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Analysis of Operational Factors Towards Achievement of Space Control

...Transforming the Familiar

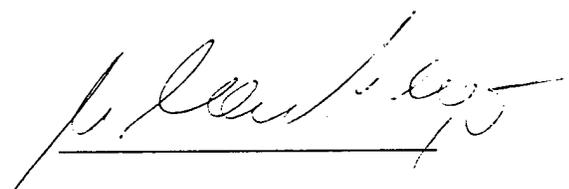
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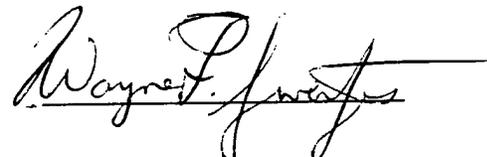
A paper submitted to the faculty of the Naval War College in partial satisfaction of the requirements of the Department of Joint Military Operations.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

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13 February 1998


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Table of Acronyms

AOR	Area of Responsibility
ASAT	Anti-Satellite Weapon
BMD	Ballistic Missile Defense
C2	Command and Control
C2W	Command and Control Warfare
CINC	Commander-in-Chief
DEW	Directed Energy Weapons
GEO	Geosynchronous Orbit
GPS	Global Positioning System
HEO	Highly Elliptical Orbit
HVA	High Value Asset
KKV	Kinetic Kill Vehicle
LEO	Low Earth Orbit
LOC	Lines of Communication
MEO	Medium Earth Orbit
NCA	National Command Authority
SBIRS	Space Based Infra-Red System
UFO	UHF Follow On

ABSTRACT

US military forces are directed to develop the capability and doctrine for Space control. To effectively employ forces in its achievement, the tasked operational commander will require an understanding of the operational factors space, time, and force. Analysis of these factors reveals the following:

The unique character of Space alters the concept of position, and therefore positional defense, complicating the Space denial mission. The nature of time in Space warfare may obviate the use of anti-satellite weapons for Space defense and protection against deployed weapons systems, requiring other approaches to the problem. The nature of current forces is unsuitable for the day when enemy forces are capable of Space denial actions, requiring a change of philosophy in force architecture.

For protection of our critical Space systems, territory and citizens, US forces must defeat enemy threats before they reach orbit. The operational commander must consider attacking control sites, Space system production facilities, and launch complexes along with orbiting Space forces.

Since satellite defense will be extremely difficult, no single Space system should be so critical as that its loss or denial would significantly degrade conduct of its mission area. Systems designers should continue to pursue current initiatives in low observables technology, and satellite constellations. Contemporary Space systems do not comply with this design philosophy, therefore the architecture must change to reflect the demands imposed by Space warfare. Access to orbit must be improved with spacelift systems capable of generating sortie rates comparable to today's tactical aircraft, rather than today's reusable launch vehicles. Additionally, improvement in the ability to maneuver satellites is required.

PREFACE

This paper was begun as a means of drawing parallels in Operational Art applications between current terrestrial and future Space warfare. Having done some prior study of current Space systems and capabilities, I was intrigued by the fact that the US currently advocates achievement of Space control and denial missions, but has no forces for their conduct. I wondered how future forces would be used to achieve Space control, and determined to use the principles of Operational Art to investigate the question. As it happens, this subject was a much more ambitious undertaking than intended. Intentionally limited to "only the operational factors," it attempts this analysis to determine general concepts for employment of generic weapons in future Space warfare. It intentionally avoids specific, quantifiable system capabilities in favor of broad weapons and systems types. Where examples were required for clarity, occasional reference was made to contemporary systems or specific weapons concepts. The more time spent thinking about the subject, the larger it appeared. I fear I have merely scratched the surface.

To avoid muddy thinking and unclear analysis of operational factors in Space, they have herein been analyzed in "cookbook" fashion as separate, unrelated entities. In the real world, the operational commander tasked with Space control will find them intricately inter-related as he attempts to deny, protect and strike from Space. To be of use, the individual points ascertained by analysis of separate factors had to be integrated. The "Conclusions and Recommendations" chapter provides examples of this integration, going beyond the "Combined Factors" to implications provided by the sum of the analysis.

The appendix, "Orbit" provides a skeletal background for the body of the paper. While not thorough enough to provide a full dissertation on orbitology, it provides enough information to support the analysis within the paper, and should be read first by those unfamiliar with general principles of orbit.

My thanks to Professor Milan Vego, whose patience must surely have been worn thin. Also to Captain Read Saunders, USN and Colonel William Gibbons, USMC; they never batted

an eye as the paper grew and evolved. Thanks also to CDR Wayne "Doc" Sweitzer, for his encouragement. And lastly, thanks to my wife, who thought we were on shore duty, and that she would be seeing me around the house.

INTRODUCTION

Although military Space¹ systems have existed since the dawn of the Space age in the late 1950's, the United States does not currently apply destructive military force from or against Space based systems. If military Space systems follow the model of military aircraft in the inter-war years, this will change. When an enemy attempts to destroy US Space systems, deny access to Space, or direct ballistic missiles through Space at our citizens or property, the National Command Authority (NCA) will direct its military to intervene. As the taboo against weapons in Space fades, offensive and defensive weapons will proliferate. This logic supports current US advocacy of Space control and denial mission areas for its Space forces.

To competently and efficiently plan the use of and employ Space forces, the operational level commander and his staff will examine the operational factors space, time, and force as part of the process. Their initial attempts to employ operational art in the development of plans may encounter unexpected snags. They will find that the nature of the medium tends to transform familiar terrestrial concepts, and that the forces they command are ill suited for combat.

This paper examines the operational factors space, time, and forces in the Space medium to shed light on this emerging area of warfare, expose these transformations, and recommend "course changes" where it appears that current philosophies will hamper the future ability to achieve Space control. It will be shown that the nature of the space transforms the concept of position, with implications for Space denial. The nature of time also provides challenges for Space defense, providing little warning upon which to react. The nature of current forces and Space combat will be shown to be incompatible. Recommendations will follow from these revelations.

FRAMEWORK FOR SPACE WAR

Operation Desert Storm is referred to, by some, as the first Space war.² Terrestrial forces (land, sea and air) capitalized on the capability of US communications, navigation, missile warning, meteorological and surveillance satellites to expel Iraqi forces from Kuwait. Command and Control (C2) between the theater of operations and the NCA was near instantaneous due to secure satellite communications. These systems also provided coordination between naval and ground force commanders to allow smooth integration and synchronization of efforts. Global Positioning System (GPS) allowed ground forces, unaccustomed to operations in the featureless Kuwaiti desert, to navigate with confidence previously unknown to forces operating in much more familiar terrain, enabling precise maneuver and concentration of forces. Space systems provided timely warning of ballistic missile attack to ground forces, coalition members, and neighboring states, providing the time required for preparation of protective and defensive measures. Meteorological satellite information has become so commonplace that forces take it for granted. Nevertheless, the decisive conduct of the air war in the early days of hostilities was dependent upon the weather information provided by weather satellites. Space surveillance of enemy force dispositions provided the information required to plan the famous "left hook," which so surprised Iraqi ground combat elements. Had Saddam Hussein had access to similar capabilities (or the ability to deny them to coalition forces) the outcome of the war may not have been quite so lopsided. It is unlikely that future US adversaries will simply accept the advantages enjoyed by US forces, but will attempt to deny them by developing the means to destroy or negate US Space systems.

The next Space war may be as different from Desert Storm as was the air war in W.W.II from W.W.I. Certainly current systems will continue to be improved and provided to the supported commander(s). Additionally, just as offensive and defensive air weapons proliferated in the inter-war years, new weapons and capabilities are sure to migrate to the

Space environment for use in future Space wars. These new systems will attempt to enable Space control, as required by Secretary Cohen's Annual Report to the President and Congress for 1997. Space systems will shift from non-hostile, purely supporting roles, to more actively combatant missions. The new systems will provide precision strike, Space denial, Space defense, Ballistic Missile Defense (BMD), Anti-Satellite (ASAT) capabilities, and Command and Control Warfare (C2W).

Space based precision strike weapons will provide terrestrial forces the ability to attack deeply buried targets, such as command and control facilities and bunkers.³ These weapons would provide a rapid response capability, without risking the lives of aircrews flying piloted bombers.

To prevent enemy forces from taking advantage of Space based capabilities, Space denial doctrine and weapons must be developed by terrestrial and Space forces. Terrestrial forces must be prepared to attack and destroy enemy Space launch and control facilities by all available means. Intelligence will be required to locate and identify launch and satellite control facilities and antennae, and classify critical Space systems and vehicles. The purpose of Space denial is to prevent future Saddam Husseins from employing Space based systems -- to deny him technological and informational parity with friendly forces.

Space defense aims to protect our deployed Space systems from enemy anti-satellite efforts. The means to achieve this comes from myriad forces and capabilities. Stealth technology and information denial may be used to prevent the enemy from locating and targeting orbiting systems. Satellite design may allow hardening against Directed Energy Weapons⁴ (DEW), or orbital operation beyond the range of enemy ASATs. Satellites may be designed such that they may detect and avoid attack by changing their orbital parameters. Ultimately, designers may integrate weapons and defensive systems on critical military communications, imagery or navigation satellites, providing a self-protection capability

against enemy ASAT systems. Alternately, defender satellites may "ride shotgun" on high value satellites to protect key Space systems. Space defense might also be enhanced by increasing the number of satellites deployed for each function. For instance, rather than deploy 10 UHF Follow On (UFO) communications satellites, with the capability of handling 39 channels,⁵ deploy 130 "nano-satellites" capable of handling 3. Enemy efforts to attack Space communications would likely exhaust their supply of ASATs, forcing them to search for other methods of attack or entirely different target sets.

In conjunction with today's Space Based Infra-Red System (SBIRS) ballistic missile warning capability, BMD systems will be developed, possibly deployed to Space. This capability will provide protection of terrestrial targets, including US citizens and territory, deployed forces, or allies. Space basing of such systems will provide the most rapid response to ballistic missile launch. Using directed energy weapons, like a Space based laser, Space forces might destroy enemy missiles still in the atmosphere, greatly deterring their use for delivery of weapons of mass destruction. Surface based systems would be used as a layered, last ditch defense against incoming missiles that evaded Space based defenses (like Patriot missile in Desert Storm).

Anti-satellite warfare would provide both offensive and defensive capabilities in Space. To enable surprise for ground operations, Space forces must be capable of neutralizing or destroying deployed enemy surveillance systems. Intelligence organizations must be able to identify and track such critical enemy Space systems to allow targeting by ground and Space based weapons. The commander might employ ASAT satellites to destroy or disable enemy systems, using kinetic or directed energy weapons. Manned or robotic Space vehicles may be used to physically remove enemy systems from orbit, or to mechanically alter or disable enemy satellites, rendering them ineffective.

Finally, the ability to interfere with, intrude upon or deny the use of enemy Space based command and control systems will provide US commanders improved command and control warfare (C2W) capabilities. This might entail placing electronic attack packages in orbit to block critical communications, intercept and decipher communications, or disable critical command links. As the capability to intrude upon and exploit enemy C2 and information systems increases, the ability to gain control over enemy satellites might become a reality. Rather than destroying enemy Space surveillance systems, they might be selectively deactivated, blinded, blocked, jammed, or made to "malfunction" during critical phases of the ground battle, allowing the enemy to see only that which we intend.⁶

The above vision of the next Space war is a simple extrapolation of current initiatives. Through further technological developments or program cancellations, it may or may not bear resemblance to the actual future of Space warfare. Regardless, the operational level commander tasked with Space control will command some combination of current and future Space force capabilities. In concert with and support of other operational commanders, the NCA will task him to achieve Space control. He may function as the Space component commander in a joint task force, or as the regional Commander-in-Chief (CINC) for the "Space Area Of Responsibility." (AOR)⁷ His efforts may be in support of terrestrial operations; the purpose of defense and denial of Space to the enemy might simply enable the provision of surveillance, communications, and navigation (current capabilities) to ground forces in achievement of operational objectives. Alternatively, if determined that a ballistic missile system was the enemy force's operational center of gravity, precision strike, Space denial and Ballistic Missile Defense (BMD) might be the main effort in the conflict. Under these circumstances, terrestrial force commanders might support the Space force commander in Space denial, through operations to destroy enemy Space control facilities. In both cases, analysis of the operational factors will help determine the required actions.

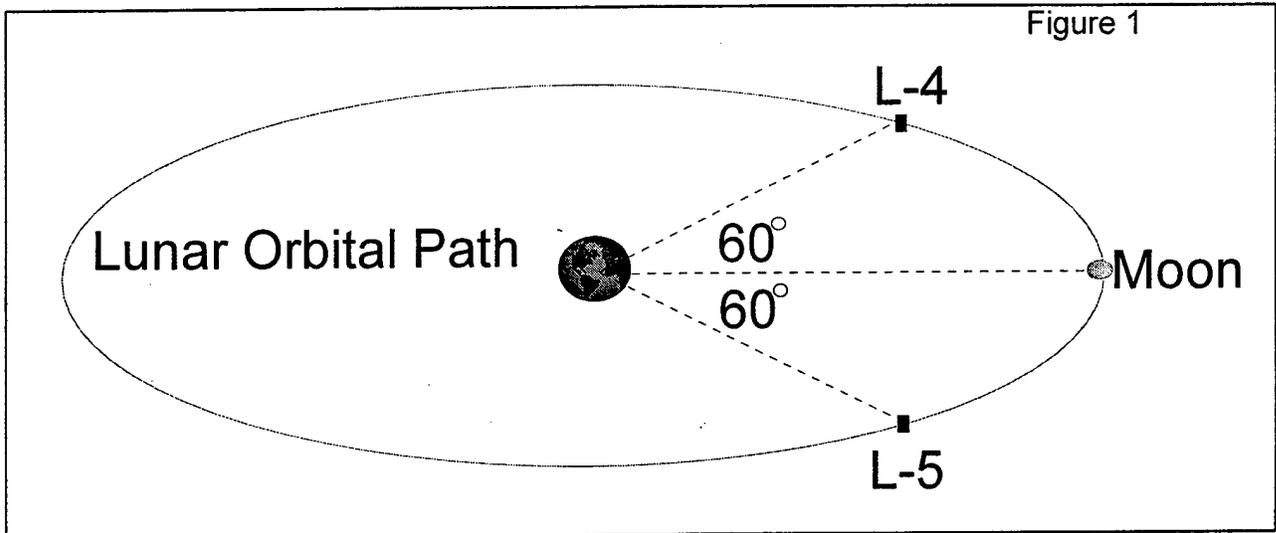
THE FACTOR SPACE

Physical Characteristics: The most fundamental questions about the factor space are: where is Space, and what are its boundaries? These sound simple enough, but oddly, experts in various fields disagree upon the defined boundaries of Space. Opinions of engineers concerned with life support systems differ from those concerned with propulsion systems. Politicians would disagree with both. The US Naval Space Command considers Space to begin at the lowest sustainable orbital altitude (approximately 90 miles).⁸ This paper will accept and use that definition. What is undisputed is the vast size of Space -- even the portion where Earth's gravity sustains orbit. Control of Space is an ambitious prospect, beyond the scale of anything yet contemplated in warfare.

Topography and Climate: While hardly intuitive, there exist "terrain features" in Space. The medium of Space defines the "landscape," which looks and behaves differently than its terrestrial cousin. Nevertheless the considerations applied by an operational commander to a terrestrial theater still apply in Space. To be effective, he must first understand the analogies between them.

The interaction between the Earth's and Moon's gravitational fields produces one of the features. There exist two stable points in the Earth-Moon system known as Lagrangian points L-4 and L-5.⁹ These positions, 60° ahead of and behind the moon's position along the lunar orbital path, are analogous to gravitational "hilltops." (Figure 1) In this context, "stable" means that objects at these positions will remain there until disturbed by an external force. Once disturbed (launched), the object would be gravity assisted towards either the Earth or Moon, while gravity would hinder an object attempting to take either position. Gravitationally speaking, the holder of positions L-4 and L-5 controls the Earth-Moon system.¹⁰ The operational commander might attempt to take advantage of the terrain by deploying kinetic ASAT weapons to these hilltops.

Lagrangian Points



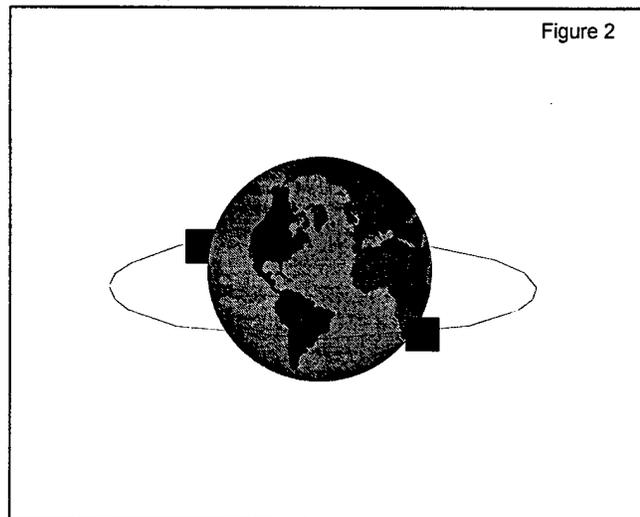
The Space “climate” has features unlike terrestrial media. It is effectively devoid of atmospheric pressure, and exhibits extremely low temperatures, making for a harsh and demanding environment. Lacking an atmosphere, there is no real weather or resistance to motion. Solar and cosmic radiation is the environmental factor that replaces weather in Space. Highly Elliptical Orbit (HEO) and Geosynchronous Orbit (GEO) systems must operate in fields of radiational disturbance known as the Van Allen belts, where high doses of radiation may interfere with systems’ operation, or accelerate their natural degradation. These radiational disturbances increase with solar flare activity on a cyclic basis, and can significantly affect Space systems’ performance.¹¹ Like traditional weather, the operational commander might plan to exploit these cycles to obscure or conceal his actions against systems susceptible to radiational interference. An example might be using a directed energy ASAT weapon to damage an enemy communications satellite during a radiational flare-up, giving the appearance of natural system degradation vice hostile action.

Shape: Space's shape and makeup are unique from a warfighter's perspective. First, Space, like air, overlies all nations and points on the planet. It borders the upper limit of the atmosphere, and has no outer limit, although its nature changes beyond Earth's gravitational influence. While it is possible to identify positions in Space, it is more useful to identify orbits, since the vast majority of positions in Space are not stable. Thus, **orbits are the equivalent of terrestrial positions**, but are unique in nature. In traditional positional defense, occupation of a position confers control over it (provided the occupying force has the strength to defend it), but Space effectively changes that. Many objects may occupy the same orbit, gaining all advantages conferred by the **locus of**

terrestrial points overflow and its relation to other orbits, without denying the position to the other force. (Figure 2) Geosynchronous and geostationary orbits are exceptional in this regard. While two objects can occupy the same GEO orbit, they would gain different advantages, based upon their synchronous terrestrial point.

Effectively, each point within a GEO orbit is a distinct "position," as are the Lagrangian points L-4 and L-5. (See Appendix A for more information on orbitology.)

2 Objects occupying the same Orbit (position)



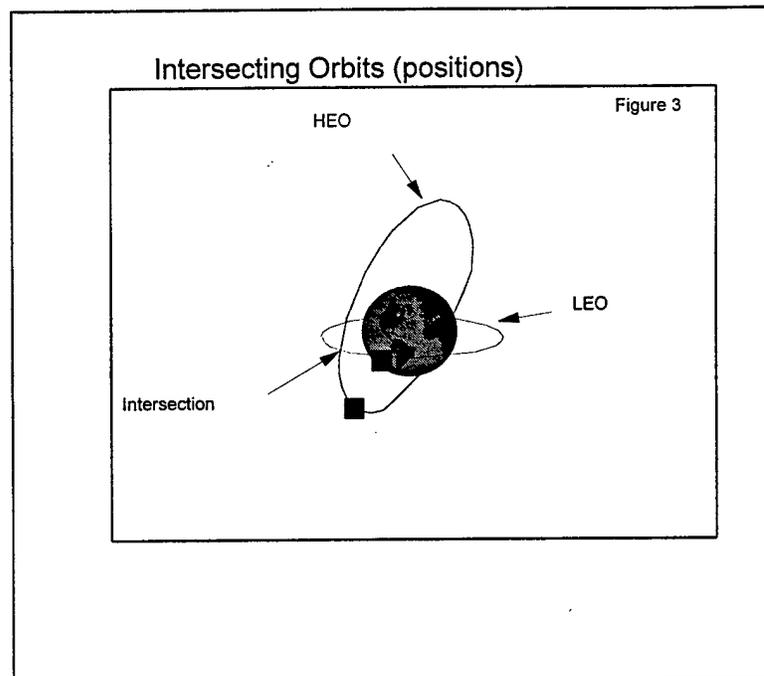
The Earth's surface contributes to the "shape" of Space. It is our point of origin for traversing Space. For Space combat operations, the surface is analogous to the "rear" areas of ground combat. Distance in Space takes on new dimensions. Distance between the surface (rear) and a given orbit's (position's) insertion point is related to the length of

terrestrial Lines of Communication (LOC). The higher the orbit, the longer the LOC, and the greater the risk of interdiction prior to achieving orbit.

Additionally, distance between points in different orbits is significant. A single point in Space may lie at the intersection of both a Low Earth Orbit (LEO) and HEO, while other points in those two orbits may be separated by hundreds of kilometers. Thus it is conceivable that two objects may not be able to

occupy two **different** positions (orbits) at the same time without coming into conflict. (Figure 3) In other words, occupation of one orbit (position) may at times deny another orbit to the enemy.

While altitude and eccentricity determine the length of one complete orbit, measuring the distance between points overflown in an



orbit is not as straightforward a task. The **ground distance** between points that a satellite will overfly can be dramatically different from the **distance the satellite must travel to overfly each**. This is because, in inclined orbits a satellite's ground track may overfly different surface points on consecutive orbits, due to the Earth's rotation. For example: the distance from New York to Los Angeles is approximately 3000 miles. A satellite traveling 30,000 mph in one orbit might overfly both in a 6 minute period. A satellite in a polar orbit might require three or four 30 minute orbits after passing New York before overflying L.A. Thus the effective distance between NY and L.A., as far as the second satellite is concerned is **not**

3,000 miles, but 90,000 - 120,000 miles, requiring 90 minutes to 2 hours. (The factor space and time are closely related.)

The distance and relation between orbiting objects is dynamic, thus, combat between orbiting systems (ASAT, Space surveillance, Electronic Attack) will be complicated by the ever changing spatial relationship between them.

Dynamics: The dynamics of the factor space are peculiar because of the nature of Space orbits. Given that two objects may occupy the same orbit, the mere act of occupying an orbit does nothing to exclude an enemy

from it, as in terrestrial warfare.

Thus “gaining space” is not a zero sum game, as in terrestrial warfare.

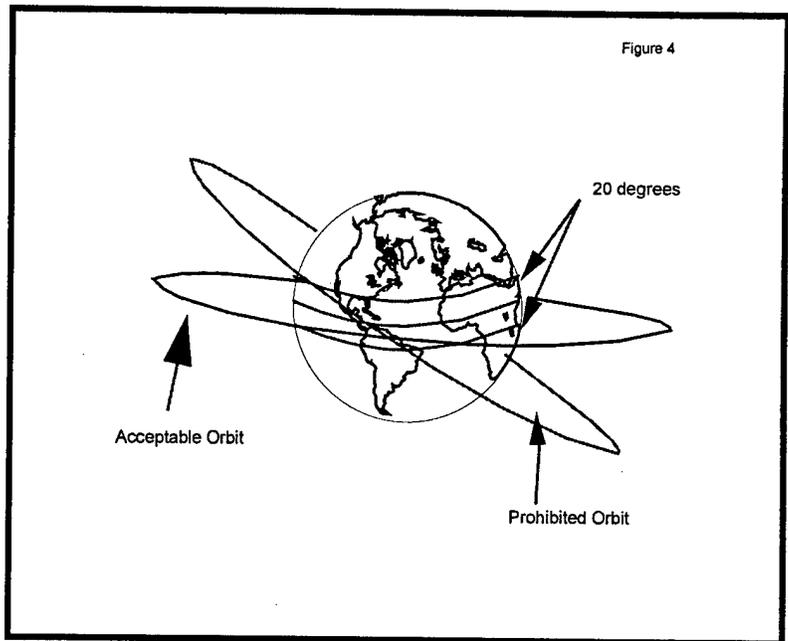
Loss of space can only occur through direct denial actions or natural phenomena which degrade or destroy the systems occupying the space.¹² Space control may

require the **blockade** of a nation’s Space LOCs; effect a total cessation of Space launches to restrict and

deny space to the enemy. If the operational commander requires control over only specific, higher latitude positions, he may choose to establish an **orbital exclusion zone**.

He would establish these zones based on their relation to the disputed surface positions. Imagine this scenario: Country “A” lies above 25° latitude, and is at war with country “B,” which lies on the equator. Inclined orbits could overlies both nations, while equatorial orbits would overlies country “B” only. Since forces (such as precision strike satellites) in both inclined and equatorial orbits would threaten country “B,” it would need to blockade country “A” to

Orbital Exclusion Zone



achieve Space control. Country "A" could simply establish an orbital exclusion zone (all orbits inclined greater than 20° , for instance) to achieve the same objective. (Figure 4) Orbits that overlie only one of the belligerents in a conflict will confer offensive advantage to its enemy, and defensive significance but no corresponding offensive advantage to that belligerent through their denial.¹³ It will be critical for a commander to understand the offensive or defensive relationship of orbits to terrestrial positions so that he may take appropriate and efficient action for Space denial.

Analysis of the factor space reveals that Space control efforts will be tremendously affected by the nature of selected orbits, the dynamic spatial relationship between friendly and enemy orbital systems, and the relationship of each orbit to subjacent surface points. While familiar concepts such as Lines of Communications and blockades may exist, the peculiar nature of position and distance transforms them. Selection of orbits is a matter of utmost importance. Reliance on traditional positional defense concepts may misguide the commander in that selection.

The Factor Time

Inevitably, thought about Space conjures images of "warp drive," creating the impression that a commander would derive great flexibility from instantaneous access to deployed Space systems and capabilities. On the contrary, the nature of Space imposes rigid time constraints upon the commander, who must adjust his plans accordingly. The nature of the factor space, discussed above, affects the nature of the factor time. The speed required of orbiting Space systems can make interaction between them occur rapidly, allowing short opportunity windows for action.

Warning and Reaction Time: In defensive missions, the factor time favors the enemy. For instance, BMD systems must be ever vigilant, and capable of instantaneous response to intercept and destroy ballistic missile attacks, which can span the globe in 30 minutes, and a given theater in considerably less. (Theater ballistic missiles may impact their targets within a few minutes of launch.) Unfortunately, the enemy can deny effective launch warning by use of underground missile silos, therefore warning time may be zero, even with the enemy silo under direct surveillance. Mobile launchers make surveillance more difficult, complicating the problem further. Extremely short reaction time is available for Space control efforts against terrestrial based Space weapons (ballistic missiles, or ASAT). Space based weapons (ASAT or strike) would further reduce the defender's warning and reaction time. The worst case for reaction time comes from terrestrial or Space based Directed Energy Weapons (DEW), reducing weapon transit time to fractions of seconds. Even Space based defensive systems would be at like disadvantage. Such is the nature of defensive warfare -- the initiative lies with the enemy, requiring constant vigilance and rapid reaction. This is particularly true during "peace time," where indications and warning may be ambiguous, and hostilities may not be anticipated.

Protecting satellites against deployed Space ASATs further complicates the problem. Since the threat sector is so large and dynamic, detection takes more time, further limiting

available reaction time. **Such rapid detection and response may prove to be impossible.** Other aspects of time may provide the solutions to these problems.

Time for deployment: Time for deployment of Space forces is currently a very limiting factor, and is due to the lengthy development cycle for Space assets. The Space Shuttle (for instance) requires a three month turn-around. Single use boosters do not have recycle time problems. However, payload mating and on-launch-pad test and preparation typically take two months or more. Development of new Space systems is an even lengthier process. The International Space Station began life as a US only project in 1982. The first components will launch in 1998.¹⁴ Production of *Endeavor*, the sixth Space Shuttle orbiter to be produced, took just under five years.¹⁵ This problem currently plagues all Space faring nations and industries. This may provide the solution to the warning and reaction time problem discussed above. Rather than attempt to defend against deployed threats, the operational commander may require the authority to attack Space systems being developed or in their deployment and preparation cycle.

The time required to develop and deploy Space systems is problematic for friendly Space control efforts. Under the current architecture, decisions to initiate deployments of forces would take months to execute. In terms of Col. John Boyd's "OODA Loop" (observe, orient, decide, act, observe...) the "Act" phase of the commander's **decision cycle** is grotesquely out of proportion to the nature of warfare. The rapidly accelerating decision capability provided by today's information systems exacerbates the disparity between phase lengths. Lacking the ability to rapidly develop and deploy systems (act), the commander's decision cycle may stall after the orientation phase, thus ceding the initiative to the enemy.

Time for Maneuver and Counter-maneuver: The purpose of maneuver is to achieve a **position** from which the enemy center of gravity, critical capabilities, or vital objectives may be attacked.¹⁶ In Space control, where position and orbit are so closely related, maneuver is transformed into the achievement of advantageous orbit, or the use of movement and mobility to achieve that orbit in pursuit of operational objectives. The time

required for maneuver depends upon the type of orbits required, the amount of fuel available to effect the maneuver, and the number of systems involved. The higher the altitude, inclination, or eccentricity of the orbits, the more time required after launch. Time for transfer from one orbit to another depends on the difference in inclination, altitude and eccentricity of the orbits -- the greater the differences, the longer the time. Maneuver may be inherent to the deployment of systems, or given the ability of satellites to conduct orbital transfer (change orbits), may occur immediately prior to operations from the new orbit. The continuous movement of orbiting systems may mask the actual maneuver of Space systems. Since many insignificant points may be overflown during the orbit, the objective of the maneuver may be difficult to distinguish by mere observation. Tradeoffs between waiting for deployment from the surface, and expenditure of critical on-orbit fuel reserves may be required, depending on the criticality of systems involved or threatened.

Counter-maneuver, intended to counteract the maneuver of enemy forces, can take place both by orbiting and terrestrial forces. The objective of the initial maneuver will determine the appropriate types of counter-maneuvers, and therefore the time required. Two examples follow:

1. Side "A" conducts orbital transfer of a missile warning satellite, to better monitor a suspected ballistic missile launch site. Side "B," aware of the maneuver, relocates the weapons or launchers. The mobility of the terrestrial force determines the time requirement.

2. Side "A" launches an electronic attack satellite to an orbit synchronous with side "B's" critical communications satellite. Side "B" must affect an orbital transfer, to an orbit compatible with its mission, and out of the electronic attack satellite's field of regard. The combined capability of the opposing forces determines the time requirement.

In both cases the time required for maneuver and counter-maneuver is situational. Advantage accrues to the side that uses the most rapid and efficient means of counter-maneuver available.¹⁷

Time for concentration and counter-concentration: The dynamic nature of different orbital paths makes concentration of force difficult to achieve. In Space, concentration of forces does not merely entail deployment of forces to a forward area in preparation for operations. Concentration of forces in perpetual motion requires synchronization and alignment of their fields of regard. Since orbits are cyclic, concentration of force from different systems will occur on a fixed and cyclic schedule. By mixing orbits, concentration can take place more or less frequently. For instance, concentration of a GEO system with a LEO system will occur as frequently as every 30 minutes, for a brief duration (every time the LEO system passes below the GEO system). Other orbits will interact differently. Systems may be placed in complementary orbits, such that they are continuously concentrated (e.g., satellite clusters). The concentration schedule will remain fixed, until further deployment, maneuver or attrition occurs. Concentration of terrestrial with Space forces can occur, but will be restricted by the schedule of the Space system, and the time required for terrestrial force concentration.

The factor time restricts the operational commander's flexibility. Time factors will prevent effective defense against deployed (orbiting) threats, and even terrestrial based threats will present challenges as DEWs proliferate. The length of the deployment cycle presents vulnerabilities which the operational commander should attack if possible. The counter-offensive is vastly preferable to the defense. For maneuver and counter-maneuver between Space and terrestrial forces, terrestrial forces may hold the time advantage due to inefficiency of deployed Space systems. The cyclic nature of orbit will determine opportunities for force concentration.

THE FACTOR FORCE

The factor force is said to be “**the most critical** for accomplishing any military objective.”¹⁸ (Emphasis added) If this statement is true, U.S. policy makers should feel distinctly uneasy about the prospects for achieving Space control. Contemporary forces do not have the capability to project destructive power, and reflect the idea of peaceful Space, rather than the combative one envisioned in the future.

Type and Mix of Forces: Designers created current U.S. Space systems, civilian and military alike, within a paradigm where Space control did not exist.¹⁹ This is readily apparent when examining the nature of current Space systems. The majority of spacelift systems are expensive, single use boosters, requiring extensive modification for individual payloads, and lengthy preparation and on-launch-pad-test timelines. This has driven satellites to be large, complex, extremely expensive and irreplaceable, since designers attempt to maximize the benefits of their limited launch opportunities.²⁰ In essence, every satellite is a high value asset (HVA). Combat loss of any single satellite would have significant repercussions.²¹ The cost and lengthy development timelines of these systems discourage the government from stocking a reserve capability, exacerbating the effects of combat loss.

This structure is acceptable under the assumption that exclusively peaceful use of Space will continue. With Space control a stated goal of U.S. military policy, a concomitant paradigm shift is necessary to provide the commander with the forces suitable for Space combat. Both the tangible and intangible elements of Space forces must be examined and reshaped.

Since the U.S. has yet to deploy Space “shooter” systems, it is elementary that the contemporary architecture is heavily sensor oriented. The current force derives combat power from information production rather than destructive capability. As Space control efforts gain importance in response to the emerging threat, this will have to change. More disturbing than the type and mix of forces is the inability to reconstitute many critical systems, or to redeploy any

strategic force reserve. Each satellite system currently deployed requires individual control, providing an inflexible, controller intensive force.²²

Force Size: The size of the current Space force is large in the sense that it would be difficult to protect, and is spread over a large area. Yet each element (communications, weather, navigation, imagery, etc.) of the force is composed of a small number of highly capable assets. The Navy's new UHF Follow On (UFO) communications system will consist of only ten satellites, and the Space Based Infra-Red System (SBIRS) early warning system, only six.²³ Failure or destruction of any of these few satellites would severely degrade the mission capability provided by their systems -- a significant vulnerability. Under the current philosophy, for instance, an imagery satellite will be designed to last many years. It will provide the highest resolution achievable, given the size limitations of the booster that will place it in orbit. This creates very expensive satellites, and results in very few being produced.²⁴ Thus, the size of the current force has much to do with the high quality of the elements.

Better suited to Space combat would be large constellations of small, inexpensive satellites with the **aggregate** capability of today's most valuable satellites. Dispersal of capability throughout linked constellations of tiny, cheap satellites will enable more rapid deployment, easier reconstitution, reduced vulnerability, greater flexibility and orbital variety, and more timely response.²⁵ Some would argue against this approach, since protecting an even greater number of satellites would make Space control more elusive. However, given the relative insignificance of individual satellites to overall force structure under such a concept, **protection of individual assets becomes less important.** Loss of any individual satellite would be less consequential, and replacement would be less expensive and take less time. A reserve of such satellites would not impose a significant financial burden. A stocked reserve would mitigate the consequences of failure or combat loss, provided that it could be

rapidly deployed as the need arose. The operational commander will require cost effective Spacelift systems capable of such rapid response.²⁶

Public Support, and the Will to Fight: Space is, by treaty, neutral territory, to be used in peace for the good of all mankind.²⁷ This view is deep rooted in the American psyche, creating a problem for development of the weapons required for Space control. Because the “will to fight” relies upon the warfighter’s belief in the ethical nature of his actions, the pervasive view of the “sanctity of Space” will be counterproductive to warfighter morale during a Space war. Public support for Space control efforts will suffer from the ethical question as well, at least until an enemy attack demonstrates the necessity of Space weapons.

Training and Education: Training of the vast majority of military personnel in Space systems and capabilities is practically non-existent. Ambiguity between the reality of deployed military systems to Space, and international law inhibits doctrinal and technological development, and the cooperation of allies in fielding Space control forces. So controversial is the idea of weaponized Space, that there is reluctance by USCINCSpace to even discuss weapons concepts.²⁸ Clearly, change is required to prepare more military personnel to consider the conduct of Space control. The opinion of the public, upon whose support the government depends, must also be shaped by education to the possible threats to our Space forces and capabilities.

The tangible and intangible elements of force are ill suited to the stated mission. Within the current paradigm, the operational commander faces many obstacles. Doctrine and forces for Space control must develop in parallel. Doctrine must recognize and compensate for current limitations while providing conceptual guidance for force improvements. As the force mix becomes more balanced between sensor and shooter systems, the vulnerability of deployed systems will decrease. Likewise, as lift capability and operational tempo increase,

cost will decline. As a result, the requirement for extremely complex satellites will decrease, further reducing U.S. vulnerability to attack.

Space control forces and systems must provide the commander real-time access to Space to exploit enemy vulnerabilities or the successes of his own prior actions. Examples of required capabilities are: maneuver or counter-maneuver of Space assets to more advantageous orbits; deploying reserve systems; using Space forces to reinforce operational deception schemes²⁹; or destroying an enemy Space asset that has become vulnerable for a discernible period.

Designed for a peaceful environment, today's Space force will prove unwieldy in combat. Destruction of individual satellites will significantly degrade overall capability. Lacking a reserve, reconstitution will happen too slowly to be effective. Public support and warfighter morale will suffer from ethical dilemmas. The commander's flexibility in employment of forces will suffer from lack of access to Space and lack of maneuver capability. These are all consequences of the underlying philosophy of the sanctity of the Space environment. Education of warfighters and public threat awareness are required to allow doctrinal and force evolution concomitant with achievement of Space control.

THE FACTOR SPACE - TIME - FORCE

Now that the factors have been examined in isolation, they must be combined. The interaction of the factors produces significant effects.

The operational commander tasked with Space control will have a tremendous amount of space relative to the allotted forces for controlling it. Space defense satellites will defend against terrestrial and Space based threats, further increasing the disparity of scale between the number of weapons and their area of regard. The same may be true for a Space Based Laser, with an ASAT as well as strike role. Thus the force to space ratio in Space control will be characteristically low. Even with a shift in philosophy from large, high value satellites to networked constellations of tiny, inexpensive ones, the force - space ratio will remain low due to the vastness of the area.³⁰

While certain orbits may lend themselves to particular force applications, (LEO for imagery, GEO for communications, etc.) there may be other considerations of the factor space that will dictate compromise. The boundary between the atmospheric realm and Space is undefined and indefinite. Atmospheric drag may affect satellites below 300 nautical miles, leading to orbital decay, thus restricting the use of the lower orbits for long life-span satellites.³¹ The nature of satellites optimized for GEO orbits may be incompatible with radiational interference, requiring design modification or sub-optimal deployment.

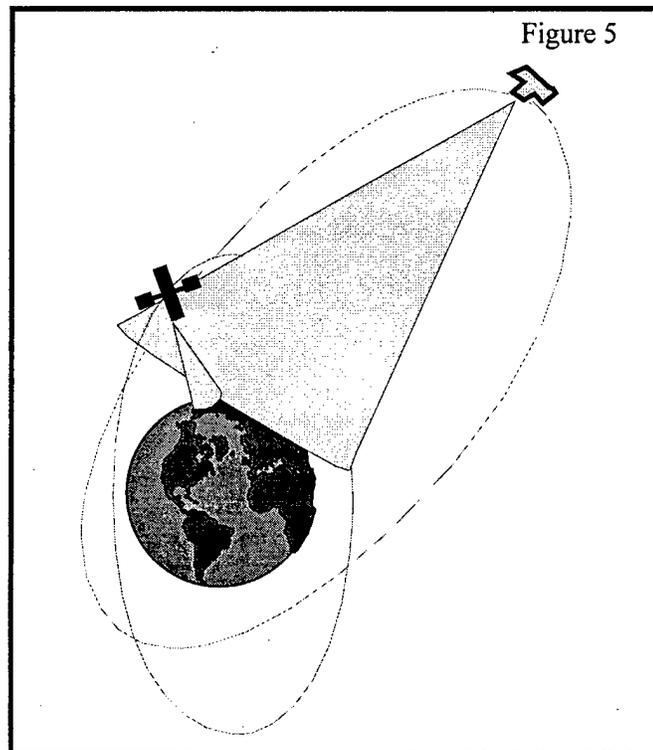
In conflict between satellites, orbital selection will again be critical. While system design will dictate the flexibility of deploying "shooter" satellites, certain aspects of this area will be fundamental. Kinetic Kill Vehicle (KKV) weapons satellites should be deployed to high altitude orbits to take full advantage of gravity.³² These high orbits are also defensively advantageous against enemy kinetic ASAT systems, providing greater reaction time against weapons launches. Since directed energy weapons are unaffected by gravity, the offensive

advantage of high altitude is not applicable, while the defensive advantages still apply. Against an enemy using DEWs, the defensive advantage of high altitude is also lost.

To provide the greatest effect from the fewest satellites, correct selection of orbit is imperative. This is applicable in both Space-to-Space, and Space-to-ground applications. Satellites placed in high altitude orbits may be capable of simultaneous terrestrial and Space surveillance. A lower orbit reduces the number of orbits within the sensor field of view during terrestrial surveillance.

(Figure 5) For strictly Space-to-Space surveillance, low altitude is preferable, providing an uncluttered background for search. Each type of orbit will have inherent advantages and disadvantages, which must be weighed in regard to the satellite function and threat. Threat related considerations must be secondary to functionality considerations (safety of the satellite is irrelevant if the satellite cannot perform its mission), but

LEO vs HEO Satellites



both must be taken into consideration. Low altitude orbits are vulnerable to surface launched ASAT attacks, but provide a good position from which to monitor or attack higher altitude satellites.³³ High altitude orbits provide lesser probability of detection from the surface, in addition to the advantages listed above. Transiting low, medium and geosynchronous orbital altitudes, a Highly Elliptical Orbit is an efficient and flexible option for deployment of a "shooter" satellite. (Figure 6)

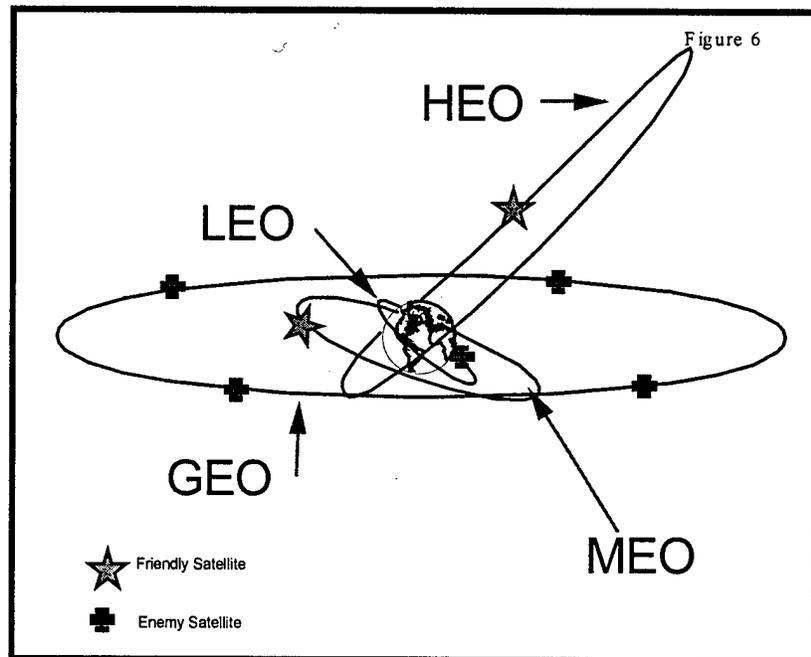
Force Deployment: Practical or political reasons may constrain access to orbital Space. Lacking Space based orbital transfer capability, fixed launch sites provide unequal access to different orbits.³⁴ It takes longer and requires more fuel or larger boosters to occupy certain orbits (positions) based upon a given launch site location or payload weight. The same practical limitations apply to an enemy force (while not necessarily the political constraints). Careful study of orbital significance, lift capacity and payload type may reveal enemy strategy. The commander could employ his forces efficiently to deny access to only those specific orbits

advantageous to the enemy, or detrimental to friendly strategy. Constrained by force size, this analysis may help the commander to restrict enemy operations within the battlespace, and achieve Space control. Use of flexible launch systems and concepts such as “Sea Launch”³⁵ and

“Black Horse TAV,”³⁶ may mitigate the limitations caused by launch site position, offering flexible, omnidirectional launch from mobile positions. Such systems would be critical to a Space force's ability to achieve mobility and flexibility, but would therefore be a primary target for enemy Space denial efforts.

Lines of communication from the surface to Space are quite restrictive. Fixed launch sites will predominate among launch facilities for many years to come. U.S. Space launch

HEO system transits LEO and GEO



facilities are located in Cape Canaveral, Florida and Vandenberg AFB in California.³⁷ Russia has only two primary sites and China three.³⁸ A Space based system tasked with monitoring Space systems launch could cover the LOCs relatively easily. Thus interdiction of these from Space also becomes relatively simple, given the tools, since detection assets can focus on a limited threat sector. Space LOC interdiction could be conducted by Space, air or ground forces.

As previously discussed, deployment of forces to Space is complex and expensive. These factors combine to slow the tempo of deployment to space, which means that force -- time is relatively static. Changing the capability of forces will alter this static nature. Real-time access to the theater, and capability for maneuver within the theater are the critical enablers. The US must develop and provide the commander forces which provide these capabilities. With these issues solved, the commander's concept of time becomes less restricted.

Culmination: Due to their nature, Space forces are susceptible to culmination over time. Clausewitz defined the culminating point as "the point where the remaining strength is just enough to maintain a defense, and wait for peace."³⁹ Defined in the Space context, it is the point when the overall force application capability has been depleted by maneuver, counter-maneuver, and weapons expenditure. After this point, resistance to the enemy denial effort is not possible, and Space systems may be unable to support operations. Regardless of the level of investment in lift and orbital maneuver capability, an effective surface based ASAT capability, combined with attack against control facilities will enable a commander to force culmination of the enemy Space control effort. Even with improved access, the remoteness of the Space theater will cause its operational cycle length to greatly exceed that of terrestrial forces. The more robust a Space force structure is, the more time it will take to maintain and sustain it, (refueling and re-arming of weapons satellites, repositioning, re-deployment, etc.). By high tempo attack from the ground, it would be possible to overtax the

enemy. Forcing combat satellites to exhaust their fuel supply before re-supply is available would culminate Space control efforts. Terrestrial forces dependent upon Space systems support would become less effective, and perhaps vulnerable through this effort. For this reason, offensive action by terrestrial forces against enemy Space systems should be foremost in the mind of the commander.

The operational commander may base orbital selection decisions on the relationship between space and time. The altitude of an orbit affects both its circumferential distance, and the speed required to sustain the orbit. Higher altitude orbits cover longer paths at slower speeds. In LEO, a satellite will circumnavigate the Earth many times per day; in HEO, perhaps twice; in GEO, exactly once per day. Once positioned in Space, satellites will move relative to the Earth and every other satellite on a repetitive, predictable and cyclic basis until maneuvered. Effective monitoring of Space will allow the commander to accurately predict opportune times for action, based on the orbital placement of targets, weapons, and systems.

The nature of orbital Space is such that it legally and effectively offers direct access to the enemy's depth. Thus, it is a direct extension of the terrestrial space in which the enemy will operate -- indeed a portion of his depth. Depending on the technological competence of the enemy, he may or may not have access to this critical portion of his space. A competent Space-faring nation will have access to everyone's. Effective Space control will seal off the theater from enemy forces, similar to a maritime blockade (albeit with a military, vice economic objective). Thus the operational depth of the belligerents seamlessly adjoins and is accessible from Space. Although directly superjacent to the surface, the Space overlying a nation is not analogous to the waters immediately off its coast. It is no easier to occupy the space overhead than its orbital locus around the globe (the entire orbit is one "position"). Thus, the orbital space overhead the enemy's LOCs (launch sites) is operationally indistinguishable from that overhead friendly LOCs within a given orbit. Yielding access to an operationally significant orbit confers immediate consequences. The commander cannot

permit enemy Space forces to deploy from their depth. **Consequently, trading space for time is not efficacious in Space control.**

CONCLUSIONS AND RECOMMENDATIONS

It is difficult and time consuming to determine all relevant factors for a warfare scenario of the future. Examination of the operational factors in isolation, followed by fusion of the analysis is a good starting point for determination of general concepts and principles for employment of future forces.

From the factor space, orbital selection emerges as one of the key concerns for employment of Space systems. Closely related to terrestrial positions, selected orbits are crucial to achievement of Space control. Satellite functional concerns must be balanced with offensive and defensive characteristics of the selected orbit, and the enemy's capabilities. Position is a concept transformed by the medium. Distance calculations are difficult due to the dynamic nature of Space. Some of the critical distances involved, such as that between deployed satellites, are constantly changing. The dynamic nature of Space operates on a cyclic time schedule. The spatial relationship between orbiting forces will be repetitive until deployment, attrition, or maneuver occur.

Defense of Space systems will be difficult or impossible upon proliferation of Directed Energy Weapons, due to inadequate warning and reaction time. Lengthy deployment and development timelines will provide the opportunity needed by the commander for preemptive Space protection, and denial. Greatly restrictive to friendly Space control efforts, these timelines must be overcome by development of forces under new philosophies. Today's Space forces are vulnerable in a combat environment, due to their inability to detect or avoid attack, or to be reconstituted following loss. Each element of contemporary forces will require protection. In addition to providing for such protection, future systems architecture should disperse capability and value over large numbers of satellites ("spreading the eggs amongst many baskets.") Underpinning force developments,

the military and government must provide warfighters and the public education about threats to the nation.

Fusion of the above analysis leads to new understanding of Space control operations. We have determined that "position" has unfamiliar characteristics in Space. Since Space forces support terrestrial operations, the locus of points comprising and overflowed by an orbit, in aggregate determine "a position." Thus positional defense for Space denial is different from terrestrial warfare. To deny a surface position to the enemy, ground forces need only occupy that position and defend themselves. To deny access from Space to that surface position, **all orbits** overlying it must be denied to the enemy. This cannot be accomplished by mere occupation of orbits that overlie the surface point. Additionally, there is no way to trade space for time, since access to a significant orbit immediately yields the advantages of all points which comprise it. These facts indicate that use of ASAT for Space denial may be impotent for preemptive strategies. Denial of Space must be proactive; conducted in the enemy's depth before his forces can achieve orbit. To this end the commander could institute orbital exclusion zones and Space blockade operations.

Fortunately, the current length of deployment cycles creates the vulnerability we require for exploitation against the enemy within his depth. It is a vulnerability we must overcome ourselves. This dictates development of new forces, such as lift systems with aircraft-like sortie rates. Defenses other than ASAT systems must be developed. Low observable technology in combination with high altitude orbit would improve survivability of forces, but might require design modifications to deal with radiational interference of the environment. Rapid threat detection, and satellite protection and maneuver capability must be pursued. Low force-space ratios will require US forces to understand enemy capabilities, so that the commander can efficiently thwart hostile strategies.

Change is required, in line with the following recommendations:

- The services must increase warfighter education on Space systems, capabilities and vulnerability.
- US military Space capabilities must be dispersed in large, maneuverable constellations of satellites, to make them less lucrative as targets.
- Research and design of offensive and defensive Space weapons must continue.
- Space system development and deployment timelines must be shortened to reduce US vulnerability to Space denial efforts.
- The US must design and procure flexible, rapidly recyclable spacelift systems for military use.

Analysis of operational factors in Space is an intriguing process. The transformation of familiar concepts like position is unexpected and counter-intuitive. Other familiar ideas are likewise transformed. Analyses of lines of communication, forces and positions indicate the demise of the idea of trading Space for time -- a defensive strategy that has hitherto stood the test of time.

The possibilities, capabilities, and restrictions of Space warfare will transform warfare itself. It's a new world.

NOTES

¹ To differentiate between the medium, Space and the factor space, the former will be capitalized throughout the paper.

² Covault, Craig, quoting General Merrill McPeak, USAF. "Desert Storm Reinforces Military Space Directions," Aviation Week and Space Technology, 8 April 1991, 42. In his 3 February 1998 address to the Naval War College, General Howell Estes III, USCINCSpace, indicated that he would disagree, but conceded the tremendous role Space forces had in the war's outcome.

³ The kinetic energy of de-orbited weapons enables deep penetration, for destruction of underground facilities. These energy levels are difficult to achieve with air delivered weapons. See Air University, Spacecast 2020, (Maxwell AFB, AL, 1994), appendix O.

⁴ Directed energy weapons include laser and particle beam weapons, which destroy targets with less fragmentation and debris than kinetic weapons. In Space warfare this is significant, since Space debris is hazardous to friendly Space systems. See General Accounting Office, Space Station -- Delays in Dealing with Space Debris May Reduce Safety and Increase Cost. Report to the Chairman, Subcommittee on Government Activities and Transportation; Committee on Government Operations; House of Representatives. (Washington: 6 April 1990) 3.

⁵ Mehuron, Tamar A. "Space Almanac," Air Force Magazine, Vol. 79, No. 8, (Washington, D.C., Air Force Association, August 1996) 34.

⁶ Brown, Tommy C. "Is the US Prepared to Execute Operational Space Control?" (Fort Leavenworth, KS: US Army Command and General Staff College, 19 May 1995) 39.

⁷ USCINCSpace, General Howell Estes, advocates designation of Space as an AOR, which would change his position from a functional to a regional CINC. See Headquarters, Air Force Space Command: "Guardians of the High Frontier" (Peterson AFB, CO, 1997).

⁸ Naval Space Command, Space Support Team. Naval Warfighter's Guide to Space, (Dahlgren, VA, 1 November 1996) 2.

⁹ There are 3 other Lagrangian points that are unstable, and therefore not significant at the Operational level. G. Harry Stine, Confrontation in Space, (Englewood Cliffs, NJ: Prentice Hall, 1981) 59 - 62.

¹⁰ Ibid.

¹¹ Muolo, Michael J. Space Handbook: An Analysts Guide to Space, Volume Two. (Maxwell Air Force Base, AL: Air University Press, December 1993) 8 - 16.

¹² Under international law, all Space is neutral territory, and all nations have equal access, on a not-to-interfere basis with other nations. Thus, each nation ostensibly has equal influence in Space, given sufficient technology and funding. Space Control efforts will violate these laws. Department of the Navy, The Commander's Handbook on the Law of Naval Operations (NWP 1-14M) (Washington, D.C.: October 1995) 2-11.

¹³ The converse would also hold, i.e., that an orbit that confers defensive advantage to country "B" will confer offensive advantage to country "A," but not necessarily defensive advantage to country "A" since it would overlie country "B's" forces or territory only.

¹⁴ Lewis, Robert. "International Space Station History." International Space Station Homepage. 4 December 1997 <<http://station.nasa.gov/reference/history/index.html>> (31 January 1998).

¹⁵ Enticknap, Sarah, and Eddy, Bob. "Archives." The NASA Shuttle Homepage. 31 January 1998. <<http://shuttle.nasa.gov/archives.html>> (31 January, 1998).

¹⁶ Vego, Milan N. NWC 1035 On Operational Art (Draft) (Newport, RI: Naval War College, September 1997) 129.

¹⁷ Maneuver of deployed satellites is inefficient due to fuel requirements. In general the attacker should attempt to force orbital transfer upon his enemy, avoiding it himself. While new fuels technologies could mitigate the inefficiency, their production uncertainty is fairly high. The author feels this area of discussion to be beyond the scope of the work, and will not delve further into fuels, power sources, or propulsion systems technology.

¹⁸ Vego. 67.

¹⁹ While it is true that Space denial was contemplated in the early 1960's, and ASAT weapons were experimented with in the 1970's and 1980's, the pre-eminent philosophy in Space systems has remained aligned with the "Space sanctuary" school of thought. See Brown, 1.

²⁰ USAF Scientific Advisory Board, New World Vistas, Space Technology Volume, (Washington D.C., Department of the Air Force 15 December 1995) 12.

²¹ Mork, Brian J. "Subsumptive Architecture of Populous Satellite Constellations." November, 1995. <<http://pcisys.net/~mork/usats.htm>> (22 December 1997).

²² Ibid.

²³ Mehuron, 34.

²⁴ MILSTAR, a Command and control satellite constellation will be composed of six satellites. Costing over \$1 Billion, the US launched the first of these satellites in 1994. The last satellite will deploy in 2002. Mehuron, 34.

²⁵ Mork, 8.

²⁶ US spacelift currently costs around \$10,000 per pound of payload. Air University, Spacecast 2020 (appendix H).

²⁷ The 1963 Treaty on Outer Space established this concept. See US Congress, Senate Committee on Foreign Relations, Treaty on Outer Space. Hearings (Washington, D.C., US Govt. Print. Off., 1967) 127.

²⁸ Estes, Howell M., "An Address", Lecture, U.S.. Naval War College, Newport, R.I.: 3 February 1998. USCINSPACE indicated the sensitivity of the issue, and focused his discussion on other mission areas.

²⁹ Orbital transfer of a non-essential satellite to a position above decoy forces could convince an enemy that the decoy force was the primary effort in a conflict.

³⁰ For more on constellation theory, see Mork.

³¹ Muolo, Volume Two, 73.

³² KKV's are projectiles that use kinetic energy as their destructive force, as opposed to explosives. They may be employed against any target; terrestrial or Space based. Space launched KKV's against terrestrial targets benefit from reentry velocity, which greatly boosts their kinetic and thus destructive energy. For more information, see Air University Spacecast 2020, Vol. 2: O-15 - O-17.

³³ Certain types of directed energy weapons propagate well in Space but not in the atmosphere, and would require Space basing if developed. LEO would be a good position for such weapons, since their speed and orbital period would allow them to revisit possible targets frequently, while isolating the target axis above the

satellite. For DEW considerations, see Dietrich Schroeer, Directed -Energy Weapons and Strategic Defense: A Primer , Adelphi Papers #221 (London: International Institute for Strategic Studies, Summer 1987) 7 - 11.

³⁴ For a given booster lift capability, it is more difficult to achieve a highly inclined orbit, than an equatorial orbit. A booster will use the Earth's rotation to its advantage in placing a satellite in orbit by launching on an easterly trajectory. Launch of a weapon loaded booster over populated territory may not be politically feasible (due to mishap consequences), limiting use of western US launch sites. Additionally, the heavier the payload, the more thrust or fuel the booster must expend to place it in a given orbit. This may limit the placement of heavy payloads to LEO or relatively un-inclined orbits. For a discussion of additional orbital transfer concepts, see Mork, .8.

³⁵ Sea Launch is a commercial project that will provide sea based Space launch capability.

³⁶ Black Horse TAV is a concept developed within Air University, Spacecast 2020 (Appendix H: Spacelift). It is a fighter sized craft capable of launching horizontally from a runway, air refueling, and placing a 1, 000 lb. payload in LEO. It would operate with similar cycle rates to current aircraft, and could land on runways currently in use by aircraft. A fleet of 40 is envisioned, with lifetime costs similar to current aircraft, and a ten fold reduction in cost-per-pound-to-orbit over current space lift systems.

³⁷ A third facility began construction in Kodiak Island, AK in 1996. Mehuron, 48.

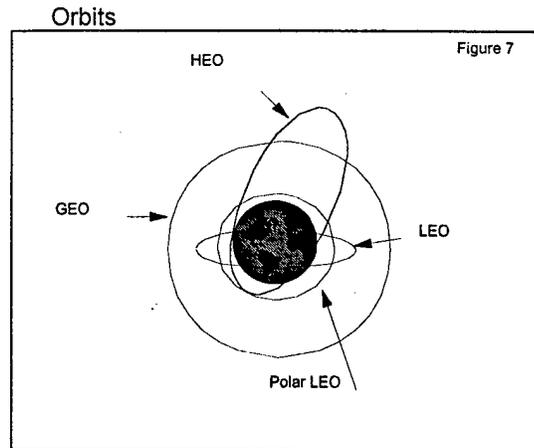
³⁸ Ibid. 40.

³⁹ Von Clausewitz, On War, edited and translated by Michael Howard and Peter Paret (Princeton, NJ: Princeton University Press, 1976, 8th printing 1984) 528.

Appendix A

Orbit

To understand Space, a basic understanding of orbitology is required. Objects in orbit are continually “falling” towards the planet’s surface. The reason they remain in Space, rather than crashing to the surface is because their velocity component parallel to the surface



is sufficient to compensate for the curvature of the planet. A more technical explanation is that the centrifugal force acting on the orbiting satellite (due to its speed) is in equilibrium with the centripetal force provided by gravity. Since gravity acts from the center of mass of the planet, satellites orbit around a planet’s center in a single plane of motion which may intersect the planet along any **major axis**. Thus a satellite cannot orbit around a fixed latitude, other than the equator, but may be **inclined** in order to pass over higher latitudes or the poles. Orbits can be circular, where the satellite holds a fixed **altitude** above the surface or, more commonly, elliptical. In elliptical orbits, the planet’s center lies at one of the foci of the elliptical path. The further apart the foci of the ellipse are, the greater the **eccentricity** of the orbit is said to be. Orbits are classified as Low Earth Orbit (**LEO**), between 150 to 800 kilometers altitude; Medium Earth Orbit (**MEO**), between 800 and 35,000km; geosynchronous Orbit (**GEO**), at approximately 36,000km; and Highly Elliptical Orbit (**HEO**), in which a satellite’s altitude varies in along an elliptical path, from 250km at perigee to a maximum of approximately 700,000km at apogee (See figure 7). LEO is useful

for close observation by surveillance systems, and allows rapid revisit of locations on Earth's surface. It is disadvantageous for viewing large areas of the surface at one viewing, due to its proximity and speed. MEO orbits are commonly used for navigation satellites, like the US GPS and Russian GLONASS systems. GEO is useful for systems requiring a stationary position or continuous view of one portion of the Earth's surface. Communications satellites are routinely placed in these orbits. HEO orbits are useful because of their varying satellite speed along their orbital flight path and broad field of view from apogee. By varying the **orientation** of the orbit, the satellite will decelerate to view the objective surface area for prolonged periods towards the orbital apogee (high point), and accelerate towards perigee, which will be oriented over areas of lesser interest.

The rotation of the Earth beneath a satellite complicates visualization of a satellite's **ground track**. Equatorial orbits are fairly straightforward, as are geostationary orbits, but HEO and inclined orbits are more difficult to visualize. As altitude increases, velocity decreases, lengthening the **orbital period**. Since the planet's rotation is a fixed value, it becomes apparent that by altering the altitude, shape and inclination of an orbit, an infinite number of ground tracks are possible. In a polar orbit, a satellite may literally overfly every point on the planet.

Once placed in orbit, objects are in continual motion without further expenditure of effort (energy or fuel). Satellites in geosynchronous and geostationary orbits appear motionless relative to the planet's surface, but are actually moving at sufficient speed to match the planet's rotation. Geostationary orbits are very precise geosynchronous orbits, which literally do not move in space relative to their position over the equator. Geosynchronous orbits oscillate north and south of the equator in a "figure eight" pattern as

viewed from the planet's surface. The dynamics and subtleties of orbit lend Space control some of the peculiar characteristics examined in this paper.¹

¹ For more information on orbitology, see Muolo, Michael J. Space Handbook: An Analysts Guide to Space, Volume Two (AU-18). (Maxwell AFB, AL: Air University Press: December, 1993) Chapter 1.

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