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US SPACE SYSTEM SURVIVABILITY

Strategic Alternatives for the 1990s

ROBERT B. GIFFEN

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Strategic Alternatives for the 1990s

by

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FOREWORD

Space, the new frontier, is also becoming the new national security "high ground," potentially more important to US defense efforts. The security potential of space has been the subject of recent studies aimed at developing a cohesive national space strategy; this has included efforts by the National Security Council, the Secretary of Defense, and the Air Staff. The successful use of space to defend US interests will require more than placing space systems in orbit; these systems must also be able to survive.

In this monograph, Colonel Robert B. Giffen, USAF, examines strategies to assure the survivability of US space systems. His analysis leads him to conclude that incorporating survivability into the initial design of a space system is essential. This includes deciding what capability must survive, and to what level of conflict it must endure. As the author points out, the largest obstacle to implementing survivability will be cost, which must be paid in the initial appropriation.

The US Air Force has recently created a Space Command (with coequal responsibility for air defense of the Nation), symbolizing new recognition of the national security significance of space. This study proposes a set of issues and approaches that US policymakers must address as they confront the space age and seek to assure that the United States is the master of the ultimate high ground. We at the National Defense University are pleased to have supported this study which explores this new dimension of the national security effort.

JOHN S. PUSTAY
Lieutenant General, USAF
President

ABOUT THE AUTHOR

Colonel Robert B. Giffen, US Air Force, wrote this monograph while a Senior Research Fellow with the National Defense University and concurrently a student at the National War College. He is a distinguished graduate of the United States Air Force Academy and was graduated *summa cum laude* from the University of Heidelberg, where he earned a PhD in Astrodynamics as an Olmsted Scholar. Colonel Giffen is a senior pilot and a graduate of the United States Navy Test Pilot School, with five years of test pilot experience and more than 200 combat missions as a special operations and combat rescue pilot in Southeast Asia. His most recent assignments include Deputy Director for Space Operations within the Cheyenne Mountain Complex at Headquarters, North American Aerospace Defense Command, and Deputy Head for Astronautics at the USAF Academy. He has published articles in the journal *Astronomy and Astrophysics* and presented papers before the German Astronomical Society, the International Astronomical Union, the Air University Airpower Symposium, the USAF Academy Military Space Doctrine Symposium, and the Fletcher School of Law and Diplomacy. Colonel Giffen is currently serving as Professor and Head, Department of Astronautics, USAF Academy, Colorado.

GLOSSARY OF TERMS

ASAT: anti-satellite.

Autonomy: the ability of a satellite to operate independently without command and control from the ground; includes the ability to perform navigation, attitude control, internal system control, and self-diagnosis.

C3: command, control, and communications.

Connectivity: the ability to maintain continuous communication between the National Command Authority and strategic and tactical forces.

Critical node: that component of a system whose failure results in total system failure.

Direct-ascent interception: ASAT interception of a satellite in orbit by launching directly from the earth (as opposed to maneuvering an ASAT already pre-positioned in orbit).

Eccentricity: the amount an orbit varies from the circular; the more eccentric an orbit becomes, the more squashed it is.

EHF: extremely high frequency (30,000 to 300,000 MHz).

EMP: electromagnetic pulse; a propagated bundle of electromagnetic energy.

Exoatmospheric: at an altitude above the sensible atmosphere (approximately 40km).

Faraday cage: an arrangement of grounded parallel conductors acting as an electrostatic screen such that induced currents cannot circulate.

Fault-tolerant processors: microprocessor computers capable of internally correcting or overcoming self-induced errors.

Geosynchronous satellite: a satellite which revolves around the earth in exactly one day so that it appears stationary to an observer on the earth.

Health management: the ability of a satellite to maintain its own environmental systems; *e.g.*, temperature control.

Housekeeping: the ability of a satellite to maintain its own maintenance systems; e.g., power distribution.

Inclination: the angle between a satellite's orbital plane and the plane of the Equator.

Molniya orbit: a highly eccentric semi-synchronous orbit inclined 63.4 degrees to the Equator.

Outgassing: the undesired release of trapped gases into the vacuum of space; can cause contamination of other satellite components or undesired thrust.

Perturbations: small disturbances of a satellite in orbit caused by gravitational anomalies, drag, solar pressure, etc.

Scintillation: undesired transient changes in the carrier frequency of a communications wave.

Semi-synchronous satellite: a satellite that completes exactly two orbits per day.

Spoofing: the act of disabling a satellite by deliberately interfering with its command and control.

Stealth technology: technology enabling an object to become "invisible" to both radar and optical sensors.

Sun-synchronous orbit: a low earth orbit inclined at about 98 degrees to the Equator, which always maintains the same relative position to the sun.

Surge arrestor: like a lightning arrestor, protects circuits from overvoltage conditions.

Waveguide cutoff: a device used to protect waveguides, which are used for transmitting very high frequency energy.

PREFACE

In this monograph I propose a systematic way to reduce the vulnerability of our critical space assets. The focus is on space systems vital to the national defense, and on the survivability of these systems across the spectrum of conflict. There is a gap between popular journalism and complex technical documentation, so I have written this monograph to help interested but inexpert readers understand how we can defeat and, conversely, how we can protect military space systems.

The study is organized in building-block sequence, so that each chapter prepares the reader for the next topic. Chapter 1 identifies the need to develop strategies for space system survivability consistent with current national military strategy. Chapter 2 discusses the basics of military space systems, including the fundamentals of satellite orbits and the performance in space of traditional military activities such as communication, navigation, surveillance, and reconnaissance. Chapter 3 presents a brief comparison of current US and Soviet space systems. *Readers knowledgeable about space systems and US and Soviet space assets can skip directly from Chapter 1 to Chapter 4.* Chapter 4 concentrates on how to defeat space systems. The heart of the paper is Chapter 5, which discusses the range of strategies for making space systems survivable. Chapter 6 looks at integrating these strategies into a cohesive, purposeful, national strategy for space system survivability. Finally, the Epilogue discusses how to implement that strategy.

Because I also hope to encourage public debate on space system survivability with this monograph, I have limited the discussion to unclassified material. This restriction limits analysis to generic, rather than specific, military space systems, but in no way alters the results or conclusions of the paper. In researching this topic, I relied upon the open literature, informal interviews with approximately 50 experts in both government and industry, and my own expertise.

This research would not have been possible without the help and generous cooperation of the System Project Offices within Space Division (the USAF organization responsible for the development and procurement of most US space systems) and several offices within the Air Staff. I received valuable criticism from Colonel Charlie Heimach, Lieutenant Colonel Jim Gaston, and Ms. Lee Hanna, fellow students at the National War College, Colonel Fred Wisely of the Space Division, Major Chuck Friedenstein of the USAF Academy, and Major Pete Swan and Captain Cathy Swan, both PhD candidates at UCLA, each of whom read and commented upon the monograph in one of its many drafts. I am also indebted to my fellow researchers, who provided guidance thoughout the preparation of this research. I was fortunate to enjoy the capable assistance of Ms. Evelyn Lakes, Editor, National Defense University Research Directorate, for editing and bringing this monograph to press. Finally, I want to give special thanks to Colonel Fred Kiley, my most serious critic, for his valuable contributions throughout the preparation of this manuscript.

EXECUTIVE SUMMARY

We increasingly depend on space systems for the traditional military missions of communication, navigation, surveillance, and reconnaissance. Current space systems also serve as a force multiplier for our strategic and tactical forces and help us maintain a credible deterrent posture.

Many of these systems are becoming vulnerable to a host of enemy threats, however. The Soviets, who launch payloads at a rate seven times greater than the United States, clearly intend to dominate space. Although the US technical advantage has made up most of this difference, recent Soviet developments of anti-satellite (ASAT) weapons may make Soviet dominance a reality. Space—the ultimate high ground—will play an ever-increasing role in our national security and must not be lost to the Soviets. To prevent such a loss we need to implement a comprehensive survivability strategy for all future military space systems.

A space system consists of three equally critical segments: the satellite, the ground support stations, and the C3 link between the space and ground segments. Negating any one of these segments can effectively destroy the entire system. The space segment can be defeated by "spoofing," that is, by interfering with the command and control of a satellite, or by direct attack. Orbital interceptors, directed energy weapons, and space mines can also threaten the satellite. Both the ground command and control stations and the user communications facilities are susceptible to sabotage or to direct attack—whether terrorist, conventional, or nuclear. Jamming, either by electromagnetic interference or by exoatmospheric nuclear detonations, can render the C3 link useless. Relay communication satellites integrated into the C3 link are vulnerable to both spoofing and direct attack.

To counter these threats, several strategies are available:

Doing Nothing. Some space systems do not have a vital wartime mission, so incorporating survivability measures in these systems may be unwarranted. This strategy requires identifying these expendable assets and planning to do without them in time of war.

Deterrence. Conceptually, deterrence protects your systems by telling the enemy that if he gets yours, you'll get his. This "stand-off" strategy is effective when the enemy values his space systems as much or more than you do yours, and when you have the capability to negate his systems. Deterrence depends on nearly balanced capabilities, but balances are precarious in space because technical breakthroughs can drastically shift capabilities—and vulnerabilities.

Negotiation. Negotiation can serve to put a cap on the number of enemy assets, and it can specifically prohibit "practicing" interference with space assets. Negotiation requires a position of strength, however, and can never guarantee survivability.

Hardening. Some protection against nuclear effects, spoofing, sabotage, terrorist attack, laser illumination, and jamming results from hardening physical systems, increasing security, encrypting, and using Extremely High Frequency (EHP)—or higher frequencies—to communicate.

Mobility. Using maneuverable satellites, putting them in other than-geosynchronous orbits, and employing mobile ground stations are three methods of complicating the enemy's targeting problems.

Autonomy. Making satellites more autonomous decreases dependence on, and therefore vulnerability to, attacks on ground stations.

Proliferation and Deception. By increasing the number of satellites and ground stations, and by using decoys, we can make the enemy's targeting problem difficult: he has many targets to kill, and he can't discern the right ones.

Reconstitution. The only way to guarantee survivability of certain space functions is to provide for quick replacement of destroyed systems with new ones, stored on pre-positioned launch vehicles.

To make our wartime space systems survivable, we must use a mix of these strategies in a comprehensive survivability plan. First, we must develop and deploy an anti-satellite, or ASAT, capability of our own and begin negotiations with the Soviets to limit the use of weapons in space. Next, we must use hardening, mobility, maneuver, autonomy, and orbit selection to increase survivability—and make defeat costly for the enemy. After taking these measures, we can use proliferation, deception, and reconstitution to insure a continuing capability. Full military exploitation of the Space Shuttle will increase our space system survivability at the least cost.

Finally, and perhaps most important, we must make space system survivability a national priority by establishing an Executive Agent for Space within DOD to insure that

- the requirements of survivability are defined for each space system (tell us where to spend the dollars);

- the proper strategy to meet these requirements is selected (tell us how to spend the dollars);

- with the support of OMB and the Congress, each program is funded to implement the selected strategy, and these funds are protected, or "fenced" (give us the dollars).

1
WHY SURVIVABILITY?

US MILITARY FORCES ALERTED

WASHINGTON, D.C. (AP) A spokesman for the Defense Department announced early this morning that all US military personnel were placed on alert status at approximately 4 a.m. today.

This first total alert since the Cuban Missile Crisis intensifies the atmosphere of fear and astonishment which has mounted across the country during the past week, following unexpected aggressive actions by the Soviet Union.

First hints of a possible Soviet threat appeared six days ago in satellite reports of significantly increased activity at launch sites used to orbit Soviet killer satellites. Soviet activity in the vicinity of US satellite ground command and control stations both in Europe and the United States had apparently caused concern as early as two weeks ago, according to reports not released until yesterday.

Concern erupted into general alarm during the night, however, with the incapacitation of a major portion of US space systems. With a systematic sequence of ironically simple procedures, the Soviets have effectively destroyed US space-based defense and communications machinery.

Only a handful of the hundreds of sophisticated satellites which comprise the US system remain operational at this time, following the massive blackout accomplished by jamming and sabotage performed entirely by Soviet stations located in trawlers stationed off the US east and west coasts and by ground stations located in Cuba. Although not confirmed, Pentagon officials hinted that several satellites may have been incapacitated by Soviet laser weapons. Ground, air, and sea forces are seriously crippled by the loss of communication, intelligence, and navigation information previously provided by these now-useless space assets. The US Killer Satellite program, well underway since 1979 but not yet operationally deployed, sits helpless.

After almost four years of massive defense budgets, outraged Americans listened this morning in shock to the Pentagon explanation that last night's Soviet take-over of our highly vulnerable space assets could have been prevented by "survivability" precautions, but that such precautions had been largely omitted because they would have cost too much. As a result, literally billions of dollars of our space assets apparently have now been turned into space junk.

This Orwellian news report is, of course, fiction; yet it does headline some real issues—and real vulnerabilities—of US space assets. Our military dependence is, perhaps, not as great as the article implies, nor are our systems quite so vulnerable; however, while we, as a nation, forge ahead in the development of sophisticated space systems to support our national security, we must insure that the deployment of these systems is consistent with our overall military strategy.

MILITARY DEPENDENCE ON SPACE

Space-based systems are critical to the effective employment of US military forces throughout the spectrum of conflict. Communication satellite systems provide vital connectivity with all military forces by insuring uninterrupted communications, command, and control (C3) links to both strategic and tactical forces.[1] Space-based sensors serve as an integral part of the US early warning and attack assessment network. Intelligence collection relies overwhelmingly on space-based assets. Overhead space systems provide data to assure verification of treaty compliance. Tactical exploitation of our space-based systems serves as a force multiplier to our tactical and strategic forces throughout the spectrum of conflict. In short, the military depends on space systems to get the job done.

THE NEED FOR SURVIVABILITY

Simply stated, because these space systems are critical to national security, they must be made to survive long enough to do their jobs. For the purposes of this study, survivability of a space system is the ability of that system to perform the designated mission through the appropriate level of conflict. Some systems, for example, may need to function only during limited conventional conflict, whereas others may need to continue operating during total nuclear war. As clarified and restated by Presidential Directive 59, the primary document expressing US nuclear doctrine, the focus of our national military strategy is on flexible response and countervailing tactics. The goal today is an enduring capacity to conduct nuclear war for several months. This basic strategy, in effect for many years, will prevail for the foreseeable future.[2] Reliance on space systems is an integral part of this strategy; these systems, therefore, must be designed to survive at the same level as the forces they support. In short, to maintain a credible deterrent posture, certain space systems must be able to survive for months.[3]

US POLICY ON THE MILITARY EXPLOITATION OF SPACE

Although much has been made of the slogan "exploiting space for peaceful purposes," neither US national policy nor international agreements on the use of outer space prohibit the exploitation of space for military purposes. President Carter made it clear in Presidential Directive 37, National Space Policy, that the United States has the inherent right both to use space to support national objectives and to protect and defend all US assets in space. Current international agreements place only minor limitations on the military use of space. Specifically, the Outer Space Treaty of 1967 prohibits space deployment of weapons of mass destruction—nuclear, chemical, or biological—and restricts the use of the moon and other celestial bodies exclusively to peaceful purposes. In addition, the Anti-Ballistic Missile (ABM) Treaty prohibits the use of space-based anti-ballistic missile systems. To sum up, the United States can take steps to insure the survivability of its space assets, to include deployment of defensive systems, without changing current national space policy or abrogating any international agreements.

2
THE BASICS

"Take the high ground and hold it" is an old axiom of warfare. Space, the new "high ground," remains unfamiliar terrain for many. To prepare the reader to understand the problems of survivability of space systems, this chapter explains some of the characteristics of satellite orbits and tells how the traditional military missions of communication, navigation, surveillance, and reconnaissance work from space. Only through such understanding can we explore an enemy's methods for defeating space systems, the topic of Chapter 4. Chapter 3 examines specific US and Soviet space systems. *Readers already knowledgeable in these matters may wish to proceed directly to Chapter 5 for its discussion of survivability strategies.*

SPACE—THE NEW HIGH GROUND

During the past 25 years, both the Americans and the Soviets have spent many billions of dollars in the military exploitation of space. The US Department of Defense spent more than $50 billion on military space systems between 1958 and 1978 and will spend nearly $6 billion in 1982.[1] In an era of limited resources and tight budget constraints, why are we spending so much in space? First, space offers the superiority intrinsic to the high ground. Second, like the sea, space is an international medium with no territorial limitations; satellites orbiting the earth can observe the entire globe without violating the territorial claims of other countries.[2]

Many claim that space is already the ultimate high ground.[3] In fact, space systems are at this very moment performing essential military missions, but before we discuss these missions, let's examine some characteristics of satellites and what these satellites can and cannot do.

WHAT'S A SATELLITE?

The moon is a natural satellite of the earth; the earth, in turn, is a satellite of the sun. Like the moon, man-made satellites revolve around the earth, balanced like the water in a bucket you swung over your head as a kid. If a satellite speeds up, it goes into a higher orbit; if it slows down, it drops into a lower orbit. If it goes too slow, it will hit the earth. To put a satellite in orbit requires an expenditure of energy—potential energy to raise it up and kinetic energy in the form of velocity to keep it up. If a satellite is in a high enough orbit to be free of atmospheric drag, it will stay there forever.[4] Satellite orbits are generally separated into three categories:

- low earth orbits (LEO) from about 150 km to 1500 km;

- medium altitude orbits from 1500 km to 35,800 km;

- high altitude orbits from geosynchronous altitude (35,800 km) and beyond.

It's the LEO satellites that run into problems with atmospheric drag. Let's take a closer look at this category.

LOW EARTH ORBITS

A satellite orbiting at an altitude of 150 km—very close to the earth's surface—travels about 7800 meters per second, or more than 17,000 miles per hour. Figure 2-1 shows graphically how low this orbit is. Even though the earth's atmosphere at this altitude is extremely thin, considerable drag acts on the satellite to slow it down. In fact, it could stay in orbit at this altitude for only one day before decaying back in, while a satellite at 370 km will remain in orbit for a year.[5] So drag is a significant problem, but these lower altitudes are nevertheless important because the lower the satellite, the more clearly it can see objects on the earth's surface. To stay in these low orbits, a satellite must be able to thrust periodically to kick itself back up.

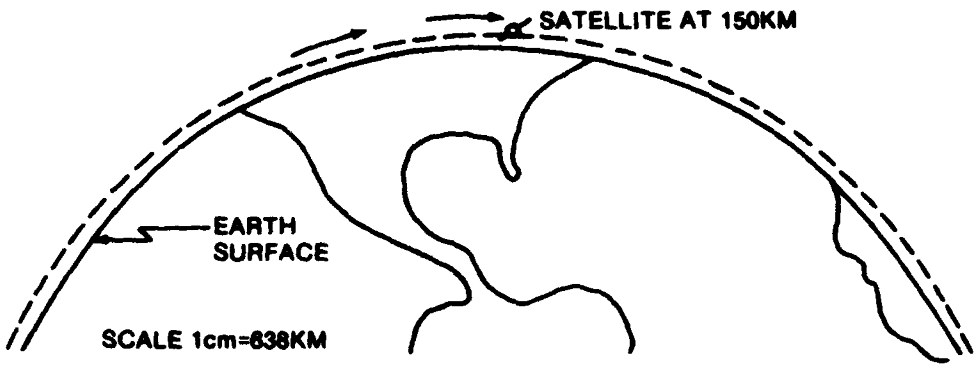


FIG. 2-1. Scale drawing of a satellite in low earth orbit.

Although we think satellites can see large areas as they orbit above the earth's surface, we find this not true at low altitudes. As Figure 2-1 suggests, at this low altitude, a typical satellite skims the globe once in about ninety minutes. During this period, its sensor can "see" a narrow ribbon of the earth's surface about as wide as a large metropolitan city, and equal in area to less than one percent of the earth's surface.[6] Many satellites, particularly those with observation missions, use this lower region of the LEO band where trade-offs between drag, area coverage, and optical resolution (which decreases with the square of the altitude) are constantly necessary. Many other missions, however, use the upper portion of the LEO band where these considerations are not a problem. Of about 4600 man-made objects tracked by the North American Aerospace Defense Command (NORAD) in January 1982, 3800 (or 83 percent) were in the LEO band.[7]

Medium Altitude Orbits

The higher the altitude of a satellite, the longer the satellite takes to orbit the earth. Satellites in the medium altitude band (between 1500 km and 35,800 km) take from 2 to 24 hours to circle the earth. High radiation from the Van Allen Radiation Belts makes this region inhospitable to long-duration manned flights and also creates hazards to electronic systems on unmanned satellites. With one exception, little advantage is gained from using medium altitude orbits; consequently, this region is sparsely populated. NORAD tracks about 650 objects in this broad band. The exception is the semi-synchronous orbit at an altitude of 20,700 km. Satellites at this altitude, because they revolve around the earth in exactly 12 hours, repeat an identical track or ground trace over the earth every 24 hours and are therefore uniquely suited for some communications and navigation missions.

High Altitude Orbits

At an altitude of 35,800 km, a satellite moves at the same relative speed as a point on the equator of the earth. Satellites at this altitude, called geosynchronous satellites, are unique in that they appear to be stationary to an observer on earth. One common misconception, however, is that these geosynchronous satellites can be positioned over any point on the globe—for example, over Moscow or Washington, D.C. Not true. Geosynchronous satellites appear to be stationary only when positioned over a point on the Equator. Even though this stationary feature is restricted to those satellites positioned over the Equator, geosynchronous satellites still have some distinct advantages. Not only do they see large expanses of the earth, but they also make excellent platforms for communications relays and surveillance missions. Figure 2–2 shows the coverage given by one geosynchronous satellite. Positioning three of these satellites equally spaced over the Equator provides total coverage of the globe.

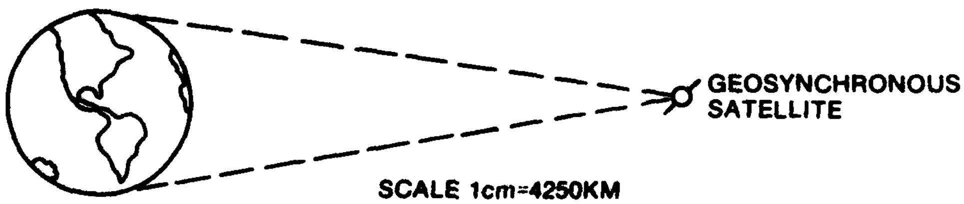


FIG. 2–2. Scale drawing of a satellite in geosynchronous orbit.

Beyond geosynchronous altitude, satellites travel slower relative to the earth and appear to regress through the sky. Although fewer than a dozen satellites use orbits higher than geosynchronous altitude, these orbits do offer advantages for increasing satellite survivability and will be discussed in greater detail in Chapter 5.

INCLINATION AND ECCENTRICITY

Two other characteristics of a satellite's orbit, inclination and eccentricity, play important roles in satellite missions. Envision a LEO satellite that skims the earth right above the Equator; it isn't inclined to the Equator and therefore has a 0-degree inclination. This satellite will see only the terrain around the Equator—it will never be over Miami or Moscow or Rio. If we incline this orbit, say, by 45 degrees as shown in Figure 2–3, then the satellite will eventually see all the terrain between 45 degrees North and 45 degrees South latitude because the earth is slowly rotating underneath the satellite's orbit, at a rate of one revolution per day. Now take this concept one step further and rotate the orbital plane to an inclination of 90 degrees into a polar orbit. Everything between 90 degrees North and 90 degrees South latitude (or the entire globe) rotates underneath the orbit. From a typical 90-minute low altitude polar orbit, a satellite could photograph the entire earth's surface, although this process would take many days. Remember, this satellite could see less than 1 percent of the earth's surface with each revolution.

Two types of orbits, identified by their inclination, are of particular practical value. The first is a sun-synchronous low earth orbit at about 98 degrees inclination. At this inclination and altitude, the satellite's orbital plane will always maintain the same relative orientation to the position of the sun, a feature well suited for weather and stra-

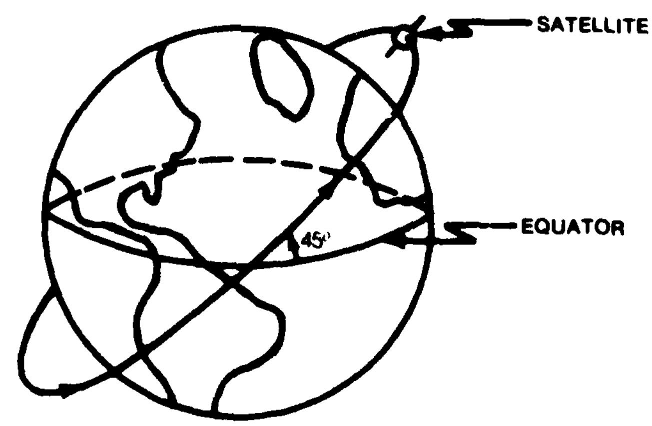


FIG. 2–3. A low earth orbit inclined 45 degrees to the equator.

tegic reconnaissance.[8] The second orbit, one with an inclination of about 64 degrees, provides stability to the orientation of non-circular orbits. An understanding of orbital eccentricity is necessary, however, before we discuss this concept in detail.

No orbit is exactly circular. All orbits are at least a little less than perfect, or "eccentric." An orbit's eccentricity, the measure of how squashed it is, is determined by the minimum and maximum altitudes it achieves as it circles the earth. A LEO satellite, for example, with a perigee (minimum altitude) of 1490 km and an apogee (maximum altitude) of 1500 km, has an eccentricity of 0.001 and is nearly circular, while a semi-synchronous satellite with perigee of 1500 km and apogee of 38,000 km has an eccentricity of 0.7 and is quite elongated. Figure 2-4 shows these two orbits drawn to scale. Both orbits are actually ellipses with the earth at the primary focus. As a satellite moves around an eccentric orbit, it goes faster near perigee than it does near apogee. This characteristic can be advantageous when an eccentric orbit is also inclined to the Equator. For example, a semi-synchronous orbit inclined 64 degrees with an eccentricity of 0.7 and with perigee located in the Southern Hemisphere at 64 degrees South, will spend 11.7 hours in the Northern Hemisphere. It travels 6 times faster at perigee than at apogee. This particular orbit, called a Molniya orbit, is well-suited for communications satellites used in the Northern Hemisphere.[9] Why? Because a satellite in this orbit stays

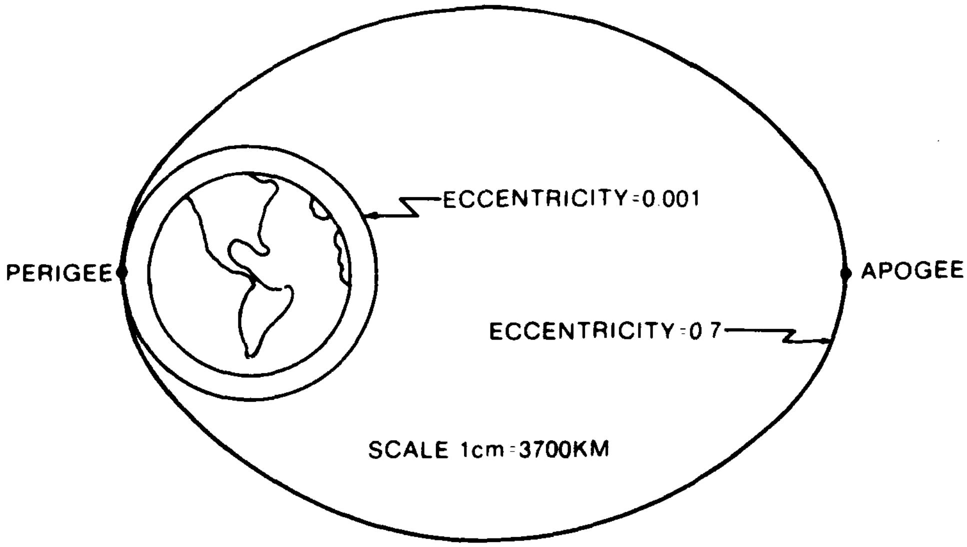
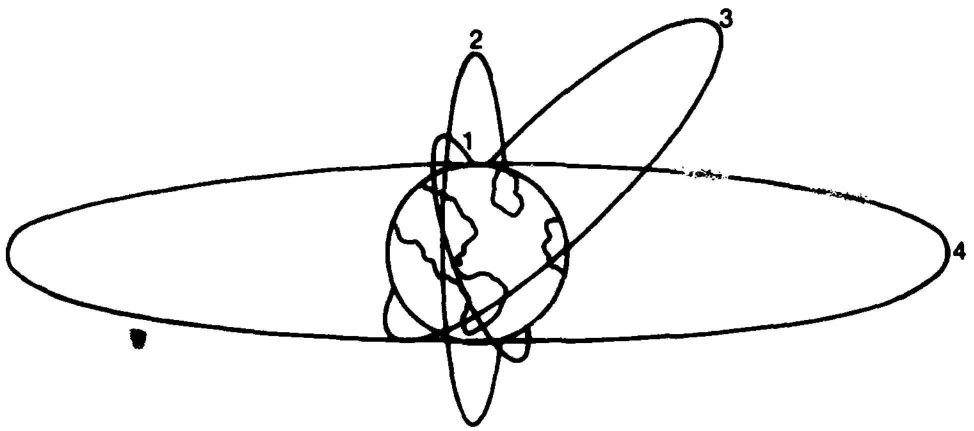


FIG. 2-4. Comparison of a highly eccentric orbit to a nearly circular orbit.

over the Northern Hemisphere about 23 out of every 24 hours, repeats the same ground trace every 24 hours, and can be less expensive to place in orbit than a geosynchronous satellite. The inclination of 64 degrees is important because the relative positions of perigee and apogee are stable.[10]

Eccentric orbits can also reduce drag and increase satellite lifetime. A photo satellite using an eccentric orbit can fly very low (about 100km) by placing the perigee of the orbit over the target area. The satellite then dips down into the atmosphere to take pictures, reducing the time it spends exposed to high drag. The rest of the time it remains above the atmosphere. Such techniques can greatly decrease maneuver requirements.

In summary, most military satellites use one of the four orbits depicted in Figure 2-5:



1-LOW EARTH ORBIT WITH 98-DEGREE SUN-SYNCHRONOUS INCLINATION
2-MEDIUM ALTITUDE SEMI-SYNCHRONOUS ORBIT
3-MOLNIYA ORBIT
4-EQUATORIAL GEOSYNCHRONOUS ORBIT

FIG. 2-5. Typical military satellite orbits.

LAUNCHING AND MANEUVERING IN ORBIT

Both the direction of launch and the location of the launch site affect the performance of any launch vehicle. Except for launches from the North or South Poles, eastward rotation of the earth will boost or retard the vehicle. From Cape Canaveral, for example, firing due east, the Space Shuttle can place the orbiter vehicle plus approximately 25,000 kilograms (55,000 lbs.) of payload into orbit; launching due west from Vandenburg in California, however, the Space Shuttle cannot achieve orbit, even when empty. In launching payloads into orbit, the earth's rotation has a significant effect, with the greatest advantage gained by launching due east from the Equator, and greatest disadvantage by firing due west.

Launching due east will place the satellite payload into an orbit with an inclination equal to the latitude of the launch site. From Cape Canaveral this is a 28-degree inclined orbit. By launching either toward the north or the south from this site, a satellite can be placed in a 90-degree polar orbit.[11] An orbit with inclination less than 28 degrees cannot be achieved directly from Cape Canaveral, however, because the launch site never rotates underneath this orbit. For example, since an equatorial orbit passes only over the Equator and never "sees" Cape Canaveral, to achieve this orbit requires an additional maneuver to change the inclination or plane of the orbit. Plane changes are very expensive in terms of velocity: placing a satellite into an equatorial low earth orbit from Cape Canaveral can require a more than 50 percent increase in the velocity requirements of the launch vehicle.[12] Similarly, changing the altitude of a satellite from low earth orbit to geosynchronous orbit can also add a 50 percent increase in velocity requirements. Combining these maneuvers does result in increased efficiency, but placing a satellite in a geosynchronous equatorial orbit from Cape Canaveral still requires about 60 percent more velocity capability than placing it into a low 28-degree orbit, and with an increase in velocity requirements comes an exponential increase in fuel requirements: the more velocity required, the more fuel required; the more fuel required, the more additional fuel needed to carry that fuel, and so on.

Two other factors affecting both launch and maneuver capability involve time—the time when launched and time that elapses in flight. Time of launch is important when trying to achieve a specific orbit. For example, intercepting another satellite requires sequencing both the launch time and the maneuver time to arrive at the target. This is a complex process because both the target and the launch site are moving. Time of flight becomes important when intercepting high altitude satellites. It takes three to six hours to intercept a satellite in geosynchronous orbit, long enough for the target satellite itself to maneuver out of the way.

All these considerations affect the design of launch vehicles. Before the first three successful missions of the Space Shuttle in 1981 and early 1982, all launch vehicles were expendable. Launch costs with expendable vehicles have been so high that each satellite payload has been designed to minimize weight. To place a satellite in a nominal low orbit costs from $25 to $60 million, and launching a typical satellite in geosynchronous orbit can cost as much as $125 million.[13] Exploitation of reusable launch systems such as the Space Shuttle should eventually bring these costs down so that size rather than weight will become the critical factor.

Because launch costs are so high, most satellites are designed to be long-lived. For this reason, they must operate for several years without servicing, use independent power supplies, and withstand extreme temperature changes and harmful natural radiation. The net result has been heavy, and therefore astronomically expensive, satellite payloads. A sophisticated communications satellite, for example, can cost as much as $500 million to procure and launch into orbit.

MILITARY SPACE MISSIONS

Because space is the new high ground and is free from national jurisdiction, it is well suited for the military missions of communication, navigation, surveillance, and reconnaissance. Let's look briefly at how we already are using satellites to perform these missions.

COMMUNICATIONS

Almost all communications satellites use either geosynchronous or Molniya orbits. Three geosynchronous satellites provide total earth coverage, with marginal coverage in the polar regions (above 70 degrees North and below 70 degrees South), whereas four Molniya satellites are required to give total coverage to one hemisphere. The advantage of the Molniya orbit over the geosynchronous orbit is the lower cost required to launch into orbit. Low earth orbits can also be used for communications satellites, but it would take at least 24 satellites to provide the same coverage as 3 geosynchronous satellites.

Communications satellites receive ground signals from ground transmitters, amplify these signals, and retransmit them to other ground receivers. The advantages of using satellites for communications are obvious—they provide direct line-of-sight communications and eliminate the need for miles of cable or numerous, closely-spaced microwave relay towers. These satellites also provide the capability for direct, continuous contact with mobile air, land, and sea forces.

Navigation

Because satellite motion is so predictable and position information so accurate, satellites make excellent reference platforms for earth-based navigation systems. Navigation receivers on a ship, for example, can tap into information from navigation satellite systems and locate themselves to within about 10 meters. The most accurate navigational information uses four satellites simultaneously. To maintain worldwide coverage, a satellite navigation system must have several satellites positioned in various orbits. One "constellation" providing worldwide coverage uses 18 satellites in semi-synchronous orbits. Lower orbits are also used for navigation but either require more satellites or provide decreased coverage.

Space-based navigation systems are revolutionizing military navigation because of the significant advance in positional accuracy they provide. Such navigational accuracy can give both tactical and strategic forces a decided advantage. Any pilot, company commander, or ship's captain will attest to the value of knowing position to within 1000 meters, let alone 10 meters.

Surveillance

In performing the world-wide surveillance mission, space-based sensors are the only systems capable of providing continuous, complete coverage. Three surveillance missions are currently performed from space: early warning, nuclear detonation detection, and weather monitoring. Early warning sensors located in geosynchronous orbit can provide immediate warning of intercontinental or submarine-launched ballistic missile attack. By sensing the missiles rising through the atmosphere, such systems add critical minutes to strategic warning and validate information gathered by land-based radar early warning systems. These warning systems are an integral component of our nuclear deterrent posture.

Nuclear detonations are most efficiently detected by satellites. Sensors mounted on satellite platforms can automatically sense nuclear explosions and determine where the detonations occur, information essential for verifying nuclear test ban treaties and also useful during wartime for strategic strike assessment.

Satellite weather coverage has improved both forecasting and realtime weather information over the past decade to the point that it influences our daily lives. Nearly every local television news station and newspaper use satellite weather photographs to depict weather. Accurate, realtime weather information can also enhance strategic and tactical force deployments. Current information on cloud coverage, wind, and sea state can be invaluable to the tactical commander in effectively employing his forces.

Strategic weather information is usually obtained from geosynchronous satellites while detailed tactical weather data are best gathered from satellites in low sun-synchronous orbits. Optical, infrared, and radar sensors measure cloud coverage, height, and thickness, and local wind and sea-state conditions.

Reconnaissance

Military reconnaissance is similar to surveillance, but focuses on obtaining detailed information of a specific nature. Strategically, space-based sensors can observe enemy weapons development, verify compliance to arms limitation treaties, and aid in strategic targeting. Tactically, satellites can determine deployments of land, sea, and air forces prior to and during armed conflict. Intelligence information gathered from satellites can act as a force multiplier to the commander. Knowing where the enemy is, how strong he is, and what he is doing will always be the most valuable information the commander can have, and often is the decisive factor in battle.

DEFINING A SPACE SYSTEM

A satellite is only one part of an entire system designed to provide a service to the user. Equally important are the launch system, the command-and-control network, and the user's data-link system. A failure of any portion of this system can render the system useless. Figure 2–6 schematically shows how components of a satellite system relate.

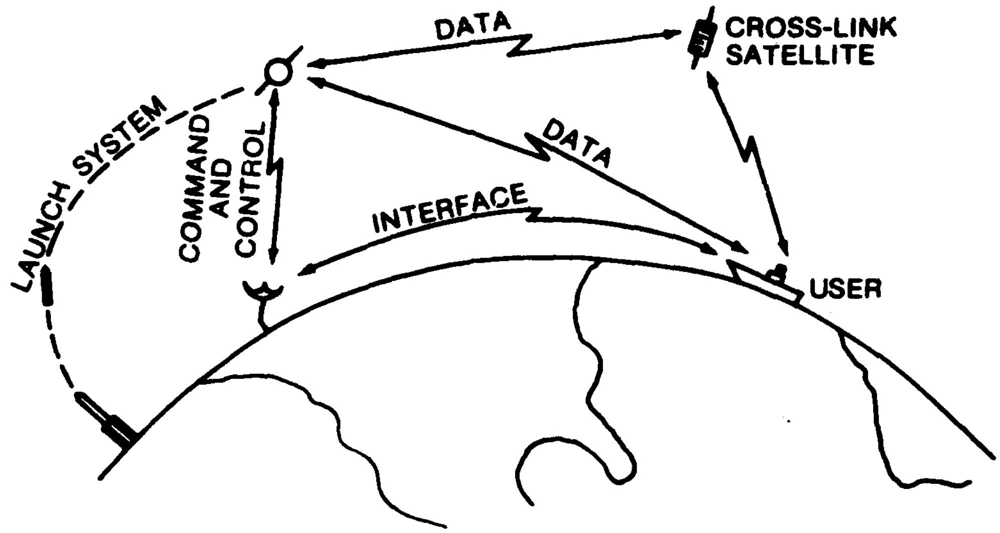


FIG. 2–6. Components of a satellite system.

Launch System

Space systems rely on launch systems or "replenish" on-orbit satellites. The frequency of replenishment depends on the satellite's design life and its mission. Some low orbit satellites are designed to be short-lived; for example, photo-reconnaissance satellites are often de-orbited every few weeks to return exposed film, and then new satellites are launched to replenish the system. Some communications systems, on the other hand, can function for years without on-orbit replenishment.

Launch systems consist of expendable or re-usable launch vehicles and some type of supporting launch site. Manned re-usable vehicles, such as the Space Shuttle, offer greater flexibility in terms of on-orbit checkout and repair, but expendable launchers are less vulnerable in a hostile environment. Historically, launch sites have been huge, permanent complexes, but other means of launching payloads are certainly possible. Mobile launchers and hardened ballistic missile silos could also be used to support space launches.

Command and Control Segment

Once on orbit, to accomplish its mission a satellite must stay functionally healthy, and it must be controlled and directed toward specific tasks. Many satellites require constant monitoring and intervention to turn systems on and off, to direct maneuvers, to maintain stable pointing attitudes, to function properly in the earth's shadow, to keep proper spin rates, etc. The command and control demands may be so high that the satellite will fail catastrophically within a few hours, like a radio-controlled model airplane, without help from ground controllers. Other satellites, by contrast, can function independently for months, like a tethered balloon.

Ground command and control networks are frequently very complex, consisting of several ground antenna stations located throughout the world and at least one mission control center manned 24 hours a day by experienced engineers and analysts. Some satellites even cross-link with other satellites to communicate to the appropriate ground stations. Normally large sophisticated computers are required to do the complex calculations necessary to keep a satellite healthy. The more tasks a satellite can accomplish on board—the more autonomous the satellite is—the less dependent it is on ground stations for survival.

User Communication Segment

Part of getting the job done is providing the required information to the user. This task may be as simple as transmitting the data directly, or it may require a satellite cross-link (Figure 2–6). In the case of surveillance and reconnaissance satellites, the data may first have to be processed by a ground station and then relayed to the user in a readable form.

An understanding of all these components of satellite systems will be important when we examine how to defeat a satellite system, in Chapter 4.

3
US AND SOVIET SPACE SYSTEMS: A SATELLITE GAP?

THE SOVIET INTENT

The highly publicized success of the Apollo moon-landing program and the near flawless performances of the Space Shuttle have created the public view, at least within this country, that the United States is clearly leading the Soviets in the exploitation of space. After all, the Soviets still haven't been able to land a man on the moon and their reusable shuttle vehicle is apparently still on the drawing board.[1] But let's take a close look at some hard data. Figure 3–1 graphically shows the comparison between the annual number of space payloads launched into orbit since 1971 by the Soviet Union and the number launched by the United States. Surprising? Many critics claim that this comparison is meaningless because the United States launches sophisticated, multi-mission satellites as a single payload, while the Soviets launch relatively simple, single-purpose satellites which are short-lived. In 1981 the Soviets orbited seven new payloads for every one new US payload; perhaps more impressive is the annual payload weight the Soviets place in orbit—660,000 pounds—ten times that of the United States. Even US high technology cannot compensate for this differential in launch rate.[2] Since 1958 the Soviets have launched 1686 payloads to 945 for the United States, and of these payloads, 71% were launched since 1970, versus only 29% for the United States.[3] (See Appendix for the payload launch statistics for the period 1971–1981.)

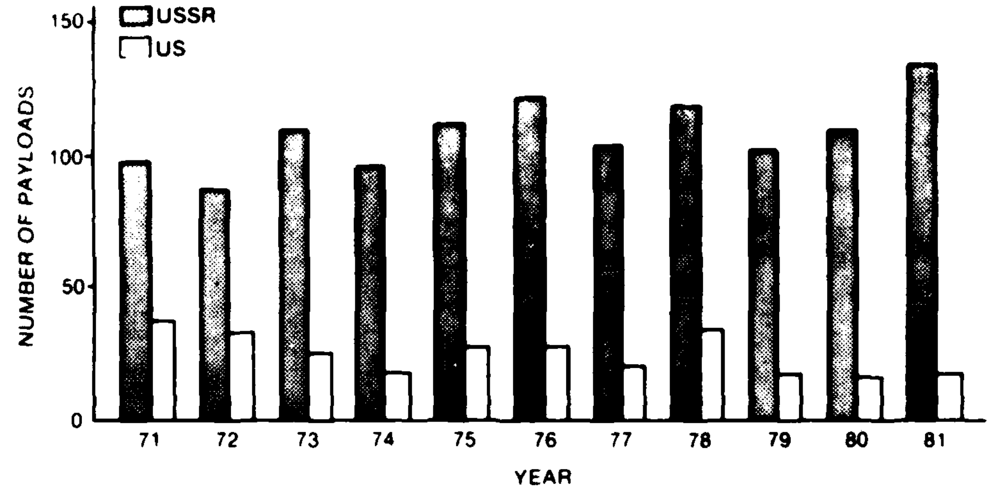


FIG. 3–1. Comparison of U.S. and Soviet Payload Launch Rates, 1971–1981. (Source: *Norad Space Computation Center Satellite. Catalog,* 1 April 1982)

What do all these figures really mean? Who's actually ahead in the military race to dominate space? To answer these questions, we must first look at how space doctrine is incorporated in the overall military doctrine of the two superpowers.[4] From the beginning, the Soviet space program has been dominated by the military and, although a separate space doctrine does not exist, Soviet space activities are dictated by the general doctrine which guides the rest of the Soviet military—augmenting the three mission areas of force enhancement, command and control, and force projection. Included in force enhancement are the navigation, surveillance, and reconnaissance missions discussed in Chapter 2. Force projection implies the employment of combat systems in space. The apparent differences between Soviet space efforts and those of the United States in these three mission areas are subtle, yet significant. First, the Soviets have well-defined military requirements for space systems which "pull" the development of their specific space systems. The United States, on the other hand, has let technology "push" the development of many space systems without clearly defined military requirements. The resulting Soviet systems—crude by US standards—are simple, rugged, and effective in performing specific mission requirements. US systems, by contrast, are frequently capable of "gee whiz" performance, but are often complex and expensive. Second, the Soviets are reluctant to declare any military capability obsolete; so even when they develop a new space system that does a specific mission better than an old ground-based system, they keep the old system, too. The Soviets are, therefore, less dependent on their space systems than the United States is. Third, the Soviets have continually used military men in space. As of January 1982, the Soviets had launched 41 manned Soyuz flights and have had military men in space almost continuously since 1971.[5] The three short US Space Shuttle flights in 1981 and early 1982, by contrast, marked the first US manned space flights since the Apollo-Soyuz mission in 1975. Finally, the Soviets have demonstrated their intent to project military strength through exploitation of space combat systems. The best indicator of intent is the operational Soviet anti-satellite (ASAT) program with its proved capability to intercept low earth orbit satellites with killer satellites. Some sources even claim that the Soviets are now operating an ASAT battle station with multiple infrared guided interceptors.[6] The US ASAT system has yet to get off the ground; in fact, the United States has made no final decision whether to deploy its ASAT.[7]

The Soviet intent to dominate space is clear. Since Soviet Premier Khrushchev spelled this out in the early 1960s, Soviet progress has been slow, but consistent. How close the Soviets are to achieving dominance depends, of course, upon current capabilities of US and Soviet space programs and on future trends.

CURRENT STATUS

In the areas of communications, navigation, reconnaissance, and in some surveillance functions, the technological advantages of the United States have enabled us to maintain a substantial lead over the Soviet Union. The Soviets, meanwhile, have developed a superior capability to perform ocean surveillance, particularly of US naval forces, and they have the only operational ASAT program in the world. Many experts think the Soviets are well ahead in the development of directed-energy research, namely, laser and particle beam weapons.[8] Their progress is uncertain, but there is no doubt that the Soviets are outspending the United States in developing these weapons.

Although the overwhelming superiority of the Soviets in numbers of payloads launched does not necessarily mean that the Soviets are winning the space race, it does demonstrate a superior launch capability. Not only do the Soviets launch more payloads, they also place heavier payloads in orbit. The Soviets, with a full stable of already proved launch vehicles, are continuing development of larger, more efficient rockets.[9] In contrast, the US stable has one reliable thoroughbred, the Space Shuttle, and many empty stalls. The policy not to develop any new space launch vehicles has left the United States with few expendable launchers in reserve.[10] If the operational deployment of the Space Shuttle falls any further behind schedule, the US may have to delay placing currently planned payloads in orbit.

The much touted technology advantage of the United States over the Soviets in space development has narrowed markedly over the past decade. Although the United States still maintains a comfortable lead, the Soviets have made significant advances through their own research and development efforts and through the "technology transfer" obtained directly from US and foreign manufacturers.[11] Most gains the Soviets have made in microelectronics have been the result of this technology transfer. The US technical lead still exists, but it narrows every year.

In the last decade, US policymakers have been faced with the dilemma of wishing to reserve space for peaceful purposes and needing to exploit space militarily. In a time of limited resources and a sluggish economy, military space advocates have had difficulty pushing their programs through the fiercely competitive budget process. The lack of either a central space organization or a definitive military space doctrine has further hampered these efforts. The Soviets, by contrast, face few of these obstacles, and Soviet space advocates have little difficulty funding military space programs. The important effect is not that the Soviets are spending more for space than the United States, which they are, but that they get more *military* capability for their space dollar than the United States does.

Because the Soviets use many simple, single-mission payloads for their military space missions and are reluctant to retire obsolete back-up systems, their total orbital force structure is less vulnerable to attack than that of the United States. This security is particularly true of space-based communications systems. Our heavy reliance on a few highly sophisticated communications satellites, to carry approximately 70% of all US military communications, for example, makes the US communications systems particularly vulnerable to attack. A lesser Soviet reliance on their space-based communications systems coupled with their extensive launch resources, makes overall Soviet military communications capability less vulnerable to attack.

FUTURE TRENDS

The outcome of the US-Soviet race for space will depend primarily on the outcome of the US Space Shuttle program and on the ability of the Soviets to close their "technology gap." A successful Shuttle program would provide the US with the capability to place more and larger payloads in space and would provide the flexibility to service these payloads in orbit or return payloads to earth for reconfiguration. With this capability would come a significant advantage. Also necessary, of course, is the upper-stage capability to place large payloads in medium and high altitude orbits. The current Inertial Upper Stage (IUS) program which would provide this boost capability has been fraught with cost overruns and developmental problems.

The Soviets, on the other hand, are pushing to expand their launch capability to blast three to four million pounds into orbit annually. If they decide to attain this launch capability and succeed in closing the technology gap, they clearly will surpass the United States in developing a military space capability.

Although today any existing satellite gap favors the United States, primarily because of the giant leap taken in the 1960s, the space race may develop a classic irony. The consistent, determined progress of the Soviet tortoise in exploiting space may ultimately lead to victory over the American hare.

4
HOW TO DEFEAT A SPACE SYSTEM

The ultimate goal of defeating any space system is to prevent the product of that system from reaching the user by neutralizing the space segment, the ground segment, or the communications-command-control (C3) link between the two. In planning the method of attack, two factors are critical to a successful strategy. First, the attack strategy must be cost-effective. It may not make sense, for example, to target a geosynchronous communications satellite system with several large anti-satellite boosters if that system can be just as effectively defeated by electronic jamming. Second, the strategy must minimize the risk of escalating the level of conflict. For example, during a limited conventional conflict, a direct attack on the command and control facility of a tactical reconnaissance satellite may result in a totally different enemy response than a more subtle laser attack against the satellite's optical sensors. The net result is the same; yet, the latter attack is much less risky. So the attacker will want to defeat a space system in the cheapest way without risking unexpected conflict escalation.

This chapter will first focus on the methods of defeating the space segment, the ground segment, and the C3 link between these two segments, and then will conclude with a brief discussion of effectiveness of each threat during different levels of conflict.

NEGATING THE SPACE SEGMENT

Knocking out the satellite is obviously the most straightforward way of defeating a space system. But before we can attack satellites directly or "spoof" their systems, we must have a space targeting system to tell us both where the satellites are and what the probable mission of each is.

TARGETING NETWORK

You can't direct a weapon against a satellite unless you know where it is. Unfortunately, keeping track of satellites in space is more difficult than most people realize. The problem is sorting out the few hundred active payloads from the 4500 trackable objects, all of whose orbits are to varying degrees changing because of maneuvers, drag, and small perturbations. NORAD uses about 30,000 observations each day from radar and optical trackers located throughout the world and tries to fit these observations to known objects through use of complex computer algorithms. The Soviets have a similar system. The tracking problem is further complicated because active satellites frequently make unannounced maneuvers, are launched without prior notification, and are difficult to distinguish from debris and inactive satellites. The higher the altitude of a satellite, the more difficult it is to track. Geosynchronous satellites, for example, are not routinely tracked by radar because they are out of range of most surveillance radars. These satellites are normally tracked optically, a process subject to both weather and lighting conditions. As a result, the higher a satellite the more inaccurate its track and, hence, the more difficult it is to target. Only when a satellite has been identified and continuously tracked can it be targeted.

SPOOFING

Spoofing is a subtle, effective means of defeating a satellite. Spoofing is either controlling an enemy satellite directly or making the satellite—or the ground controller managing the satellite systems—think that an on-board system needs to be controlled when it actually does not. For example, if you know the correct frequencies, codes, and transmission sequences to control the maneuver engines of an enemy reconnaissance satellite, then when the satellite is over your territory, you simply send a transmission to fire the engines. The satellite will either become disoriented or lost, or will burn all its fuel. The advantage of spoofing an enemy satellite is that the enemy may never know what happened. Even if he suspects foul play, he may have difficult proving it.

DIRECT ATTACK

Direct attack by a variety of ASAT weapons is the surest way of killing a satellite, but also the most expensive. Direct attack includes employing directed-energy weapons, orbital interceptors, and space mines.

Ground-based Directed-Energy Weapons. Directed-energy weapons use either coherent-light energy (laser) or particle-beam energy to irradiate and damage the target satellite. Both these weapon systems require enormous amounts of power and accurate pointing systems to keep the beam on target. Range is limited because of atmospheric dispersion and attenuation of the beam. The advantage of these weapons is that, once developed, they can instantaneously damage or interfere with any low earth orbit satellite passing over their position. Laser weapons can be effective against satellite sensors and solar panels, while particle-beam weapons have the potential to destroy systems internal to the satellite. Both weapons demand precise targeting information and extremely accurate pointing systems to find and then to eliminate their target.

Orbital Interceptors. Using conventional, nuclear, or impact warheads, orbital interceptors kill a satellite by a direct one-on-one attack. Manned interceptors can knock out a reconnaissance satellite by simply spray-painting the optical sensors or by turning off critical systems. Non-nuclear orbital interception can be accomplished either by direct ascent, as with the US Miniature Homing Vehicle (MHV), or by maneuvering interceptors already in orbit, as with the Soviet killer satellites. In either case, precise targeting information is needed prior to initiating the attack, so that the interceptor comes close enough to the target for its terminal guidance system to take over and complete the intercept. Nuclear interceptors, on the other hand, have a large kill radius—on the order of hundreds of kilometers—and can be targeted at a point in space. In space, nuclear warheads kill by radiation and electromagnetic pulse rather than by blast effect. The disadvantages of using nuclear warheads include possible interference with or destruction of nearby friendly satellites and, in a conventional conflict, unintended conflict escalation.

Orbital interception is a complex and expensive process. The first requirement is an accurate surveillance network to provide precise targeting information. The second is a sophisticated launch vehicle with enough booster capability to place the warhead on target (in the case of geosynchronous targets, this vehicle may be quite large). The third requirement with a conventional warhead is a complex terminal guidance system to complete the intercept. In short, orbital interception is not easy, and it's not cheap.

Space-based Directed-Energy Weapons. Multiple-shot laser and particle-beam weapons mounted on a satellite platform pose a unique threat. With little atmospheric dispersion or attenuation, these weapons have a built-in defense against orbital interception. Power requirements, pointing accuracy, and targeting information still present significant challenges, but such a weapon, particularly if manned, would be formidable.

Space Mines. After launch, a space mine stays dormant in the vicinity of the target satellite (within 1000 km). When the time to attack comes, the mine is switched on, locks onto the target satellite, maneuvers within lethal range, and explodes its conventional or nuclear charge. Satellites at geosynchronous altitude are particularly vulnerable to space mines.[1]

Table 4–1 shows the vulnerability of the four popular military orbits to each satellite threat. Here C stands for current threat, either demonstrated or within current capability, P denotes potential threat before the year 2000, and (-) means no threat, either current or potential. All of these threats involve complex, high-technology weapons systems that are expensive both to develop and to deploy.

	ORBIT			
THREAT	LEO	SEMI-SYNCH	MOLNIYA	GEOSYNCH
Spoofing	C	C	C	C
Ground-based directed energy	C*	-	-	-
Space-based directed energy	P	P	P	P
Orbital Interceptor	C	C	C	C
Space Mine	-	-	-	C

**Only current threat is low-power laser capable of damaging some sensors on low earth orbit satellites.*

TABLE 4–1. SUMMARY OF VULNERABILITY OF MILITARY ORBITS

As I will discuss in Chapter 5, spoofing is relatively easy to counter; the remaining threats, however, are more difficult to defeat.

ATTACKING THE GROUND SEGMENT

The objective of attacking the ground segment is to incapacitate either the command and control ground station or the user's communication ground station. Negating either of these links in the space system chain will stop the user from getting the product. The attack can be subtle, as in the form of sabotage, or direct, as in terrorist, conventional, or nuclear action. In either case, the ground station must be accessible to the enemy and it must be critical to the continuing operation of the space system. A mobile ground station, for example, may not be accessible. Or a satellite system that can operate autonomously for long periods without command and control may be unaffected by loss of its command and control ground station.

SABOTAGE

Most fixed ground stations are dependent upon central support systems for continuous operation. In many cases, sabotaging one of these support functions is relatively simple; in fact, it may be difficult to detect as an overt act. Since many satellite systems are dependent on nearly realtime command and control for continued operation, any interruption of this link could degrade satellite operation and ultimately lead to the loss of the satellite. So sabotage can be an effective method of degrading or negating an enemy's space capabilities prior to actual outbreak of hostilities. Sabotage is particularly attractive because it's cheap and, when operating against a free and open society such as the United States, it's easy.

DIRECT ATTACK

Depending upon the level of conflict, direct terrorist, conventional, or nuclear attack can be effective in defeating any space system that relies on a fixed ground station for its operation. Terrorist attacks can be particularly effective because they can be disguised to avoid identifying an aggressive act with a particular nation, thus avoiding confrontation between nations. Conventional attacks are most likely during limited theater conflicts against those stations located in that theater. Nuclear attacks, on the other hand, would be most effective against homeland stations immediately prior to a global nuclear war.

JAMMING THE COMMAND, CONTROL, OR COMMUNICATIONS LINK

One of the most effective means of defeating a space system is to jam or block the communications link between either the satellite and the user or the satellite and the ground command and control station. Electromagnetic interference, exoatmospheric nuclear detonation, and elimination of communications relay satellites are all effective methods of blocking communications.

ELECTROMAGNETIC INTERFERENCE

The principle of electromagnetic jamming is to saturate the airways with electronic noise at the same bandwidth that the enemy is using to communicate. This same technique has been used for decades to block undesired propaganda broadcasts. The higher the frequency, the more directed the communications broadcast becomes and the more difficult it is to jam. Essentially, as the frequency goes up, the beam becomes narrower, forcing the jammer to move closer to the receiver or transmitter. Making the jammer mobile allows it to get closer to the broadcast beam. A trawler located a few miles off shore, next to a major satellite control facility or a remote telemetry site, for example, could be very effective in jamming communications with several satellites. Jammers operating from orbiting satellites would be even more effective against the C3 link. The advantages of electromagnetic jamming are its potential effectiveness and its low cost and risk.

EXOATMOSPHERIC NUCLEAR DETONATION

High altitude (above 40 km) nuclear bursts have the effect of jamming satellite communications by absorption or scintillation of the broadcast frequency. This effect can last from seconds to hours depending on the frequency transmitted—the higher the frequency, the shorter the duration of the interruption. A single detonation can have widespread effects: for example, a one-megaton detonation at 100 km above the central United States can block UHF communications for almost 30 minutes over the entire country.[2] Even though such a burst would appear to be no more than a momentary flash, it would not likely go undetected and would, therefore, risk escalation to nuclear war.

NEGATING RELAY SATELLITES

If a particular space system relies on a communications satellite to relay communications to either the user or the command and control ground station, then that satellite becomes a critical node whose loss would effectively defeat the space system. If a single communications satellite or satellite system serves as the relay for several other space systems, then it becomes a high priority target and should be defeated by the most cost-effective method of those discussed earlier.

Another way to look at threats to space systems is to analyze each threat during the period prior to a global nuclear exchange when all home-based space assets—primarily the space targeting network and the command and control facilities—are still intact. Under these conditions, *all the threats* discussed earlier are active threats; however, after the initial exchange of nuclear weapons, the picture changes significantly. Because we'll have lost our targeting network and will no longer know where the enemy satellites are, we'll have to rely primarily on jamming, detonating pre-positioned space mines, or launching surviving nuclear warheads targeted against points in space corresponding to the last known enemy satellite positions. Any enemy satellites launched or activated after the initial nuclear exchange will be difficult to defeat because their existence will probably go undetected.

Now that we've looked at how to defeat space systems, we can switch sides and analyze how to defend our own satellites against these threats.

5
MEETING THE THREAT

No space system is immortal. If the enemy desires, he can expend enough resources to defeat any system; however, a range of strategies exists to minimize system vulnerability. The advantages and disadvantages of each strategy depend upon the mission of the space system and the projected level of conflict. The purpose of this chapter is to study the merits of each strategy separately and to analyze how well each meets the threats presented in the last chapter.

DOING NOTHING

On the surface, doing nothing to protect space systems appears naive. Yet it might be appropriate for selected space systems that do not have a vital wartime function under certain scenarios. For example, a high resolution reconnaissance space system may no longer be necessary after the outbreak of global nuclear war. Or the nation may decide that insuring survivability of certain capabilities in space may not be as cost-effective as either doing without or finding some other means to perform the same function. The basic tenet of this strategy is a willingness to lose the capability provided by the space system, forcing the development of a national strategy designed to operate without these space assets or to use an alternate capability. In the example of reconnaissance satellites, an alternative capability might be provided by high altitude reconnaissance aircraft, since violation of airspace would no longer be a restriction during global war. The key to this strategy is identifying these expendable assets and planning accordingly.

DETERRENCE

Deterrence as a strategy is conceptually simple: you protect your space systems by telling the enemy that if he gets yours, you'll get his. Maintaining any deterrent space defense posture has two fundamental prerequisites. First, the enemy must value and rely on his space systems as much or more than you do, and, second, you must have the capability to negate his systems. Deterrence is a cheap way to make space systems "survivable." It does, however, have serious pitfalls. Deterrence is not infallible—a rapid development in enemy capability can create a "window of vulnerability" through which the enemy can defeat your systems, while preventing your retaliation. Countervalue deterrence based on threatening other assets (if you shoot down my satellite, I'll mine your harbors) may be unconvincing, difficult to implement, and result in unplanned escalation.

A deterrent space strategy presents a unique problem: detecting enemy interference. It's difficult to maintain deterrence if you don't know whether your spacecraft just failed accidentally or the enemy interfered with it. To foil a clever enemy, sensors which detect interference—impacts, laser illumination, nuclear detonation, and other aggressive acts—must be installed on all military space platforms.

A deterrent space defense strategy is an option only provided the enemy believes that potential losses as a consequence of his actions far exceed any gains he may achieve. In short, a deterrent strategy in space must be founded on capability, not on bluster.

NEGOTIATION

As a space survivability strategy, negotiation can serve two purposes: it can put a cap on the number of enemy assets, and it can specifically prohibit any interference with space assets. Negotiating arms limitations can be cost-effective in limiting a potential arms race in space by stunting the growth of ASAT weapons, but it certainly cannot guarantee survivability.[1] The main drawback of relying on negotiation is the difficulty of verifying compliance with arms agreements. Converting a directed energy anti-aircraft weapon to an ASAT weapon or a low altitude orbital interceptor to a high altitude one is not technically difficult and could quickly throw open a large window of vulnerability. Nor does negotiation make ground stations less vulnerable. And, of course, during actual hostilities, arms limitation agreements are of little value.

Negotiating an agreement not to interfere with each other's space assets prevents the enemy from practicing his interference techniques during peacetime, a valuable arrangement because any interference immediately raises a warning flag that the enemy may be initiating an attack. Without such an agreement, the enemy could constantly practice interference, thereby masking his aggressive intentions, while at the same time decreasing the effectiveness of routine space systems, especially intelligence satellites.

Any negotiated arms limitation must be based on a position of strength. An agreement limiting ASAT development, for example, would be of little use if one side had no ASAT capability. The I-won't-develop-mine-if-you-don't-use-yours philosophy would be a one-sided agreement, of questionable value to "my" side.

HARDENING

Hardening is aimed at making the ground segment, space segment, and the C3 link less vulnerable to physical attack. Hardening can do little to defend against a one-on-one nuclear attack, but it can eliminate or reduce the probability of success of a "cheap shot." We can't guarantee 100% survivability, but we can make it expensive for the enemy to defeat our systems.

GROUND SEGMENT

Because they need exposed C3 antennas, permanent ground stations will always be vulnerable to direct nuclear or conventional attack. Preventing electromagnetic pulse (EMP) coupling from high-altitude nuclear bursts and minimizing the vulnerability to sabotage and terrorist attack are two ways of hardening the ground segment.

Prevention of EMP Coupling. High altitude nuclear bursts generate an electromagnetic pulse which can couple into unprotected circuits and cause either circuit upset or burnout. Incorporating faraday-cage, filter, surge-arrestor, waveguide-cutoff, and fiber-optic technology in ground site design can provide significant protection against this threat. The problem is cost. Hardening new facilities to meet global EMP protection standards requires an additional 10% of the total installation cost. Retrofitting current sites is even more expensive, and maintenance to insure the integrity of EMP protection requires additional funds.[2]

Hardening Against Sabotage and Terrorist Attack. Susceptibility to sabotage and terrorist attack can be minimized by proper site location and design, and by increasing physical security. Locating ground stations away from urban areas and in terrain easy to defend can make sabotage and terrorism more difficult. The best way to defend against both sabotage and terrorism, however, is to eliminate critical operational nodes within the ground station by employing redundant and backup systems.

SPACE SEGMENT

Although satellites will always be vulnerable to a direct nuclear attack, hardening can reduce the vulnerability to orbital interceptors, laser illumination, and nuclear radiation effects.

Defeating Orbital Interceptors. They key to defeating an orbital interceptor is first to know that he's coming. Once you know he's coming, then the object is to defeat his terminal guidance system, which will be radar, infrared, or optical. Radar guidance can be jammed, and infrared can be fooled using decoy heat sources. Defeating optical guidance systems requires stealth technology. The main problem is anticipating which countermeasure to use. Once you've designed your system to defeat a given terminal guidance threat, employed that system on your satellite, and launched the satellite, you may find the enemy changing frequency, wavelength sensitivity, or design of his terminal guidance. Your countermeasures have become obsolete, and retrofit of an orbiting satellite is difficult! The problems of adequate warning of impending interception and the need for long-lived countermeasures make countering orbital interception an impractical way to increase survivability.

Laser Hardening. 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. Shielding against particle-beam weapons, on the other hand, is not effective because the particle beam penetrates shielding easily and causes molecular damage to components within the satellite. Some protection against directed energy weapons may be afforded by spinning the satellite when it comes under attack, thereby spreading out the effect of the energy beam. Such action would, of course, degrade the mission performance of many satellites.

Nuclear Effects Hardening. Radiation from nuclear detonations causes EMP and trapped electron effects that reduce spacecraft life by creating noise in sensors and by destroying electronic components. These effects can be mitigated by hardening electronic components, shielding sensitive parts, and designing the system to withstand increased radiation. All of these concepts are within the state-of-the-art and, when employed, reduce the probability of the enemy achieving multiple kills with a single nuclear burst.[3]

C3 Link

Anti-jamming measures can enhance the survivability of the C3 link by overcoming enemy electromagnetic countermeasures and limiting the disruptions from exoatmospheric nuclear detonations. Transmitting at Extremely High Frequency (EHF) decreases the debilitating effects of nuclear scintillation and absorption from minutes to seconds. Using EHF also narrows the transmission beam such that a jammer has to be almost in the line of sight between the transmitter and receiver. Using even higher frequency communications yields similar results—jamming must physically interrupt the beam to block the signal. Automated fast frequency hopping can also make jamming more difficult, but is not as effective as transmitting at EHF or higher frequencies. All these measures require great expenditures, both for design and building of new transmitters and receivers and for retrofitting thousands of existing transmitters and receivers.

Enemy spoofing efforts, on the other hand, are not so difficult to defeat. Encrypting command and control transmissions is relatively inexpensive and, with today's technology, can be 100% effective against spoofing.

MOBILITY AND MANEUVER

Employing mobile ground stations and satellites with increased maneuver capability can greatly improve the survivability of both the ground and space segments.

MOBILIZING GROUND STATIONS

Assuming their locations remain covert, mobile ground stations essentially counter the threats of sabotage, terrorist, and direct conventional or nuclear attack. The problems in making both user and command and control ground stations mobile depend on the mission of the space system. The worst case is a low altitude reconnaissance satellite that requires both frequent command and control and a great deal of processing to get the reconnaissance information into usable form. In this case, the mobile command and control station would have to be manned by highly trained personnel, would have to possess extensive computer hardware and software capability, and would require sophisticated means of communication with both the user and the satellite. A mobile user ground station would have similar requirements to process the data. Although these capabilities are within the current state-of-the-art, they are both expensive and manpower-intensive.

The higher the satellite, the easier it is to control; so it's simpler to make the satellite's ground station mobile. Likewise, the simpler the satellite mission, the easier it is to make the user stations mobile. A high altitude weather surveillance satellite, for example, needs little command and control or data processing to maintain orbit or send weather pictures directly to mobile user terminals. In short, the more dependent the space system is on ground stations, the more expensive protecting its C3 link will be.

MANEUVERABLE SATELLITES

Adding a maneuver capability to satellites decreases their vulnerability to orbital interception, particularly if the satellite is in a medium altitude orbit or higher. Although maneuver of LEO satellites complicates the enemy's targeting problem, the difficulty is obtaining sufficient warning to enable a maneuver prior to interception. Intercepting satellites in higher orbits requires a much longer time of flight, provides more warning time and, therefore, provides more time for the satellite to maneuver out of range of the interceptor's terminal guidance system. Minimum time of flight to geosynchronous altitude, for example, is from three to six hours. A small maneuver a couple of hours prior to interception can place the target well out of range.

The disadvantages of adding maneuver capability to satellites are two: payload weight is sacrificed for additional fuel, and satellites requiring precise pointing or position information suffer degraded performance during maneuvers. Furthermore, maneuvering offers little protection from attack by directed energy weapons.

Maneuver capability does little to counter the threat of space mines targeted against geosynchronous satellites, since the mines would be co-located with the targets, and little, if any, warning time would be available to maneuver out of range. The best defense against a space mine is to avoid using geosynchronous orbits for satellites performing wartime missions. This defense is quite drastic because the unique advantages of geosynchronous orbits would be sacrificed. To provide approximately the same coverage as three geosynchronous communications satellites requires eight satellites in Molniya orbits (or four to provide the same coverage in just the Northern Hemisphere). Since these communications satellites would no longer appear stationary to earth observers, additional costs would be involved to enable the ground antennas to track the now-moving satellites. Although mines placed in orbits other than geosynchronous would still be a threat, any such action would immediately telegraph enemy intentions because a geosynchronous orbit has only one orbital plane, with an exact altitude of 35,800 km. Placing a payload next to another satellite in this orbit can be easily justified based on mission requirements alone. Doing the same thing in a Molniya orbit, however, can't be justified because an infinite number of other orbits would satisfy the same mission requirements.

Another alternative is to place satellites in orbits at altitudes higher than geosynchronous. Like the Molniya orbit, these higher orbits are less vulnerable to space mines and also difficult to intercept by direct attack. First, the time of flight for interception would be high—on the order of a day—which would provide adequate warning of attack; second, these satellites would be hard to track accurately and, therefore, difficult to target. Satellites placed in these higher orbits, say at 100,000 miles, could be stored at these high altitudes until needed and then maneuvered down to lower altitudes during wartime.

AUTONOMY

The objective of developing autonomy in satellites is to eliminate vulnerable and expensive fixed ground stations and provide more direct interface with the users. The more functions a satellite can perform on board to provide its own command and control and data processing, the less dependent it becomes on support from ground stations. Incorporating redundant, fault-tolerant processors and housekeeping software on board the satellite reduces external command and control requirements. Such a satellite performs its own health management, positioning, and command sequencing. Adding on-board data processing can also enable the satellite to interface directly with its user. The initial investment required to develop autonomous systems is significant, but the long-term potential is for reducing system cost and increasing system survivability.

PROLIFERATION AND DECEPTION

The fundamental principle behind the strategy of proliferation and deception is to complicate the enemy's targeting problem: proliferation gives him too many targets to kill, and deception prevents him from finding targets. These methods can be employed both for ground stations and satellites.

GROUND STATIONS

Making satellites more autonomous (and, therefore, less dependent on ground stations) and using advanced microelectronics technology allow simpler, more compact ground stations. Eliminating critical single-node segments of the ground network by using mobile, redundant ground stations, each of which can control more than one satellite system, will significantly decrease space system vulnerability. Adding deceptive tactics, such as using decoy ground stations and hiding mobile ground stations, will further complicate the enemy's targeting problem and increase space system survivability. The disadvantages of employing a mobile, redundant ground network are additional expense, increased manning requirements, and the need for a coordinated, centralized control.

SATELLITES

Orbiting many small simple payloads and piggy-backing payloads on other satellite platforms are two means of proliferation. Many missions, including some surveillance, communications, and reconnaissance functions, can be accomplished by relatively simple, small payloads. A single launch vehicle can place several of these payloads in orbit as individual satellites, or the payloads can take advantage of the support systems provided on large satellites and be scattered around on several different large platforms. In either case, the net effect is to proliferate potential targets, forcing the enemy to expend more resources to kill the space segment of a satellite system.

Combining proliferation with deception has the potential of making the space segment practically invulnerable. To illustrate, let's look at two examples. We can launch a few payloads and hide them in space—hide them by using techniques of minimizing both the radar and optical return and by using only cross-link communications to relay information to and from ground stations. Specifically, we can launch two payloads, one normal satellite and one "invisible" satellite, into geosynchronous orbit with a single launch vehicle. When the destination orbit is reached, we separate the two payloads covertly, but communicate only through the announced payload. The enemy never knows the other payload is there. An alternative approach would be to launch many small, single-mission payloads using one multi-payload launch vehicle. Interspersed with these payloads would be dummy decoys having the same physical characteristics as the functional payloads. All payloads could use small kick motors to randomly disperse their orbits. The functional payloads would remain dormant in orbit until activated when needed during hostilities. If we design all payloads either identical in size, shape, and mass properties or make each randomly different, the enemy would be unable to determine functional payloads from decoys. Upon activation, satellites could be maneuvered to orbits appropriate to their mission requirements.

Proliferation and deception are valid survivability strategies only for relatively simple, low-cost payloads. Proliferating complex, high-resolution reconnaissance satellites, for example, would be prohibitively expensive, as would large, multi-channel communications satellites. This strategy would be suitable, however, for simple communications relay, nuclear detection, and tactical reconnaissance missions.

RECONSTITUTION

Reconstituting essential space assets after hostilities begin may be the only method of insuring that critical missions survive. Space systems requiring large complex satellites not suitable for proliferation may require backup satellites stored on pre-positioned launch vehicles ready to replace satellites lost to enemy action. Missiles in hardened silos, mobile launchers, or missile-launching submarines offer launch-on-demand capability to reconstitute space assets. The problems encountered with this strategy limit its use to those missions considered absolutely vital. The cost of developing backup satellites capable of long-term storage and the need to dedicate launch vehicles make this an expensive approach. Such a strategy may also require sacrificing missile silos or submarine launch tubes normally used for strategic weapons because of limitations imposed on the total number of these launch facilities by strategic arms limitation agreements. The problems and cost of providing reconstitutable space assets are significant; however, it may be the best strategy for guaranteeing survivability of some space systems.

THE INVULNERABLE SPACE SYSTEM

By employing the strategies discussed here, can we design and deploy an invulnerable space system? Before we answer that question, let's try to match the threats presented in Chapter 4 to the defense strategies analyzed in this chapter for each of the segments of a space system.

GROUND SEGMENT

As shown in Table 5–1, the best defenses for protecting fixed ground stations are to harden against sabotage and nuclear attack by increasing physical security, and to incorporate EMP countermeasures to decrease the vulnerability of the overall ground segment. The key strategy for increasing survivability of the ground segment, however, is redundant mobile ground stations. Ultimately, designing autonomy into satellites decreases dependence on the ground segment and best increases the survivability of the total space system.

THREAT	PRIMARY DEFENSE	CONTRIBUTING DEFENSE
Sabotage	Physical Security Mobility	Satellite Autonomy Proliferation
Terrorist Attack	Mobility	Satellite Autonomy Proliferation
Conventional Attack	Mobility	Satellite Autonomy
Nuclear Attack	Mobility, Harden Against EMP	Satellite Autonomy Proliferation

TABLE 5-1. COMPARISON OF THREAT VERSUS DEFENSE FOR THE GROUND SEGMENT

SPACE SEGMENT

Table 5-2 shows a comparison of selected defenses for each threat to the space segment of a satellite system. This comparison and previous discussion indicate that the optimum combination of strategies would be to employ maneuverable satellites, hardened against spoofing and laser illumination, at medium altitude or higher orbits but not in geosynchronous ones, and to proliferate and decoy to avoid enemy detection and tracking. Further protection against all of these threats can be provided by reconstitutable satellites prepositioned on dedicated, survivable launch systems.

THREAT	PRIMARY DEFENSE	CONTRIBUTING DEFENSE
Spoofing	Hardening	Autonomy
Ground Laser	Hardening Higher Orbits	Proliferation and Deception
Ground Particle Beam	Higher Orbits	Proliferation and Deception
Orbital Interceptor (Conventional)	Higher Orbits Maneuvers	Proliferation and Deception, Hardening
Orbital Interceptor (Nuclear)	Very High Orbits, Maneuvers	Proliferation and Deception
Space Laser	None	Proliferation and Deception
Space Particle Beam	None	Proliferation and Deception
Space Mine	Avoid Geosynchronous Orbit	Proliferation and Deception

TABLE 5-2. COMPARISON OF THREAT VERSUS DEFENSE FOR THE SPACE SEGMENT

C3 LINK

Use of EHF and higher frequencies is one of the best ways to decrease the vulnerability of the C3 link to electromagnetic interference and exoatmospheric nuclear detonations. (See Table 5-3.) Increasing satellite autonomy and making ground stations mobile also make enemy interference more difficult. And, of course, eliminating single critical nodes, such as relay satellites, or protecting these nodes, also adds to the survivability of the C3 link.

THREAT	PRIMARY DEFENSE	CONTRIBUTING DEFENSE
Electromagnetic Inteference	EHF and Higher Frequencies	Satellite Autonomy Mobile Ground Stations
Nuclear Detonation	EHF and Higher Frequencies	Satellite Autonomy Mobile Ground Stations
Loss of Relay Satellite	Proliferation (Elimination of Single Critical Node)	(See Figure 5–2.)

TABLE 5–3. COMPARISON OF C3 LINK THREAT VERSUS DEFENSE

As to the question of whether we can make space systems invulnerable, the answer is a qualified yes—*qualified because we can't* guarantee 100% survivability, but yes because by using a combination of the strategies discussed in this chapter, we can achieve a high probability of survivability. The key element is first deciding what must survive, and then requiring that survivability be a nonnegotiable part of every space program.

6
MATCHING SURVIVABILITY TO REQUIREMENTS

The first and most important step in developing a comprehensive survivability strategy is deciding which assets must survive and to what level of conflict they must survive. Only after completing this process of matching survivability strategies to actual requirements can the strategies discussed in the previous chapter be integrated into a comprehensive survivability plan.

DECIDING WHAT MUST SURVIVE

Anticipating wartime mission requirements for space systems across the spectrum of conflict is the most important task in formulating survivability strategy, and also the most difficult. By looking briefly at the issues involved in the missions of communication, navigation, surveillance, and reconnaissance, however, we can better understand the complex questions and processes involved in determining space system requirements.

COMMUNICATIONS

To determine military communications requirements, we consider both strategic communications, those required by the National Command Authority to maintain the continuity of government and connectivity with strategic forces, and tactical communications, those required by theater and task force commanders for the command and control of their tactical forces. Certain questions need to be answered: What space communications systems must survive to launch retaliatory bomber, missile, and submarine attacks? Must all of these assets survive a first strike? How are surviving strategic forces directed to launch a second strike? How does the NCA receive damage assessments and second-strike targeting information?

Can a naval task force operate without space-based communications? Do local wing and battalion commanders or ships' captains rely on space-based communications to operate effectively in limited theater war? Can the Rapid Deployment Joint Task Force operate without space communications? These are just a few of numerous questions that must be answered to determine which space-based communications systems must survive and for how long.

Navigation

Similar questions arise in determining the survivability of space-based navigation systems. Do strategic bomber forces need these systems to effectively find and destroy their targets? Should space-based navigation systems that enhance ICBM guidance systems be survivable? Can strategic submarine forces function effectively without navigation satellites to update their positions prior to launching their missiles? Navigation satellites offer the potential to significantly increase the combat effectiveness of tactical forces. What effect do such satellites have on the successful employment of these tactical air, land, and sea forces? Space-based navigation platforms can serve as a force multiplier for both strategic and tactical forces; the importance of this effect should determine the level of survivability needed for these systems.

Surveillance

Two space surveillance missions—missile launch warning and nuclear detonation detection—are critical to US national security, but do their respective space systems need to survive across the entire spectrum of conflict? What detection capabilities are needed to execute an effective second strike? What kind of weather information is necessary to support strategic nuclear forces? Do tactical commanders need this same type of information to conduct a theater war? That surveillance from space is vital to warn of impending attack and to provide accurate weather information is undeniable, but the answers to where, when, and for how long this capability must survive are complex.

Reconnaissance

The requirements of strategic reconnaissance systems are significantly different from those of military reconnaissance in wartime.

For example, a high-resolution photo reconnaissance satellite may require camera resolutions of about one foot to obtain valid intelligence information, while a tactical photo-reconnaissance satellite used to follow enemy troop movements or to count tanks and aircraft will certainly have much grosser resolution requirements. Some pertinent questions are: How long must strategic reconnaissance resources survive? What reconnaissance capability do theater and field commanders require at different levels of conflict? Do tactical commanders need satellite reconnaissance data in real time? All these issues must be addressed before resources are expended on survivability measures for reconnaissance space systems.

Once we've decided which space assets must survive and how long they must survive, we then have to choose strategies to make each particular system—communications, surveillance, navigation, and reconnaissance—survivable. And more important, *we must restrict the use of space systems in all exercises and war games to only those assets which will survive.* We defeat the fundamental purpose of war gaming if we "play" with assets we won't have in actual conflict.

MAKING THE SYSTEM SURVIVE

To help a space system survive (remember, we can't ever guarantee 100% survivability), we must maximize the benefits of each strategy discussed in Chapter 5 by integrating parts of each into an overall plan that will meet the survivability requirements at the last cost. No simple task. How do we start? *By first developing and deploying an anti-satellite capability of our own.* Only with such a capability can we maintain a credible deterrent posture and also enter into meaningful negotiation to limit further weapons development in space. Without such a capability, countervalue deterrence (you shoot my satellites, I'll sink your ships) is risky and weak—risky because it can lead to unexpected escalation, and weak because it lacks credibility. Once we have this capability, we can negotiate from a position of strength to obtain specific agreements prohibiting interference with space systems and limiting further development of weapons in space. As in any arms limitation agreement, we must insure that compliance is verifiable and assume that the enemy—in our case the Soviets—will test and push all agreements to the limit.

Next, *we must use hardening, mobility, maneuver, autonomy, and orbit selection techniques on the space system to increase survivability by minimizing the possibility of the enemy defeating the system with one shot.* Both the satellite system and permanent ground stations must be hardened to some level against the EMP effects of proximity nuclear detonations, to eliminate the enemy's capability to defeat multiple targets with a single nuclear weapon, or "cheap shot." Anti-jamming techniques—fast frequency hopping and E.H.F. and higher frequency technology—should be used on vital C3 links. Where possible, the system should use mobile ground stations. Satellite orbits should be high enough to keep satellites out of the range of ground-based directed energy weapons and to provide adequate warning of orbital interception. Satellites in these higher orbits must have maneuver capability to evade direct attack. To avoid the threat of space mines, essential satellites must not be placed in geosynchronous orbits. Future satellite systems should decrease dependence on ground stations by using on-board, autonomous command and control systems. Obviously, trade-offs are involved in incorporating all these techniques into a single space system: you simply can't buy everything. The objective is to look at the entire space system, find the vulnerable links, and incrementally strengthen these links by adding appropriate survivability measures.

After exploiting these measures, the next level to increase space system survivability is *using proliferation, deception, and reconstitution to insure continuing capability throughout all levels of conflict.* If the payloads of a particular space system are relatively simple and numerous, such as communications and navigation satellite systems, then we can exploit the unique features of the Space Shuttle to proliferate and decoy these payloads. For example, to insure communication connectivity with strategic forces through all levels of conflict, we can use the Space Shuttle to deploy a proliferated system of small communications satellites which would remain dormant in orbit until required to send out emergency action messages to strategic ICBM, bomber, and naval forces. The Space Shuttle could carry several of these small satellites into orbit on a single launch. Astronauts could check out the satellites while still in the payload bay and then activate small kick motors to send each satellite into a different orbit. Interspersed with each group of real satellites would be several decoy payloads as described in Chapter 5. Seventy-five such payloads—25 actual communications satellites and 50 decoys, randomly placed in orbits between 500 and 600 km—would make this communications capability practically invulnerable to orbital interception. If deceptively deployed, these satellites might be impossible to properly catalog and track, and thereby not vulnerable to directed-energy weapons. Adding pop-off shrouds to each payload would provide additional protection against laser illumination and would frustrate attempts optically to discern real payloads from decoys.

The disadvantages of such a proliferation strategy are considerable. Such a scheme will be economically feasible only for simple payloads in low earth orbit. Although the Space Shuttle will have extra payload space to accommodate small payloads, the problems of integrating these payloads to be compatible with the primary Shuttle payload are complex. Just a few of the factors to be considered in deploying mixed payloads with the Shuttle are electromagnetic interference between payloads, "outgassing" or leaks of harmful materials, and maneuver requirements. The Shuttle offers such an advantage in launch capability, however, that we cannot allow these problems to hinder the full military exploitation of this system. Of course, if proliferation and deception tactics are used to make the space segment survivable, then a similar effort must be extended to the supporting ground stations. Proliferating these stations, keeping locations covert, and using mobile stations where possible will add the same level of protection to the ground segment. Likewise, the C3 link must use multiple satellite cross-link and anti-jamming techniques to insure that the entire space system has the same level of survivability.

For space systems unsuitable for proliferation and deception, particularly those requiring a few complex satellites, reconstitution is the only method for increasing survivability. As explained in Chapter 5, these satellites will be pre-positioned on hardened launch vehicles for possible deployment after the initial assets have been lost. The primary disadvantage of this strategy is its expense. Launch vehicles must be dedicated solely to a particular payload and payloads must be constantly checked and monitored to insure they will function after launch. The launch system must be properly hardened or deceptively deployed to survive attack. The command and control network necessary to launch the vehicle and get the satellite working when in orbit must be maintained. These problems notwithstanding, reconstitution is the only way to guarantee continuity of operations for certain crucial space missions.

An effective survivability strategy must begin with the decision of which space-based capabilities must survive to support strategic and tactical forces throughout the spectrum of conflict. Following this decision, we must develop an overall survivability plan for each space system. And most important, this plan must be strictly enforced during all stages of design, development, and deployment of the space system.

PAYING THE PRICE: AN EPILOGUE

As we have seen, determining survivability requirements and picking the right strategies to meet these requirements are not simple tasks, but neither one is as difficult as actually implementing the chosen strategy. As of 1982, more thnn twenty government agencies are involved in some way in establishing requirements for space systems. Realizing that the Army, Navy, Air Force, State Department, Defense Intelligence Agency, National Security Agency, Central Intelligence Agency, and others all have valid communications requirements essential to the national security, how can anyone determine which of these agencies will pay the expenses necessary to insure survivability of these communications capabilities? Or how can anyone decide who will pay for making multi-user navigation satellite systems survivable? The problem of getting these agencies to share the cost of developing the capability has already proved difficult; devising a method of sharing survivability costs will be even more difficult. Many users have the view that survivability would be nice to have—as long as it doesn't cost them anything.

Making space systems survivable also involves trade-offs between survivability and primary mission capability. Adding maneuver capability, hardening against laser illumination and EMP, and installing sensors to detect attack all take valuable weight and space that could otherwise be used to increase mission capability. Satellite program managers are constantly faced with the dilemma between satisfying the user by getting every possible ounce of capability out of a system and making the system survivable enough to do the mission it was designed for. Survivability adds nothing at all to capability in a peacetime environment and is frequently the first to suffer during program budget cuts or cost overruns. Paying for survivability is like buying auto insurance—if you don't expect to have an accident, it doesn't seem worth the price.

A PARALLEL

The recent emphasis on the resurgence of US naval power presents an interesting parallel to the issue of survivability of space systems. Take, for example, the naval Carrier Battle Group (CBG), the mainstay of naval sea power. The mission of the CBG is threefold: to show US presence, to maintain control of the sea, and to project power to any area of the globe. The primary offensive capability to perform these missions is provided by the aircraft aboard the aircraft carrier, the heart of the CBG. Typically, this carrier is armed with approximately 20 to 30 attack aircraft, 15 fighter aircraft, two photoreconnaissance aircraft, and 20 support aircraft for air refueling, electronic countermeasures, and anti-submarine warfare.[1] So a typical carrier has about 35 to 45 actual warfighting aircraft. From 1 to 3 supply ships are also necessary to provide the carrier and its complement of aircraft with fuel, ammunition, and food. The threats to this wartime capability come from attacking enemy aircraft, surface ships, and submarines. To protect the carrier against these threats, the typical CBG has 3 to 5 guided missile cruisers or destroyers, 3 to 5 frigates or destroyers, one Towed Array Sonar System frigate and 1 or 2 attack submarines. These 8 to 13 escort ships exist primarily to protect the carrier against enemy attack. In short, to make the carrier with its 35 to 45 offensive aircraft survivable in a wartime environment, we deploy a Carrier Battle Group totaling 10 to 17 ships.

Similar examples exist with our deployment of other forces. A prime illustration is the Airborne Warning and Control System (AWACS) aircraft. Here we use up to 24 fighter aircraft to protect a single AWACS airplane because we know it is a prime enemy target. Likewise, we allocate huge resources to protect our strategic missile forces. The current debate on the basing configuration of the MX missile focuses not on the weapon itself, but rather on the best way to insure its survivability.

The point of this discussion is that we have decided that the Carrier Battle Group, the AWACS, and our strategic missile forces are valid national security requirements, and we have committed the necessary resources to insure the survivability of these capabilities. In so doing, we are spending many times the basic system cost just to protect the system. We could easily apply this same rationale to those space systems which we identify as essential to our national security, for the cost of making space systems survivable is far less than that of making aircraft carriers, AWACS airplanes, or strategic missiles survivable.

THE BOTTOM LINE

Survivability of vital space assets must be a national priority. It just doesn't make sense to spend billions in space if you can't use those assets when they are needed most. To insure their survivability, the President, through the National Security Council structure, should formulate a national space policy directing the Department of Defense to create a single Executive Agent for Space within DOD. This Executive Agent would be responsible for insuring that every US space system used for national security incorporates appropriate survivability measures to match its wartime requirements. Further, this same national space policy would hold the Office of Management and Budget (OMB) accountable for guaranteeing that survivability funds are fenced throughout the life cycle of each space system program. Finally, Congress should endorse this policy as a national priority and, through its control of the purse, make sure that it remains a national priority.

In summary, to insure space system survivability, the DoD Executive Agent for Space must:

- Define the requirements of space system survivability to the appropriate levels of conflict (tell us where to spend the dollars);
- Select the proper strategies to meet the requirements (tell us how to spend the dollars);
- With the support of the OMB and the Congress, fund each program to implement selected strategies and fence these funds (insure that we get the dollars).

APPENDIX

SPACE PAYLOAD LAUNCH RATES, 1971–1981

YEAR	COUNTRY		
	US	USSR	OTHERS
1981	18	135	14
1980	16	110	4
1979	17	101	5
1978	33	119	12
1977	20	104	12
1976	27	122	8
1975	28	111	16
1974	19	95	12
1973	24	109	2
1972	32	88	9
1971	38	97	12
TOTALS	272	1196	106

Source: *NORAD Space Computation Center Satellite Catalog*, 1 April 82.

ENDNOTES

CHAPTER 1

1. The need for this connectivity is spelled out in Presidential Directive 53, National Security Telecommunications Policy, and further defined by the National Communications System letter, same subject, dated 15 November 1979.

2. Secretary of Defense Harold Brown made it clear in his graduation speech to the Naval War College (20 Aug 1980) and in his testimony to the Senate Foreign Relations Committee (16 Sep 1980) that the concept of flexible response and countervailing strategy is not new but has remained the policy of this country since the 1960s. This concept has been reaffirmed by the Reagan Administration.

3. During a broadcast of CBS's "Face the Nation," 4 Oct 1981, Secretary of Defense Caspar Weinberger pointed out the seriousness of the communications survivability problem when referring to our ICBM forces, saying, if "... you couldn't communicate with them [ICBMs], it's not going to do anybody any good." Secretary Weinberger further discusses the need for survivability in his *Annual Report to the Congress*, Fiscal Year 1983, pp. III–85 through III–89.

CHAPTER 2

1. These dollar amounts do not include substantial sums expended by other federal agencies on the military exploitation of space to gather intelligence. NASA also spent an additional $66 billion between 1958 and 1978 and will spend nearly $6 billion in 1982 for civilian space programs: US Office of Management and Budget, *Budget of the United States Government, Fiscal Year 1982,* p. 123; General James V. Hartinger, Commander-in-Chief, North American Aerospace Defense Command, Speech before the Air Force Association Symposium, Los Angeles, CA, 12 November 1981; Trudy E. Bell, "America's Other Space Program," *Science*, December 1979, p. 6; and "The New Military Race in Space," *Business Week*, 4 June 1979, pp. 136–49.

2. As mentioned in Chapter 1, according to Article II of the Outer Space Treaty, "Outer space . . . is not subject to national appropriation by claim of sovereignty . . ." Ecuador and other countries situated on the Equator have since voiced the opinion that geosynchronous satellites located directly above their countries do, in fact, violate their territorial sovereignty because the satellites do not pass through the extended limits of their national borders but rather remain stationary within these limits. No action has been taken, however, to amend the Outer Space Treaty.

3. Under Secretary of the Air Force, Edward C. Aldrich, clearly declared space as the ultimate nigh ground for the Air Force in a speech given to the American Astronautical Society in Washington, D.C., on 6 November 1981. He further stated that the Air Force is not only exploiting this high ground, but has become dependent on space-based systems for such missions as communication, navigation, and intelligence gathering. Dr. Hans Mark, former Secretary of the Air Force, has, over the past several years, consistently advocated the exploitation of space as the ultimate military high ground.

4. The best single reference for understanding the dynamics of space systems is Roger R. Bate, Donald D. Mueller, and Jerry E. White, *Fundamentals of Astrodynamics* (New York: Dover Publications, Inc., 1971). Another reference oriented more toward the layman is Robert Giffen et al., *Course Text, Astronautics 332,* Vols I and II, (USAF Academy, CO: Department of Astronautics).

5. Satellite lifetime is a function not only of altitude, but also of size, shape, and density. For further discussion, see Bate, Mueller, and White, *Fundamentals of Astronautics*, p. 153.

6. At 150 km, a camera with a field of view of 14 degrees can see an area approximately 37 km wide. In one pass around the earth this camera can provide photographic coverage of 1.5 million square kilometers or about 0.3% of the earth's surface.

7. Of this number (3800), only a few are actually functional satellites; the majority are rocket bodies, fairings, and fragments of space platforms. For a complete compilation and statistical analysis of all space objects currently tracked by NORAD, see US Department of Defense, Headquarters North American Aerospace Defense Command, *CLASSY Satellite Catalogue Compilations* (HQ NORAD/J5YS, published quarterly).

8. Because the earth is not exactly spherical, orbits are perturbed slightly each day. One of these perturbations causes the orbital plane to precess. The earth itself revolves around the sun at a rate of about 1 degree per day (the earth travels 360 degrees in 365 days). At an inclination of about 98 degrees, the precession of a low earth orbit is equal to the rate the earth

revolves around the sun; therefore, the orbital plane always maintains a fixed orientation with respect to the sun.

9. This orbit has been used extensively by the Soviets for communications and surveillance satellites. Because the Soviet launch sites are at such northerly latitudes, a significant savings in launch costs is realized when they use the Molniya orbit instead of the geosynchronous orbit.

10. Another perturbation caused by the aspherical earth affects the stability of the position of perigee in eccentric orbits. At inclinations of other than 64 degrees, perigee and apogee positions wander around the orbit. At 64 degrees this effect is null, and the perigee position remains fixed.

11. Political restraints also dictate launching only toward the easterly direction from Cape Canaveral because other azimuths (north, south, or west) would place the flight path over populated areas. For this reason, too, Vandenburg is used for launching all polar orbits.

12. This effect is so significant that the French have built a large launch complex near the Equator in French Guiana at Kourou where they can launch almost directly into a geosynchronous orbit maximizing the effect of the earth's rotation.

13. Launch costs can be misleading. The $25 million figure is based on placing a 5500-pound payload in 100-nautical-mile polar orbit using a Delta 3920 launch vehicle, while the $60 million figure uses a Titan 34D/IUS launch vehicle to place 27,600 pounds in the same orbit. For the geosynchronous orbit, a Titan 34D/IUS launch vehicle costs $125 million to place a 4000-pound payload in orbit. Both figures for the Titan booster are based on a procurement of 6 vehicles per year. Procuring only one vehicle per year jumps the costs to $181 million and $251 million, respectively. All dollar figures are in 1981 dollars. These data are based on an interview with Lt. Col. Vic Whitehead, HQ USAF/RDSL, Pentagon, Washington, D.C., 23 November 1981.

CHAPTER 3

1. The Soviets have officially announced their intention to develop a reusable space shuttle system with the first launch projected for 1987. They claim their shuttle will place payloads in orbit for about $40/lb compared to $300/lb for the US Space Shuttle. "Soviet Shuttle Program Integral to Orbital Station," *Aviation Week and Space Technology*, 1 March 1982, p. 24.

2. For a short but succinct summary of the Soviet space program, see Casper Weinberger, Secretary of Defense, *Soviet Military Power* (Washington, DC: US Government Printing Office, 1981), pp. 79–80.

3. All of the payload data in this paragraph were obtained from the *Space Computational Center Satellite Catalog* (1 April 1982) published quarterly by the Space Analysis and Data Division, Headquarters NORAD, Cheyenne Mountain Complex, Colorado Springs, Colorado.

4. In April, 1981, the USAF Academy held a three-day Military Space Doctrine Symposium, during which both US and Soviet military space doctrines were discussed in detail. These discussions, as well as the symposium final report, form the basis of my presentation here. Paul Viotti, ed., *Military Space Doctrine, The Great Frontier, The Final Report for the USAFA Military Space Doctrine Symposium, 1–3 April 1981* (USAF Academy, Colorado, 1981).

5. For a detailed history of the Soviet manned space program through 1980, see James E. Oberg, *Red Star in Orbit* (New York: Random House, 1981).

6. "Killer Satellites," *Aviation Week and Space Technology*, 26 October 1981, p. 15.

7. Craig Covault, "Space Defense Organization Advances," *Aviation Week and Space Technology*, 8 February 1982, pp. 21–22.

8. The Pentagon's top scientist, Dr. Richard Delauer, claims that "As early as next year [1983], Soviet laser weapons in space may threaten US communications and surveillance satellites. . . ." *Air Force Times*, 8 March 1982, p. 2.

9. The Soviets are developing a launch vehicle capable of placing from 390,000 to 455,000 pounds of payload in orbit. (The US Saturn 5, used to launch the Apollo moon shots, could place 280,000 pounds in orbit; the Space Shuttle has a maximum payload capacity of 65,000 pounds.) "Soviet Booster Advance Believed to Exceed Saturn 5 Capability," *Aviation Week and Space Technology*, 2 November 1981, pp. 48–49.

10. At least four studies are underway to explore possible future US launch vehicles, but no commitment has been made to develop a new vehicle. "Boeing to Conduct Launch Vehicle Study," *Aviation Week and Space Technology*, 7 December 1981, p. 22.

11. Secretary of Defense Weinberger discusses this topic in detail in *Soviet Military Power*, pp. 80–81.

CHAPTER 4

1. Some experts disagree that the space mine is an actual threat. Their argument is that mines need accurate positioning information to target geosynchronous satellites, information which is not yet available. A recent unpublished study by the General Research Corporation, however, shows mines not only are a credible threat, but that a Soviet SL-12 launch vehicle has the capability to place two 1150 kg (380 kg warhead, 450 kg electronics, 160 kg propulsion, and 160 kg structure) mines in geosynchronous orbit, each with the capability of destroying any non-maneuverable geosynchronous target. Col. Charles E. Heimach, who initiated this study, provided me insight into the overall issue of space survivability and I have incorporated some of his ideas in both this chapter and Chapter 5. See Charles E. Heimach, "Space Survivability—A Philosophy/Policy Argument, "*A Book of Readings for the United States Air Force Academy Military Space Symposium,* Vol. 1 (3 April 1981) pp. 23–42.

2. An unclassified presentation on the nuclear effects on space systems was presented by Gordon K. Soper of the Defense Nuclear Agency at the Air Force Systems Command Innovative Strategy Conference on 10 Nov 1981. Although this information has not yet been published, additional information on nuclear effects on all three segments of space systems can be obtained by contacting DNA/RAE, telephone 202-325-7016.

CHAPTER 5

1. An excellent reference on the issues of space arms control measures is Donald L. Hafner's "Averting a Brobdingnagian Skeet Shoot," *International Security*, (Winter 1980–1981) pp. 41–60. I have used some of his arguments in this section, although I don't agree with Hafner's view that negotiation offers "the only prospect of reducing the survivability problem to manageable proportions" (p. 60).

2. Gordon K. Soper, Defense Nuclear Agency, briefing presented to Air Force Systems Command Innovative Strategy Conference, Ft. McNair, Washington, DC, 10 November 1981.

3. In 1962, the United States detonated a nuclear weapon in space to study its effects. This shot, called Operation Starfish, caused unexpected damage to seven satellites and was therefore never repeated.

EPILOGUE

1. The information on typical Carrier Battle Group composition was obtained from unclassified portions of training and war gaming course material used by the Tactical Training Group—Pacific, US Pacific Fleet, San Diego.

ANNOTATED BIBLIOGRAPHY

The following annotated bibliography lists seven unclassified sources which will provide the reader a comprehensive background on military space systems.

Aviation Week and Space Technology (Published weekly). New York: McGraw-Hill, Inc.

The best periodical for current information on US and Soviet space systems. Includes discussion of new systems, future trends, policies, and editorial evaluations.

Lamping, Neal E., and MacLeod, Richard P., "Space—A National Security Dilemma: Key Years of Decision." Unpublished report, Washington, DC: The National Defense University, July 1979.

This study presents excellent insight into efforts to formulate national security policy for future military activities in space. Although the paper is unpublished, copies may be obtained from the National Defense University Research Directorate, Ft. McNair, Washington, DC 20319.

Mathews, J. M., ed., *TRW Space Log*. Redondo Beach, CA: TRW Defense and Space Systems Group, TRW, Inc., 1980.

This small book is published annually and contains details of spacecraft, Soviet Space activity, and a complete log of all launches since Sputnik 1 was orbited in 1957.

Oberg, James E., *Red Star in Orbit*. New York: Random House, 1981.

An excellent reference covering the Soviet space program from 1957 through 1980, with particular emphasis on the Soviet manned space program. Includes a comprehensive annotated bibliography.

Copies of the following three entries can be obtained directly from the Department of Astronautics, USAF Academy, CO 80840.

Swan, Peter A., ed., *Military Space Doctrine: The Great Frontier*, 4 Vols., USAF Academy, CO, 1981.

This four-volume set is a compilation of papers submitted to the United States Air Force Academy Military Space Doctrine Symposium, 1–3 April 1981. It contains over 50 individual papers dealing with US and Soviet space doctrine, operations, and organization, and serves as an excellent reference on current thinking in these areas.

Syiek, Michael A., ed., *The Great Frontier,* USAF Academy, CO, 1981.

This book contains over 45 articles from the open literature discussing the past, present, and future US and Soviet space programs. If I were just starting to learn about the military in space, I would read this book first.

Viotti, Paul, ed., *The Great Frontier: Military Space Doctrine, The Final Report,* USAF Academy, CO, 1981.

This report presents the consensus of 246 leaders of the Air Force space program to questions posed to them in three areas: US space operations doctrine, US space organization doctrine, and USSR space operations and organizational doctrine.

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(See page ii for ordering information.)

82–4 *US Space System Survivability: Strategic Alternatives for the 1990s*. Robert B. Giffen.

82–3 *Soviet Intentions and American Options in the Middle East*. Benson Lee Grayson.

82–2 *The German Army and NATO Strategy*. Stanley M. Kanarowski.

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81–1 *Ballistic Missile Defense and Deceptive Basing: A New Calculus for the Defense of ICBMs*. Raymond E. Starsman. (AD No. A104391) (GPO)

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