capability
IR	infrared
IRBM	intermediate-range ballistic missile
ISR	intelligence, surveillance, and reconnaissance
ISRO	Indian Space Research Organization
ISS	International Space Station
ITW/AA	integrated tactical warning and attack assessment
JADC2	Joint All-Domain Command and Control
JFACC	joint force air component commander
JFC	joint force commander
JFSCC	Joint Force Space Component commander
JIST	joint integrated space team
JNWC	Joint Navigation Warfare Center
JOPC	Joint Overhead Persistent Infrared Planning Center
JP	joint publication
JPSS	Joint Polar Satellite System
JTAGS	joint tactical ground station
JTF-SD	Joint Task Force–Space Defense
KSSC	Kwajalein Space Surveillance Center
LC	launch complex
LEO	low Earth orbit
LOS	line of sight
LSSC	Lincoln Space Surveillance Complex
LTRS	Launch and Test Range System
LWIR	long-wave infrared
MASINT	measurement and signature intelligence
MCS	master control station; mission control segment
MDA	Missile Defense Agency
MEO	medium Earth orbit
MetOp	meteorological operational (satellites)
Micro-PNT	Microtechnology for Positioning, Navigation, and Timing
MILAMOS	Manual on International Law Applicable to Military Uses of Outer Space
MILSATCOM	military satellite communications
MIT	Massachusetts Institute of Technology
MRBM	medium-range ballistic missile
MSI	multispectral imagery
MSSS	Maui Space Surveillance System
MUOS	Mobile User Objective System

MWC	Missile Warning Center
NASA	National Aeronautics and Space Administration
NASIC	National Air and Space Intelligence Center
NDAA	National Defense Authorization Act
NDS	Nuclear Detonation (NUDET) Detection System
NE	near Earth
NFL	new foreign launch
NGA	National Geospatial-Intelligence Agency
NMCC	National Military Command Center
NMT	Navy Multiband Terminal
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NRO	National Reconnaissance Office
NSA	National Security Agency
NSDC	National Space Defense Center
NSS	*National Security Strategy*
NUDET	nuclear detonation
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OPSEC	operations security
OPIR	overhead persistent infrared
OSC	offensive space control
PAR	phased array radar
PARCS	Perimeter Acquisition Radar Attack Characterization System
PAVE PAWS	Precision Acquisition Vehicle Entry Phased Array Warning System
PNT	positioning, navigation, and timing
POES	Polar Operational Environmental Satellite
PPL	preplanned launch
PPS	Precise Positioning Service
PULSE	Program in Ultrafast Laser Science and Engineering
QA	Quantum Apertures (program)
QuASAR	Quantum-Assisted Sensing and Readout
RAF	Royal Air Force
RF	radio frequency
RGS	relay ground station
ROCkN	Robust Optical Clock Network
RPO	rendezvous and proximity operations
RTS	Reagan Test Site
SACC	suppression of adversary counterspace capabilities
SAR	synthetic aperture radar
SARSAT	search and rescue satellite-aided tracking
SATCOM	satellite communications
SBIRS	Space-Based Infrared System
SBSS	Space-Based Space Surveillance System
SCA	space coordinating authority
SCN	Satellite Control Network

SDA	Space Development Agency; space domain awareness
SDP	space doctrine publication
SDS	space defense squadron
SecDef	secretary of defense
SEW	space electromagnetic warfare
SFB	Space Force base
SFS	Space Force station
SHF	super-high frequency
SIGINT	signals intelligence
SLBM	submarine-launched ballistic missile
SLD	Space Launch Delta
SLS	Space Launch System
SMART-T	Secure Mobile Anti-jam Reliable Tactical Terminal
SNL	Sandia National Laboratories
SOCC	Satellite Operations Control Center
SOI	space object identification
SoL	Safety-of-Life (frequency)
SOPS	space operations squadron
Space C2	Space Command-and-Control (system)
SPADOC	Space Defense Operations Center
SPO	system program office
SpOC	Space Operations Command
SpRCO	Space Rapid Capabilities Office
SPS	Standard Positioning Service
SPSS	space surveillance squadron
SSA	space situational awareness
SSC	Space Systems Command
SSN	Space Surveillance Network
SST	Space Surveillance Telescope
STARCOM	Space Training and Readiness Command
STOIC	Spatial Temporal and Orientation Information in Contested Environments
SWS	space warning squadron
TACDAR	tactical detection and reporting
TES	theater event system
TPFDD	time-phased force and deployment data
TRANSEC	transmission security
TT&C	telemetry, tracking, and commanding
UEWR	upgraded early warning radar
UFO	Ultrahigh-Frequency Follow-On (system)
UHF	ultrahigh frequency
ULA	United Launch Alliance
UN	United Nations
UNCOPUOUS	United National Committee on the Peaceful Uses of Outer Space
UNOOSA	United Nations Office for Outer Space Affairs
USASMDC	United States Army Space and Missile Defense Command
USCYBERCOM	United States Cyber Command
USNO	United States Naval Observatory
USSF	United States Space Force

USSPACECOM	United States Space Command
UTC	Coordinated Universal Time
VHF	very high frequency
VTVL	vertical takeoff, vertical landing
WGS	Wideband Global SATCOM
WSF-M	Weather System Follow-on – Microwave
WW	weather wing

Bibliography

The Aerospace Corporation. "Dedicated to the Space Enterprise." Accessed September 19, 2022. https://aerospace.org/.

Affens, David W., Roy Dreibelbis, James E. Mentall, and George Theodorakos. "Taking the Search out of Search and Rescue." In Richard B. Langley, "Innovation: The Distress Alerting Satellite System." *GPS World*, January 1, 2011. https://www.gpsworld.com/.

Agreement between the Government of Canada and the Government of the United States of America on the North American Aerospace Defense Command. Signed April 28, 2006, by Gordon O'Connor, minister of national defence, for the Government of Canada, and by David H. Wilkins, US ambassador to Canada, for the Government of the United States of America. https://www.treaty-accord.gc.ca/.

Air Force Doctrine Publication 3-14. *Counterspace Operations*, August 27, 2018. Curtis E. LeMay Center for Doctrine Development and Education. https://www.doctrine.af.mil/.

Air Force Research Laboratory. "Space." Accessed December 13, 2022. https://afresearchlab.com/.

Air University Public Affairs. "Space Delta 13 Activates to Lead STARCOM Education and Accessions," September 14, 2021. https://www.airuniversity.af.edu/.

Albon, Courtney. "US Space Force Preparing to Decommission Legacy Command and Control System." C4ISRNet.com, March 16, 2022. https://www.c4isrnet.com/.

Andersen, Hans-Erik, Tobey Clarkin, Ken Winterberger, and Jacob Strunk. "An Accuracy Assessment of Positions Obtained Using Survey and Recreational-Grade Global Positioning System Receivers across a Range of Forest Conditions within the Tanana Valley of Interior Alaska." *Western Journal of Applied Forestry* 24, no. 3 (July 2009): 128–36. https://www.fs.usda.gov/.

Anthony, Sebastian. "Our Terrifying Reliance on GPS, and the Need to Develop a Ground-Based Alternative." ExtremeTech, November 7, 2014. https://www.extremetech.com/.

Associated Press. "China Plans Space Station Completion, Many Launches in 2022," January 6, 2022. https://apnews.com/.

Austin, Lloyd. To Secretaries of the Military Departments et al. Memorandum. Subject: "Tenets of Responsible Behavior in Space," July 7, 2021. https://media.defense.gov/.

Australian Government, Department of Industry, Science and Resources, Australian Space Agency. "About the Australian Space Agency." Accessed December 12, 2022. https://www.industry.gov.au/.

Baghal, Lisa A. "SATCOM Supply Versus Demand and the Impact on Remotely Piloted Aircraft ISR." Maxwell AFB, AL: Air Command and Staff College, March 2016. https://apps.dtic.mil/.

Baker, David, ed. *Jane's Space Directory: 2003–2004*. Alexandria, VA: Jane's Information Group, 2003.

Ball Aerospace. "Weather System Follow-On – Microwave." Accessed November 22, 2022. https://www.ball.com/.

Bell, Aaron J. "Analysis of GPS Satellite Allocation for the United States Nuclear Detonation Detection System (USNDS)." Master's thesis, Air Force Institute of Technology, March 20, 2002. https://apps.dtic.mil/.

Bloomfield, Lincoln P. "The Prospects for Law and Order." In *Outer Space: New Challenge to Law and Policy*, edited by J. E. S. Fawcett, 145–60. Oxford: Clarendon Press, 1984.

Blue Origin. "New Shepard." Accessed December 15, 2022. https://www.blueorigin.com/new-shepard/.

Bonnette, Bridget. "18 SOS Activates New Detachment in Support of JTF-SD." Space Operations Command, July 15, 2022. https://www.spoc.spaceforce.mil/.

Boucher, Marc. "McGill Manual on International Law Applicable to Military Uses of Outer Space: Volume I–Rules." SpaceQ, July 29, 2022. https://spaceq.ca/. (For the published manual, see Jakhu and Freeland, *McGill Manual,* https://www.mcgill.ca/.)

Bowman, Chaz. "GIANT: GPS Interference and Navigation Tool." Linquest Corporation. Accessed September 22, 2022. http://www.linquest.com/.

Boyer, K. William. "Cavalier Air Force Station to be Renamed Cavalier Space Force Station." *Stars and Stripes*, July 29, 2021. https://www.stripes.com/.

Brookhaven National Laboratory. "Research Facilities." Accessed September 19, 2022. https://www.bnl.gov/.

Buckley Space Force Base. "2d Space Warning Squadron." Fact Sheet. Accessed December 2, 2022. https://www.buckley.spaceforce.mil/.

———. "6th Space Warning Squadron." Accessed December 13, 2022. https://www.buckley.spaceforce.mil/.
———. "Space Delta 4 – Missile Warning." Fact Sheet, current as of July 2020. https://www.buckley.spaceforce.mil/.
———."12th Space Warning Squadron." Fact sheet. Accessed October 25, 2022. https://www.buckley.spaceforce.mil/.
Byrne, John Paul, Robin Dickey, and Michael P. Gleason. A *Space Policy Primer: Key Concepts, Issues, and Actors* 2nd ed. El Segundo, CA: Aerospace Corporation, Center for Space Policy and Strategy, January 2021. https://csps.aerospace.org/.
Camp, William W., Joseph T. Mayhan, and Robert M. O'Donnell. "Wideband Radar for Ballistic Missile Defense and Range-Doppler Imaging of Satellites." *Lincoln Laboratory Journal* 12, no. 2 (2000): 267–80. https://archive.ll.mit.edu/.
Cohen, Raphael S., Nathan Chandler, Shira Efron, Bryan Frederick, Eugeniu Han, Kurt Klein, Forrest E. Morgan, Ashley L. Rhoades, Howard J. Shatz, and Yuliya Shokh. *Peering into the Crystal Ball: Holistically Assessing the Future of Warfare*. Santa Monica, CA: RAND Corporation, 2020. https://www.rand.org/.
Combined Force Space Component Command. Space-Track.org. Accessed May 23, 2022. https://www.space-track.org/.
Congressional Research Service. "Defense Primer: The United States Space Force." Report no. IF11495. In Focus, updated November 16, 2022. https://crsreports.congress.gov/.
———. *FY2023 NDAA: Active Component End-Strength*. CRS Insight. Report IN11994. Washington, DC: Congressional Research Service, August 23, 2022. https://crsreports.congress.gov/.
Continental United States North American Defense Command – First Air Force, AFNORTH and AFSPACE (CONF-1AF). "First Air Force Takes Command of Det 3 Rescuers as Part of New Space Command Mission," July 15, 2021. https://www.1af.acc.af.mil/.
Cooper, John Cobb. *Explorations in Aerospace Law: Selected Essays by John Cobb Cooper, 1946–1966.* Edited by Ivan A. Vlasic. Montreal: McGill University Press, 1968.
Cooper, Mindy. "Engineers Demonstrate Pulsed Thermography Inspection for GLOBUS II." Wright-Patterson Air Force Base News, June 5, 2008. https://www.wpafb.af.mil/.
Cornell Law School, Legal Information Institute. "Customary International Law." Accessed March 6, 2022. https://www.law.cornell.edu/.
Cowing, Keith. "Blue Origin Launches Four Commercial Astronauts to Space and Back." SpaceRef, July 20, 2021. https://spaceref.com/.
Crossman, Joshua. "The 6th Space Warning Squadron: Ever Aware." Space Operations Command, March 19, 2021. https://www.spoc.spaceforce.mil/.
Defense Acquisition University. "Space Acq RDT May 2018." PowerPoint slides. Accessed November 3, 2022. https://www.dau.edu/.
Defense Advanced Research Projects Agency (DARPA). "About DARPA." Accessed May 13, 2022.
———. "Adaptable Navigation Systems (ANS) (Archived)." Accessed December 2022. https://www.darpa.mil/.
———. "DARPA Pursues Tactical-Grade Clock That Maintains Precision Over Time," May 17, 2022. https://www.darpa.mil/.
———. DARPA Selects Research Teams to Enable Quantum Shift in Spectrum Sensing," August 4, 2021. https://www.darpa.mil/.
———. "Micro-Technology for Positioning, Navigation and Timing (Micro-PNT) (Archived)." Accessed December 2022. https://www.darpa.mil/.
———. "Program in Ultrafast Laser Science and Engineering (PULSE) (Archived)." Accessed December 2022. https://www.darpa.mil/.
———. "Providing GPS-Quality Timing Accuracy without GPS," January 20, 2022. https://www.darpa.mil/.
Defense Information Systems Agency. "Our History." Accessed November 25, 2022. https://www.disa.mil/.
Defense Intelligence Agency. *Challenges to Security in Space: Space Reliance in an Era of Competition and Expansion*. Washington, DC: Defense Intelligence Agency, 2022. https://www.dia.mil/.
Defense Visual Information Distribution Service (DVIDS). "4th, 5th and 16th SPCS Re-designation," April 15, 2022. https://www.dvidshub.net/.

———. “Space Delta 4 Detachment 1 Deactivates, Then Reactivates as 3rd Space Communication Squadron,” March 24, 2022. https://www.dvidshub.net/

DeLaPena, Cordell A. “Military Communications and Positioning, Navigation, and Timing [PNT] Overview with GPS Update.” Briefing to PNT Advisory Board, May 4, 2022. https://www.gps.gov/.

Department of Commerce. Office of Public Affairs. “Department of Commerce and Department of Defense Sign Memorandum of Agreement to Advance Coordination in Space.” Press release, September 9, 2022. https://www.commerce.gov/.

Department of Defense. *Defense Space Strategy Summary*. Washington, DC: Department of Defense, June 2020. https://media.defense.gov/.

———. *Fiscal Year (FY) 2023 Budget Estimates*. Justification Book Vol. 1 of 1. *Procurement, Space Force*. Washington, DC: Department of the Air Force, April 2022. https://www.saffm.hq.af.mil/.

———. *Fiscal Year (FY) 2022 Budget Estimates*. Air Force Justification Book, Vol. 3b of 3. *Research, Development, Test and Evaluation, Air Force*. Vol. 3, pt. 2. Washington, DC: Department of the Air Force, May 2021. https://www.saffm.hq.af.mil/.

———. *Global Positioning System (GPS) 2008: A Report to Congress*. Washington, DC: Department of Defense, October 31, 2008. https://www.esd.whs.mil/.

———. Selected Acquisition Report (SAR). *Space Based Infrared System High as of FY 2020 President’s Budget*. Defense Acquisition Management Information Retrieval (DAMIR). RCS: DD-A&T (Q&A) 823-210. Washington, DC: Department of Defense, December 2018. https://www.esd.whs.mil/.

———. *Summary of the Joint All-Domain Command and Control (JADC2) Strategy.* Washington, DC: Department of Defense, March 2022. https://media.defense.gov/.

Department of Defense Directive 5105.60. *National Geospatial-Intelligence Agency (NGA)*, July 29, 2009. http://www.esd.whs.mil/.

Department of Defense Research and Engineering Enterprise. “About Us.” Accessed November 3, 2022. https://rt.cto.mil/.

Director, Operational Test and Evaluation. *Mobile User Objective System (MUOS): Multi-Service Operational Test and Evaluation-2 Report.* Washington, DC: Department of Defense, June 2016. https://apps.dtic.mil/.

“DMSP – Block 5D-3 Spacecraft Overview.” Spaceflight101. Accessed October 2022. https://spaceflight101.com/.

Dolman, Everett C. *Astropolitik: Classical Geopolitics in the Space Age*. New York: Frank Cass Publishers, 2002.

———. “Geostrategy in the Space Age: An Astropolitical Analysis,” *Journal of Strategic Studies 22*, nos. 1–2 (1999): 83–106. https://doi.org/10.1080/01402399908437755.

Eglin AFB, “20th Space Surveillance Squadron.” Accessed November 28, 2022. https://www.eglin.af.mil/.

Erwin, Sandra. “Falcon 9 Launches GPS Satellite in First National Security Mission with Reused Booster.” *Space News*, June 17, 2021. https://spacenews.com/.

———. “NOAA’s Former Satellite Now Providing Weather Data to the U.S. Military.” *Space News*, September 8, 2020. https://spacenews.com/.

———. “Space Force Orders New Weather Satellite from Ball Aerospace.” *Space News*, November 11, 2022. https://spacenews.com/.

Erwin, Sandra, and Brian Berger. “A Race against Time to Replace Aging Military Weather Satellites.” *Space News*, May 24, 2021. https://spacenews.com/.

European Space Agency. “Anatomy of a Spacecraft.” Accessed July 27, 2022. https://www.esa.int/.

———. “ESA Facts.” Accessed December 12, 2022. https://www.esa.int/.

———.“ESA’s Space Environment Report 2022,” April 22, 2022. https://www.esa.int/.

———. “Member States and Cooperating States.” Accessed December 12, 2022. https://www.esa.int/.

———. “What Is Galileo?” Accessed December 12, 2022. http://www.esa.int/.

Federal Aviation Administration. “About the Office of Commercial Space Transportation.” Accessed November 1, 2022. https://www.faa.gov/.

———. “Spaceports by State,” September 13, 2022. https://www.faa.gov/.

Federal Communications Commission. “What We Do.” Accessed July 24, 2022. https://www.fcc.gov/.

Field Manual 3-14. *Army Space Operations*, October 2019. https://armypubs.army.mil/.

Finckenor, Miria M., and Kim K. de Groh. *A Researcher's Guide to: International Space Station; Space Environmental Effects*. NP-2020-09-018-JSC. Johnson Space Center, Houston: National Aeronautics and Space Administration, 2020. https://www.nasa.gov/.

557th Weather Wing. Fact Sheet. Accessed November 29, 2022. https://www.557weatherwing.af.mil/.

Fleet Numerical Meteorology and Oceanography Center. "Overview." Accessed October 2022. https://www.fnmoc.navy.mil/.

Foley, April J. "Nanosat Employment: A Theoretical CONOPS for Space Object Identification." Master's thesis, Naval Postgraduate School, June 2014. https://core.ac.uk/.

France, Martin E. B., and Jerry Jon Sellers. "Real Constraints on Spacepower." In *Toward a Theory of Spacepower: Selected Essays,* edited by Charles D. Lutes and Peter L. Hays, 57–96. Washington, DC: National Defense University Press, 2011. https://ndupress.ndu.edu/.

Fritz, Jason. "Satellite Hacking: A Guide for the Perplexed." *Culture Mandala*: *Bulletin of the Centre for East-West Cultural and Economic Studies* 10, no. 1 (December 2012–May 2013): 21–50. https://cupdf.com/.

Galloway, Jonathan F. "Originating Communications Satellite Systems: The Interactions of Technological Change, Domestic Politics, and Foreign Policy." In *Beyond the Ionosphere: Fifty Years of Satellite Communication*, edited by Andrew J. Butrica, 171–92. Washington, DC: National Aeronautics and Space Administration, NASA History Office, 1997. https://archive.org/.

Government of Canada, Department of National Defence. "Space Situational Awareness and the Sapphire Satellite." Backgrounder, January 30, 2014. https://www.canada.ca/.

Hahn, Garth R., Anthony Kellar, and Steven Stubblefield. "Satellite Communications: Operating Together for National Defense." *Army Space Journal 3*, no. 1 (Winter/ Spring 2004): 24–27.

Harris, Bryant. "White House Arctic Strategy Calls for Enhanced Military Presence." *Defense News*, October 7, 2022. https://www.defensenews.com/.

Harrison, Todd, Kaitlyn Johnson, Joe Moye, and Makena Young. *Space Threat Assessment 2021*. Washington, DC: Center for Strategic and International Studies, April 2021. https://csis-website-prod.s3.amazonaws.com/.

Hattendorf, John B. "The Uses of Maritime History in and for the Navy." *Naval War College Review* 56, no. 2 (Spring 2003): 13–38. https://digital-commons.usnwc.edu/.

Hays, Peter L., James M. Smith, Alan R. Van Tassel, and Guy M. Walsh, eds. *Spacepower for a New Millennium: Space and U.S. National Security*. New York: McGraw-Hill, 2000.

Hitchens, Theresa. "Near-Term Funds for Second Space Fence Radar Uncertain." Breaking Defense, August 25, 2021. https://breakingdefense.com/.

———. "Rocket Science: How Space Force Acquisition Works, with Many Players and Dual Hats." Breaking Defense, July 27, 2022. https://breakingdefense.com/.

Hong, Andy. "South Korea's Space Program Is a Big Deal." Diplomat, July 1, 2022. https://thediplomat.com/.

Hutchins, Ryan. "Cyber Defense of Space Assets." Tufts University, 2016. http://www.cs.tufts.edu/.

International Court of Justice. "Statute of the International Court of Justice." Accessed April 30, 2022. https://www.icj-cij.org/.

International Institute of Humanitarian Law. "San Remo Manual on International Law Applicable to Armed Conflicts at Sea." Accessed December 2022. https://iihl.org/.

International Trade Administration. "Commercial Space: Market Overview." Accessed March 15, 2022. https://www.trade.gov/.

Jakhu, Ram S., and Steven Freeland, eds. *McGill Manual on International Law Applicable to Military Uses of Outer Space*. Vol. 1, *Rules*. Montreal: Centre for Research in Air and Space Law, 2022. https://www.mcgill.ca/.

James, Thomas L. "Commander's Vision: To Protect and Defend the Space Domain." Joint Task Force–Space Defense, July 28, 2021. https://media.defense.gov/.

Joe, Leland, and Isaac Porche III. *Future Army Bandwidth Needs and Capabilities*. Santa Monica, CA: RAND Corporation, 2004. https://www.rand.org/.

Johnson, Robert. "USSPACECOM Chief Highlights Link Between Space, Cyber Domains." Potomac Officers Club. Posted July 28, 2021. https://potomacofficersclub.com/.

Joint Ballistic Missile Defense (BMD) Training and Education Center (JBTEC). Joint Integrated Air and Missile Defense Training. "JBTEC Common Course Student Reference Supplement," July 29, 2021.

Joint Publication 1. *Doctrine for the Armed Forces of the United States*. Joint Publications Capstone Series, Joint Chiefs of Staff, March 25, 2013 (incorporating change 1, July 12, 2017). https://irp.fas.org/.

Joint Publication 2-0. *Joint Intelligence*, October 22, 2013. https://irp.fas.org/. (Updated May 22, 2022, not available online at the time of this publication. See https://www.jcs.mil/.)

Joint Publication 3-14. *Space Operations*, April 10, 2018 (incorporating change 1, October 26, 2020). https://www.jcs.mil/.

Joint Publication 5-0. *Joint Planning*, December 1, 2020. https://irp.fas.org/.

Joint Publication 6-0. *Joint Communications System*, June 10, 2015 (incorporating change 1, October 4, 2019). https://irp.fas.org/.

Joint Task Force–Space Defense. "18th Space Defense Squadron." Fact Sheet, May 2, 2022. https://www.jtf-spacedefense.mil/.

Jones, Andrew. "China's Tiangong Space Station." Space.com, August 24, 2021. https://www.space.com/.

Kan, Shirley. *China's Anti-Satellite Weapon Test*. Congressional Research Service Report for Congress. RS22652. Washington, DC: Library of Congress, April 23, 2007. https://sgp.fas.org/.

Kang, Tae-jun. "South Korea's Quest to Be a Major Space Power." Diplomat, March 27, 2015. https://thediplomat.com/.

Kerr, Julian. "Space Command Begins Operations." *Australian Defence Magazine*, March 24, 2022. https://www.australiandefence.com.au/.

King, Gilbert. "Going Nuclear Over the Pacific." *Smithsonian Magazine*, August 15, 2012. https://www.smithsonianmag.com/.

Kirchner, Timothy. "Hall Assumes Command of the 11th Space Warning Squadron." Defense Visual Information Distribution Service (DVIDS), September 24, 2021. https://www.dvidshub.net/.

Klaes, Dieter, and Kenneth Holmlund. "The EPS/METOP System: Overview and First Results." ResearchGate, January 2007. https://www.researchgate.net/.

Klein, John J. "Corbett in Orbit: A Maritime Model for Strategic Space Theory." *Naval War College Review* 57, no. 1 (Winter 2004): 59–75. http://www.jstor.org/.

Kwon, K. J., and Jethro Mullen. "South Korean Rocket Successfully Puts Satellite in Orbit." CNN, January 30, 2013. https://www.cnn.com/.

Larson, Wiley J., and James R. Wertz. *Space Mission Analysis and Design*. 3rd ed. El Segundo, CA: Microcosm Press, 1999.

Lawrence Livermore National Laboratory. "TESSA [Testbed Environment for Space Situational Awareness]: Tracking Space Debris." Accessed September 19, 2022. http://computation.llnl.gov/.

Lee, James G. "Counterspace Operations for Information Dominance." In *Beyond the Paths of Heaven: The Emergence of Space Power Thought*, edited by Bruce M. DeBlois, 249–301. Maxwell AFB, AL: Air University Press, 1999. https://media.defense.gov/.

Lethbridge, Cliff. "Falcon Heavy Fact Sheet." Spaceline. Accessed December 14, 2022. https://www.spaceline.org/.

Leveson, Irv. "The Economic Benefits of GPS." *GPS World*, September 1, 2015. http://gpsworld.com/.

Liopiros, Kostas, and Edward Lam. "Extremely High Frequency Satellites Offer Flexibility." *Signal* 44, no. 11 (July 1990).

Lockheed Martin, "On Atlas' Shoulders." Accessed October 21, 2022. https://www.lockheedmartin.com/.

———. "Space Fence." Accessed October 24, 2022. http://www.lockheedmartin.com/.

Lopez, C. Todd. "SPACECOM Built for Today's Strategic Environment." Department of Defense News, September 27, 2019. https://www.defense.gov/.

Luckenbaugh, Josh, "Just In: Space Force Partners with Norway to Launch Arctic Comms Satellite." National Defense, August 31, 2022. https://www.nationaldefensemagazine.org/.

Lowenthal, Mark M., and Robert M. Clark, eds. *The Five Disciplines of Intelligence Collection*. Thousand Oaks, CA: CQ Press, 2016.

Lupton, David E. *On Space Warfare: A Space Power Doctrine*. Maxwell AFB, AL: Air University Press, 1998. https://apps.dtic.mil/.

Machi, Vivienne. "US Military Places a Bet on LEO for Space Security." Via Satellite, June 2021. https://interactive.satellitetoday.com/.

Mahan, Alfred Thayer. *The Influence of Sea Power upon History, 1660–1783*. New York: Hill and Wang, 1963.
Malik, Tariq. "Jeff Bezos' Blue Origin Launches Private Spaceship Test Flight." Space.com, 30 April 2015. https://www.space.com/.
Mann, Adam. "What Was the Space Race? Origins, Events, and Timeline." Space.com, July 8, 2022. https://www.space.com/.
Massachusetts Institute of Technology, Lincoln Laboratory. "Haystack Ultrawideband Satellite Imaging Radar." Accessed October 25, 2022. https://www.ll.mit.edu/.
———. "Reagan Test Site." Accessed November 28, 2022. https://www.ll.mit.edu/.
———. "Space Systems and Technology." Accessed November 3, 2022. https://www.ll.mit.edu/.
McConnaughey, Paul K., Mark G. Femminineo, Syri J. Koelfgen, Roger A. Lepsch, Richard M. Ryan, and Steven A. Taylor. "Draft Launch Propulsion Systems Roadmap: Technology Area 01." Washington, DC: National Aeronautics and Space Administration, November 2010. https://www.nasa.gov/.
McGill University (Montreal). "Manual on International Law Applicable to Military Uses of Outer Space." Accessed August 2022. https://www.mcgill.ca/.
Meub, Kristen. "Armoring Satellites to Survive, Operate through Attacks." Sandia Lab News, October 24, 2019. https://www.sandia.gov/.
Missile Defense Advocacy Alliance. "Space-Based Infrared System (SBIRS)," September 2022. http://missiledefenseadvocacy.org/.
———. "Upgraded Early Warning Radars (UEWR)," December 2018. https://missiledefenseadvocacy.org/.
Missile Defense Agency (MDA). "Agency in Brief." Accessed May 2, 2022. https://www.mda.mil/.
———."The Ballistic Missile Defense System (BMDS)." Accessed November 3, 2022. https://www.mda.mil/.
———. "Cobra Dane – AN/FPS-108." Fact sheet, August 23, 2022. https://www.mda.mil/.
———. "Our Mission." Accessed May 2, 2022. https://www.mda.mil/.
The MITRE Corporation. "Center for Data-Driven Policy: Tangible, Measurable, and Innovative Ideas to Inform Public Policy." Accessed May 2, 2022. https://www.mitre.org/.
Mojave Air and Space Port. "Discover." Accessed December 1, 2022. https://www.mojaveairport.com/.
Morgan Stanley. "Space: Investing in the Final Frontier," July 24, 2020. https://www.morganstanley.com/.
National Aeronautics and Space Administration (NASA). "Artemis I: About the Mission." Accessed December 1, 2022. https://www.nasa.gov/.
———. EarthData. "What Is Synthetic Aperture Radar?" Accessed November 22, 2022. https://www.earthdata.nasa.gov/.
———. Kennedy Space Center. "What Is the 'Range'?" Accessed December 19, 2022. https://www.nasa.gov/.
———. "Launching from Both U.S. Coasts," May 14, 2009. https://www.nasa.gov/centers/.
———. "NASA Centers and Facilities." Accessed May 2, 2022. http://www.nasa.gov/.
———. "NASA Selects Orion Crew Exploration Vehicle Prime Contractor." Press release 06-305, August 31, 2006. https://www.nasa.gov/.
———. "NASA's Space Launch System Is the Rocket for the Ride to Mars." NASA news release, September 22, 2015. https://www.nasa.gov/.
———. *NASA Strategic Plan 2022*. Washington, DC: NASA, 2022. https://www.nasa.gov/.
———. "Our Missions and Values." Accessed May 2, 2022. https://www.nasa.gov/.
———. *Small Spacecraft Technology State of the Art Report*. NASA/TP-20210021263. Moffett Field, CA: Ames Research Center, October 2021. https://www.nasa.gov/.
———. "Space Launch Report: Delta II Data Sheet," updated October 20, 2018. https://sma.nasa.gov/.
———. "Space Launch System." Fact sheet FS-2021-11-53-MSFC, 2021. http://www.nasa.gov/.
———. "Space Shuttle Era," August 3, 2017. https://www.nasa.gov.
———. "Splashdown! NASA's Orion Returns to Earth after Historic Moon Mission." NASA press release 22-129, December 11, 2022. https://www.nasa.gov/.
———. "Thermal Systems." Accessed July 7, 2022. https://mars.nasa.gov/.
———. "What Is a Lagrange Point?" Wilkinson Microwave Anisotropy Probe (WMAP) Science Team, March 27, 2018. https://solarsystem.nasa.gov/.

———. “Who Works Where: Workforce Profile Cube.” Workforce Information Cubes for NASA. Accessed May 2, 2022. https://wicn.nssc.nasa.gov/.

National Coordination Office for Space-Based Positioning, Navigation, and Timing. “Architecture Evolution Plan (AEP).” GPS.gov. Accessed September 22, 2022. https://www.gps.gov/.

———. “GPS: Control Segment.” GPS.gov. Accessed March 22, 2022. http://www.gps.gov/.

———. “New Civil Signals.” GPS.gov. Accessed September 22, 2022. https://www.gps.gov/.

———. “Space Segment.” GPS.gov. Accessed September 22, 2022. https://www.gps.gov/.

National Geospatial-Intelligence Agency (NGA). “NGA’s Mission.” Accessed May 13, 2022. https://www.nga.mil/.

National Oceanic and Atmospheric Administration. “NOAA’s Newest Satellite Heads toward Orbit,” November 10, 2022. https://www.noaa.gov/.

———. “Our Mission and Vision.” Accessed November 3, 2022. https://www.noaa.gov/.

National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite and Data Information Service. “History of NOAA Satellites.” Accessed October 26, 2022. https://www.nesdis.noaa.gov/.

———. “Joint Polar Satellite System.” Accessed December 8, 2022. https://www.nesdis.noaa.gov/.

National Reconnaissance Office. “About NRO.” Accessed September 15, 2022. https://www.nro.gov/.

———. “What We Do.” Accessed September 15, 2022. https://www.nro.gov/.

———. “Who We Are.” Accessed September 15, 2022. https://www.nro.gov/.

National Security Agency/Central Security Agency. “Mission and Combat Support.” Accessed May 13, 2022. https://www.nsa.gov/.

———. “Profiling DEFSMAC on National Space Day 2021,” May 7, 2021. https://www.nsa.gov/.

National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board. “Comments on Jamming the Global Positioning System—A National Security Threat: Recent Events and Potential Cures,” November 4, 2010. http://www.gps.gov/.

National System for Geospatial Intelligence. *Geospatial Intelligence (GEOINT) Basic Doctrine*. Publication 1.0, April 2018. https://www.nga.mil/.

National Telecommunications and Information Administration. “225–328.6 MHz,” May 1, 2015. https://www.ntia.doc.gov/.

Naval Meteorology and Oceanography Command. “Fleet Numerical Meteorology and Oceanography Center.” Naval Oceanographic Portal. Accessed November 30, 2022. https://www.metoc.navy.mil/.

Northrop Grumman. “Milstar Payloads.” Accessed September 26, 2022. https://www.northropgrumman.com/.

O’Callaghan, Jonathan. “How Many Countries Have Rockets Capable of Reaching Space?” Space Answers, March 21, 2013. https://www.spaceanswers.com/.

Office of the Director of National Intelligence. *Annual Threat Assessment of the U.S. Intelligence Community*. Washington, DC: Office of the Director of National Intelligence, February 2022. https://www.dni.gov/.

Paikowsky, Deganit. “Why Russia Tested Its Anti-Satellite Weapon.” *Foreign Policy*, December 26, 2021. https://foreignpolicy.com/.

Paracha, Sobia. “Military Dimensions of the Indian Space Program.” *Astropolitics* 11, no. 3 (2013): 156–86. https://doi.org/10.1080/14777622.2013.842453.

Partlow, Raymond G. “Space System Vulnerabilities and Defenses.” Research report. Maxwell AFB, AL: Air Command and Staff College, March 2010. https://apps.dtic.mil/.

Payton, Gary E. “Air Force Space Acquisition.” *High Frontier* 6, no. 1 (November 2009): 3–4). https://www.afspc.af.mil/.

Potter, E. B., and Chester W. Nimitz, eds. *Sea Power*. Englewood Cliffs, NJ: Prentice Hall, 1960.

Prasad, K. V. *Principles of Digital Communication Systems and Computer Networks*. Boston: Charles River Books, 2004.

Presidential Memorandum for the Secretary of Defense. Establishment of United States Space Command as a Unified Combatant Command. 83 Fed. Reg. 65483 (Dec. 18, 2018). https://www.govinfo.gov/.

Prince, Ryan. “GSSAP 5 and 6 Join the Fleet.” US Space Force, Space Operations Command. News release, February 7, 2022. https://www.spoc.spaceforce.mil/.

Raju, Nivedita. “Russia’s Anti-satellite Test Should Lead to a Multilateral Ban.” Stockholm International Peace Institute, December 7, 2021. https://www.sipri.org/.

Ray, Justin. “U.S. Launches Its Highest Capacity Military Communications Satellite.” Spaceflight Now, December 8, 2016. https://spaceflightnow.com/.

Rendleman, James D. “Lawful Response to Attacks on Space Systems.” *Space and Defense* 4, no. 1 (Winter 2010): 3–52. https://www.usafa.edu/.

Richardson, Elizabeth. “National Security Space Organizations 101.” Center for Strategic and International Studies, July 2, 2020, updated June 14, 2022. https://aerospace.csis.org.

Richelson, Jeffrey T., ed. “Space-Based Early Warning: From MIDAS to DSP to SBIRS.” Electronic Briefing Book. National Security Archive, January 8, 2013. http://nsarchive.gwu.edu/.

Royal Air Force. “RAF Fylingdales: What Does the Royal Air Force Station Do?” Forces.net, November 15, 2019. https://www.forces.net/.

Ryan, Dorothy. “The Space Surveillance Telescope in Western Australia Captures Its First Image.” Lincoln Laboratory, Massachusetts Institute of Technology, February 2, 2021. https://www.ll.mit.edu/.

Sagdeev, Roald, and Susan Eisenhower. “United States–Soviet Space Cooperation during the Cold War.” NASA. Accessed February 2022. http://www.nasa.gov/.

Sandia National Laboratories. “About Sandia.” Accessed September 19, 2022. https://www.sandia.gov/.

———. “Sandia Technology in Space.” Publication SAND2012-1873P, 2012. https://www.sandia.gov/.

Santamarta, Ruben. *SATCOM Terminals: Hacking by Air, Sea, and Land*. Technical white paper. Seattle: IOActive, Inc., August 11, 2014. https://www.blackhat.com/docs/.

Schmitt, Michael. “Tallinn Manual 2.0 on the International Law of Cyber Operations: What It Is and Isn’t.” Just Security, February 9, 2017. https://www.justsecurity.org/.

Secmation. “Transmission Security (TRANSEC).” Accessed March 2022. https://secmation.com/.

Sellers, Jerry Jon. *Understanding Space: An Introduction to Astronautics*. 3rd ed. New York: McGraw Hill, 2005.

Skybrokers. “Intelsat.” Accessed March 15, 2022. https://sky-brokers.com/.

———. “PanAmSat.” Accessed March 15, 2022. https://sky-brokers.com/.

Smith, Josh. “Explainer: Why North Korea’s Satellite Launches are So Controversial.” Reuters, March 7, 2022. https://www.reuters.com/.

Smith, Marcia S. “NASA’s Space Shuttle Columbia: Synopsis of the Report of the Columbia Accident Investigation Board.” RS21606. CRS Report for Congress, September 2, 2003. https://ntrs.nasa.gov/.

Snodgrass, Roy. “Commercial SATCOM Support—Current/Future.” Presentation. 2007 LandWarNet Annual Armed Forces Communications and Electronics Association Conference, Fort Lauderdale, FL, August 21, 2007.

Solodyna, Craig V., and Gerald P. Banner. “Narrowband and Wideband Radar Signatures in Support of the Space Catalog.” Paper presented at the 4th US-Russian Space Surveillance Conference. US Naval Observatory, Washington, DC, 2000. https://fdocuments.in/.

Space Commission. Space Management and Organization. *Report of the Commission to Assess United States National Security, Space Management and Organization*. Washington, DC: The Commission, January 11, 2001. https://fas.org/.

Space Development Agency. “Who We Are.” Accessed July 24, 2022. https://www.sda.mil/.

Space Doctrine Publication 1-0. *Personnel: Doctrine for Space Forces,* September 7, 2022. https://www.starcom.spaceforce.mil/.

Space Doctrine Publication 5-0. *Planning*, December 2021. https://media.defense.gov/.

Space Exploration Technologies Corp. (SpaceX). “Falcon Heavy.” Accessed December 14, 2022. https://www.spacex.com/.

———. “Falcon 9.” Accessed December 14, 2022. https://www.spacex.com/.

———. “Space Station: Transporting Humans to the Orbiting Laboratory in the Sky.” Accessed October 24, 2022. https://www.spacex.com/.

Space Foundation Editorial Team. “Space Foundation Releases the Space Report 2022 Q2 Showing Growth of Global Space Economy.” Space Foundation, July 27, 2022. https://www.spacefoundation.org/.

Space Foundation. *The Space Briefing Book: A Guide to Modern Space Activities*. Colorado Springs: Space Foundation, 2019. https://www.spacefoundation.org/.

Space Systems Command Public Affairs. "Wideband Global Satellite Communications Program Completes Major Milestone in Development of WGS-11+ Satellite and Ground System," February 1, 2022. Space Systems Command. https://www.ssc.spaceforce.mil/.

Space War staff writers. "Boeing Completes On-Orbit Handover of Wideband Global SATCOM Satellite to USAF." Space War, January 29, 2008. https://www.spacewar.com/.

Spirent. "What Is an Ephemeris?," August 1, 2010. https://www.spirent.com/.

Stokes, Mark, Gabriel Alvarado, Emily Weinsten, and Ian Easton. U.S.-China Economic and Security Review Commission Project 2049 Institute and Pointe Bello (Firm). *China's Space and Counterspace Capabilities and Activities*. Washington, DC: U.S.-China Economic and Security Review Commission, March 30, 2020. https://www.uscc.gov/.

Sweetman, Bill, and Kimberly Ebner, eds. *Jane's Space Systems and Industry: 2007–2008*. Alexandria, VA: Jane's Information Group, 2007.

Tarantola, Andrew. "There Isn't an ICBM Around That Can Sneak Past This Radar Array." Gizmodo, March 12, 2013. https://gizmodo.com/5989481/.

310th Space Wing. "310th Operations Group." Accessed November 30, 2022. https://www.310sw.afrc.af.mil/.

Torkelson, Ashley. "Defining the Line: Why the Department of Defense Should Reconsider United States Space Command's Area of Responsibility." Over the Horizon Journal, January 30, 2020. https://othjournal.com/.

Union of Concerned Scientists (UCS). "UCS Satellite Database." Published December 8, 2005; updated May 1, 2022. http://www.ucsusa.org/.

United Launch Alliance. "Atlas V." Accessed October 21, 2022. https://ula.bsshost.me/.

———. "ULA Sets Path Forward for Inaugural Vulcan Flight," October 12, 2022. https://www.ulalaunch.com/.

United Nations. 2011 Treaty Event—Towards Universal Participation and Implementation. "Understanding International Law." Fact Sheet #1, 2011. https://treaties.un.org/.

United Nations Office for Outer Space Affairs. "Committee on the Peaceful Uses of Outer Space." Accessed March 2022. https://www.unoosa.org/.

———."Space Law Treaties and Principles." Accessed March 2022. https://www.unoosa.org/.

———. "Treaty on the Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies." Accessed March 2022. https://www.unoosa.org/.

United States Air Force. "Air Force Research Laboratory." Fact Sheet. Accessed May 2, 2022. https://www.af.mil/.

United States Army Acquisition Support Center. "Secure Mobile Anti-jam Reliable Tactical Terminal (SMART-T)." Accessed December 16, 2022. https://asc.army.mil/.

United States Army Space and Missile Defense Command (USASMDC). "Technical Center." Fact sheet. Accessed September 19, 2022. https://www.smdc.army.mil/.

United States Coast Guard (USCG). *NAVSTAR GPS User Equipment Introduction*. Alexandria, VA: USCG Navigation Center, September 1996. https://www.hsdl.org/.

United States Congress. House. Committee on Armed Services. *National Defense Authorization Act for Fiscal Year 2019: Report of the Committee on Armed Services, House of Representatives on H.R. 5515 Together with Dissenting Views (Including Cost Estimate of the Congressional Budget Office)*. 115th Cong., 2d Sess. Washington, DC: U.S. Government Publishing Office, 2018. https://www.congress.gov/.

———. *National Defense Authorization Act for Fiscal Year 2020: Conference Report to Accompany S. 1790*. 116th Cong., 1st Sess., Report 116-133. Washington, DC: U.S. Government Publishing Office, 2019. https://www.congress.gov/.

United States Cyber Command Instruction (USCCI) 3000-06. *Cyberspace Forces Mission Alignment Process,* January 8, 2021.

United States Department of State. *Treaties in Force: A List of Treaties and Other International Agreements of the United States in Force on January 1, 2020*. Washington, DC: Dept. of State, January 1, 2020. https://www.state.gov/.

United States Geological Survey. "What Is Remote Sensing and What Is It Used For?" Accessed April 29, 2022. https://www.usgs.gov/.

United States Naval Research Laboratory. "About Us." Accessed November 3, 2022. https://www.nrl.navy.mil/.
United States Navy. "UHF Follow-on Program." Fact Sheet, December 11, 2003. SpaceFlight Now. https://spaceflightnow.com/.
United States Space Command (USSPACECOM). "Frequently Asked Questions." Accessed November 2, 2022. https://www.spacecom.mil/.
———. Mission." Accessed November 2, 2022. https://www.spacecom.mil/.
———. Organizational Fact Sheet. Accessed April 29, 2022. https://www.spacecom.mil/.
———. "Warfighting Units." Accessed April 29, 2022. https://www.spacecom.mil/.
United States Space Force. "Geosynchronous Space Situational Awareness Program." Fact sheet, March 22, 2017 (current as of October 2020). https://www.spaceforce.mil/.
———. "Global Positioning System." Fact sheet, March 22, 2017 (current as of October 2020). https://www.spaceforce.mil/.
———. "Ground-Based Electro-Optical Deep Space Surveillance." Fact sheet, March 22, 2017 (current as of October 2020). https://www.spaceforce.mil/.
———. "Milstar Satellite Communications System." Fact sheet, March 22, 2017 (current as of October 2020). https://www.spaceforce.mil/.
———. "Perimeter Acquisition Radar Attack Characterization System." Fact Sheet, March 22, 2017 (current as of October 2020). https://www.spaceforce.mil/.
———. "Space Based Infrared System." Fact sheet, March 22, 2017 (current as of October 2020). https://www.spaceforce.mil/.
———. "Space Based Space Surveillance." Fact sheet, 22 March 2017 (current as of October 2020). https://www.spaceforce.mil/.
———. Space Capstone Publication. *Spacepower: Doctrine for Space Forces*, June 2020. https://www.spaceforce.mil/.
———. Space Force News. "Space Force Begins Transition into Field Organizational Structure," July 24, 2020. https://www.spaceforce.mil/.
———. "Upgraded Early Warning Radars." Fact Sheet, March 22, 2017 (current as of October 2020). https://www.spaceforce.mil/.
———. "USSF Mission." Accessed 15 March 2022. https://www.spaceforce.mil/.
———. "USSF Organization." Accessed March 15, 2022. https://www.spaceforce.mil/.
———. "Wideband Global SATCOM Satellite." Fact sheet, March 22, 2017 (current as of October 2020). https://www.spaceforce.mil/.
United States Space Force, Office of Current Operations (USSF/COO). Apsides #6, "Space Force Component Primer," November 19, 2021.
United States Space Force, Space and Missile Systems Center. "CCS-C Assurance and Capacity Enhancement (CACE)." Briefing, October 19, 2020. https://afcea-la.org/.
———. "GPS Modernization," June 25, 2014. YouTube video, 7 min., 2 sec. https://www.youtube.com/.
———. Public Affairs. "Counter Communications System Block 10.2 Achieves IOC, Ready for the Warfighter." Space Force News, March 13, 2020. https://www.spaceforce.mil/.
United States Space Force, Space Base Delta 1. "15th Space Surveillance Squadron." Fact sheet, October 2022. https://www.spacebasedelta1.spaceforce.mil/.
———. "4th Space Operations Squadron." Fact sheet, current as of August 2022. https://www.spacebasedelta1.spaceforce.mil/.
———. "Space Delta 9 – Orbital Warfare." Fact Sheet, current as of September 2020. https://www.spacebasedelta1.spaceforce.mil/.
United States Space Force, Space Operations Command (SpOC). "About Space Operations Command." Accessed March 15, 2022. https://www.spoc.spaceforce.mil/.
———. "Advanced Extremely High Frequency System (AEHF)." Fact sheet, October 14, 2020 (current as of August 2021). https://www.spoc.spaceforce.mil/.
———. "Cobra Dane Radar." Fact Sheet, March 2017 (current as of October 2021). https://www.spoc.spaceforce.mil/.

———. “Combined Space Operations Center / Space Delta 5 Fact Sheet,” current as of August 2021. https://www.vandenberg.spaceforce.mil/.
———. “Defense Meteorological Satellite Program.” Fact sheet, March 22, 2017 (current as of February 2023). https://www.spoc.spaceforce.mil/.
———. “Defense Support Program.” Fact sheet, March 22, 2017 (current as of October 2021). https://www.spoc.spaceforce.mil/.
———. “Space Delta 2.” Fact sheet, July 24, 2020. https://www.spoc.spaceforce.mil/.
———. “Space Delta 3.” Fact sheet, July 24, 2020. https://www.spoc.spaceforce.mil/.
———. “Space Delta 4.” Fact sheet, August 15, 2018 (current as of July 2020). https://www.spoc.spaceforce.mil/.
———. “Space Delta 6.” Fact sheet, current as of July 2020. https://www.spoc.spaceforce.mil/.
———. “Space Delta 7.” Fact sheet, July 24, 2020. https://www.spoc.spaceforce.mil/.
———. “Space Delta 8.” Fact sheet, current as of September 2022. https://www.spacebasedelta1.spaceforce.mil/.
———. “Space Delta 9.” Fact sheet. Accessed March 15, 2022. https://www.spacebasedelta1.spaceforce.mil/.
———. “Space Delta 18.” Fact sheet, June 22, 2022. https://media.defense.gov/.
———. “Space Force to Partner with Johns Hopkins University SAIS for Service-Specific IDE, SDE,” October 26, 2022. https://www.spoc.spaceforce.mil/.
United States Space Force, Space Systems Command (SSC). “About Space Systems Command,” May 25, 2022. https://www.ssc.spaceforce.mil/.
United States Space Force, Space Training and Readiness Command (STARCOM). “Space Training and Readiness Command: Who We Are.” Accessed March 15, 2022. https://www.starcom.spaceforce.mil/.
———. “Space Training and Readiness Command: How We Do It.” Accessed March 15, 2022. https://www.starcom.spaceforce.mil/.
University of Adelaide (Australia). “The Woomera Manual on the International Law of Military Space Operations.” Information booklet. Accessed August 2022. https://law.adelaide.edu.au/.
“US Space Force Declares IOC of Infrared Weather Satellite EWS-G1.” Air Force Technology, September 9, 2020. https://www.airforce-technology.com/.
USSTRATCOM Directive (SD) 505-1. Vol 2. *Space Surveillance Operations – Event Processing*, February 13, 2004. USSTRATCOM Reading Room. Posted December 8, 2014. http://www.stratcom.mil/.
USSTRATCOM Directive (SD) 523-2. *Theater Event Systems (TES) Architecture and Operations*, May 3, 2004. Freedom of Information Act 14-070. USSTRATCOM Reading Room. Posted September 2, 2014. https://www.stratcom.mil/.
Vandenberg Space Force Base. “About Us: History.” Accessed April 19, 2022. https://www.vandenberg.spaceforce.mil/.
———. “Combined Force Space Component Command.” Fact sheet, current as of October 14, 2021. https://www.vandenberg.spaceforce.mil/.
———. “Missile Warning Center Fact Sheet,” August 4, 2020. https://www.vandenberg.spaceforce.mil/.
Van Niekerk, Andries F., and Ludwig Combrinck. “The Use of Civilian Type GPS Receivers by the Military and Their Vulnerability to Jamming.” *South African Journal of Science* 108, nos. 5/6 (May–June 2012). https://www.researchgate.net/.
Venable, John. “U.S. Space Force.” In *2023 Index of U.S. Military Strength*, edited by Dakota L. Wood, 455–80. Washington, DC: The Heritage Foundation, 2023. https://www.heritage.org/.
Walker, Amy. “Global Network Design Unifies Army Modernization Efforts.” US Army, December 5, 2019. https://www.army.mil/.
Wall, Mike. “A Lifelong Dream and 20 Years of Work: How Blue Origin and Jeff Bezos Arrived at Their 1st Astronaut Launch. Space.com, July 19, 2021. https://www.space.com/.
———. “North Korea Launches Satellite to Space.” Space.com, February 8, 2016. https://www.space.com/.
———. “SpaceX Launches South Korea’s 1st-Ever Moon Mission, Lands Rocket at Sea.” Space.com, August 4, 2022. https://www.space.com/.
Waterston, John. “Spatial, Temporal, and Orientation Information in Contested Environments (STOIC) (Archived).” Defense Advanced Research Projects Agency. https://www.darpa.mil/.

Weeden, Brian, and Victoria Samson. *Global Counterspace Capabilities: An Open Source Assessment.* Washington, DC: Secure World Foundation, April 2022. https://swfound.org/media/.

Werner, Debra "Who's Keeping Satellites Safe from Cyberattacks?" SpaceNews, April 19, 2017. https://spacenews.com/.

White, Dottie. "53rd Signal Battalion Conducts Change of Command." US Army website. Peterson AFB, May 24, 2016. https://www.army.mil/.

White House. "Fact sheet: Vice President Harris Advances National Security Norms in Space." Press release, April 18, 2022. https://www.whitehouse.gov/.

———. Presidential Memoranda, Donald J. Trump. Space Policy Directive-4. Establishment of the United States Space Force, February 19, 2019. https://media.defense.gov/.

———. Presidential Memoranda, Donald J. Trump. Space Policy Directive-3. National Space Traffic Management Policy, June 18, 2018. https://trumpwhitehouse.archives.gov/.

White, Irvin. *Decision-Making for Space: Law and Politics in Air, Sea, and Outer Space.* West Lafayette, IN: Purdue University Press, 1971.

Williams, Dalton. "Small Island, Big Mission – Ascension Island Supports 45 SW." Space Launch Delta 45. Accessed December 19, 2022. https://www.patrick.spaceforce.mil/

Wilson, Tom. "Threats to United States Space Capabilities." Paper Prepared for the Commission to Assess United States National Security Space Management and Organization. Washington, DC: Space Commission, January 2001. https://fas.org/spp/.

Wisconsin Project on Nuclear Arms Control. "Iran Missile Milestones: 1985–2022." Iran Watch, June 29, 2022. https://www.iranwatch.org/.

World Economic Forum. "What If Space Was the Next Frontier for War?" *Time*, October 3, 2012. https://world.time.com/.

World Meteorological Association. "International Space Agencies Mark 50 Years of Collaboration on Meteorological Satellites," June 17, 2022. https://public.wmo.int/.

Wright, David, Laura Grego, and Lisbeth Gronlund. *The Physics of Space Security: A Reference Manual*. Cambridge, MA: American Academy of Arts and Sciences, 2005. https://www.amacad.org/.

Yoon, Min-sik. "Korea, U.S. Agree on Space Program Partnership." *Korea Herald,* February 29, 2016. http://www.koreaherald.com/.

Zak, Anatoly. "Russian Space Industry in the 2010s." RussianSpaceWeb. Accessed February 2022. http://www.russianspaceweb.com/.

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