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DEFENDING THE FINAL FRONTIER:

COMMERCIAL SPACE SYSTEM VULNERABILITIES TO DIRECTED ENERGY WEAPON THREATS

by

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Abstract

Investment in commercial space systems is exploding. As the military faces ever-tighter fiscal constraints, leasing commercial systems to support military requirements is becoming significantly more cost effective, hence the US military, almost without knowing it, is becoming increasingly reliant on the capabilities provided by commercial space systems. Given this reliance, not to mention the economic importance of this sector to the nation's financial health, the question of whether these systems are susceptible to attack deserves careful consideration. This study examines the unclassified literature to determine if a laser threat to commercial space systems is realistic, whether commercial space systems are vulnerable to laser attacks, and whether US military doctrine is sufficient for dealing with whatever threat emerges.

In answering this question, we must first understand the critical assumption in this question: the satellites are targets because the perpetrator desires to keep their attack covert. Without this assumption, it is difficult to imagine any potential adversary dedicating the time and resources necessary to develop such a technologically challenging weapon system as the other portions of the space system (e.g. the ground segment or the electronic link between the ground and space) are significantly more vulnerable to direct attack than is the space system. The idea of a laser attack against satellite systems is not new, but is it realistic? This study results in a conclusive affirmative response: weapons-quality lasers are realistic threats today. Understanding there is a threat, we must then consider whether our systems are vulnerable. Again, the study concludes all commercial space systems are vulnerable to one degree or another. Finally, US Joint and Air

Force doctrine are examined to determine whether they are sufficient to the task of "explaining the 'best' way to fight" with regards to these types of attacks. Regrettably, both Joint and Service doctrine are largely silent.

The study recommends aggressive implementation of four suggestions from the Air Force Scientific Advisory Board to understand the capabilities of commercial space systems as well as how they can either benefit or threaten US military operations. This includes whether they are used by an adversary for their benefit or whether the adversary denies their use for friendly operations. In addition, the cornerstone recommendation is to develop the ability to detect laser attacks on space systems, thus denying potential adversaries the covertness they desire in pursuing this capability.

Part 1:

Introduction

> *In this information age, the US military depends on national and commercial space systems of both domestic and foreign (or international consortia) origin. Deception, disruption, denial, degradation, or destruction of these space systems and services could seriously affect US warfighting capabilities.*
>
> — National Air Intelligence Center[1]

The fact the US military is heavily dependant on military space systems to support its warfighting capability most probably will not surprise most readers; however, the fact the military is heavily dependant on commercial space systems supporting that same capability most probably does surprise all but those most closely involved in this area of military readiness. This is to say nothing of the economic impact provided by US commercial space systems to the national or global economies. As USAF General (ret) Howell M. Estes III, former commander in chief of US Space Command and commander of Air Force Space Command, has said, "We are the world's most successful spacefaring nation, one of the major reasons the U.S. holds its current position in today's league of nations. But we are also the world's most space-dependent nation, thereby making us vulnerable to hostile groups or powers seeking to disrupt our access to and use of space."[2] More specifically, one report titled "The State of the Space Industry" estimated 1996 revenues for the global space industry exceeded $76 billion.[3]

Conceptual Framework

Accepting the importance of commercial space systems to our nation, the question the USAF must address is how to ensure the freedom to operate these systems in a potentially hostile world environment, and perhaps even more broadly, how to incorporate the defense of space systems into the defense of the nation. This study will identify the threat to commercial space systems posed by directed energy weapons, specifically destructive laser weapons, via a review of the unclassified open source literature. Included in the analysis of the threat will be a discussion of the legal ramifications arising from international law. Having obtained a clear understanding of the threat, the next section will examine the vulnerabilities inherent in the systems as well as the three generic orbits used by commercial systems. Understanding the magnitude of the threat as applied to the vulnerabilities, the study will then examine the doctrine of the US military establishment, assessing adequacy and suggesting modifications where appropriate.

Identification of Assumptions

Understanding the threat to US space systems is an exploding area of research filled with numerous permutations and potential scenarios. In order to keep this discussion focused as well as the desire to keep the study unclassified, several assumptions help constrain the scope of the project.

Project Classification

As much of the current discussion on this topic is conducted via unclassified media, the author strongly desires to produce a product usable in these discussions. For this reason, the study will remain unclassified. Implementing this restriction eliminates consideration of the

most current information on the topic, however does not detract from the overall purpose of the study; that is to understand the scope of the threat posed by laser weapons directed against the vulnerabilities of commercial space systems and then finally, to understand DoD doctrine in response to these threats.

Desire to Remain Covert

A variety of strategies are available to attack space systems, however, as will be developed in following sections, the potential repercussions of being identified as the attacker are severe; it is therefore logical to assume the motivation for using a laser weapon to attack a commercial space system is the perpetrator's desire to remain undetected. US National Security Policy is clear and unequivocal regarding the gravity with which attacks against national infrastructure are viewed; attacks against our information infrastructure (of which commercial space systems are part) are attacks against the vital interests of the US and will be met with the full military and diplomatic power available to the US government.[4] The logic for this assumption is quite simple; if an adversary was unconcerned about detection, there are far more effective means to destroy the system rather than attacking the space segment, i.e. the on-orbit satellite vehicle. Chief among these is an attack against the ground control segment; generally housed in typical office buildings, satellite control stations are vulnerable to the full spectrum of physical and electronic attack. Attacks against these facilities are generally more difficult to hide: the perpetrator of such an attack is quite probably going to be identified.

Directed Energy Weapons

This study will only consider the use of laser weapons as a means to attack commercial space systems. Studying only laser weapons is a function of the available literature; while other forms of attack are possible, there simply is insufficient unclassified documentation available to

understand the potential threat they pose. Among these other means are kinetic kill or particle beam technologies and pulse technologies, encompassing both electromagnetic and radio frequency. In general terms relative to weapon development, particle beam research is on the decline while pulse technology research is on the increase. The key feature of laser weapons as applied to this study is their inherent tendency to be covert thereby supporting the above assumption regarding the reason an attack would be executed in the first place.

Detect, Track and Target Capability

Detecting, tracking and targeting an orbiting space vehicle with the level of precision necessary to guide a directed energy weapon attack is not a trivial endeavor; however, for the purposes of this study, we must assume any adversary capable of generating a weapons-quality laser is also capable of accomplishing the difficult task of determining where to point the laser to achieve the desired effect. The author acknowledges this is a significant assumption as the technology (not to mention the associated cost) to accomplish detection, tracking, and targeting is arguably as significant as that required to generate a laser weapon. However given this relationship, we must assume an adversary's decision to seek a laser weapon is coupled with a decision to acquire, if necessary, the means to employ it against space targets.

Notes

[1] National Air Intelligence Center, *Threats to US Military Access to Space*, Wright-Patterson Air Force Base, Ohio, 1998.

[2] Gen. Howell M. Estes III, Commander, U.S. Space Command, North American Aerospace Defense Command and Air Force Space Command, prepared remarks presented at the Air Force Association Annual Symposium, Los Angeles, Oct. 18, 1996. Available online at http://www.defenselink.mil/speeches/1996/s19961018-estes.html

[3] Scott Pace, "Policy Challenges for the Second Space Age", *Merchants and Guardians: Balancing US Interests in Global Space Commerce*, eds. John M. Logsdon and Russell J. Acker,

Notes

International Space Policy Forum, Elliott School of International Affairs, The George Washington University, May, 1999.

[4] The White House, *A National Security Strategy for a New Century*, December 1999, p. 12.

Part 2

Problem Background

> *If an adversary is able to effectively employ offensive counterspace operations to deceive, disrupt, deny, degrade, or destroy US space systems, the force multiplication effect they provide would be reduced or eliminated. As a result, US forces might suddenly find themselves in a much weaker position. This could lead to much more expensive victories, or even to defeat.*
>
> — National Air Intelligence Center[1]

This section explains the relevance of the research question by answering a fairly simple question: "Why does the military care about the potential for attacks against commercial space systems?" As described below, the answer to this question has two components, including the relative explosion in the numbers of commercial space systems and the recognition of space infrastructure as a center of gravity for the United States.

The Explosion of Commercial Space Systems

"By the end of 1995, more than 30 countries and organizations – including the Czech Republic, Israel, Indonesia, and Brazil – had orbited communications or imaging satellites or individual payloads aboard satellites. The mushrooming commercialization of space, projected to top $500 billion within the next decade, is also causing concern within the US defense community."[2] Further proof of the increasing volume of space systems is evidenced by the current United Nations registry of objects launched into outer space which is provided at Appendix A. What follows is a brief description of commercial space systems and their utility.

Commercial Systems Described

There are two broad categories of commercial space systems: communications and earth sensing. Commercial communication systems serve the same purpose as military systems: providing voice and/or data networks to connect multiple users. In fact, during DESERT SHIELD/STORM, commercial communication systems augmented over-taxed military systems to carry mission critical communications traffic. Ten different COMSAT systems were used during the conflict, carrying 90% of the total communications traffic: of this, 24% was carried via commercial systems.[3] As warfighter demand for ever-increasing bandwidth can only be expected to increase while military procurement budgets decrease, the only logical conclusion possible is US military reliance on commercial space systems will explode in the future. Commercial systems are vastly more capable in terms of the volume of traffic they are capable of carrying as they are designed specifically for moving large quantities of data. For example, the military does not have any systems capable of efficiently transferring video information[4] whereas companies such as Home Box Office, Showtime and others make a living doing exactly that function. The military recognized the potential of these systems however and recently acted to change this situation. Using a leased portion of the Orion satellite owned by the Direct TV company, the Air Force Space Warfare Center completed a proof of concept test where combat video footage from unmanned aerial vehicles was transferred from the theater back to the US for analysis.[5] The success with this demonstration led to a military system called Global Broadcast System (GBS), which is being fielded as this study is written.

Earth sensing describes satellite systems whose mission is to gather data about the earth itself. These missions include earth imagery, weather analysis/prediction, surface mapping, ice/water analysis, etc. Two of the best known are the US-owned Landsat and the French-owned SPOT systems. Both of these systems are hyperspectral, meaning they receive light in several

wavelengths simultaneously, and both are completely commercial operations. In the case of Landsat, US law requires Landsat data be made available for sale to any individual or nation on a nondiscriminatory basis. The Secretary of Defense has the authority to block the sale of Landsat data for national security reasons, but has to date not established any criteria for restricting data or limiting access to Landsat information.[6]

Military Utility

To date, no commercial enterprise has orbited a system called a "spy satellite," however as we have seen above, the difference between military and commercial systems is one of degrees; and the degree to which they are different is rapidly closing. As the table below indicates, capabilities provided by commercial imagery systems have dramatic military utility. For the record, both the Landsat and SPOT satellite systems provide imagery in support of the civil, and therefore the military, applications identified.

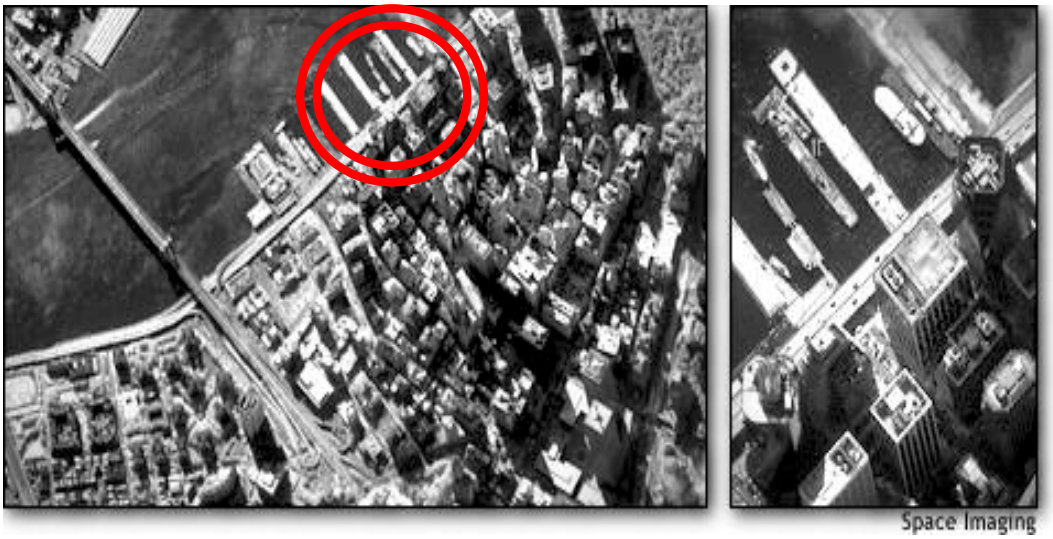
Table 1. Civil/Military Uses of Multispectral Imagery

Civil Application	Military Application
Soil Features	Terrain Delineation, Attack Planning, Trafficability
Surface Temperature	ASW Support, Trafficability, Air Field Analysis
Vegetation Analysis	Terrain Delineation, Camouflage Detection
Clouds	Weather, Attack Planning
Snow Analysis	Area Delineation, Attack Planning
Surface Elevation	Mapping, TERCOM
Ice Analysis	Navigation, ASW Support
Water Analysis	Amphibious Assault Planning
Cultural Features	Targeting, BDA

Source: Major James G. Lee, *Counterspace Operations for Information Dominance*, Table 7, p. 18.[7]

The primary distinction between military and commercial imagery systems is resolution, i.e. to what degree of accuracy does the system collect imagery. The resolution of US military systems is obviously highly classified information, however William E. Burrows, in his book *Deep Black* published more than 10 years ago, used open source material and some educated guessing to arrive at resolution of around 0.5m.[8] Assuming this is moderately accurate, this resolution was significantly greater than the best imagery available from commercial systems, which was around 5m – until now. In late 1999, the Ikonos satellite achieved orbit and, in marketing its capabilities, the system's US owners published the 1m-resolution image in Figure 1 below on the Internet. The picture on the left is "normal" commercial imagery, while the picture on the right indicates the imagery Ikonos is capable of generating and represents the area circled (top, center) on the left hand photograph.

Figure 1: Ikonos 1-meter Imagery



Source: ACSC AY2000 Space Briefing, Maj James Cashin, et al, slide 69 (left), Jan 99[9]

While the US government has an agreement in place to require the satellite's owners to stop imaging when directed (referred too as "shutter control") all other imagery generated by this system would be available to any person or nation with sufficient funds. To address the

increased capability of commercial systems, the USAF Scientific Advisory Board made the following recommendations regarding the commercialization of space:

> The Air Force, representing the Department of Defense should establish an integrated product team to:
>
> - Maintain a continuous assessment capability of commercial space systems and their supporting communications and ground infrastructures, which may be potentially useful or threatening to the United States.
>
> - Act, or enable a clear path to higher authority to recommend action, as a result of these assessments.
>
> - Infuse commercial technology-operational capability awareness throughout the relevant planning, acquisition and operational elements of the USAF.[10]

Obviously, the advisory board is taking commercial space capability very seriously, however the recommendations make it clear the military still has a long way to go in capitalizing on these capabilities. Perhaps most alarming is the military's fixation on use of commercial space systems by adversaries; to date, we are paying very little attention to the level of dependence we ourselves have on commercial systems.

Space as a Center of Gravity (COG)

"COGs are defined as those characteristics, capabilities, or localities from which a military force, nation, or alliance derives its freedom of action, physical strength, or will to fight. COGs are those centers of power that if defeated or disrupted will have the most decisive result."[11]

"Of every dollar spent (on space) by governments around the world, the United States government spends seventy-five cents."[12] However, government spending is no longer the largest component of space investment, nor is the impact of space investment limited to a small portion of the economy. According to John W. Douglass, President CEO and General Manager of Aerospace Industries Association (AIA),

> From 1993 to 1997, space sales grew by 170 percent, a rate ten times faster than the growth of the commercial airplane business. Total space sales exceeded aircraft sales in 1997 for the first time in the history of our country--$32 billion versus $30.6 billion. In 1997, the aerospace industry was responsible for $59 billion in exports and $22 billion in imports. This resulted in a positive trade balance of $37 billion—the single biggest trade balance of any sector in the entire American economy.[13]

Appendix B is an illustration of how Air Force doctrine recommends developing plans to attack COGs, but for purposes of this study, it is clear from the definition above commercial space has become an economic COG for the United States and that the military's increasing reliance on commercial systems renders them ripe for attack.

Summary

Clearly, commercial space systems are an ever-growing component of the US economy. In addition, US armed forces are becoming ever more reliant on commercial satellite systems in conducting military actions: as the number of commercial systems grows, our reliance will only increase over time. Given these plainly stated facts, it is incumbent upon the military to take those steps necessary to understand the potential threats to this center of gravity in terms of the vulnerabilities of our systems and develop doctrine to help prepare our forces for conflict, should conflict become necessary.

Notes

[1] National Air Intelligence Center, *Threats to US Military Access to Space*, Wright-Patterson Air Force Base, Ohio, 1998.

[2] Johnathan S. Landay, "Drawing Battle Lines in Space", in *The Christian Science Monitor*, p.3, 17 Dec 97 edition, available online at http://www.csmonitor.com/durable/1997/12/17/us/us.3.html.

[3] David N. Spires, *Beyond Horizons: A Half Century of Air Force Space Leadership*, p. 246, Air Force Space Command in association with Air University Press, Peterson Air Force Base, Colorado, 1998.

[4] Personal experience of the author.

[5] Air University, Space Capabilities Briefing to the Aerospace Basic Course, briefing prepared by the US Air Force Wargaming Institute, 1999, slide 84.

Notes

[6] Maj James G. Lee, *Counterspace Operations for Information Dominance,* School of Advanced Airpower Studies, p. 8, Air University, Maxwell Air Force Base, Alabama, October 1994.

[7] ibid, p. 18

[8] William E. Burrows, *Deep Black: Space Espionage and National Security*, Random House, New York, 1986, p. 132.

[9] Air Command and Staff College, Major James Cashin, et al, in AY2000 Space Systems Briefing, Operations Forces (OF) 515 slide 69 (left side), presented 11 Jan 00, Air University, Maxwell AFB, AL.

[10] US Air Force Scientific Advisory Board, "Military Foundations of Space Application", *Force 2025, Vol 12: Forward to the Future*, p. 194-5, Air Command and Staff College, Air University, Maxwell Air Force Base, Alabama, May 1999.

[11] Air Force Doctrine Document 2, *Organization and Employment of Aerospace Power*, United States Air Force, 28 Sep 98, p. 79. Hereafter cited as "AFDD-2."

[12] John M. Logsdon, "Does the United States Have a National Strategy for Space?", in *Merchants and Guardians: Balancing US Interests in Global Space Commerce*, ed. John M. Logsdon and Russell J. Acker, International Space Policy Forum, Elliott School of International Affairs, The George Washington University, May 1999.

[13] John W. Douglass, "Issues in Global Space Commerce", in *Merchants and Guardians: Balancing US Interests in Global Space Commerce,* ed. John M. Logsdon and Russell J. Acker, International Space Policy Forum, Elliott School of International Affairs, The George Washington University, May 1999.

Part 3

Understanding the Issue

> *Clearly, we must develop the necessary capabilities to deter adversaries from threatening our space systems and if necessary, defeat hostile or aggressive acts.*
>
> — General Richard B. Myers, USAF
> Commander in Chief, USSPACECOM[1]

> *Take advantage of the enemy's unpreparedness; travel by unexpected routes and strike him where he has taken no precautions.*
>
> — Sun Tzu[2]

Using Air Force doctrine as indicated in Appendix B, we see the first question we must answer following the identification of a COG is whether it is critical. Certainly this is a debatable point when applied to the current state of commercial space systems, but it certainly seems feasible the impact to both the nation's military capability as well as its economy renders commercial space systems critical. Given it is critical, we then must answer whether the COG is vulnerable to direct attack. There are many components of a space system broadly categorized as the ground segment, the space segment, and the link or electronic pathway connecting the ground and space segments together. This study focuses on space vehicles because they may be attacked covertly, hence the question becomes are space vehicles vulnerable to direct attack? The next question in the COG attack process then requires we determine if a military attack is feasible, and in doing so, consider the availability of forces and the risks associated with conducting the attack.

Current discussion on this topic assumes the space segment is vulnerable and an attack is feasible: this section examines those assumptions for their validity. First, we will examine the vulnerabilities of the space segment in terms of their construction and orbits. At that point, we will examine the forces and risks associated with an attack in terms of lasers and international space law to determine whether an attack is truly feasible.

Are Commercial Space Systems Vulnerable?

Understanding if an adversary can "reach" a friendly system to apply force, and if so, whether the system is susceptible to the expected attack is the key measurement of vulnerability. We will therefore examine the vulnerabilities associated with common orbits used by commercial systems followed by an examination of vulnerabilities associated with the construction of commercial space systems.

Orbital Vulnerabilities

Commercial space systems, as well as the majority of military systems, utilize three general orbits in accomplishing their assigned function: low earth orbit (LEO), medium earth orbit (MEO) and geosynchronous orbit (GEO). These terms relate to the altitude of the orbit, i.e. the distance from the surface of the earth to the orbiting satellite. As MEO orbits are rarely used by commercial systems it is included above for accuracy, however will be ignored in the following discussion. Again, in very general terms, the orbital measurements concerning satellite vulnerability are the speed of the satellite and its distance relative to the surface of the earth. These factors arise from the fact an adversary must first detect a space system, track it, then direct the laser onto the system for the length of time necessary to destroy the satellite. What

follows is a very high-level discussion of the generic orbits including the typical uses for these orbits and the relative vulnerability of the different altitudes.

Low Earth Orbit. LEO is defined as between 200 - 500 miles (320 – 800 kilometers) above the surface of the earth.[3] LEO is the altitude at which the vast majority of earth sensing satellites (e.g. weather and imagery) orbit the earth for the simple reason they are closer to the thing they are sensing and thus are able to achieve greater degrees of efficiency.[4] Additionally, a global communication system consisting of dozens of satellites servicing handheld receivers recently achieved operational capability (Iridium) while a second global constellation (Teledisic) is planned for the next few years. These communication systems achieve the required "dwell time" over the surface of the earth through utilization of numerous satellites. By definition, this orbit is closest to the earth's surface, however relative to a spot on the earth, space systems at this altitude travel faster than at any other altitude with speeds exceeding 17,000 miles per hour.[5] In other words, if a satellite in LEO were to pass directly over a spot on the earth, it would be in view of that spot for a period of approximately 10 - 16 minutes. If this opportunity to engage the target were missed, an adversary would have to wait some period of days, depending on a myriad of orbital parameters, before the opportunity to engage the system over the same spot was again presented. Compared to the other orbits in relative terms, this orbit is more vulnerable due to altitude and less vulnerable due to speed. In other words, LEO systems are hard to find, hard to track, but easy to kill individual satellites; assuming a large number of satellites in a constellation, losing a few satellites might yield negligible results minimizing the results of an attack. However, even with a large number of satellites, strategically rendering several inoperative could result in the desired degradation

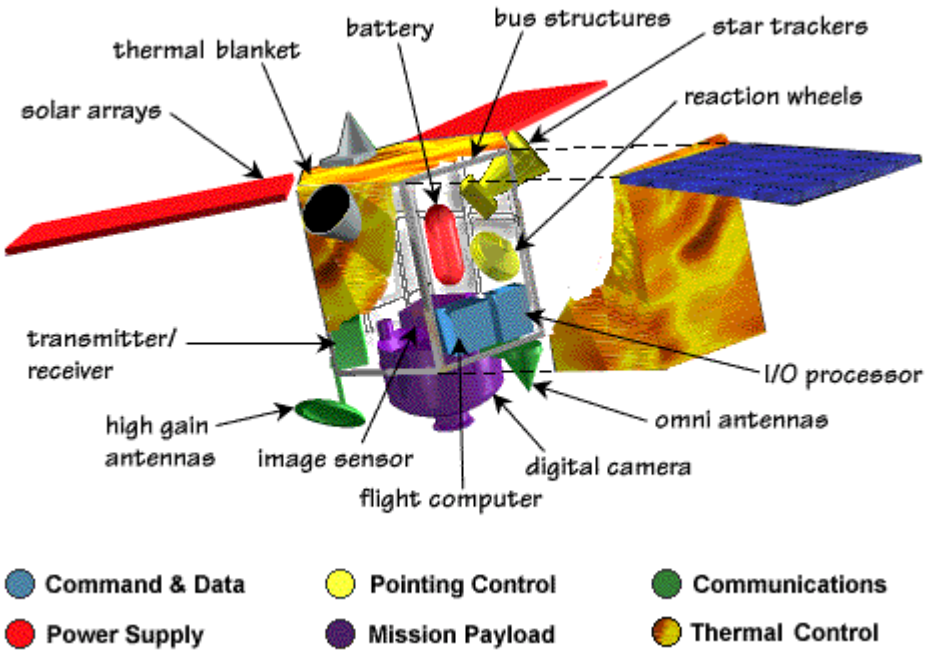
Geosynchronous Earth Orbit. Satellites in GEO fly at an altitude of 22,300 miles above the surface of the earth, taking a full 24 hours to complete their orbit. As the earth completes a full rotation every 24 hours, GEO satellites remain positioned over a spot on the earth. For this reason, GEO is a very desirable altitude for communication satellites. From this location, a satellite views approximately one-third of the earth's surface, while the converse is also true: continuous satellite coverage is possible from any location on the earth within the satellite's field of view. This fact leads to an obvious vulnerability in terms of this orbit's susceptibility to laser attack: the satellite does not move relative to the earth, i.e. it has a relative speed of zero. On the other hand, it is a very long way away from the surface of the earth; generating a laser of sufficient quality to convey sufficient energy to damage a satellite at GEO will not be easy. In other words, GEO systems are easy to find, easy to track, but difficult to kill.

Construction Vulnerabilities

"Satellites have some characteristics that make using lasers against them difficult. The 'kill mechanism' by which lasers can destroy satellites is different from that used to destroy ballistic missiles."[6] The difference between killing a satellite and a missile is quite simple; missiles are full of fuel designed to burn where as satellites generally have very small quantities of fuel on board. In other words, the vast majority of a missile contains potentially explosive material whereas a satellite does not. This does not mean that satellites are invulnerable. "Directed energy weapons can be be employed to achieve a destructive hard kill, a nondestructive soft kill, or a nonlethal temporary disruption or degradation."[7] As depicted in the illustration in figure 2, satellites are literally full of electronic equipment operating in the vacuum of space. Electronics require certain ambient operating temperatures in order to function properly; the extreme cold of space coupled with the undiluted energy from the sun, the relative position of which changes as

the vehicle moves through its orbit, combine to make temperature control one of the satellite engineer's biggest headaches. Raising vehicle temperatures via laser strike or damaging the vehicle's ability to perform temperature maintenance by degrading the heating/cooling mechanisms are equally catastrophic. Also consider, many satellites' specific purpose is to image the earth, i.e. to receive light. A laser of even minimal power could be capable of "blinding" a satellite by overwhelming its ability to receive light.

Figure 2: Anatomy of a Satellite



Source: Tech Museum: The Satellite Site[8]

"Reducing the vulnerability of a satellite to laser illumination can be effected by shielding soft components such as solar panels and by shuttering or filtering optical and infrared sensors. The more powerful the laser, the more shielding necessary and the more expensive the spacecraft becomes; however, shielding does increase survivability."[9] Defending space systems through shielding or design is the primary difference between military and commercial space systems.

For example, the mission of the Milstar communications satellite is to provide secure communications for command and control of US nuclear forces throughout a full-scale nuclear war; it has virtually complete redundancy in electronic components and tremendous quantities of gold-foil shielding as well as on-board computers and sensors to detect and respond to electro-magnetic pulse events. It is also the most expensive satellite placed on orbit to date at a cost of over $1 billion per satellite.[10] Commercial industry simply has no need to accept the costs associated with building systems of such robustness, not to mention the cost of getting the additional weight on orbit. In other words, while shielding may have some beneficial effect in protecting space systems, today's market place does not allow the luxury of incurring additional expense to meet an unproven threat.

Does a Laser Threat Exist?

Whether or not a threat exists is a crucial question, especially given the ever-shrinking defense budgets confronting the US armed forces. The nation and its military services simply cannot afford to treat every concern as a threat to our vital interests nor dedicate the resources to defend against such threats when identified. In considering whether a threat exists, we must understand the state of technology and the legal implications of attacking space vehicles.

The State of Current Technology

Understanding how lasers work is well beyond the scope of this study, but understanding in general terms whether the scientists building lasers are capable of building weapons-quality machines is very important. Volume 2 of the *Space Handbook* published by Air University contains an excellent description of the differing types and capabilities associated with current

laser technology. In general terms then,

> A high-energy laser weapon is a system that attempts to inflict damage on an aerospace vehicle by placing large amounts of energy on a small area. The result is a thermal kill, such as weakening and eventual rupture of structural components, ignition or combustion of flammable materials, or destruction of thermally sensitive items in vital components.[11]

Types of Lasers. Scientists continue to experiment with a wide range of lasers including solid-state, gas, semiconductor, liquid, chemical, eximer, and free electron lasers.[12] The wide range of possible weapons is illustrative of the tremendous technical challenge inherent in producing weapons-quality systems. "The main problem with making a laser into a weapon is generating a reliable, high-power beam with good beam quality."[13] Scientists must balance the power generated by the laser beam with the power required to generate the beam: a balance termed efficiency. Of the lasers being studied, the chemical, free electron and to a lesser extent, the solid-state systems hold the greatest promise for weapons implementations. Efficiency is the primary reason chemical and free electron lasers have surged ahead of their peers, however the incredible power output of the solid-state system – demonstrated at over 10,000 megawatts, albeit with very poor efficiency – keeps it in the running.[14]

Current Developments. The US laser weapon on the leading edge of achieving operational status is being tested by the Air Force for a missile defense role and is called the airborne laser or ABL. This system is scheduled for initial operational capability (IOC) in 2002 and full operational capability (FOC) in 2008 with a fleet of seven Boeing 747-400 aircraft with integrated ABL, however it was 20 years in the making and required significant technological breakthroughs.[15] Lt Col John Anderson, chief of the Starfire Optical Range at Phillips Laboratory, is quoted in *Airman* magazine as saying,

> We shine a laser into the night and look at the return for backscatter, then adjust a deformable mirror to correct for that. This mirror has 341 actuators that change at a rate of about 1,000 per second. The end result is that it increases the beam's

> intensity on a target. It's a key enabling technology. Without it, you'd have too much beam spreading to do enough damage. If this doesn't work, the whole program doesn't work.[16]

Laser weapons therefore exist (more or less) today. Given the anticipated power output ("multi-megawatt") and the fact ABL flies at approximately 40,000 feet (above much of the atmosphere and all weather), the argument that ABL could engage LEO satellites appears quite valid. An important consideration to remember however is the cost of this system: the program development and risk reduction (PDRR) contract was awarded for $1.1 billion to a Boeing-led team of companies. Note these funds are to take the contractor from design to working prototype; these funds do not put ABL equipped aircraft in the air.[17] Before assuming cost will prevent other nations from acquiring this capability once fielded by the US, we should again refer to Appendix A and look at the spacefaring nations listed. The cost to develop systems is extremely high; costs to acquire existing technology drop dramatically. To the best of our knowledge, the former Soviet Union (now Russia) is the only other nation believed to have a credible laser weapon.[18] The ground-based laser at Sary Shagan is estimated to have a satellite hard-kill capability at altitudes up to 400 kilometers and a soft-kill capability at altitudes up to 1,200 kilometers.[19] In other words, a credible laser threat to commercial space systems exists – today.

The Legal Implications of Laser Attacks

Several treaties and conventions agreed to by the United States serve to establish domestic and international law concerning the use of space. A summary of these instruments with the principle or constraint they implement is included in Appendix C. We will focus on two specific areas for this study: international norms and constraints on the use of space for military purposes.

International Norms. While the list in Appendix C is fairly extensive, the United States mirrors other nations in adhering to the principle of what is not specifically prohibited by international law is permissible. "Thus, even though the list of prohibited acts is sizable, overall there are few legal restrictions on the use of space for nonaggressive military purposes."[20] Following this premise to its logical conclusion we realize Iraq would have been within the constraints of international law to attack our space systems during the Persian Gulf conflict. In addition, the nations that signed these treaties are also a possible point of contention; all of the documents listed in Appendix C were signed by the Soviet Union, a nation that no longer exists. In the case of the ABM treaty, the agreement was bilateral: made exclusively with the USSR. The US has "adopted a policy of continuing to observe the requirements of all treaties and to apply their provisions to the independent states that have emerged" from the dissolution of the Soviet Union, however the US would certainly have the legal basis to argue all treaties were null and void.[21]

Use of Space for Military Purposes. The only weapons specifically mentioned in any space related treaty are ABM systems, nuclear weapons or other weapons of mass destruction: lasers or antisatellite weapons are not mentioned and are hence allowed. The one exception to the antisatellite provision is mentioned in the ABM Treaty of a restriction on interference with a nation's "national technical means" to verify the terms of the treaty. This clause is understood to mean the surveillance satellites of the US and USSR, and again following the norms identified above, means the commercial systems of spacefaring nations are legal targets. One important fact however deserves special mention.

Article III of the Outer Space Treaty specifically calls out the requirement for states to conduct themselves in accordance with international law "including the UN Charter."[22] This is

important because the UN charter in article 51 specifically allows states to act in self-defense if attacked by another; in other words, a state using a laser to attack a satellite owned by the United States has committed an act of war under international law. Certainly, proving an attack was committed would be extremely difficult, hence the desire to obtain laser weapons to conduct a covert attack. Simply put, the ramifications of exposure are significant indeed.

Summary

To understand how an adversary might attack our space COG, this section examined the vulnerabilities of our space systems and the capabilities of potential forces in light of the risks associated with using those forces. Our conclusions are summed up as follows:

- Each orbit is susceptible to attack, to one degree or another.
- Satellite systems are vulnerable to laser weapon effects, ranging from interruptions, to damage, to destruction.
- The technology required to build laser weapons is complex but proliferating
  - It appears likely the US will field a destructive laser weapon in the near future.
  - Russia has a confirmed laser antisatellite capability.
  - Other nations can be expected to acquire the technology once primary research and development are completed, as was the case with satellite systems themselves.
- International law provides nations significant recourse for overt attacks; covert attacks, by definition, are beyond the scope of international law.

In other words, the systems are vulnerable to attack, and the forces necessary to conduct the attack exist today, at least in Russia. A prediction on when these forces might become more widely available is essentially impossible; numerous Internet searches indicate the United States is virtually the only nation actively seeking laser weapons. Obviously, authoritarian societies are unlikely to publicize their activities and therefore some uncertainty as to the future proliferation of laser weapons must be acknowledged.

Notes

[1] General Richard B. Myers, USAF, Commander in Chief US Space Command, Commander North American Aerospace Defense Command, and Commander Air Force Space Command, Prepared responses to advance hearing questions supporting confirmation hearings before the Armed Services Committee of the US Senate, available online at http://www.senate.gov/~armed_services/statement/980623rm.htm, 23 Jun 98.

[2] Sun Tzu, *The Art of War*, translated by Samuel B. Griffth, p. 134, Oxford University Press, 1971.

[3] Tech Museum: Satellite Site, "General Information", Lockheed-Martin Corporation hosted web site, available online at http://www.thetech.org/hyper/satellite/4/4a/4a.1.html

[4] ibid

[5] ibid

[6] Maj William L. Spacey III, *Does the United States Need Space-Based Weapons?*, p. 17, College of Aerospace Doctrine, Research, and Education, Air University Press, Maxwell Air Force Base, Alabama, September 1999.

[7] Lee, p. 31.

[8] Tech Museum, http://www.thetech.org/hyper/satellite/5/5.html

[9] Colonel Robert B. Giffen, "US Space System Survivability: Strategic Alternatives for the 1990s," p. 36, National Security Affairs Monograph Series 82-4, National Defense University Press, Fort Lesley J. McNair, Washington D.C., 1982.

[10] Personal experience of the author.

[11] Air University, *Space Handbook Volume 2: An Analysts Guide*, prepared by Maj Michael J. Muolo, edited by Maj Richard Hand, et al, p. 260, Air University Press, Maxwell Air Force Base, Alabama, December 1993. Hereafter cited as "Handbook, Vol 2".

[12] ibid, p 253-255.

[13] Spacey, p. 12.

[14] ibid, p 252-256

[15] Airman Magazine, "Set Lasers on Stun", April 1997, available online at http://www.af.mil/news/airman/0497laser2.htm

[16] Lt Col John Anderson, as quoted by Airman Magazine, "Set Lasers on Stun", April 1997, available online at http://www.af.mil/news/airman/0497laser2.htm

[17] Airborne Laser Program Website, available online at http://www.de.afrl.af.mil/abl/index.html

[18] NAIC, p. 15.

[19] Lt Cmdr James S. Green, USN, *U.S. Plan for Space Control*, Air War College, 3 Mar 89, p. 7.

[20] Handbook Vol 2, p. 57.

[21] ibid, p. 57.

[22] United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Article III, entered into force 10 Oct 67.

Part 4

Does Military Doctrine Answer the Concern?

> *At the very heart of war lies doctrine. It represents the central beliefs for waging war in order to achieve victory. It is fundamental to sound judgment.*
>
> — General Curtis E. LeMay
> USAF, 1968

In this section we examine the doctrine of the United States military forces to determine first if it addresses the potential for conflict involving commercial space systems and second whether that treatment is adequate. Determining adequacy is admittedly an exercise in judgment as advocates frequently disagree on the level of emphasis placed on certain areas of doctrine; this contention was made crystal clear in the message of the various guest speakers addressing the AY00 class at the Air Command and Staff College at Maxwell Air Force Base.[1] The considered judgment is however necessary, as the epigraph from General LeMay above helps illustrate: if we hope to achieve victory in any future space combat involving commercial satellite systems, we must first do the thinking necessary to generate a workable doctrine.

The State of Doctrine

"Good doctrine is founded on military experience, tempered where experience is lacking by military theory, and appreciates how advancements in technology, strategy, and operational tactics will change the nature of warfare."[2] In military parlance, the discussion we are having concerns space control: the ability to ensure the availability of space to ourselves while denying

it to our adversaries. The following discussion looks at Joint and Air Force doctrine for space control in terms of military experience, theory, and the changing nature of warfare.

Joint Doctrine

Experience. "Despite its importance to the success of the joint team, there is almost no mention of space forces in the joint capstone and keystone doctrine publications."[3] This is a truly disheartening assessment of Joint doctrine, and regrettably accurate. When taken to the next level and examined for consideration of commercial space systems, Joint doctrine is absolutely silent. This silence is difficult to understand given the admittedly limited yet still pointed experience the US military has acquired in recent conflicts. In DESERT SHIELD/STORM, diplomatic intervention was necessary to restrict Iraq's access to SPOT imagery, imagery they had been purchasing for some time. While the owners agreed to restrict dissemination of their imagery to Iraq and the media, the weakness of diplomacy is illustrated by the fact this voluntary act was dependent on no other company selling imagery to the media; if that happened, all bets were off.[4] In ALLIED FORCE, once again diplomacy was necessary to deny satellite TV capability to the Serbian leadership. Joint doctrine completely fails to acknowledge counterspace activities will both be necessary and most likely conducted against space assets owned by either commercial interests or nations other than the combatants.

Theory. Where no experience exists, theory should fill the void in doctrine. To date, we have no experience with laser attacks against commercial space systems, however, we also have no theory on how to deal with such an attack should it occur. Even more alarming, we have no means to positively identify when an attack is occurring. Joint Publication 3-14, the keystone document for space operations tactics, techniques and procedures in coordination for literally years, is now out for coordination as the second (final) draft. While commercial space systems

are mentioned in the document, this author believes its presence is more the function of aggressive word processing rather than careful consideration of potential threats.

Changing Nature of Warfare. Joint doctrine is simply missing the fact that civilian space systems are becoming potent providers of military capability for nations with limited organic space capability, as well as providing significantly increased capability for US forces. Additionally, regardless of the agreements in existence at the initiation of hostilities, the commercial nature of these systems facilitates the rapid procurement of space capabilities for any nation with sufficient funding. The key realization Joint doctrine must address is the use of destructive force is almost certainly not an option in denying space assets to an adversary while recognition of an enemy attack on friendly systems is currently not possible.

Air Force Doctrine

Given the Air Force controls over 90% of DoD space assets, we would expect service doctrine for the employment of at least these military forces to be abundant. It is not. "Space is included in Air Force basic doctrine only because aerospace is taken to mean both air and space; consequently, Air Force basic doctrine has very little to say about the organization, training, equipping, and employment of space forces."[5] Given this assessment, the further realization that Air Force doctrine also remains completely silent on commercial space systems comes as no surprise.

Experience. Of all the services, the Air Force experience best prepares it for embracing the concept of commercial space systems as integral components of military power. The Air Force is closely tied to civilian industry and government space entities, and has the longest experience with the capabilities provided by space systems. AF experience is being ignored in its doctrine.

Theory. Air Force space theory is closely tied to airpower theory by definition of the term aerospace. Many writers inside and outside the Air Force have begun questioning the appropriateness of this association as many of the tenets of airpower apply quite differently to space power, if at all. "Official space doctrine fails to accommodate the physical differences between the atmosphere and space and attributes capabilities and technologies of aircraft to space systems."[6] The principles of war identified in both Joint and service doctrine are applicable to the employment of space forces but in different ways, similar to the differences between air and land power, yet these differences are not acknowledged in AF doctrine. Space power is not the same as airpower, nor is it employed in the same manner; AF theory must address the differences.

Changing Nature of Warfare. The AF does recognize the explosion of military space systems and the resulting increased capability is changing the nature of warfare, at least anecdotally. However, recognition of the emergence of commercial space systems as contributors to that military capability is a relatively recent discovery and as yet is unrecognized in any AF doctrine.

Summary

Notwithstanding the earlier discussion on the application of judgment and the potential for disagreement, certainly the absolute lack of doctrine on a subject must be assessed as inadequate. We applied Air Force (and Joint) doctrine to determine commercial space systems are a COG for the US, determined the systems were vulnerable, and determined attacks were feasible, both in terms of the availability of forces and the legal risks associated with an attack. In other words, US military doctrine recognizes it must be prepared to fight – if not in space, at least over space systems -- yet remains silent on how to do it. Commercial space systems add additional

constraints, issues, and concerns over and above military systems, the line between which is rapidly fading .

Notes

[1] Personal experience of the author.
[2] Hanbook Vol 1, p. 67.
[3] Major Robert D. Newberry, *Space Doctrine for the Twenty-First Century,* p. 1, Air University Press, October 1998.
[4] Spacey, p. 55-56.
[5] Newberry, p. 1.
[6] Major Steven R. Peterson, *Space Control and the Role of Antisatellite Weapons*, p. 14, Air University Press, Maxwell Air Force Base, Alabama, May 1991

Part 5

Conclusions

> *It's politically sensitive, but it's going to happen. Some people don't want to hear this, and it sure isn't in vogue … but – absolutely – we're going to fight **in** space. We're going to fight **from** space and we're going to fight **into** space.*
>
> — General Joseph W. Ashy
> *former commander in chief*
> *United States Space Command (emphasis in original)*

Commercial space systems are vulnerable to laser attack by virtue of their orbits and their construction. Lasers capable of inflicting damage on space systems exist and will most probably proliferate in the near future. Military doctrine is inadequate for the use of military space systems, and is silent on the subject of commercial space systems. Those are the facts.

"Words kill!" The Army is fond of that mantra with good reason; the difference between "seize" and "occupy" quite probably means life or death if you are the object of an assault. The difference between "aerospace" and "air and space" is also significant. The original intent in using the aerospace term was to initiate a cultural change: to better integrate the capabilities of space throughout the Air Force and the other services. The result however is the inability to distinguish between the two distinct mediums of air and space. The Air Force vision document *Global Engagement: A Vision for the 21st Century Air Force* had it right in saying we are an "air force transitioning to an air and space force." The remainder of that phrase, "on an evolutionary path to a space and air force," remains open to debate.[1]

The recommendations of the Air Force Scientific Advisory Board presented in section 2 are key components in the transition to recognizing commercial space systems for what they truly are: targets. The Air Force should move expeditiously to implement these recommendations, which essentially provide the knowledge necessary to act if required.

Knowing how to act, i.e. doctrine is not so simple. Without question, the first step we must take is the realization that air and space are not the same: forces do not operate the same and therefore cannot be employed the same. It takes a different frame of reference to employ, much less fully exploit, space forces to include commercial space systems than it does to employ air forces. Chief among these differences is the ability to apply military force at all; in the case of commercial systems, use of military force may be the least desirable of several alternatives assuming it is possible in the first place. The Air Force must take the lead in examining the "holes" in our current doctrine by understanding the vulnerabilities of our nation to attacks against commercial space systems. This in itself is sufficient material for another study.

Quite probably the single most effective action we could take is to eliminate, or at least significantly reduce, the possibility of an adversary successfully conducting a covert attack on our space systems, i.e. develop a means to recognize laser attacks when they occur. Incorporating such a capability into military doctrine on how the US would respond to such an attack would significantly shift the balance against a potential aggressor, perhaps mitigating the threat all together. Once the ability to act covertly is reduced or eliminated, attacks against commercial space systems becomes much less probable.

Notes

[1] United States Air Force, *Global Engagement: A Vision for the 21st Century Air Force*.

Appendix A

Registration of Objects Launched into Outer Space

Launching State	No. of Objects	Launching State	No. of Objects
Australia	4	Japan	55
Canada	10	Korea, Republic of	1
China	17	Mexico	2
Czech Republic	3	Russia (incl USSR)	1760
ESA	35	Spain	3
France	99	Sweden	4
Germany	9	Ukraine	1
India	20	United Kingdom	15
Italy	3	United States of America	1936

Grand Total: 3977

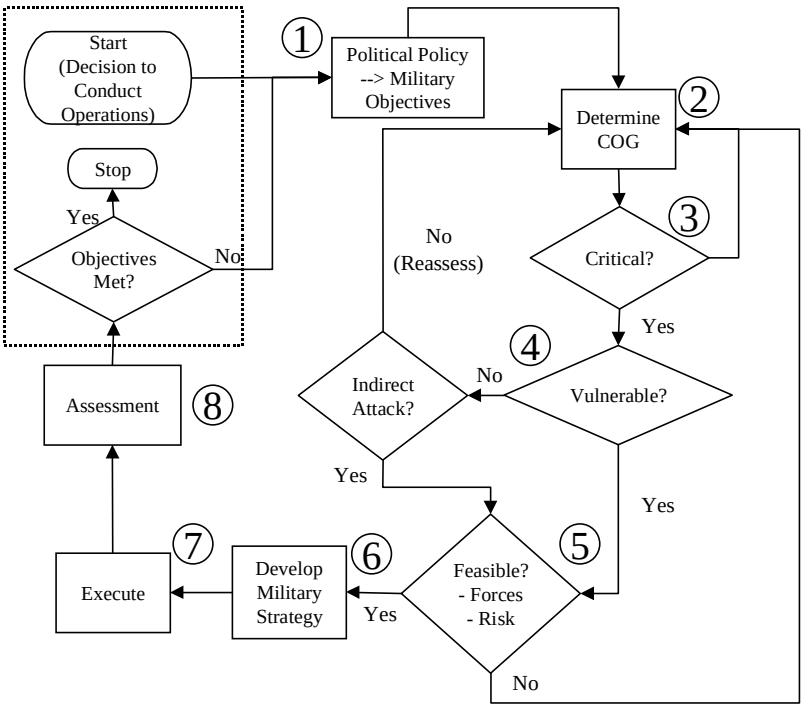
Source: United Nations Space Registration Convention, as of 25 Oct 99.[1]

Notes

[1] United Nations Registration of Objects Launched into Outer Space, available online at http://www.un.or.at/OOSA/treat/reg/reglst.html

Appendix B

Developing and Attacking a COG



1. Receive overall policy and military guidance from above.
2. Analyze the adversary for possible centers of gravity.
3. Determine if candidate COGs are Truly critical to the enemy strategy.
4. Determine if identified COG(s) or their linkages are vulnerable to direct attack. If not, examine for possible indirect attack.
5. Determine if the method of influencing the COG is feasible, considering such questions as number and quality of friendly forces, ROE, level of conflict, projected losses, etc.
6. Develop overall military strategy to support the military objectives. Among other factors, the strategy must consider objectives, threat, environment, mechanism, and Law of Armed Conflict.
7. Execute the strategy and attack or influence the COG as part of the military operation.
8. Assess the success of the attack and study the overall impact on adversary strategy (operational assessment). Assess adversary reaction to the attack and determine if follow-up attacks are required or if a new COG should be sought.

Steps identified within the dashed line are content added by the author.

Source: AFDD-2, Table 6-2, p. 80.

Appendix C

International Agreements that Limit Military Activities in Space

Agreement	*Principle/Constraint*
United Nations Charter (1947)	- Made applicable to space by the Outer Space Treaty - Prohibits states from threatening to use, or actually using, force against the territorial integrity or political independence of another state (Article 2(4)) - Recognizes a state's inherent right to act in individual or collective self-defense when attacked. Customary international law recognizes a broader right to self-defense, one that does not require a state to wait until it is actually attacked before responding. This right to act preemptively is known as the right of anticipatory self-defense (Article 51).
Limited Test Ban Treaty (1963)	- Bans nuclear weapons tests in the atmosphere, in outer space, and underwater. - States may not conduct nuclear weapon tests or other nuclear explosions (i.e. peaceful nuclear explosions) in outer space or assist or encourage other to conduct such tests or explosions (Article 1).
Outer Space Treaty (1967)	- Outer space, including the Moon and other celestial bodies, is free for use by all states (Article I). - Outer space and celestial bodies are not subject to national appropriation by claim of sovereignty, use, occupation, or other means (Article II). - Space activities shall be conducted in accordance with international law, including the UN Charter (Article III). - The Moon and other celestial bodies are to be used exclusively for peaceful purposes (Article IV). - Nuclear weapons and other weapons of mass destruction (such as chemical and biological weapons) may not be placed in orbit, installed on celestial bodies, or stationed in space in any other manner (Article IV). - A state may not conduct military maneuvers; establish military bases, fortifications, or installations; or test any type of weapon on celestial bodies. Use of military personnel for scientific research or other peaceful purpose is permitted (Article IV)

Agreement	*Principle/Constraint*
Outer Space Treaty (1967) (cont)	- States are responsible for governmental and private space activities, and must supervise and regulate private activities (Article IV). - States are internationally liable for damage to another state (and its citizens) caused by its space objects (including privately owned ones) (Article VII). - States retain jurisdiction and control over space objects while they are in space or on celestial bodies (Article VII). - States must conduct international consultations before proceeding with activities that would cause potentially harmful interference with activities of other parties (Article IX). - States must carry out their use and exploration of space in such a way as to avoid harmful contamination of outer space, the Moon, and other celestial bodies, as well as to avoid the introduction of extraterrestrial matter that could adversely affect the environment of the Earth (Article IX). - Station, installations, equipment, and space vehicles on the Moon and other celestial bodies are open to inspection by other countries on a basis of reciprocity (Article XII).
Antiballistic Missile (ABM) Treaty (1972)	- Between the US and USSR. - Prohibits development, testing, or deployment of space-based ABM systems or components (Article V). - Prohibits deployment of ABM systems or components except as authorized in the treaty (Article I). - Prohibits interference with the national technical means a party uses to verify compliance wit the treaty (Article XII).
Liability Convention (1972)	- A launching site is absolutely liable for damage by its space object to people or property on the Earth or in its atmosphere (Article II). - Liability for damage caused by a space object, to persons or property on board such a space object, is determined by fault (Article III).
Convention on Registration (1974)	- Requires a party to maintain a registry of objects it launches into Earth orbit or beyond (Article II). - Information of each registered object must be furnished to the UN as soon as practical, including basic orbital parameters and general function of the object (Article IV).
Environmental Modification Convention (1980)	- Prohibits military or other hostile use of environmental modification techniques as a means of destruction, damage, or injury to any other state if such use has widespread, long-lasting, or severe effects (Article I).

Source: Space Handbook Vol 1, Air University (AU-18), Table 1, pg 55-56.

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