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The Impact of Space Activities Upon Ordinary Citizens and the World

"Let us conquer space!" was the rallying cry of a faction in the US Congress early in the 19th Century. Their strategy was to use federal funds to build a paved road westwards from Maryland through the Cumberland Gap, toward the open spaces of Ohio.

In proportion to modern federal budgets, the project was to be as expensive as the Apollo program a century and a half later.

Opponents argued that it would be a "road to nowhere," that at the far end would be only "empty desolation and howling savages." There were a dozen more worthy and more immediately beneficial projects for the expenditure of public money.

After long debate, the highway—called the "National Road"—was built, and as with later cases of federal investments in new frontiers, it paid off magnificently. Likewise, federal investments in and subsidies of canals, railroads, advanced ocean-going technologies, aircraft, and so forth have opened doors and lowered thresholds for public and commercial traffic to flow through. Federal spending on military forces has protected this flow of commerce as each opportunity and technology came along, both from overt hostilities and from natural dangers.

The arguments in today's "conquest of space" have likewise already been won. After decades of debate on what would be worthwhile to do in space, government (both civil and military) and commercial programs are in full swing, taking advantages of the unique opportunities that space access offers. To the extent that these applications have become invisible mainstays of modern life, most Americans seem to remain unaware of how deeply space assets are woven into the fabric of their daily lives.

But exploitation of space is a two-edged sword. Insofar as space applications have often proved superior to old earthbound ways of doing things, the better ways have come to dominate and push out the former systems. In some areas, such as communications, astronomy, or other scientific research, space remains a specialized supplement to competing or complementary ground systems. In other areas—weather forecasting, navigation, reconnaissance—space systems have so outclassed former competitors that these functions soon (if they're not already) will be nearly impossible to perform without the space systems, as ground-based systems atrophy and wither away.

Exploitation of space is thus also a dependence on space. More specifically, it is a dependence on the security and dependability of space-based assets against all threats, both man made and natural. As these dependencies grow, so too do the vulnerabilities and—for anyone wishing us ill—the temptations. The vulnerabilities can be exploited along a full range of power, from publicity-seeking and thrill-seeking spoofing, to blackmail or terrorist-motivated interference, to national-policy-influencing damage, to intentional crippling assaults coordinated with earthside actions.

Before examining more closely the specifics, we must review the unique characteristics of "space" and their implications on space operations. This is also important because of the time-honored human practice of thinking by analogy, of speculating based on perceived parallels. Because space is quite literally "unearthly," such attempts to extend earthside experience to space often are misleading, sometimes spectacularly and dangerously so.

And while we're at it, it's also important to define certain terms used freely about space, such as "space control," "space power," etc. These common terms often seem to have different meanings and reflect different assumptions from different users. This ambiguity may hide true disagreements or may allow the appearance of a counterfeit consensus. Certainly, poor definitions prevent the construction of reliable theories on top of them.

"Understanding space" is still a challenge today not because people know so little about space, but because they know so much about space that isn't accurate. "It ain't what yuh dunno what'll make yuh look lak a fool," goes the old Appalachian proverb, "It's what yuh DO know, what ain't so." And joking about "rocket scientists" rests on the unspoken assumption that ordinary citizens won't EVER be able to understand space, which is a dangerous abdication of their responsibility as citizens and as customers.

Whether it's the still widespread notion that spacecraft float in space because they are "beyond Earth's gravity," or the still-seen misconception that rockets need something external to push against (as in the notorious *New York Times* put-down of Robert Goddard), or the more subtle misunderstanding that the reason objects heat up when hitting the atmosphere is "air friction,"[1] most of us still are burdened with inaccurate ideas about space. These misunderstandings—this knowledge that isn't so—lies in wait to ambush, deflect, and divert people from adequate understanding of space and from the sound decision making that such understanding enables.

"Space" is disconnected from most of the complexities of "earthly" life, and so its parameters and principles can be listed—it's a short list—and understood relatively quickly. Here are some of the key characteristics of "space" along with a few implications for operating there.

Space really IS "unearthly." It's not LIKE our earthside environment. There are some obvious differences, and some not so obvious ones. The implication is that much ordinary "common sense" doesn't apply. One has to be cautious at making analogies with "everyday life." This implies that while it's true that space is a physical frontier, it's also a mental one.

Space is BIG. Most of the Universe is "space." Solid objects like planets or other globs of matter ("the thick stuff") are tiny dust motes

1 Objects heat up when hitting the atmosphere because the shock wave that forms around the object compresses the atmosphere. When a gas is compressed, it gives off heat. That heat is transferred to the object by conduction through the atmosphere, raising the temperature of the object. That's different from the heat that aircraft experience, which is caused by friction in the laminar flow over the aircraft's surfaces, which is also conducted to the aircraft.

in a universe consisting mostly of space. This implies that once you know how to operate in one area of space, you basically can operate anywhere in the Universe that you can get to. Its very size imposes a new form of isolation in terms of communications time delay. This time delay is enough to be noticed and to irritate customers using geosynchronous satellites for two-way telephone conversations.

Space is NEARBY. Just a hundred kilometers above us, the physical conditions are those of "outer space." Neglecting air drag, a cannon shell fired vertically at 1,600 m/sec (about one mile per second) will reach "space" in about three minutes. Space is as close as your pager, your mobile telephone, your GPS navigator, and your television remote, and it will soon be as close as your laptop computer. Space used to be a barrier, but like the oceans, it is being transformed into a medium for transportation and a medium for harvesting.

Since space extends "up" forever, so "high above" the rest of Earth, objects in space have a VANTAGE POINT for viewing large areas on the ground, or for being seen by two different areas on the ground so as to relay signals. So it's often the best place from which to view the "big picture" of the Earth's surface and atmosphere, or the "little picture" of specific areas of high interest. Like an antenna on a skyscraper or a mountain, it can serve as a location for communications relay equipment. Furthermore, the global coverage provided by space includes areas of the world that are denied to earthside elements of US national power.

Space is mostly EMPTY of matter. There are random molecules, atoms, and ions flying around, but no "air pressure"—it's a "hard vacuum." This implies that there is no physical "speed limit" since there's nothing to slow down fast objects; also, there's nothing to "push against," so wings and rudders and parachutes and things like that don't work. On the other hand, without crosswinds and currents, future flight paths are simple to predict because there are few forces acting on objects. Also, the emptiness means there's nothing to absorb radiation, either as protection or as veiling of our view of distant objects.

Space is often FULL of energy flow. Usually, there's uninterrupted sunlight (except when in the shadow of a stray piece of matter). Ultraviolet rays can give unprotected skin a sunburn in seconds, and cause severe eye damage in minutes through a too-transparent window. In fact, as Ted Johnson of Boeing puts it, those of us in space are bathed in energy. There is more than enough energy to sustain billions of lives, if we could learn how to efficiently harness it. BUT paradoxically, space can also be very cold since it's an infinite heat sink. The temperature of an inert spacecraft at Earth's distance from the sun will stabilize passively slightly below the freezing point of water. The temperature of the unlit floors of craters at the Moon's north and south poles have cooled far lower and created "cold traps." These "cold traps" catch and accumulate passing water molecules to form the ice layers recently confirmed by space probes (the same logic, and some intriguing radar data, suggests that sun-scorched Mercury also has ice in its polar craters).

Space has physical effects on people who travel there and the hardware that we send there (since it's different from conditions we evolved under). It will quickly kill an unprotected human being and may disable unprotected equipment. The concern for space engineers is how MUCH of Earth's natural environment you need to carry with you to keep you and / or your equipment functional.

Next, after looking at the characteristics of the space environment, what are the characteristics of SPACE FLIGHT?

Spaceflight is NEW. After millennia of dreaming, there's been no more than half a century of human physical access to "space." This means it's still often SURPRISING, both in scientific terms and in unpleasant discoveries of new ways to "crash and burn"—and we should expect it to keep surprising us for a long time to come. And since it's so strange, most earthside analogies are strained at best, and are misleading at worst. Spaceflight is only a few decades younger than powered flight within the atmosphere. This chronological relationship has led to some of the strained or misleading analogies.

Spaceflight is EXPENSIVE and HARD. As a result, new technologies are required which often have later, wider applications in earthside industries. This implies that no known raw material is costly enough to be profitably exported to Earth from space. However, INFORMATION is precious and massless, and there's where the profits are—space often provides information-transfer services much more cheaply than corresponding earthbound alternatives. In the future, high-value low-mass materials such as pharmaceuticals, or high mass objects such as small metallic asteroids, MIGHT prove worthwhile to export back to Earth.

Spaceflight today operates through an extremely narrow series of "choke points," ranging from the handful of operational launch sites to the limitations on communications paths and ground stations. To a much greater degree than any other current human activity (especially those associated with "air power" or "sea power"), spaceflight is disproportionately vulnerable to breakdowns—accidental or deliberate—at these choke points.

Spaceflight is POLITICAL and DIPLOMATIC. The "Show-Off" factor and the symbolism have always been major motivations for government financing of major programs. For example, the goal of Project Apollo, to demonstrate American technological superiority, was fully accomplished. Today, the International Space Station is a diplomatic tool to keep other potential space competitors engaged in a project led by the United States, and especially to keep Russia's aerospace industry tilted westwards.

Spaceflight is INTERNATIONAL in scope. Whatever any one country decides to forego, another country may chose to develop or exploit. Even emerging economies such as Brazil and India recognize the value of having a space industry, and build their own rockets and satellites.

Spaceflight sprang from MILITARY roots (Chinese, Congreve, V2, ICBM) but is now surprisingly "peaceful"—possibly the most genuine "swords into plowshares" metamorphosis in history. However, those plowshares can also quickly change back into swords. The 1991 Gulf War demonstrated the exceptional military utility of space systems.

Spaceflight is still RARE. Fewer than 400 people have actually traveled into space since 1961. They have accumulated little more than ten full years of presence in space. Only about 600 active satellites and probes are currently in operation. However, this rarity will change in the very near future. Many more satellites will soon be in orbit about our planet as a result of a commercial explosion into the space-based services market. The International Space Station will increase the small number of people in space, but not to the same scale as the change in number of satellites.

Spaceflight is USEFUL in practical terms: applications satellites for communications, navigation, observation (weather, military reconnaissance, mapping, etc.), advertisements, etc., comprise a large fraction of all activities. These applications are returning substantial dividends and there seems to be a much larger market for even more services.

Spaceflight has had an overwhelming cultural and social impact (science fiction, environmental awareness, internationalism, UFOs, etc.), and is probably THE most long-range historical achievement of this century.

Lastly, what are the characteristics of SPACECRAFT, the objects we build to fly into space and perform functions there? And what are the implications of those characteristics?

Spacecraft are EXPENSIVE—most are worth several times their weight in gold to build. Yet they are usually even more expensive to reuse or recycle, because the major cost is not the metal but the human attention to preparing for flight. This latter feature implies that the reusable versus throwaway booster question is not clear-cut. Should the premise of inexpensive spacelift prove true, it may be much smarter to build less reliable, and less expensive, spacecraft.

Spacecraft follow predictable paths because there is only a small number of factors influencing their movement: gravity; air drag (at least in lower orbits); photon pressure from the Sun (if the vehicle is large and lightweight); and artificial impulses, both accidental and deliberate. This implies that you can prepare position predictions days or weeks in advance. Therefore, you can also predict when you will see a satellite days and weeks in advance. If you are a spy satellite, when you get over a target of interest, you can assume that your target knew you were coming and has prepared camouflage and countermeasures—unless you are disguised and they don't recognize you as an observation platform.

Spacecraft require deliberate attitude (orientation, or pointing) control. Although some functions (e.g., an omni antenna, or measurements of radiation fields) don't care which way the vehicle is pointing, others, such as high-gain dish antennas or a telescope, require extremely precise pointing. There is no easy "anchor" or "foundation" in space to maintain spacecraft orientation. There are technological solutions (like jets, momentum wheels, gravity booms, and other devices) and there are various forces that disturb a vehicle's attitude (unintended venting, aerodynamic torque, gravitational torque, etc.). There are even some passive techniques, such as gravity-gradient, which on a small scale mimic the Moon by keeping a vehicle's same side facing the Earth.

Spacecraft are "crewed," although most have their human controllers back on Earth, and only a few carry their controllers along with them. Humans rely on automata to assist controlling spacecraft, but must also instruct the automata on how to react to various situations. Automated and remote-controlled systems are improving all the time while human capabilities and costs (in space and on the ground) are currently at a plateau.

Spacecraft with crews tend to use older, proven, more reliable technology, while unmanned vehicles (more expendable, in theory) can use innovative, advanced technologies. As examples, Mir represents mid-1970's USSR technology; and the shuttle is based on the same era (both have had more advanced components added over the years). Deep space probes and expensive unmanned satellites can take greater technological risk. But the latest unmanned satellites, both commercial and government, are at the very edge of the "state of the art" in structural materials, avionics, etc.

Spacecraft are beyond any national territorial sovereignty, as with the high seas, but they carry "bubbles" of back-home law with them. Besides requiring a whole new set of lawyer jokes, this feature suggests that issues of crime, privacy, property, liability, and other legal issues cannot be left behind. Law seeks precedents, and space law relies largely on maritime law for this otherwise-lacking historical record.

These are all important points about space, about space flight, and about space vehicles. We must get the details right before constructing more complex structures upon them. But we also need to step back from time to time to get the "big picture," which we often miss because of over-concentration on subsets of the issue.

The impact of space exploration on society is so broad as to be almost invisible, because most of us have forgotten, or never knew, what popular consciousness was like prior to the beginning of space exploration. But just as the Age of Maritime Exploration, beginning in the 1500s and 1600s, made Europeans realize that the Earth truly WAS round, and that travelers could leave Europe and reach very different regions. Similarly, the Age of Space has made all earthlings realize that this is but one of many worlds. Along with that realization has come the realization that humans can leave Earth and carry out their activities on a far broader scale.

In one generation, the phrase "Crying for the Moon" as a metaphor for eternal frustration has been transformed to the cliché, "If we can go to the Moon, why can't we X," as a metaphor for easy accomplishment.

Centuries-old scientific puzzles have been answered by this exploration, and many traditional scientific paradigms have been overthrown. For example, the origin of the Earth and Moon is much better understood. Also, the extent of violent processes—mainly collisions, but also unexpected forms of volcanism and "continental drift"—which have formed and shaped the worlds we have explored is also now realized.

And that has led to a consequent realization, still in the process of making its cultural impression around our home planet. Earth is not "immune" to natural processes that go on in space, whether they be solar variations, space dust, meteorites and asteroids, and even radiation outbursts from nearby stars. It's more than just the tides—everything on Earth from climate to magnetic fields to vast geologic processes seems to be influenced by outside events.

So "space" is not something "elsewhere" that can be dispassionately studied or ignored as the whims of fashion decree. We live precariously on one world which is located IN space, not apart from space, and our survival as a nation, as a species, and as a world may depend on what we discover about natural processes in space — and what we someday choose to try to do about them.

"Space power," as wielded by instrumentalities of national will such as military forces, then becomes more than merely a convenient tool—or weapon—for the continued struggle for status among Earth's nations. In the not too distant future, it may become the key to long-term survival.

Space visionary Carl Sagan, commenting on the extinction of the dinosaurs 65 million years ago, remarked that it happened because “the dinosaurs didn’t have a space program.” While Hollywood-style asteroid impacts correctly stress the kind of danger to Earth’s biosphere that can occur naturally, there are many other hazards already known, and doubtless many more to discover.

This book is not about space science or space exploration, although it will touch lightly on those subjects. Instead, it is about policies for the use of space power and strategies to reach the goals defined by such policies. It is also about theories of how and why to use space power. To understand these ideas, more definitions are required for the sake of clarity.

Policy is a goal or aim of a government, society, national group or other organization.

Official policy is a goal or aim consciously chosen by the leadership of an organization. It may be publicly articulated or kept secret. By extension, official policy also includes the identification of what are considered legitimate or illegitimate actions to attain such goals.

Strategy is a plan to use the resources available to achieve a policy.

Military strategy is a plan to use all relevant resources to achieve a policy through the threat or use of armed force.

Space Control is the combination of abilities to enter, to deny entry to, and to exploit the area above the Earth’s atmosphere. Air Force Doctrine Document 2-2[2] (23 August 1998) defines Space Control as the means by which space superiority is gained and maintained to assure friendly forces can use the space environment while denying its use to the enemy.

Space power is the combination of technology, demographic, economic, industrial, military, national will, and other factors that contribute to the coercive and persuasive ability of a country to politically influence the actions of other states and other kinds of players, or to otherwise achieve national goals through space activity. The Air Force Doctrine Document 2-2 defines space power as the ability to exploit civil, commercial, intelligence, and national security

2 *Space Operations.* Air Force Doctrine Document 2-2, HQ Air Force Doctrine Command, United States, 23 August 1998.

space systems and associated infrastructure to support national security strategy and national objectives from peacetime through combat operations. The 1998 Rand study, SPACE: EMERGING OPTIONS FOR NATIONAL POWER,[3] defines space power as the pursuit of national objectives through the medium of space and the use of space capabilities.

Space power theory is a theoretical concept of how and why space resources work with other factors to contribute to implementation of policy and achieve defined goals. A theory proceeds from facts, makes assumptions, and predicts a result caused by the relationship of factors within the concept.

Air Force Doctrine Document 2-2 further defines a number of military-related “space power” concepts:

THE ROLE OF MILITARY SPACE POWER. As an integral element of national capabilities, space systems influence operations throughout the conflict spectrum. Space supports Service, joint, and multinational operations across the range of military operations, from peacetime engagement to general war. Space forces contribute at all levels of military activity—strategic, operational, and tactical.

OFFENSIVE COUNTERSPACE. Offensive Counterspace operations destroy or neutralize an adversary’s space systems through attacks on the space, terrestrial, or link element of space systems.

DEFENSIVE COUNTERSPACE. Defensive Counterspace operations consist of active and passive actions to protect US space-related capabilities from enemy attack or interference.

The Rationale for Human Space Activity

The reasons for groups of mankind to agree to pay for the high cost of space vary by the composition of the group. British spaceflight theorist R. C. Parkinson[4] lists those groups as explorers, adventurers,

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3 *Space: Emerging Options for National Power.* 1998. Dana J. Johnson, Scott Pace, and C. Bryan Gabbard, RAND, United States.

4 Parkinson, R.C. 1998. “Review of Rationales for Space Activity.” Journal of the British Interplanetary Society. Vol. 15, pp. 275–280.

colonizers, technologists, merchants and profiteers (to avoid pejorative connotations I'll refer to the last group as "vendors").

"Explorers" go to space to learn the answers to big, nonmaterial questions. They are interested in learning the history of the solar system, trying to discover if there is life somewhere other than Earth, to measure unusual processes which occur in new environments, etc. The underlying motivation of this group is human curiosity. Because this group is often comprised of noted scientists, they have political influence beyond their small numbers.

The "Adventurers" are a related group who want to go where no one else has ever been. They want to participate in great adventures of humankind, like going to the Moon and exploring Mars. Adventurers are bored by space activities that can be construed as routine, such as shuttle flights and satellite launches. Of course, Adventurers would be excited to actually attend a routine space launch. They do believe that spaceflight is a good thing in its own right.

In Parkinson's definition, those who believe that the future of mankind includes manned spaceflight are "Colonizers." Colonizers are sure that the cumulative benefits of manned space flight will provide the resources necessary for human survival in the future. They also tend to believe that humankind will have to perfect manned spaceflight to ensure the survival of the species against some unknown disaster in the future. Colonizers place a priority on human spaceflight, the development of an economic superstructure to reduce the cost and encourage the growth of space activities, and finally, to increase public participation in space activities. Often those in the "Colonizer" class are so far ahead of everyone else they deserve to be called "Dreamers," in both the positive and negative sense of that term.

Parkinson would consider three of his groups more practical and realistic than the others. The "Technologist" supports the growth of technology, particularly sophisticated hardware. They are most impressed by the "spin-offs" of high technology into other uses. Technologists believe in the intrinsic value of the newest, most expensive, most sophisticated solution to a current challenge. They believe technology can solve any problem.

"Merchants" are concerned with the useful application of space activity to life on Earth. In the long term, they are very similar to the "Colonists," but the short term and what is immediately useful is most important to them. Merchants assume that market forces will eventually make other space applications useful.

The "Vendors" are merchants who market to the combined space community. Their focus is on the short term and making a profit immediately. They make the instruments of space operations, rockets, satellites and the like. Vendors have the best understanding of the near-term motivations of government and commercial decision makers and seek to accomplish the immediately achievable. They furnish part of the market forces that make space profitable for the merchants.

Since most space programs today sprang from government programs, it is obvious that government rationales are some combination of the foregoing groups of the space community. But governments have their own rationales for space operations. Parkinson lists them as defense, internal order, taxation, education, welfare, and economic activity.

Defense is an obvious space activity. However, the details of what space provides to national defense are probably not well understood even by most educated people. Many assume, for example, that some sort of missile defense system is already in place, while not appreciating the critical needs of systems of navigation and communications. Internal order, achieved using both space and non-space means, includes a sense of well-being by the ordinary citizen, an essential trust in the government's ability to provide services, to resolve disputes, and to provide justice. It is closely related to Economic Activity and Education.

Economic Activity is the role of the government in providing the infrastructure of national life and business activity. It includes roads, sewers, bus lines, electrical power, and many other things in addition to space-related services. Included in this category is the encouragement of exports. An example of economic activity is the commercial GPS industry in the United States, with more manufacturers of GPS receivers than any other country, supported by both a large internal market and a large export market for the services of a government space activity.

Qualified people to develop this activity are provided by Education. Most nations understand that a well-educated workforce is an invaluable national resource. Besides providing the skill to develop the high-tech systems to expand modern lifestyles and modern markets, well-educated citizens generate high income and pay high taxes. Space is part of this lifestyle and provides a sense of adventure and glamour to the study of science and mathematics.

Welfare is the expenditure of government funds on the citizens of the state. It includes expenditures on health care, support to dependent children and support of industries vital to the economic and national security health of the nation. Space expenditures provide the job creation support to well-educated, hardworking, technically-knowledgeable experts, while the medical and technological "spin-offs" of space technology has greatly assisted the government to provide assistance to less well-off citizens as well.

Governments and private groups are now operating in space for essentially the same purposes they operate on Earth. Governments are mostly motivated by issues related to national security, economy, and status. National Security as defined includes the gaining of information, the development of industries to provide an industrial base, and advertising a nation's high-tech capabilities. Private groups—ranging from international corporations to universities to amateur radio clubs—have a much wider range of motivations.

In terms of national security, there are both military and non-military applications. For both applications, there are concerns: short-range, long-range, and in between.

For military uses, space offers an unmatched vantage point for observation of potentially hostile activity anywhere in the world. Appropriately, the first President to so much as mention space reconnaissance in public was Lyndon Johnson, the early space program's biggest booster. "I wouldn't want to be quoted on this," LBJ told a small group of educators in Nashville in March 1967, "but we've spent thirty-five or forty billion dollars on the space program. And if nothing else had come out of it except the knowledge we've gained from space photography, it would be worth ten times what the whole program has cost. Because tonight, we know how many missiles the enemy has and, it turned out, our guesses were way off. We were doing things we didn't need to do. We were building things we didn't need to build. We were harboring fears we didn't need to harbor."[5]

Space is also a medium through which physical force or electromagnetic energy can be projected. This can be by missiles launched from Earth against other Earth targets or against targets already in space, or it could be in the form of radar pulses or laser beams. Space also offers a deployment area for stationing weapons for use both against in-space targets and against surface targets.

National security is also served by enhancing national technological levels, and the development of space projects often serves to elevate the technical competence of industrial teams, and accelerate the acquisition of advanced capabilities. As a result, new solutions become available to other pressing technological challenges.

National diplomatic ends are also served by using space activities to advertise national competence in technologies related to military capabilities, and to bind other nations into joint ventures. Because of its still-potent symbolism, space can often bestow on the associated negotiations a futuristic aura that works to the advantage of those perceived as dominant.

The American public very inadequately appreciates the dollar value of commercial space activities. In 1996, world space technology industries made profits of about $75 billion. In 2000, such profits are expected to reach about $125 billion.[6] Figure 1-1 shows these significant trends.

In non-government arenas, small private groups experiment with unusual applications, while would-be profit-making corporations seek to convert the unique characteristics of space and space vehicles into moneymaking activities. By the end of 1997, about $100 billion had been spent on commercial space activities since their inception.

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5 "Satellite Spying Cited by Johnson." *The New York Times*. March 17, 1967. Internet source: (http://webster.hibo.no/asf/Cold_War/report1/williame.html) found by Rusty Barton, San Jose, California.

6 The State of the Space Industry—Annual Outlook for 1997. May 1997. SpaceVest, Space Publications, KPMG Peat Marwick, Virginia Tech Center for Wireless Communications.

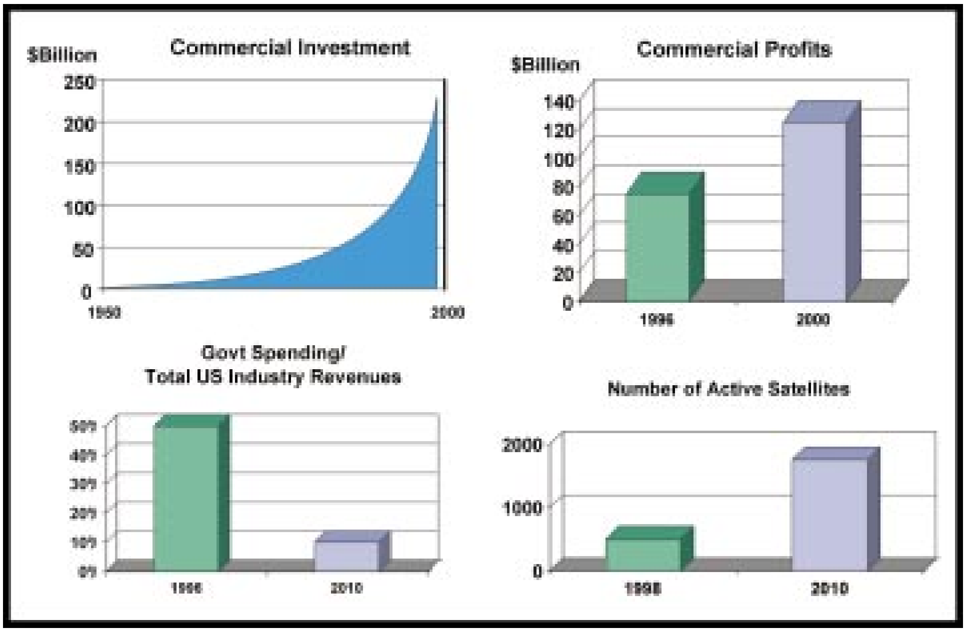

FIGURE 1-1. The Growth of Commercial Space Activities.

An estimated $125–$150 billion more will be invested over the next three to five years. During the first decade of the 21st Century, continuing high levels of profit are expected to bring a torrent of both American and foreign funds—in the area of $650–$800 billion—to the global space industry. By 2010, cumulative American investments in space alone will reach $500–$600 billion or about as much as the value of present American investments in Europe. That same year, revenues from global commercial space activities are projected at $500–$600 billion. By 2020, the national space industry should be producing 10%–15% of American Gross Domestic Product (GDP).

It is conservatively estimated that since the beginning of the US space program in the late 1950s, derived technology has added about $2 trillion in present dollars to the American economy. As much as double that figure could be added to the US GDP in the next quarter century. For the past quarter century, government investments in space science and technology have led to far greater returns than has money put into any other ventures. This ratio of investment to profit seems almost certain to continue for the next half-century or so.

There are now (1998) about 600 active satellites orbiting the Earth. Perhaps another 1,500–2,000 will be placed in orbit by 2010. A majority will perform telecommunications functions, and probably two thirds will be American-built.

The US Government or American corporations own nearly half of current satellites. Ten years from now, when their total number has tripled or quadrupled, that fraction may decline somewhat due to the growth of foreign space technology firms, but it should still be roughly in the 35%–45% range.

Another trend is the ratio of government to private satellite ownership. While more or less holding its own in absolute terms, the scale of government space activities is declining rapidly relative to that of commercial enterprises, measured by total number of spacecraft and by the total investment in spacecraft. In 1996, global civil and military government space expenditures were roughly $58 billion, about 70% of which was American. As noted above, the revenues of American space technology firms alone were roughly one and a half of that.

Barring the unexpected, NASA’s annual budget should remain indefinitely in the $13–$14 billion range in present dollars. Estimating future military space spending is more difficult. American defense spending may rise slightly from present levels over the next decade but it will likely remain in the area of $260–$270 billion a year. Meanwhile, the proportion devoted to military space activities will probably rise from its present 10% to as much as 15%, or perhaps $40 billion.

But this means that, at most, all US Government spending on space would be about $50 to 60 billion during the 2010 fiscal year. That would amount to only about 10% of the expected revenues of the American space industry that same year.

Furthermore, much of government spending on space will be purchases of commercially available equipment. These figures help explain why continuation of the present course of national space policy will lead to its domination by commercial considerations in a decade’s time, if not sooner.

We now use near-Earth space for communications, navigation, terrestrial monitoring, deep-space observation, timekeeping, and direct broadcast activities. We will soon be able to utilize near-Earth space for imaging across different portions of the electromagnetic spectrum with less than one-meter Earth-surface resolution, for the emplacement of large space laboratories for bioengineering and other experimentation, and for carrying out worldwide mobile telephone and data transmissions, etc. In the next generation beyond that, we are likely to construct platforms for gravity-free materials production, for the exploitation of solar power, for large-scale hypersonic transportation and space tourism,[7] as well as the expansion and improvement of previous uses of orbital space and the introduction of applications not even yet imagined. Consider a few examples of space-related solutions that are increasingly important to key global markets:

- Telecommunications was the first real commercial moneymaker in space, and it represents the largest sector of commercial space activities. Hundreds of public and private concerns worldwide own, operate, and utilize satellite systems for a variety of services. Satellites, as an integral part of the world's telecommunications infrastructure, provide critical support for services such as long-distance data transmission, television broadcasting, and cable TV. In the developing world, satellites are delivering basic telephone service to millions of people for the first time. Emerging economies are using satellite technology to support rapid growth. In the United States and Europe, satellite technology is enabling new services such as personal communications systems, distance learning, telemedicine, and private networks. Piggyback radio relays on low-orbit satellites detect air and sea distress beacons ("SARsat") and have saved thousands of lives. A space-based "Global Air Traffic Control System" is being discussed. Growth rates of 20 to 30 percent

7 Koelle, H. H. 1998. "Spaceflight in the 21st Century: Projections, Plans, Chances, and Challenges." *Journal of the British Interplanetary Society.* Vol. 51, pp. 251–266.

annually are expected to continue in many segments of this sector.

- Satellite-based telecommunications systems have vast market potential. Demand for personal communications services is booming worldwide. The rapidly expanding economies of Europe, South America, and Asia face the task of implementing telecommunications systems to meet growing societal and business demands. For the developing world, satisfying the demand for basic telephone service remains a challenge. In all of these markets, satellite-related wireless systems provide a cost-effective and technologically robust solution to fulfill market demand. Further, space industry solutions are also meeting other critical market needs such as direct-broadcast satellite television, satellite broadcasting for cable distribution, fixed wireless telecommunications, global mobile communications, and integrated content services.

Over the past two decades, data from Earth-sensing satellites have become important in helping to predict the weather, improve public safety, map the Earth's features and infrastructure, manage natural resources, and study environmental change. In the future, the United States and other countries are likely to increase their reliance on these systems to gather useful data about the Earth. By the early 21st Century, satellite remote sensing systems will generate prodigious quantities of data about Earth's atmosphere, land, oceans, and ice cover. The value of these data will depend on how effectively they can be used. Turning remotely sensed data into useful information will require adequate storage and computer systems capable of managing, organizing, sorting, distributing, and manipulating the data at exceptional speeds.

Once dominated by the governments of the United States and the Soviet Union, Earth remote sensing is now a broad-based international activity. This development has transformed the ground rules for intergovernmental cooperation and offers new opportunities to reduce the costs and improve the effectiveness of overlapping national remote sensing programs. In conjunction with this trend, the emergence of the private sector is likely to play a crucial role in the future of satellite remote sensing. Firms have already taken the lead in linking data sources to data users by turning raw data into productive information. In addition, several private firms have begun to market raw data from privately financed remote sensing systems.

Space-based Geographic Information Systems (GIS) provide detailed and precise terrestrial data needed by a variety of markets. For example, farmers use GIS tools to analyze and manage their crops thereby improving crop yields and enhancing competitiveness in an increasingly global marketplace. Insurance companies utilize GIS data to assess claims following a flood or fire disaster. Timber companies, government agencies, and environmental groups use GIS data to monitor forests.

Space-based systems provide crucial data for environmental monitoring, both in real-time weather forecasts and in long-term trend assessments. Killer hurricanes and typhoons don't catch people by surprise anymore, and less violent and much slower climatic trends, such as El Niño, can be detected more easily from space. In the debate over "global warming" and the disputed role of human industrial and agricultural activities in the process, space-based sensors are providing the critical raw data to measure and characterize the process.

Today's space-based Global Positioning System (GPS) technology enables tracking of objects with pinpoint precision—a critical capability with many applications. Transportation companies can monitor their fleets more closely to adhere to tight delivery schedules. Construction companies use GPS to streamline the process of surveying complex building sites. Automobile manufacturers are using GPS to offer consumers value-added services such as location and direction finding, trip tracking, and emergency response assistance.

Space Industry Macro-Trends

After more than 40 years of space activity, there have recently been some noticeable new trends in the world's space industry infrastructure. SpaceVest, a privately owned space industry research company,[8] lists them as globalization; deregulation / privatization; capital market acceptance; technology convergence; government funding stability; and emergence of new industry leaders. SpaceVest goes on to define them as follows:[9]

Globalization. The space industry is inherently global by nature. More than 20 countries have active national programs related to the development of space infrastructure, with the United States, Europe, Russia, China, and Japan leading the way. In addition, many developing nations have become significant purchasers of space-related products and services such as satellite-based telecommunications systems and remotely-sensed data. Emerging markets in Central Europe, Russia, Africa, South America, and the Pacific Rim represent significant opportunities for the space industry, particularly the telecommunications sector. These opportunities have led to a number of firms expanding internationally through mergers, acquisitions, and strategic partner arrangements.

Deregulation/Privatization. The global trend toward deregulation of telecommunications has given rise to a multitude of new competitors, services, and markets serviceable by the space industry. Additional space-related commercial opportunities are being created by the privatization of many traditional government space activities. For example, Europe has established private marketing organizations for launch vehicles (Arianespace, Starsem, etc.) and remote sensing satellite data (Spot Image). In the United States, government-owned national launch ranges are now licensed to private concerns, and many suppliers of defense-related space infrastructure who formerly sold exclusively to the government are now permitted to compete commercially.

Capital Market Acceptance. The financial community is increasingly recognizing the emergence of the space industry as a mainstream industrial activity with powerful growth characteristics. Successful financial performance should continue to attract capital to

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8 *The State of the Space Industry—Annual Outlook for 1997.* May 1997. SpaceVest, Space Publications, KPMG Peat Marwick, Virginia Tech Center for Wireless Communications.

9 Definitions reprinted with the permission of SpaceVest.

the industry, thereby institutionalizing the space industry in the capital markets. While capital market acceptance is still not as widespread as for information technology ventures, the financial community has begun to recognize that many ventures with a space component are not as risky as previously thought. Nevertheless, satellite telecommunications projects still remain the preferred space industry investment.

Technology Convergence. The convergence of telecommunications and information technologies will continue to fuel commercial growth for advanced "infocom" products and services for a global mobile community. The inherent "look-down" advantages of space-based capabilities will continue to provide an effective means for delivering services and gathering information on a regional or global basis.

Government Funding Stability. Space-based capabilities have become integral to the defense community. Continued stability of research and development expenditures for both civil and defense initiatives is expected. Expenditures related to deploying space infrastructure are expected to continue, with a higher utilization of commercially-developed capabilities. This increasing reliance on space assets for defense operations will provide a revenue base for continued space technology development.

Emergence of New Industry Leaders. The small-to-medium-sized firms in the space industry generally have been on the forefront of commercial innovation. They often possess the low-cost structures and commercially oriented market behavior necessary to capitalize quickly on market opportunities and to compete effectively. Given the substantial size of the worldwide space industry and the emergence of numerous commercially viable niches, many of these companies can experience ample growth without inviting significant competitive response.

This chapter has introduced features of "space power" as it relates to the real world, and has provided a foundation upon which we can venture higher to consider how space power is formed, how it is wielded, and how it can be preserved and enhanced. These are the themes to turn to next.

Appendix 1 to Chapter 1

Useful Principles of Orbitology

Note: This appendix provides a basic explanation of how things move through space, particularly orbital space. It is meant to provide the non-expert with enough of an understanding of orbital mechanics to understand the capabilities and limitations of space operations as currently practiced. An understanding of current space operations will facilitate an understanding of the argument of the following chapters.

To illustrate the principles of orbital motion, Isaac Newton used the image of a cannon firing a shell horizontally from the top of a tall mountain. That was four hundred years ago. Since then, numerous other strained and stretched analogies have been offered: a weight whirling at the end of a string, or a motorcyclist zooming around inside a wide circus barrel, or even electric trains on circular tracks.

Some earthside principles are actually even helpful. Airmen know the technique of trading altitude for speed in a dive. Seamen appreciate the tremendous inertia of ships, which makes changing course a laborious process; they and artillerymen also know about correcting for crosstrack windage or current. Auto and horse racers know the value of the "inside track" in the turn.

These images—especially Newton's mountaintop cannon—turn out to be helpful in appreciating why satellites move through space the way they do, and how they can be controlled and steered. By applying very simple principles of motion through space, these unearthly concepts can become familiar and understandable.

History is also full of misjudgments caused by reliance on faulty analogies, on Earth as well as in space. Astronomers once constructed elaborate systems of cycles and epicycles to explain planetary motion. By imagining that space vehicles were "beyond Earth's gravity," early analysts conjured up images of satellites ominously hanging over surface points such as cities and military bases. Images from Hollywood show winged space vehicles swooping through arcs, or sometimes "stopping"—and always "right side up" relative to the camera angle. And even today, the greatest barrier to understanding spaceflight is often not technological or academic, but psychological.

Imagine You Are In Orbit

So now you've just been fired out of Newton's cannon from a mountain 200 km high. Imagine yourself moving horizontally across Earth's surface at about 8,000 meters per second, 200 km up in space. And imagine yourself still firmly in the grip of Earth's gravity, which relentlessly pulls you toward our planet's center. Although you feel that you are really high above the Earth, you are not so high when seen in context. If Earth were a peach, you would just be skimming the top of the fuzzy hairs.

In a single second, you move forward 8,000 meters (about 5 miles), and in that same second, you fall toward Earth's center by about 5 meters (16 feet). After this first second, you are on a slightly shifted course but at the same speed you were originally.

Meanwhile, you observe that Earth's surface below you is not flat. In keeping with the roundness of the planet, it gently recedes. In fact, if you have the proper forward speed, the surface recedes at the same rate as you fall towards it. You fall "over the horizon" in a continuous path that never reaches the ground. After about 90 minutes, you have completely circled the planet.

You are in "free fall," and since there is nothing to impede your free fall, you are weightless. You and everything loose in the vehicle float in midair. Even though some experts confusingly use the term "zero gravity" or "micro gravity" for this condition, they are only referring to the relative forces on the entire vehicle and its contents together. This common use term does NOT mean that the force of gravity is ZERO on the space vehicle.

This combination of very high SPEED and GRAVITY create the path you follow—the ORBIT. Without one or the other—that is, if you weren't moving forward at a high enough speed, or if Earth weren't pulling you DOWN—you would not be in orbit. You would hit the ground (not enough speed), or you'd fly straight off into deep space (no gravity).

The 10:1 Rule of Thumb

Consider two space vehicles in low, circular orbits around Earth. One satellite is at a higher altitude than the other. The satellite in the higher orbit takes longer to complete one lap, or "revolution." The higher the orbit, the longer it takes to complete one revolution. As a conceptual "rule of thumb," multiply the difference in altitude by ten to get a very rough idea of the relative speed difference between satellites (relative to the time to complete one orbit). For a small vertical separation—say, 1 km—between two satellites, the lower one will pull ahead of the higher one by about 10 km every revolution.

This "10:1 rule" is the result of two factors. It's mostly due to the higher satellite having a longer path to cover. But as a space vehicle's altitude increases, there is also a small drop-off in the force of gravity (you're farther from Earth's center) reducing the required forward speed that you need to stay in a circular orbit.

The rule can be applied over a wide range of near-Earth orbits. It also applies when the separation is averaged across the whole revolution, say when the vertical separation varies between 0 and 2 km every revolution, averaging a difference of 1 km.

The rule of thumb also tells us how the period of the orbit—the time it takes for one complete circuit of Earth—changes with respect to altitude. A satellite 4 km higher than another satellite will be 40 km behind it after one revolution, and since its speed is 8 km per second, it will take about 5 seconds longer to complete one revolution.

The 2:1 Rule of Thumb

Now, how can you move to a higher or lower orbit? Modifying your speed is the only way to change your altitude. Because of your tremendous forward speed, which means your movement has tremendous momentum, the most effective speed changes can only be made directly along your flight path. This will increase or decrease your total speed, which results in a different-shaped orbit.

A second rule-of-thumb, this time for orbital maneuvers, is called the "2:1 Rule." It was developed at NASA's Mission Control in Houston and so was first expressed in English units. The rule states that a velocity change—a "delta-V" in technical terms—of about 2 feet per second will result in the far side of the orbit changing by 1 nautical mile (6,076 feet) in altitude. Restating that slightly differently, a "delta-V" of 2 feet per second executed at a particular point along the orbital path will result in an altitude change of one nautical mile at a point halfway through the resulting orbital path. That's a ratio of about 1:3,000 and it also applies to the metric scale: a velocity change of 1 meter/sec causes an altitude change of about 3,000 meters at the far side of the orbit. However, the resulting orbit will be elliptical, or egg shaped, since one "delta-V" maneuver can only increase the altitude of part of the orbit. The altitude of the point at which the "delta-V" maneuver occurred did not change. More maneuvers are required to do that, so as to circularize the orbit.

One graphic application of this rule is in estimating how much velocity change is required to force an orbiting satellite to enter the atmosphere. Assuming an orbit 300 km high, if you desire to lower one end of the orbit to an altitude of zero (to guarantee atmospheric entry), you must perform a velocity change of about 300 divided by the 3000 factor, or 0.1 km/sec (i.e., 100 meters/sec). Of course, more precise computations must be made for the actual maneuver, but this kind of "rule of thumb" gives very useful qualitative results.

Note that this means the most efficient way to "deorbit" (get back into Earth's atmosphere) is to decelerate by applying propulsive thrust opposite your direction of travel ("a retrograde burn," or a negative "delta-V") half a revolution prior to landing. It turns out to be four times cheaper (in terms of applied energy, which is the same as propellant usage) than doing what might be "obvious" based on earthside experience and applying propulsion thrust to travel straight downwards toward Earth (as you'll soon learn how to estimate).

Results of Thrusting in Various Directions

You have mastered one way of looking at the relationship between speed and the shape of the satellite's orbit. From another point of view, it's informative to ask how much you change the shape of your orbit by making small rocket thrusts ("burns") in different directions. You would usually thrust along your flight path, taking advantage of momentum, but there's no reason you couldn't "burn" in other directions too: left or right, or up or down.

In each case, let's compare your motion, after changing your velocity, to the motion of another satellite that remains in your original orbit (think of it as a deployed payload if you like). You are actually comparing your changed orbital path to your original orbital path before you changed your path. Let's use a figure of 1 meter / sec as the velocity change you perform (other values will create proportionately different distances).

Thrusting Along Your Flight Path

Thrusting forward, for example, initially moves you forward as you might expect. But now you are moving faster than required to stay in your original circular orbit, and as you move forward MORE quickly than before, Earth's curved surface "falls away" more rapidly. This means you are headed toward a higher orbit that (recall the 10:1 rule) takes longer to complete each revolution. So within a few minutes, you begin to rise above your original altitude. As you coast "uphill," your forward motion relative to the original motion drops, then reverses, even as you continue to gain altitude. Within about 20 minutes you are passing your reference point (where you would have been) backwards and about 2,000 meters above your reference point (in its constant orbit), while still going forward relative to the Earth.

Half a revolution later, you are about 8,000 meters behind and about 3,000 meters above the original point. However, you are moving too slowly now to maintain a circular orbit at the higher altitude. You thus begin dropping down towards your original altitude, which you reach after an additional one half revolution. As you reach your original altitude, you are about 16,000 meters behind the original point, although you have picked up enough speed to briefly surge back towards your original location. The cycle continues until you make another velocity change.

Look how this is consistent with the 2:1 and 10:1 rules of thumb. The 1 meter / sec burn drove you to a point a little more than 3,000 meters higher after you traveled half a revolution. Your average height difference is half of this maximum, or just under 1,600 meters.

And every revolution moves you ten times that, or 16,000 meters, farther behind (horizontally) from the original point. Since your orbital speed was very slightly increased but is still close to 8,000 meters per second, it takes you an additional 2 seconds to complete each revolution. See Figure 1-2.

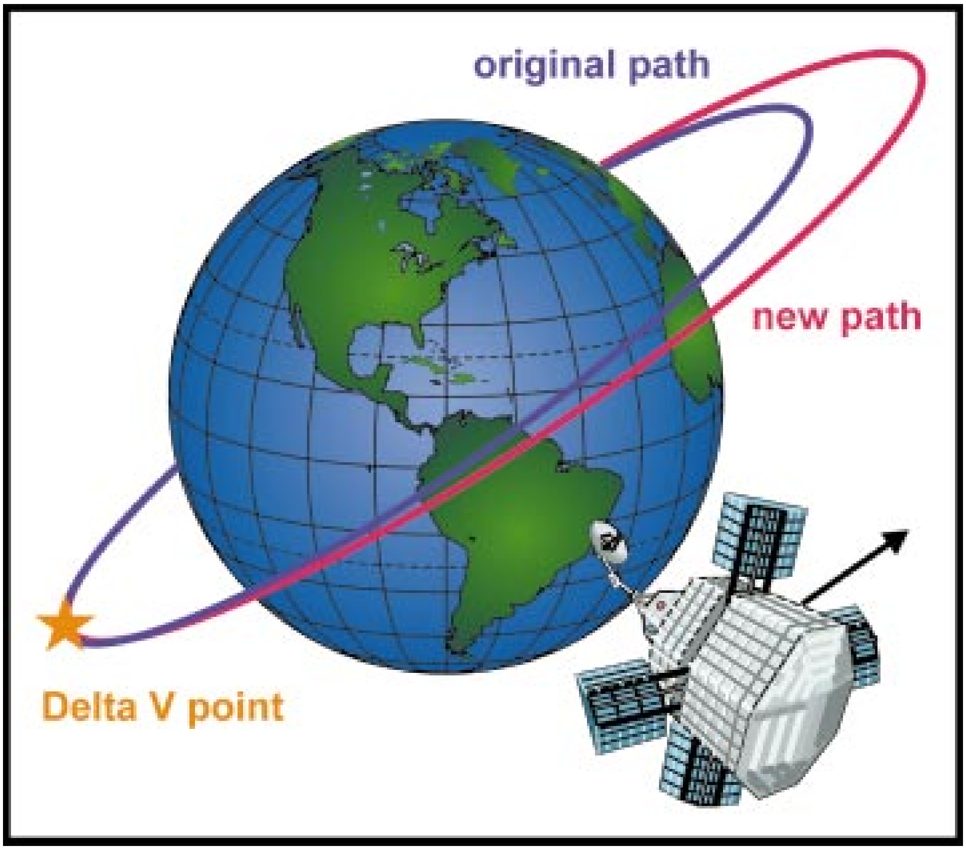

FIGURE 1-2. Thrusting Along the Flight Path.

Thrusting Upwards

On a different tack (literally), you can thrust crossways to your forward motion (vertically to your orbital path). Since the resulting vector is very small, your total speed is essentially unchanged. This means that your orbital period and average altitude would also remain unchanged. However, there would be small variations in your orbit that would repeat themselves every revolution, as follows.

A thrust upwards has the initial effect of doing what you would expect. You move upwards. But then you begin falling behind your constantly-moving reference point as your speed is no longer enough to keep pace with the lengthened orbital track.

Let's continue to use a figure of 1 meter/sec as the propulsive energy thrust you apply. After about a quarter of a revolution, your upward motion has died out, about 800 meters above and 1,600 meters behind where you started. You are still losing ground, slipping farther behind your original starting point, and then you begin falling back down towards your original altitude.

Half a revolution, about 45 minutes, after the upwards maneuver, you are about 3,200 meters behind where you started, on a mirror-image course, falling downwards at exactly the speed you first started upwards. Remember, without any change in your total orbital velocity, your motion will average out to keep you at the same average altitude.

Dropping below your original altitude, you pick up speed, and begin overtaking your original position. After exactly one complete revolution, you are precisely back where you started, moving upwards with the same speed you started with. It's deja vu all over again (Remember "Groundhog Day"—the Bill Murray movie) in orbit. Relative to your reference orbit, you follow the same path over and over again.

The only result of the vertical course change was to make the orbital path a bit lopsided, or in mathematical terms, more eccentric. Sometimes you are higher than your original orbit, and at other times you are lower. You didn't gain any permanent altitude increase by thrusting upwards. The only way to do that is to thrust forward. See Figure 1-3.

If you were in an orbit 300 km high, could you reach an altitude of zero kilometers by thrusting downwards toward Earth? The ratio described above—one meter/sec upward/downward thrust creates a changed altitude of 800 meters one quarter of a revolution later—means that you'd need a delta-V of about 400 meters/sec towards the

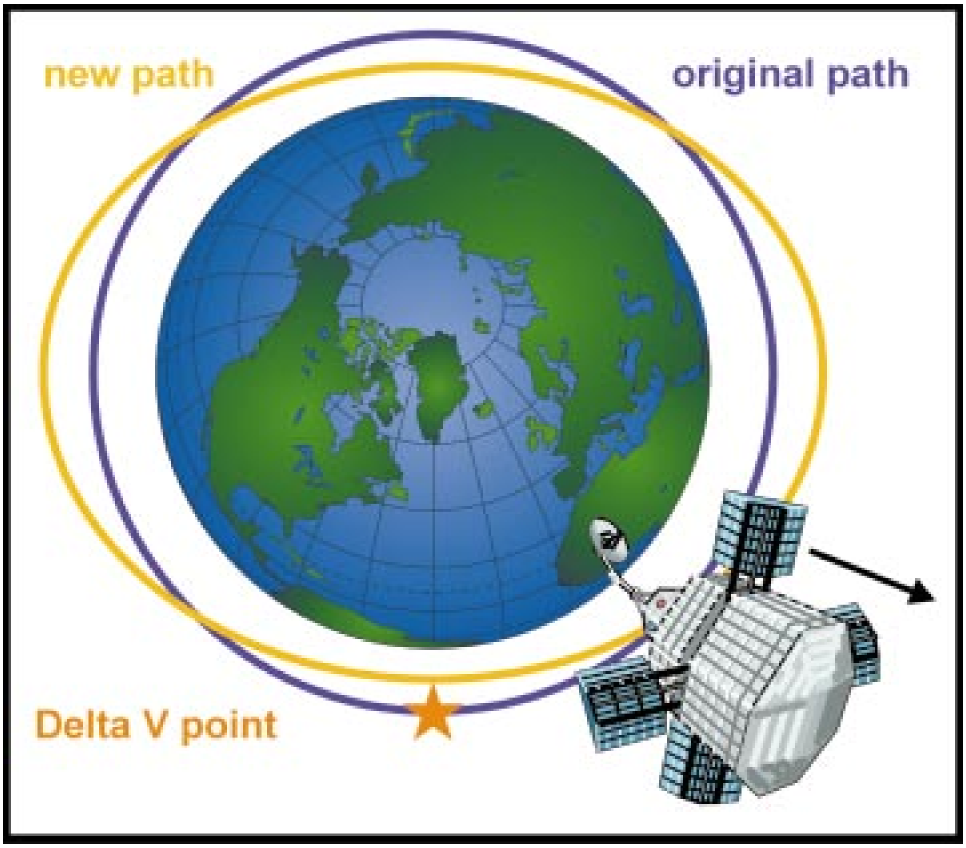

FIGURE 1-3. Thrusting Upwards.

Earth to achieve this. Compare this with the 100 meters / sec delta-V to deorbit in the most efficient manner, using a braking thrust along your flight path.

Inclination or Plane of an Orbit

Before we go any further, we need to talk about another technical characteristic of an orbit: inclination, which is very important to the usefulness of a satellite. Suppose your space vehicle was fired due east from a mountain on the Equator. Your orbital path follows the Equator. Your orbital path would not be inclined to the Equator and, therefore, would have a "0-degree" inclination. You will pass over only that part of the Earth's surface that lies on the Equator; you will never pass over Switzerland or New Zealand. If you could change the inclination, or plane, of your orbit to 45 degrees in relation to the plane of the Equator, then you will eventually pass over all of the Earth's surface between 45 degrees North and 45 degrees South latitude. You would pass over Switzerland and New Zealand, but not on each orbit. Because the Earth is slowly rotating underneath your satellite's orbit, at a rate of one revolution per day while your orbital path is revolving around the Earth every 90 minutes, from the point of view of Earth's surface, your orbital plane is shifting westward. Every time you pass over the equator heading northbound, you hit a farther west longitude.

Thrusting Sideways

Let's go back to operating your space vehicle. A horizontal sideways thrust—in orbitological terms, a thrust "out of plane"—has a similar periodic result as thrusting upwards. Initially, you move in the direction that "common sense" indicates.

Since you retain essentially the same overall forward speed you started with, your orbital period doesn't change, and so you must wind up one revolution later exactly back at your starting point. So after about a quarter revolution of travel, your off-to-the-side motion has died out, after you have gotten about 900 meters away from your starting point. You then start slipping back towards your original reference point. Half a revolution later, you pass right back through your reference point (the place where you would be if you hadn't thrusted) going in the exact opposite direction (left / right) you started to go. After this mirror image motion to the other side of your orbital plane, you wind up after one full revolution exactly back where you started. See Figure 1-4.

These figures show that changing a satellite's orbital plane in space is extremely difficult. That's because you are attempting to shift the momentum of an object traveling at a tremendous forward speed (about 8,000 meters per second) off in a different direction by making a crosswise thrust. Since a degree of latitude is 60 nautical miles, or 110

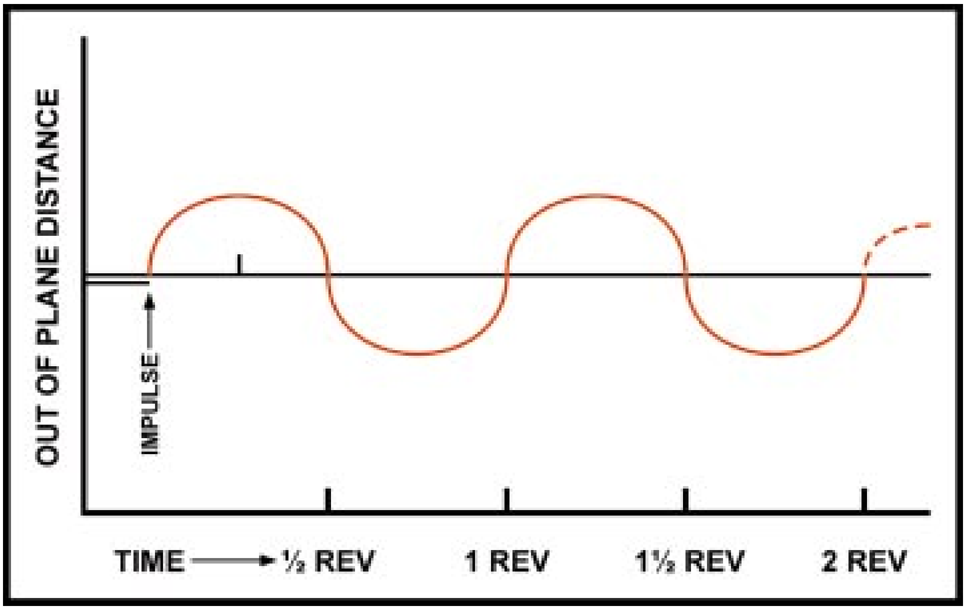

FIGURE 1-4. Thrusting out of Plane.

km, and 1 meter per second only moves you 900 meters, to get a full 110 km off to the side (to change your plane by one degree), you would have needed a burn out of plane of more than 120 meters per second. Compare that to the 100 meters per second which is enough to return to Earth.

Maneuvering in Space

Now that you are in control of your orbit, how can you change your path to get to where you want to be? Specifically, you may want to maneuver to rendezvous with another satellite, or to a specific location relative to a point on the ground. By the way, only a few nations have succeeded in accomplishing a space rendezvous. It seems easier than it really is in practice.

Solving the "rendezvous problem" depends on knowing what kind of solution you need. If it is merely to bring two objects together at any speed, there is one set of constraints. If the requirement is to bring two objects together at near-zero speed, an entirely different set of problems exists.

The first problem is one of “intercept” (deliberate collision), and aside from the tremendous speeds involved, it is not substantially different from air-to-air interception. The path of the target must be measured and predicted, and an interceptor must be steered into position close enough for the kill.

The “gentle rendezvous” problem, however, involves all the principles of orbital motion we have already discussed, including orbital planes and changing the shape of one’s orbit. It is therefore a useful mental exercise.

Because changing one’s orbital plane in space is prohibitively expensive, it is required to begin the rendezvous maneuver nearly in plane with the target. This means that the launching can occur only near those brief moments when Earth’s rotation carries the launch site through the orbital plane of the target satellite. This immediately places severe scheduling constraints on the rendezvous mission.

The preferred geometry for a rendezvous profile is for the chaser to approach the target from behind and below, which gives you an overtaking rate (remember the 10:1 rule). The desired time of arrival is picked to optimize lighting conditions and perhaps communications periods. To achieve this, the chaser’s approach rate is controlled by raising its orbit in small steps.

Some eccentricity (“wobble”) in the chaser’s orbit is desired to allow the line of sight to the target to shift back and forth during each revolution. This provides geometric visual cues as to the true range. And the closer the chaser gets, the more it must depend on its onboard sensors—visual, radar (passive or with transponder), even laser—since ground tracking doesn’t provide the required accuracy or timeliness. This is especially true for a noncooperating target, either one that is passive, or broken, or even potentially hostile.

The theoretically perfect approach paths are most economical in terms of fuel usage only if the chaser has perfect knowledge of its relative position and can perform its required course corrections precisely. Of course, this doesn’t correspond to reality, so in practice, an approach path is designed to be able to tolerate some position uncertainty and thrusting sloppiness.

Both automated and manual approach systems prefer simple control laws, which specify what corrections need to be made under what detected course deviations. They also usually contain a series of range-dependent “gates” at which the chaser must slow its approach down to specified rates. By this point, we have left the realm of pure orbitology and are using design principles from operational control theory.

Earth Surface Targets

Satellites do not, of course, fly across a uniform, featureless globe. There are specific points on the Earth’s surface of tremendous interest to the satellite’s operators. These may be communications stations, observational targets, planned landing zones, or other mission-relevant locations. It is highly desirable to optimize the changing relative position of the passing satellite to the ground locations.

Earth itself is in motion, rotating eastwards at a rate of 1,600 km per hour at the Equator, or about 15 degrees per hour. After a low-orbit satellite completes a 90-minute revolution, a point on the Equator will have rotated about 2,400 km eastward. If the satellite were in a polar orbit (one that is inclined 90 degrees to the Equator and passes over the North and South Poles), it would pass over the Equator exactly 2,400 km west of the point it crossed the Equator on the previous orbit. Each succeeding track across the Earth’s surface is thus displaced farther and farther west. This explains how you can be fired out of Newton’s cannon from a mountaintop 200 km high and not hit the mountain after only one Earth orbit (except for our equatorial orbit example earlier).

If there were a particular point on the surface that you wanted to pass over, you will need to adjust your groundtrack. It makes no sense to steer to the left or right, since we’ve seen that out-of-plane burns are tremendously expensive and of limited value. Instead, since Earth is moving sideways below your orbit, you want to give Earth more (or less) time to bring the point of interest directly below you when you reach the right point in your orbit.

You do that by delaying (or advancing) your arrival at the point in the orbit where the target passes underneath. That requires you to change the period of your orbit, and that requires you to raise (or lower) your average altitude.

Say, three days from now, you expect to pass 200 km east of a target of interest near the Equator—but you want to be directly overhead. So you want to give the target enough time to be carried eastward by Earth's rotation until it is directly below your track.

These are the steps you go through to estimate the maneuver required. Each one of these has already been explained.

Step 1. Since your satellite is traveling at 1,600 km / hour, you will need to let the Earth rotate underneath your satellite for an additional eight minutes, which essentially shifts your orbital ground track 200 km more or less, and should place your satellite over your target point.

Step 2. In three days you will be making 48 revolutions, you thus want to make each revolution last about one sixth of a minute, or 10 seconds, longer. This will give you a total of 8 minutes of delay after 48 revolutions.

Step 3. Since your satellite's speed is 8 km / sec velocity, you want to increase the distance covered on each revolution by about 80 km, so that it will take about 10 seconds longer for each revolution of the Earth.

Step 4. By the "10:1 rule" you thus want to increase the average altitude by 8 km.

Step 5. If you want to do this as cheaply as possible and use just one propulsive rocket burn, you can keep one end of the orbit the same and raise the other end by 16 km, or 16,000 meters.

Step 6. By the "2:1 rule," which actually specifies a 1:3,000 ratio of velocity change to altitude change, you will need a delta-V of about 5 meters per second to achieve this higher, slower orbit.

In summary, the best way to place yourself over a desired ground target is to exploit Earth's own rotational rate. You don't turn, you let the Earth turn. But this requires that you adjust your orbital speed by raising (or lowering) your orbit. The notion that you can get access to targets off to the side of your path by adjusting your forward speed is truly unearthly, but it's a straightforward consequence of the simple principles of orbital motion.

Geosynchronous Orbits

There are many reasons to want to control your ground track and make it fit into a pattern. You may want to repeat your track over the same ground targets every few days. You may want to maintain position with other related satellites which form a network in space, a "constellation." Any orbit which has a repetitive groundtrack is called "geosynchronous," that is, synchronized in some way with an Earth-surface reference frame.

The most famous kind of geosynchronous orbit—so famous that it often is thought to be the only kind—is one that is high above the Earth's surface (about 36,000 km) and is also in the same plane as the Equator (the equatorial plane of the Earth). A satellite at that specific altitude and at that inclination (0 degrees) circles the Earth exactly once a day. The resulting matched eastward rates of the satellite in this orbit and Earth's surface leads to the satellite holding a stationary position in the sky relative to a desired specific point on Earth. This is the so-called "geostationary" orbit, which is just a geosynchronous equatorial orbit with a period of one day.

Orbital Twist or Equatorial Shift

In practice, there are some other significant influences on the orbit of a satellite. One of those is the influence of the equatorial gravitational "bulge." Since the Earth rotates, it flattens slightly at the poles and bulges outward at the Equator. Probably the most significant and mysterious impact of the equatorial bulge is how it causes the path of an orbit to "twist" in space. Twist isn't really the right word; it's more like a long, gentle "S" turn. However, "twist" is the term used by most space operators. It's as hard to understand and as complicated as the not-right terminology indicates. But, orbital twist is important enough to be explained. For better and more detailed explanations, there are several good textbooks on orbital mechanics.

Various analogies have been suggested in orbital mechanics textbooks, having to do with right-angle forces on spinning wheels, and other strained parallels with earthside experience. But the most useful way to grasp the concept is to keep visualizing your space vehicle moving under the influence of gravity and its own forward speed—with extra localized gravitational pull as your satellite crosses the equator. Think of Earth's equatorial bulge as a ring around the planet's waist. It has its own mass, and will pull anything nearby towards it.

Now imagine your satellite approaching Earth's equator, say, from the southwest, at an angle (remember that angle with which it crosses the Equator is called the orbital inclination) greater than a few degrees. It's just been over a point well away and south of the Equator. It's aimed straight ahead for a spot above the Equator.

As it approaches the Equator, the nearest portion of the "bulge" is also pulling on it, directly toward the Equator. Its path will veer slightly toward the bulge, to the left. It will reach the Equator at a point somewhat to the left of where it had originally been headed.

North of the Equator the process is symmetrical but in the opposite direction. Now the nearest parts of this extra equatorial bulge are on the right, and it is in this direction that the satellite veers. As it finally distances itself from the Equator, the two effects—the veer to the left (south of the Equator) and the veer to the right (north of the Equator)—have balanced out to return the satellite to its original direction.

However, the original swerve to the left (westwards) is NOT counterbalanced, so the satellite's orbital plane has been effectively shifted a small amount. For a typical space shuttle flight from Florida, this shift per Equator crossing amounts to about 20 to 25 km. That's not much on an orbit that is 40,000 km long per revolution, but it can add up. For space shuttle flights, it can amount to a westwards plane shift of about five to seven degrees per day.

Now, if we apply the principles of gravitation to this effect, we can see how it works for different altitudes and inclinations. Since it is caused by the extra gravity from the equatorial bulge, the closer you are and the longer you stay close to this bulge, the bigger you should expect the effect to be.

This is exactly the case. The lower the inclination of an orbit, the longer it skirts "near" the Equator and the more it is twisted. The higher the orbital altitude, the more distant its approach to the extra mass, and so the less its orbital plane is twisted. See Figure 1-5.

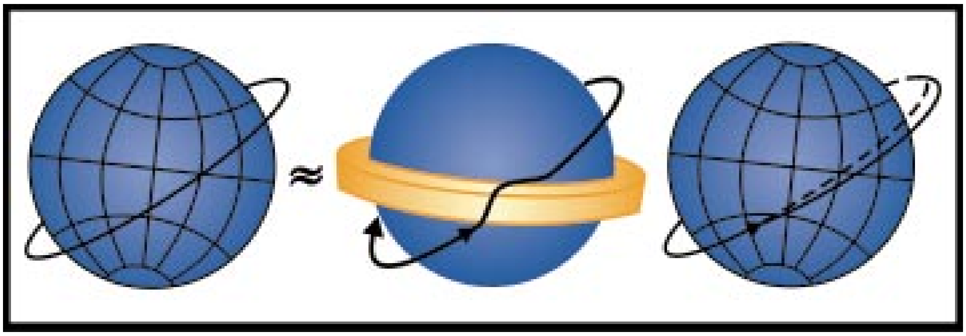

FIGURE 1-5. **Orbital Twist.**

An interesting and very useful application of this orbital twisting is connected with those orbits that are nearly perfectly north-south (near-polar) orbits that are slightly "retrograde"—that is, they approach the Equator from slightly east of south when northbound. The twisting still occurs, but this time (think of where the extra mass is closest), it is first to the right, towards the east and then to the left. Sketch this out to convince yourself.

As Earth circles the Sun once per year, it moves in its orbit and the Sun appears to move through the constellations. The rate is a little less than one degree per day, which works out to be 360 degrees in 365 days plus some hours.

If a satellite is placed in a slightly retrograde near-polar orbit, the equatorial bulge will twist the plane eastwards. The ideal situation is that the orbital plane shifts ("twists") eastward at the same rate as the Sun appears to move against the background stars, and as a result, the relationship of the orbital plane and the Earth-Sun line remains the same. This means that as the satellite passes over ground locations, the angle of sunlight—and the resulting shadows—remain fairly uniform, no matter how much time, or how many orbits, have gone by.

This is called a "sun-synchronous" orbit. It has many obvious applications to different types of observation platforms. The applications are so obvious that any object in such an orbit is presumed to be in some sort of Earth surface observation. There are a few other satellites in the same type of orbit to remain in continuous sunlight for reasons such as power, astronomical work, etc.

Recall that because the degree of orbital twisting depends on the satellite's altitude above the Earth, achieving the same amount of orbital twisting (the technical term is "precession") requires the selection of different inclinations for different operational altitudes. As the orbit gets higher (and farther from the Equatorial bulge), it must have a lower inclination so as to spend a proportionately longer time "close" to the bulge to accumulate the same amount of twisting. As a result, it will pass over a lessened north to south range of the Earth's surface; therefore, sun synchronous orbits can't be very high.

Using Orbits

Satellites in low earth orbits (LEO) have altitudes from about 150 km to 1,500 km. A satellite orbiting at an altitude of 150 km will require regular propulsive thrusting to stay in its orbit. It is slowed by the drag of the Earth's extremely thin atmosphere at this altitude. A satellite in an orbit of 150 km could stay in orbit at this altitude for only one day before decaying back, unless raised higher. Higher up, a satellite at 400 km could remain in orbit for a year without intervention, but it too would be slowed to a speed that could not keep it in orbit after about one year. For LEO orbits, drag is a significant problem. But LEO orbits are very important because the lower the satellite, the closer it is to objects on the Earth's surface. That means it can see those objects better with a telescope or pick up a less powerful radio signal from an object on the Earth. Satellites in LEO orbits do not see large areas relative to other orbital views. During a typical orbit by a satellite at LEO altitude, its field of view is 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. The most valuable aspect of LEO is its proximity to the Earth for observation and low-powered communications.

Satellites in medium altitude orbits (MEO - medium earth orbit) between 1,500 km and 35,800 km, take from 2 to 24 hours to circle the Earth. The only valued orbit, at present, at MEO is the "semi-synchronous" orbit with 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 (if they have the proper inclination as well) and are therefore uniquely suited for some communications and navigation missions.

One particular semi-synchronous orbit, named the “Molniya Orbit” after the Russian satellite which first used it, is worth mentioning because of yet another gravitational disturbance on satellite orbits. The Molniya orbit is highly eccentric—that is, its high and low points are very different. In practice, the low points are about 800 km high, and the high points are about 40,000 km.

For such elongated orbits, a subtle new kind of twisting is caused by irregularities in Earth’s gravity field (it’s not just bulgy at the equator, it’s lumpy at various spots as well). The line running from the low point to the high point is (depending on orbital inclination) shifted clockwise or counterclockwise along the orbital plane. So over a period of weeks, a satellite with a high point over Norway, say, will see that high point shift to be over Italy, then over Libya, and so forth. This interferes with the planned application of such satellites for communications relay functions over far northern areas.

At one particular orbital inclination, these kinds of gravitational disturbances cancel out, and the orbit keeps its high point pointed in the original direction. That inclination happens to be about 62 degrees, and that’s why all satellites in Molniya-type orbits use this inclination.

Geostationary earth orbits (GEO) are at a very high altitude (35,800 km). As already explained, satellites at this orbital altitude appear motionless to an observer on Earth. Their field of view includes large expanses of the Earth, so much so that three of these satellites equally spaced over the Equator theoretically provides total coverage of the Earth’s surface, except the North and South Poles. GEO (really a misnomer) positions (“slots”) are controlled by the International Telecommunications Union (ITU) and are highly prized for communications uses, including television broadcast. Some warning systems are put at GEO altitude for their wide view of the Earth.

Conclusions

Motion through space is the ultimate “unearthly trip.” Attempts to lean on “common sense” analogies often fail us. Mathematical approaches often are severely intimidating. This appendix introduces a qualitative approach using a few rules of thumb and a few basic principles. It then tries to use those rules and principles to show how they explain the essentials of orbital motion. The desired result is an improved understanding by non-experts of how and why satellites move. That understanding can then provide insight into the uses of various orbits and orbital altitudes to provide space-based services. After all, for the critical functions of space operations, the scientific and precise answers can be left to the experts in orbital mechanics.

2

The Nature of Space Power

> *"Les Yankees, ces premiers mecaniciens du monde, sont ingenieurs, comme les Italiens sont musiciens et les Allemands metaphysiciens,—de naissance."* (The Yankees, the best mechanics in the world, are engineers, as the Italians are musicians and the Germans are metaphysicians, by birth.)—Jules Verne, *From the Earth to the Moon,* 1865.

The enviable position of the United States as the leading player in space activities at the end of the 20th Century is the culmination of many factors of "space power," some of them involving foresight and hard work, and some of them involving luck and circumstances. Consequently, any strategy to exploit and expand this position must pay attention to these different types of factors and how they can be encouraged. First are the resources to be applied to the task. Secondly is the wisdom and vision to choose among an infinity of alternative strategies. Lastly is the flexibility to anticipate, respond to, and benefit from random, opportunities which cannot cease to occur.

"Space power" is a phrase that evokes parallels with historical concepts of "sea power" and "air power." Useful parallels can be drawn. But without an appreciation for how different space is from air, sea, or land (chapter 1), false analogies and resulting erroneous decisions are possible, even likely. And without some familiarity with how "space power" has already been applied, sometimes well and sometimes poorly, at other times and in other places, insights and lessons may be lost. The purpose of this chapter is to provide that familiarity.

The elements of "space power" range from the obvious hardware—space vehicles, launch and control sites—to the often overlooked human element: people whose intelligence and dedication drives the innovation, and a parent society which understands and values "space" activities, and considers the payoff worth the major effort. The more of these elements that are possessed by a user, the more flexible, reliable, and robust the applications will be.

Elements of Space Power

Elements within a nation that make it capable of wielding "space power" are outlined below. While these are the individual elements of space power, to achieve a leading or even dominant space role, a nation must also develop the attendant national and military strategies and the policies that enable it to exercise and exploit space power.

Any explicit list of elements of "space power" will probably be incomplete, and often, weaknesses in one area can be overcome by strengths elsewhere. The following elements are neither mutually exclusive nor necessarily complete.

Facilities: A user must have the obvious elements of hardware with which to conduct space operations: manufacturing facilities, launch facilities, and command and control facilities. Ideally the user owns these, although exploitation of another owner's facilities is often feasible.

Technology: Laboratories (primarily but not exclusively government-funded) must develop basic and applied research programs relevant to the full spectrum of capabilities related to desired space operations. These programs must compete favorably with defense, energy, transportation, and medical programs for funding. National and private laboratories should ideally work in cooperation with universities and develop programs that encourage students to enter the field. Access to the technology of other users—both for direct transfer and for assessment of capabilities and intentions—can often provide crucial guidance in the development of both short-term responses and long-term strategies.

Industry: Private industry must vigorously pursue space technology and applications for "business and profit" and fund their own in-house basic and applied research to maintain a competitive edge in the designing, manufacturing, deploying, and operating of space systems. This includes the innovation of modern and efficient production facilities for producing large numbers of satellites (buses and payloads) rapidly and at very competitive costs, the ability to operate space systems economically but safely, and the strategy to leverage other technologies into space-related applications.

Hardware and Other Products: The actual space vehicles (e.g., the payloads and the boosters) and the material required to operate them (e.g., fuel, power, and other utilities) are the result of industrial and financial capabilities, modulated by utilization strategies. Their quality, cost, lifetime, and other characteristics reflect original strategic intent and determine actual operational capabilities. The level of spare parts and of reserves (providing a rapid replacement of losses, or a "surge" to deploy more-numerous-than-normal assets) depends on strategies and constraints, but is an often-overlooked element of "space power" that can mitigate weaknesses in other areas.

Economy: A strong economy makes it easier to fund a strong space program, both government and commercial programs. But a weak economy should not be allowed to lead or to terminate space activities. Because space expenditures often tend to be long-term payoff investments, nations and corporations undergoing financial crises often are tempted to reduce space spending, especially since such reductions give little short-term indications of damage. But space systems currently available often depend on decisions made ten or fifteen years in the past, so short-term cutbacks often require downstream overspending, often at multiple levels of the original shortsighted savings. Space activities often require substantial new investments, with government instigation and subsidies to pioneer some technologies, and more prosperous times may allow government and private funding of a wider range of investments. But even in temporary hard times, wise users strive to protect space-related investments in future space power.

Populace: The citizenry must be well educated with sufficient numbers of engineering specialists and theoretical scientists. Because space spending is so sensitive to initial investments and to personal innovation, a high ethical level—especially in economic and legal terms—is also a benefit for minimizing losses due to administrative overhead and financial corruption. In terms of citizenship, the taxpayers need to understand the importance of government expenditures on developing space technology. Just as importantly, the populace must be comprised, in part, of an influential group of technology proponents. This will make the market for new technologies culturally important. Also, since popular culture is influenced more by noise than by opinion polls, it's important that there NOT be vociferous and energetic opponents of specific space policies since they tend to have social influence disproportionate to their absolute numbers.

Education: There must be access to a sufficient number of universities (either domestic or foreign) offering relevant engineering and science courses from undergraduate through doctorate-level, in order to generate the knowledge and talent pool required to support and grow a vibrant and vigorous space industry. In addition, domestic universities, in cooperation with the government and other institutions, must conduct research programs to keep the nation on the leading edge of space-related technology.

Tradition & Intellectual Climate: A nation's space activities require broad popular appreciation and support in order to have the endurance to tolerate both long-term economic and political variations as well as short-term setbacks. This appreciation is both for practical applications and as inspiration and affirmation of national consciousness. Public enthusiasm for space activities translates directly into a pool of candidate professional space workers and a constant source of ideas and inspiration for space policy makers (as in Verne's prescient quotation at the head of this chapter).

Visionary leadership is needed from decision makers and decision shapers in government, in commercial companies, in academia, in the news media, and at large—they must all have basic understandings of real versus unreal space possibilities. Public respect for and trust of national space organizations is also highly important and any domestic intellectual climate that hinders that relationship will diminish the national capability to develop and wield space power. The intellectual climate must include widespread popular interest in the acquisition of knowledge. New discoveries, even if not immediately applicable, must be seen as eventually providing to the general knowledge base from which practical applications will come. Academia should be excited about new discoveries and infuse students with that excitement. It is also important that the agencies responsible for exercising space power generally be respected and trusted, to avoid developing a "garrison mentality" on one side and a mistrust and aversion on the other.

Geography: The free exercise of space operations requires a launch site with ample downrange safety zones (in the multi-stage expendable booster environment) and usually a far-flung string of communications sites. This favors geographically large nations or those with good diplomatic relations with potential host nations.

Exclusivity of Capabilities/Knowledge: The most volatile aspect of power in general is related to features which one owner alone possesses, or one owner alone understands the capabilities of. Since experience demonstrates that any such benefits are bound to be short-lived, efforts to protect these features must be matched by efforts to develop replacement features.

Uses of Space Power

As users possess various elements of "space power" to varying degrees, they can exploit them in a number of specific ways. The effects of "space power" can be categorized as economic, cultural, diplomatic, and military (next chapter). Another way of looking at space power is to delineate the different ways it can be applied.

First, it can be applied as a direct benefit to the owner, through pursuit of diplomatic, civil and military applications. More and more such applications are becoming cost-effective even on their own merits alone.

Secondly, space power can be used to encourage and reward other global players. The opportunity to piggyback one player's space efforts onto existing and easily shared/transferred capabilities of another has measurable economic value.

Thirdly, space power can be used to dissuade targeted players. Discouraged and unwanted behavior can result in termination of valuable joint activities, withholding of accustomed information and other services, or isolation from the international space community.

Fourthly, space power can be utilized to avoid punishment from other players aimed at the owner of the space power elements. Each user seeks as great an immunity as it can obtain from dependence on other nations for key space power elements, but only those with the broadest infrastructure can achieve this and exploit the freedom of action it provides.

Fifthly, space power can be used to project national influence, both through the cultivation of dependency among other global players and through control of the agenda of international discussions of cooperative projects, and treaties. One nation's space power can also significantly influence the internal space policies (and other policies as well) of another player by forcing symmetric developments or by discouraging ambitions for competition or confrontation.

Lastly, space power can be used to apply force, both in space, from space, or through space, and to resist the use of force against oneself.

The United States and Space Power

US space power owes a debt for the pace of its development to the Soviet Union and its military ballistic missile program, the base of the early Soviet space program. The United States would have ventured into space activities anyway as a result of internal intellectual energy and scientific curiosity. As evidence, the US Government had announced its intention to launch a satellite into low earth orbit during the International Geophysical Year (IGY) in 1958. The advantages of geosynchronous satellite communications relay were apparent to Arthur C. Clark and his readers years before the space race. Communications relay through LEO would have been attempted and been found to be very useful in the decade following the IGY. It is likely that the space-based communications industry would have grown up without the Soviet Union. However, the public relations triumph of Sputnik forced the United States to attempt to match the Soviet space program as soon as possible. President Kennedy's commitment to put a "man on the Moon, and return him safely to Earth" in the decade preceding 1970, caused the expansion of space technology into many unimagined capabilities, in addition to manned space flight. Likewise, the need for information about Soviet military capability was the rationale for the development of space-based information sources. The requirement to support worldwide military options against possible Soviet initiatives hastened space-based weather and communications technologies.

The successful applications of “space power” by the United States have already filled many, many books. With an annual NASA budget of about $13 billion and a larger military space budget, of which the published portion is a similar size, the United States holds a dominant lead in Earth’s space activities. It has deployed and is operating the most capable earth observation systems, the most flexible orbital launch and retrieval system, the most advanced constellations of Earth-orbiting space vehicles, and the most far-flung fleet of interplanetary space probes in the history of the space age.

In the commercial space sector, US commercial advantages are equally strong. According to John Logsdon,[10] “US industry has a wide lead in all markets other than space launch.” Even here, writes Logsdon, “the European lead is fragile.” New US launcher projects include Sea Launch, new versions of the Atlas and Delta vehicles (including the use of Russian designs for rocket engines), and a possible commercial version of the DoD-sponsored Evolved Expendable Launch Vehicle. The US space industry also has probably the largest variety of innovative advanced concepts for smaller launchers. All of these potential launch systems point to significant near-future gains in this arena.

Logsdon quotes the Teal Group[11] as forecasting that US firms will be prime contractors for almost 75% of the various types of information transfer satellites over the next decade. “The United States is in this position because it adapted more rapidly than Europe and Japan to a changing economic and political climate,” Logsdon wrote. His use of the singular pronoun implies a centralized, monolithic management which in fact does not exist; more accurately, he should have worded it that “US industries are in this position

10 Logsdon, Dr. John, Director, Center for Space and Policy, George Washington University, Washington, DC. “The United States, the Only Space Superpower.” Space Policy. Nov. 1997, Vol. 13, No. 4, pp. 273–279.

11 Teal Group Corporation publishes the World Space Systems Briefing, a monthly information service that reports the status and outlook of the world’s space systems, spaceports, and markets.

because THEY adapted...” which underscores the classic advantages of distributed decision making in a highly dynamic environment.

Russia and Space Power

Besides the United States, many nations have exercised all or many of the elements of space power. A review of these other approaches to space power will show alternative strategies, which may provide new ideas for US space power, or may highlight challenges to US space power. Since it is very human to not be good at self analysis, we often learn the most from looking at others. An analytical approach to looking at someone else’s strengths and weaknesses may give us a better picture of our failings and our virtues.

Union of Soviet Socialist Republics (1957–1991): The Soviet space program has been, apart from the US program, the only other space program in the world to conduct a full range of space activities—scientific, manned, commercial and military. The Soviets possessed all elements which made up “space power.” They exercised these elements, and then they lost these elements. As a case study, the Soviet/Russian space program deserves some in-depth description, but readers may skip to the “Other Nations” section if they desire.

From the viewpoint of official Soviet culture, it was natural for the USSR to lead the world into space. Lenin himself had realized the value of embracing such space visionaries as Konstantin Tsiolkovskiy. This was useful both as a symbol of futuristic, idealized communism as the supposedly most advanced social organization on Earth, and as a distraction from harsh everyday realities. Like the United States, tsarist Russia too had a recent geographical expansion—a “Wild, Wild East” scenario where Cossacks had advanced into Siberia for centuries.

Thanks to a series of highly popular books as early as the 1920s, an entire generation of Soviet engineers and scientists were inspired to see themselves as space pioneers. As it turned out, few of them survived the Stalin purges and World War II. But by 1947, the Soviet government turned to the survivors—Sergey Korolyov, Valentin Glushko, and others—to lead a major push in rocketry that soon expanded into ground-breaking space accomplishments.

For most of its history, the Soviet space program was carried on by a collection of distinct, often mutually antagonistic entities with an ad hoc pattern of shifting alliances and animosities. Centralized decisions were often made and unmade by whim, by personal influences, or by misreading external factors. Organizational relationships were often determined by factors as arbitrarily Byzantine as hiring or marrying the children of Kremlin officials. This confusing, unstable, and inefficient system was, in the beginning, fairly effectively concealed behind the public facade of a monolithic, coordinated program.

Rocket (and nuclear weapons) development was coordinated by the deceptively-named "Ministry of Medium Machine-Building," usually referred to in its Russian abbreviation of MinObMash or "MoM." It financed a suite of specialized civilian institutes and manufacturing facilities led by brilliant but often highly-competitive "General Directors" and "Chief Designers." The Soviet armed forces (the Air Force, the Strategic Rocket Forces, and a specialized ministry-level independent unit called the "Space Forces") supported space operations by running the launch sites and tracking stations, and by training the cosmonauts. The prestigious and well-funded Academy of Sciences, especially in the early years, had significant input on programmatic decisions, although later its branches, such as the Institute for Space Research (which usually billed itself deceptively as "the Russian NASA") and the Institute of Biological and Medical Problems, shrank in significance and staffing. Later, various specialized bureaucracies such as "Interkosmos" and "Glavkosmos" were established as "fronts" for international cooperative projects.

Since the entire Soviet space program was presented to the world as "entirely peaceful," there was no need to split and duplicate facilities between a NASA-like civilian organization and a parallel military organization. Nevertheless, massive duplication and overlap existed between competing bureaus and military units.

Within a short time of the Sputnik launch (October 4, 1957), Soviet leaders quickly realized the most important result of their space activities. These "space spectaculars" convinced the West (and the Soviet public themselves) that the USSR possessed highly advanced space and missile capabilities. This high level of perceived status—scientific, technological, and military—proved to be the main (some would say only) benefit of Soviet space activities. It would be simplistic to say that the program was only funded primarily for prestige; rather, the program proved its worth when Western attitudes shaped by the public perception of the program could be exploited diplomatically and commercially.

From a very long historical standpoint, the greatest contribution to humanity from the Soviet space program may turn out to be that it energized a vigorous US response at a scale that otherwise was inconceivable. Without Sputnik, Vostok, Lunik, and other challenges to America’s political ego, it is questionable if there ever would have been an Apollo, or Viking, or Skylab. This international dynamic underscores the theme that Earth’s space activities are more than the sum of each nation’s individual programs, and shows that there is a powerful feedback mechanism among them. Decisions in one country often depend profoundly on decisions made in other countries; they also depend on perceptions and often misperceptions of other national programs.

Meanwhile, inside the real Soviet space program, the military application of all space projects was paramount from the beginning. The Vostok manned spacecraft of the 1960–1963 era was quickly adapted to serving as a photo reconnaissance vehicle. The first orbital antisatellite weapon tests in 1963–1964 were deceptively called “Polyot” missions allegedly aimed at “perfecting space technology for peaceful purposes.” Systems for placing nuclear warheads in orbit were tested as early as 1966, with false cover stories about “scientific exploration missions”—after Moscow had signed an international treaty outlawing the placement of nuclear weapons in orbit. Manned spacecraft were developed in the mid-1960s for satellite interception roles, and like designs for manned military reconnaissance platforms in the 1970s, they were to carry a space-to-space cannon (these plans were never carried out). In the 1970s, spacecraft design bureaus drew up plans for space systems to conduct Earth surface bombardment; the USSR launched several manned Salyut stations devoted to military reconnaissance and developed plans for even larger ones with better sensors. As late as 1987, on the first flight of the “Energiya” super-booster, the hundred-ton Polyus-Skif payload carried prototype space-to-space laser weapons and a collection of tracking targets.

By late 1998, enough hearsay evidence had been gathered to convince some space historians that the Soviets installed a defensive cannon on one of their early space stations, the Salyut-3 military reconnaissance vehicle, launched in 1974.[12] According to published accounts, reportedly confirmed by the spacecraft commander, Pavel Popovich, the station carried a modified Soviet jet interceptor cannon. It was a Nudelman-Rikhter "Vulkan" gun, similar to models installed on the Mig-19, Mig-21, and the Sukhoi-7.

The Soviet weapon was installed to defend against manned or unmanned American interceptor spacecraft approaching Salyut 3. The gun was fixed along the station's long axis and aimed by turning the station, guided by a sighting screen at the station control post. At ranges of less than a kilometer it could have been highly effective, as long as it was not fired crosswise to the station's orbital motion, in which case orbital mechanics would have brought the bullets back to the station within one orbit!

Specifications for the 30 mm version of this cannon are a length of about 2 meters, weight of 66.5 kg, 900 rounds per minute rate of fire, developing a muzzle velocity of 780 m / sec for a projectile mass of 410 grams. There is also a 23 mm version weighing about 40 kg. It is not clear which of the two was on the Salyut 3 space station, but in the late 1960s the Soviets did design (but never built) an "attack Soyuz" manned spacecraft carrying the 23 mm gun. Several sources confirm that after the last crew left the Salyut-3 station, the cannon was test fired to depletion via remote control.

This space cannon would have been operational in the same period that Soviet leaders such as Yuri Andropov were piously proclaiming that the USSR would "never be the first to deploy weapons in space." This defensive weapon and the public policy statements may be evidence of Soviet fear of US space capabilities or another example of Soviet duplicity, or both.

A wide range of other Soviet military space programs provided both "force enhancement" and special unique capabilities. Both

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12 The US civil space program was nearing the end of the Apollo series of flights (the Apollo-Soyuz linkup was just months away) and design of the reusable American "spaceplane" was being publicly debated.

anti-missile and antisatellite units were established within a few years of Sputnik. Reconnaissance satellites, both visual and electronic and even active radar, soon appeared. Military communications, navigation, and weather systems were developed, along with space-based missile launch warning systems. A special reconnaissance system was developed to spy on the Soviet Union itself to determine what corresponding US assets might be able to observe.

Civil applications also were developed, usually as adjuncts to military systems. Civilian communications and weather satellites began operations in the mid-1960s, at first from low and medium orbits and only much later from the 24-hour geosynchronous orbits.

Exploratory programs were also funded generously, at least at first. These included probes to the Moon, Mars, and Venus, plus a number of scientific research satellites. The pinnacle of this program occurred in 1985–1986 when two Soviet probes flew past Venus and then Halley's Comet, carrying an impressive suite of domestic and foreign scientific instruments.

Partly due to traditional Russian culture, but largely due to the overwhelmingly military nature of the infrastructure, the Soviets shrouded their space activities inside the deepest secrecy. Failures were concealed, to convey falsely inflated impressions of relative status with Western programs. Most activities were totally hidden and lied about. Massive propaganda efforts—ranging from cosmonauts lying at press conferences, to forgeries of photographs, to vicious attacks on American space efforts—drove home the messages which Moscow wanted to be received.

As an aside, it should be pointed out that although it comforted many Americans to think of Soviet space equipment as crude and clumsy, and in the darkest days of the space race to console themselves with rumors of a legion of secret Soviet cosmonaut fatalities, these too were dangerous delusions. The Soviets were capable of making world-class space systems—boosters, payloads, and manned vehicles—and Western estimates based on understating their capabilities frequently led to unpleasant surprises.

Technology aside, however, the Soviets did suffer from one long-term weakness. This was the failure of the Soviet economy to ever harvest the technological advances made inside their space industry.

So compartmentalized and restricted was Soviet space technology, that other components of Soviet industry—even other components of the Soviet aerospace industry—never even began to benefit from the "spin-offs" so characteristic of Western programs. Nor did scientific and technical research aboard Soviet manned space stations ever seem to result in any commercially available products or any world-class scientific breakthroughs. For decades, cosmonauts tinkered with materials processing experiments for a series of Soviet orbital laboratories and uncovered many interesting phenomena which were published in scientific journals. There was considerable Western anxiety that Soviet industry would be able to exploit these opportunities and make major gains in capabilities.

But aside from a few instruments handcrafted for their own use, the Soviets never came up with any detectable practical space-related benefit to the USSR's industrial base. The failure here was not within the space program itself but in the centrally planned structure of Soviet industry, which was hostile to innovation and unresponsive to "market forces" which make Western private industry much more sensitive to anticipating future customer needs. This failure to exploit industrial opportunities opened by research aboard the Salyut and Mir space stations and elsewhere was ultimately a significant factor in the economic decay of the Soviet Union.

The Soviet approach to space engineering relied on existing Soviet industrial strengths and tried to work around enduring weaknesses. With few ground test facilities (including large computers), the Soviets preferred flying prototypes as soon as possible in order to perform testing and verification in flight. This approach ensured a long series of unsuccessful early missions but it led to operational status about as quickly as would the other approach of extensive ground testing and flight testing only after verification. Although Soviet rockets were never as elegant as Western counterparts—for example, they needed twice the liftoff thrust to place equivalent weight into orbit—the hardware (especially their rocket engines) was highly efficient where it had to be, and "good enough" where that level was good enough. As a result of these approaches, their space hardware, both in absolute and relative terms, was cheaper than American hardware with no noticeable diminution in reliability.

Where the lifetime of flight avionics was limited, the Soviets chose to fly more short missions, an approach which also happened to have significant military advantages since their replacement and surge capacity was supported by a very heavily populated pipeline.

This philosophy worked adequately for routine near-Earth missions. But the limitations of this approach began to be felt in the late 1960s, as space missions became more ambitious and complex, and the inherent Soviet weakness in ground verification became critical.

The first major Soviet space setback was the loss of the moon race. Soviet space officials were caught by surprise by President Kennedy's 1961 challenge to "land a man on the moon before the decade is out and return him safely to Earth." They wasted several years in internecine bureaucratic struggles over what strategy to pursue and which specific institutes and bureaus would have leading roles. But by the late 1960s, they were deeply engaged in expensive programs to develop a super rocket (the "N-1") and to develop and fly a two-man spacecraft around the moon (the "Zond"). After that, they had plans to develop a larger Zond-class vehicle for lunar orbit flight (the "L-1"), and to develop an actual lunar lander vehicle (the "L-3").

Due to crippling organizational and leadership inadequacies, these programs all failed. Booster engine development was crippled by the refusal of one passed-over institute to allow another institute to use its engine static test stands. Consistent management was stymied by power shifts within the Kremlin and the deaths of several key personalities. When flight failures began to accumulate in 1968–1969, bitter infighting and recriminations crippled recovery efforts. With the project in ruins, the responsible institutes were suddenly subjected to a "hostile takeover" by the leadership of competing institutes. Billions of dollars and a decade of work by a hundred thousand engineers were wasted. Through careful manipulation of known Western political biases, Soviet propagandists successfully convinced many leading foreign opinion makers that the Soviet man-to-the-moon program had never actually existed and the Apollo program's victory was hollow.

By the mid-1980s, flight hardware capabilities constraints became the main limiting factor of Soviet space missions, both scientific and applications. For example, until near the very end, the Soviets never attempted deep-space missions more than a year in duration, limiting their range to 5 to 6-month voyages to Venus (where they had notable successes). They never quite managed to reliably master the 8 to 10-month voyages to Mars (where they endured a nearly unbroken sequence of dispiriting setbacks). Their geosynchronous relay satellites were limited to 4 to 6 television channels and 4 to 5-year lifetimes while corresponding Western payloads had hundreds of channels and 10 year (or more) lifetimes.

The longest-lasting Soviet space vehicles were their manned space stations in the Salyut and (since 1986) Mir programs. With remarkable tenacity, they overcame early setbacks (including the death of the first Salyut 3-man crew) and gradually extended their flight duration to a year or more. By the mid-1980s, they repeatedly demonstrated the previously absent ability to respond effectively to in-flight anomalies and breakdowns with bold, innovative repairs.

Ironically, the zenith of Soviet space technology came in a project which graphically illustrated the weaknesses of their space doctrine, the Buran space shuttle. The project appears to have been conceived as a reaction to a misperceived military threat from the corresponding NASA program. Through a research program that involved both the work of domestic laboratories and an aggressive, coordinated espionage effort, Soviet space engineers built an entirely new heavy booster—called “Energiya”—and a reusable shuttle vehicle to ride it into orbit. A single, unmanned flight occurred successfully late in 1988, without crew systems or an operational electrical power system. Completing and operating the system proved to be so expensive that the Soviet government, already teetering on bankruptcy, simply let the impressive technology wither away and die.

At the end of its life, the Soviet space program had made substantial recent technological advances to new levels of spaceflight capabilities, threatening many specialties where the United States had been dominant since the 1960s. But due to bad national leadership, much, even most of its activities had been frittered away on projects that contributed neither to national applications needs or even to useful technology development and their high cost hastened the ultimate collapse of the Soviet regime. The space program that had been a diplomatic triumph in the late 1950s, a bargain in the 1960s, an embarrassment in the 1970s, but a promising rebirth in the 1980s, became, in the end, another nail in the USSR's coffin.

Russian Federation (1992–present): Following the collapse of the USSR in December 1991, there was a short-lived attempt to maintain a looser alliance called the Commonwealth of Independent States (CIS). The former Soviet space apparatus tried to continue as a slightly modified "CIS Space Program." But within a short period, the programs of other Former Soviet Union (FSU) states (particularly Ukraine) went their own way, leaving Russia to manage its own space efforts alone.

The Russians managed to secure 75%–90% of the program's facilities or components. This included control of Baykonur, the main launch site in Kazakhstan. The greatest Russian losses were the rocket assembly plants and avionics suppliers in Ukraine, and the deep space tracking site at Yevpatoriya in Crimea. In Moscow, the MoM was preserved as a unitary administrative entity and transferred to the new Ministry of Industries. But national economic collapse and lack of funding and orders has caused MoM personnel strength to decrease to a fraction of its pre-1991 numbers. In 1992, the Russian government organized the "Russian Space Agency," modeled after the American NASA, to gradually take control of the remnants of the disintegrating space infrastructure.

Because any financial payoff from space exploration is usually long term, and because Soviet space activities turned out to have no measurable economic benefit, the new Russian government gave a very low priority to space budgets. It was no longer competing internationally for prestige vis-a-vis the United States. Even in the area of military applications, the real-dollar expenditures dropped by as much as a factor of six between 1989 and 1994.

For several years, the effects of this financial starvation were disguised by the infrastructure's ability to consume existing stockpiles of rockets, space vehicles, and other consumables, and by the lingering loyalty of the personnel (primarily the generation of workers hired young at the dawn of the space age and now nearing retirement). Routine space missions continued, at a lower rate but almost as effectively as in Soviet times. By continuing on momentum while "eating the seed corn," the cumulative debilitating effects of the neglect could be ignored.

But by 1996–1997, the serious collapse of Russian "space power" was evident all across the board. Russia's promised contributions to the International Space Station were delayed again and again. The ambitious Mars-96 mission ended in failure, the craft's plutonium "batteries" scattered across the Andes Mountains. Quality control lapses led to the losses of formerly reliable boosters. Near-fatal crises engulfed the crews on board the Mir space station. High-level arrests and accusations of corruption shook the space industry. Nine-tenths of the specialists in space-related academic institutions left to seek employment elsewhere. Non-payment of the promised lease on the Baykonur launch center led to customs hassles and the interruption of power and water supplies. After a generation of under-recruiting, a demographic crisis faced the Russian space workforce as the backbone of the space teams succumbed to old age (by 1998, 50% of the remaining space workers were over 55 years of age, in a country where the male life expectancy had dropped to 58). Aging applications satellites, long past their design lifetimes, began failing at a rate far exceeding the Russian ability to replace them. Each of these factors can be compared to the description at the beginning of this chapter of the elements of space power. The Russian space program, which once was a source of domestic pride and international prestige, was fast becoming an embarrassment and a widely-perceived waste of meager budgetary resources.

As a stopgap financial solution, Russian space firms have been taking in growing amounts of Western money. They have offered launch services (by both regular space boosters and converted strategic missiles) and space technology (such as nuclear power plants and rocket engines) for support of specific science missions. In addition, they have received some funding as a result of grants from NASA in support of International Space Station hardware and of Russian space science research in general. By 1998, the Western funding of Russian space services was approaching US$800 million per year, twice as much as Russia itself allocated to its civilian space activities (a similar amount is budgeted for military space activities).

This allowed long-overdue upgrades to facilities at the Baykonur launch site and elsewhere.

Nevertheless, such short-term prosperity and the official government commitment to the International Space Station remain very shaky foundations for the revival of the Russian space industry in the next decade or two.

Other Selected Nations and Space Power

Europe: Despite a GDP roughly equal to that of the United States, a larger but equally well-educated population and an enormously powerful technological-industrial base, Europe's space efforts generally are tightly focused and marginally financed. European nations spend about US$3 billion annually through the 14-nation European Space Agency (ESA) and a similar amount for individual national programs. With the growing administrative cohesiveness of the European Union (EU), a trend toward more unified space activities—commercial, scientific, and military—can be expected. More ambitious European space activities have been retarded by weak economies and a lack of space-mindedness among the peoples of the EU.

The Europeans are well aware of the need to further consolidate national space programs, if only to enjoy economies of scale. They know, however, that this can only be a slow process subsumed within the greater European efforts at political unity. Still, there seems little doubt that a European Confederation of fifty years hence could be a great space power, possibly even the equal of the United States.

Given the similarities between European and North American cultural, political and economic institutions, as well as the influence of joint programs such as the International Space Station, European and US space programs are likely to evolve in roughly the same directions. However, since "statism" (state dominance of national activities) remains a strong component of European life, it seems very likely that European space technology firms will operate under stricter government control than is or will be the case in the United States. For example, telecommunications are state monopolies in all European countries. Although laws governing such activities are being liberalized to allow for greater competition among European manufacturers bidding for contracts, the Europeans intend to replace national control of space-based communications and broadcasting with EU supervision.

French Space Power:[13] The lingering influence of Gaullism on French thinking, the fact that France is the leading EU state in developing strategic weapons and military space projects, and the French belief that the EU should evolve into a unified European superpower combine to give French notions about space power a special significance, separate from that of their neighbors.

Paris is subjected to enormous strain in meeting its US$800 million annual funding obligation to ESA and in maintaining national space budgets at their present US$1.5 billion level. Left unmentioned is the fact that the French-built Syracuse and Helios, as well as the proposed Horus/Osiris and Cerise future intelligence satellite projects have been partially funded by Italy and Spain since the early 1980s. There is good reason to suspect that Germany also has been quietly subsidizing these programs, as well as other French civil and military space projects.

Dr. Brian Sullivan believes that within the French national security community, opinion is sharply divided over the importance of the "American Revolution in Military Affairs (RMA)" and its relevance to possible future space warfare. For over a decade, dominant thinkers inside the French military and defense ministry have viewed war in space as virtually inevitable. After a period of hesitation, this same group has accepted the notion that information and information-based technologies will enjoy the major role in such warfare. But applying such conclusions has proved extremely difficult. Some argue that while the United States can afford to spend billions investigating such systems, France cannot and should await the outcome of American research. Others insist that France will inevitably sink to lesser-power status if it does not immediately move to develop such technologies. Otherwise, this group believes, France will fall into a position of such dependency on the United States that it will never

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13 Sullivan, Dr. Brian R., *Tomorrow the Stars.* (Working title of a draft for US Space Command.) March 1998. The entire section on French Space Power is an adaptation of Dr. Sullivan's argument.

recover. After all, the need for the French military to rely on American satellite communications 20 years ago during its intervention in the Congo motivated the development of the original French communications satellite (Syracuse I) in the first place.

The result of many combined influences has been to push the French toward finding a way to join its European allies in creating a multi-national military space program. They also seem to believe that similar scientific, technological, and commercial endeavors must be expanded under ESA auspices. The logic of these conclusions is powerful, but emotional resistance to accepting them remains strong.

Japan: Strategic space doctrine in Japan has been to build on acquired technology. Once a technology has been mastered, specialized lines of development are pursued for those technologies which promise significant industrial capabilities enhancements, as well as immediate practical applications. The most important of these developmental technologies are those that allow domestic production to replace reliance on overseas purchases of space hardware and services. With an annual budget of about US$2 billion, Japan has focused activities on specific projects, but has recently been encountering an across-the-board array of technical problems which will take more time and more money to overcome.

John Logsdon, Director of the Space Policy Institute at The George Washington University in Washington, DC, recently described a key problem with Japan's space doctrine. "The National Space Development Agency (NASDA) has a reputation for developing advanced technologies with little or no input from potential users; no NASDA-developed technology has been adopted by the Japanese space industry." He asserts that Japan's strategy is widely seen as a failure "in terms of producing adequate benefits for the Japanese government, industry, and society."[14]

As an example of US dominance, Logsdon noted that "all communications satellites currently over Japan are US manufactured . . . Attempts by NASDA to develop a domestic

14 Logsdon, Dr. John, Director, Center for Space and Policy, George Washington University, Washington, DC. "The United States, the Only Space Superpower." *Space Policy.* Nov. 1997, Vol. 13, No. 4, pp. 273–279.

communications satellite industry were halted in 1990 by a threatened US trade action."

Logsdon has noted irreconcilable conflicts between the Japanese drive toward space hardware autonomy and the desire for commercializing launch services. The advanced H-2 booster (10,000 kg in LEO) is far too expensive for successful foreign sales, and the only solution appears to be the acceptance of less expensive non-Japanese components in its manufacture.

Japan has cooperated deeply with NASA's space shuttle program and has sponsored one entire Spacelab mission and several partial missions; several Japanese astronauts have flown in space aboard shuttles. It also has signed on as a major partner in the International Space Station, and is developing a special add-on research module, the JEM (Japanese Experiment Module) which has suffered repeated delays and cost overruns.

Japan possesses many of the factors of space power, such as an educated, industrious population, a highly capable industrial technology, and a philosophy of long-term investment. However, other factors, such as government policies to preserve a strong economy, remain elusive. Even its launching sites suffer from long periods of inactivity imposed by restrictions from the fishing industry, signifying where national priorities and political power reside.

On specific projects, the Japanese space program continues to demonstrate the highest levels of competence. They are the third nation to have engaged in interplanetary probes, and they recently demonstrated an extremely impressive automated space docking system.

Yet despite high hopes and ambitions, and substantial investments of money and personnel, Japan has yet to significantly benefit from its space activities. However, the long-range determination to achieve specialized technological superiority (such as in their world-class earth observation satellites) and autonomy for critical applications appears to be undiminished.

China: Proving their claim to status, the Chinese government has obviously selected space operations as an area to prove their status as a modern great power. Space technology and intercontinental ballistic missile technologies share enough to allow the Chinese space program to leverage the military missile program. Similar technologies included guidance, range control and microelectronics. Space policy in China seems to be to get as much commercial benefit as possible from the space program and apply what is learned back into the military missile program.

A rough estimate of China's annual space budget is over US$400 million, but not exceeding US$1 billion. With the announcement of a Chinese manned space program, it is likely that the real figure is very near the high end of the estimate. In fact, Yuri Koptev of the Russian Space Agency, estimated the total Chinese space expenditure at US$1.7 billion.[15] For purposes of comparison, China's annual defense budget is estimated to be approximately US$10 billion (not including supplemental funding from commercial enterprises, purposeful deflation of funding and hidden funding of related budget items). A more useful comparison is NASA's current budget of US$13.3 billion.

China has not been exceptionally successful in garnering commercial funding of its space program. China did not announce how much they charged per launch of Iridium, Chinastar-1 and Sinosat-1 satellites launched recently. Strictly speaking, only Iridium was a foreign customer, since the others were for Chinese domestic use. A reasonable estimate for a CZ-3B launch is about US$50 million-US$60 million. Since China conducted four commercial launches in 1998, two CZ-3Bs and two 2C/SDs, China could have earned US$150 million–US$240 million to reimburse a portion of their space program. This constitutes a relatively large percentage but a relatively small total funding source.

A strong Chinese economy remains elusive. Well-publicized rocket failures make marketing of its commercial launch capability difficult. The Chinese have the ability to overcome their technical difficulties, but economics will limit China as a space power until the domestic economy can provide greater levels of government and commercial funding.

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15 Press briefing on results of government meeting (Boris Kondrashov and Yuri Koptev) provided by Federal Transcript Service, Washington, DC. (Russian Federation Government House, Nov. 12, 1998.)

Canada: While modest (US$200 million annual budget), Canada's space program demonstrates the value of highly efficient alliances with other larger programs, mainly that of the United States. By concentrating on specific technologies (such as the robot arm installed on Space Shuttles and a larger version for the International Space Station), Canada achieves world leadership status in an area of advanced robotics technology with promising terrestrial applications. It also conducts specialized applications developments, such as deploying communications and advanced earth observation systems (specifically their extremely impressive RADARSAT system).

India: For India, the primary feature of space power is autonomy and self-reliance. The modest Indian space budget (estimated at US$300 million) goes half toward booster development and most of the rest towards applications in communications and earth observation. For the time being, some payloads are launched on Russian, American, and ESA boosters pending completion of domestic booster development. Attempts to acquire advanced propulsion technology, especially cryogenic upper stage manufacturing capability, from Russia have created serious diplomatic conflicts with the United States.

Nth Country: As space technology advances in capability, minimum capabilities decline in price. Probably two dozen nations today have access to the level of space and missile technology wielded by the United States and USSR forty years ago, including medium range missiles, guidance systems, and command and control systems. Even modest surface-to-surface missiles can project force out into space to the altitudes of low earth orbit satellites, and the addition of upper stages can send lightweight packages much farther into space or even into orbit. The potential for even low-reliability Nth country antisatellite attempts, especially at in-space components where legal constraints are most nebulous, must be considered more and more likely in coming years. The lack of sophistication of such systems implies enhanced likelihood of collateral damage to non-targeted assets as well.

Non-state Organizations: Space power is no longer exercised only by nation-states. In recent years, the space arena has seen a major increase in activity of commercial organizations, both within nations, and multinational. We have seen corporations making commercial arrangements for desired satellite launching services with various branches of governments (including the United States) and with other corporations.

There has been a growing interest from other undesirable non-government entities, such as drug cartels and revolutionary/terrorist groups. It is possible some of the latter may be allowed the use of space-based services by consortia made up of friendly governments, and near-future application of US "space power" in the denial mode is becoming a more and more plausible option.

3

Impediments to the Exercise of Space Power

The exercise of the full range of space power is impeded by many factors, ranging from specific characteristics of space itself and modern space operations all the way through national and international issues. However, each of these limits is itself subject to amelioration through technological and policy development. Progress in each of these areas can lead to significant enhancement in a nation's ability to exploit space power.

The most obvious limitation on space operations is cost. In recent decades, little progress has been made in reducing the transportation cost per pound of placing payloads into orbit. This factor has distorted every other feature of space operations by limiting the size and number and accessible orbits of space objects. As a result of astronomical transportation costs, payloads must be optimized for weight and lifetime, which then drives up their price.

Associated with the cost factor is the narrowness of the bottlenecks through which space operations pass. Not only launch facilities but also equally crucial ground control facilities exist in limited number, often with no redundancy. This creates both vulnerabilities to loss of function and severe upper limits on surge capacity for expansion or replacement of in-space assets.

The second limiting factor is the nature of the space medium and of operating in it. Deployed space assets are subject to a harsh natural environment as well as to the characteristics of space (high velocities, no blockage to line of sight, etc.) which can be deliberately exploited to damage or destroy specific vehicles. This makes these assets uniquely fragile, which in turn makes them uniquely tempting targets for the application of force by unfriendly players.

Next, efficient exploitation of space power is constrained by general societal attitudes and specifically by the immature experience base of the people whose responsibility it is to gain maximum national advantage from these significant national investments. Popular culture contains many major themes connected with "space power," and most of them are unrealistic, even "anti-realistic." For example, consider the pernicious terminology of operating satellites. Operators say that they "fly" satellites; the press reports that satellites are "maneuvered"; and the informed public is left with the vision of something like aircraft or other terrestrial vehicles. Hollywood shows satellites pointing and zooming in on individual scenes anywhere in the world, at any time, permitting an impression of omnipresence. Satellites, and asteroids, are exploded, but the consequences of the debris cloud thus created is never shown. The more meaningful attributes of space power don't fit within those impressions, hampering the leader who attempts to use space power to support national interests, based on the knowledge gained by being immersed in the culture.

Accumulating, retaining, and accessing usable lessons for space power application is a formidable challenge for policy makers in the United States. Creating the organizational mechanisms through which maximum individual creativity and leadership can be exercised—in theoretical, tactical and strategic scenarios—is hindered by both the widespread presence of misconceptions and by a lack of real-world experience. The next best thing, realistic simulation, is presently inadequate concerning space power in action.

Another constraint is in the diplomatic and legal realm. Operating in space means operating on a global theater with international legal and diplomatic concerns. For more than 30 years a body of "Space Law" has accumulated. A wide variety of motivations, some explicit and some covert have impelled these treaties. They have become confused or outpaced by the extreme rapidity of technological progress, which makes terminology and concepts obsolete even as they achieve the venerable status of "tradition." In many cases, original intent has long withered away and even original meaning—as well as current meaning—is no longer clear. Despite this (and sometimes because of this), in many aspects of space power, diplomatic considerations provide significant constraints on the full exercise of potential national advantages.

Launch Costs

High transportation cost is the primary inhibitor of expanded commercial, private, and even governmental activities in space. To some degree, however, this cost itself is a threshold, a barrier to easy access to space by second and third-tier players, whether governmental or non-governmental, whose presence would at the very least complicate, and at worst endanger, current activities. As this barrier lowers, there will be both good news and bad news for the United States.

On a global scale, the gradual trend toward cheaper space launch technology will open the gates for several dozen more nations (or even corporations, institutes, or other associations) to acquire their own minimal orbital launch capability. Combined with advances in lightweight materials, electronics, and warheads, these capabilities will mean that within a few years, there will be dozens of players in low earth orbit capable of duplicating anything accomplished by the United States and the USSR in the 1960s. This includes manned spaceflight, unmanned earth observation payloads, communications relays and eavesdroppers, co-orbital antisatellite weapons, and even fractional or multiple orbit bombardment systems (both nuclear and conventional). For any nation wishing to wield a dominant role in the exercise of space power, the proliferation of players in space—with a much wider array of intentions and with much less predictable agendas—may be unpleasantly costly.

The issues connected with the technologies of spacelift capacity will be discussed in detail in an appendix to this chapter. These details are peripheral to this book’s core themes on the nature of space power and its exploitation, so that appendix is not required reading for later chapters.

Bottlenecks

Unlike the sea or the air, which is accessible from practically anywhere on the coast or the surface, space is in practical terms reachable only through extremely narrow channels.

In terms of launch sites, an interesting theoretical discussion has gone on for years about the importance of the global antipodal points (or conjugate points) of each launch site, and of the feasibility of emplacing direct-ascent antisatellite weapons at these points. Any object placed into low orbit would pass across the antipodal point about half a revolution later. But the challenge of characterizing and targeting a launch in such a short time remains daunting, especially since the antipodal points are far from the best US space tracking assets. Furthermore, if needed, space objects can perform post-launch burns that throw themselves into much higher orbits before reaching these points. Whatever their contemporary significance, antipodal points will decline in importance as the number of launch locations, land, sea, and air, proliferates from a dozen or two, to hundreds, and then to infinity, in coming years.

Over the next decade or two, the arrival of a multiplicity of players on the orbital stage will coincide with a long-overdue widening of current physical bottlenecks for space access. Currently, some of Earth's most advanced space launch systems have as few as one or two operational launch pads, making them vulnerable to interruption—natural, accidental, or deliberate. Other elements of many space systems—from manufacturing through launch through control—similarly lack any redundancy at all.

In recent years, the operational technologies to overcome this limitation have begun to appear. Air-launched rockets with satellites weighing up to 500-800 kg are now routinely launched commercially from ordinary airfields in California, Florida, and Virginia, and once from the Canary Islands. The Russians have launched small satellites using mobile ICBMs parked near minimal ground support equipment, and in 1998, they orbited a small satellite on a missile launched from a submarine. Small American commercial launchers such as the Taurus are nominally capable of being set up and launched from almost anywhere, without significant ground support.

Larger mobile satellite launch systems are also in advanced commercial development. The most impressive of these is the “Sea Launch” system, which uses ocean-going facilities to launch Ukrainian/Russian “Zenit” boosters capable of placing up to 15,000 kg in low earth orbit. The United States has also considered using operational ICBMs and SLBMs for satellite launchings with payloads in the 500 to 2,000 kg range.

Many space power related functions can be performed by small satellites which soon will be able to reach orbit from widely-scattered bases. However, the US government has continued to rely on a small number of heavy geostationary satellites, which can only be launched from a very few large ground complexes at the edge of US coastal borders. Until this policy changes, bottleneck vulnerabilities will remain and, in fact, become even more worrisome as the threat array broadens.

One unexpected unpleasantness, for example, may be associated with the future ability by some nations to orbit spacecraft from the polar regions (primarily the Arctic, with its sea as well as air access) where direct line of sight observation from geosynchronous satellites is impossible due to horizon geometry. Tactical advantages gained from achieving orbit undetected could be crucial in future space conflict scenarios.

Vulnerabilities

Outer space is a naturally harsh environment, and hazards can be exacerbated by hostile actions. Survivability of space assets is a fundamental unanswered question, especially under conditions of deliberate attack.

The issue of the vulnerability of ground-segment bottlenecks also applies to space systems, particularly those which exist only in small numbers, even only as single vehicles.

In terms of the natural environment, the conditions which damaged and even destroyed satellites in the past are now fairly well understood. Vacuum has a bad effect on some kinds of moving mechanical parts. Space dust can erode solar cells and viewing windows. Radiation, both from the Sun and from cosmic rays, can upset electronic signals and even damage components. Static charges can build up and do similar damage when they discharge. Through prediction and hard knocks, space engineers have learned how to tolerate such effects.

Worldwide space activities create their own hazards to themselves, mostly through the proliferation of “space debris.” Although the raw number of objects is intimidating, space is still very large, and the number of credible space-to-space collisions resulting in damage can be counted on the fingers of one hand. Still, for larger vehicles (the space station, a larger antenna, a solar array system, a large optical system, a solar mirror, or solar sail), the statistics are persuasive that more damaging impacts will occur. Damaging impacts are particularly likely from the population of debris objects that are too small to reliably track but are too large to shield against.

An often-overlooked vulnerability to the function of a space system can be its limited sensor range and its predictable flight path. For observation satellites, the best view is as close to the target as possible. But a satellite in low earth orbit moves so rapidly that viewed from the surface target location the satellite “rises,” crosses the sky, and “sets” in only a few minutes. Many activities of interest to the observation satellite can simply be rescheduled to avoid the brief intervals every day when the satellite is capable of seeing them.

Overcoming this predictability and consequent avoidability might require some degree of stealth (either nondetectability, or mistaken characterization). Alternate or additional solutions include using higher orbit with much longer visibility times (requiring much more advanced sensors to avoid loss of resolution), or simply using sheer numbers of randomly-orbiting small sensor platforms for which an avoidance strategy can’t be devised.

Specific types of missions occasionally tend to cluster satellites into relatively narrow regions of space. The most striking example of this is the geostationary belt, the ring of several hundred satellites around Earth’s equator at an altitude of about 35,800 km. Although there often is some variation in position—perhaps a few hundred kilometers swaying back and forth every day—the overall impression is one of beads on a string.

The geostationary orbital belt may be a ring-shaped basket, but an awfully lot of eggs are in it. In the not too distant future, there will be some interesting techniques by which a relatively small spacecraft could achieve rapid and stealthy access to the entire arc, one satellite after the other. It would then be able to perform whatever function it desired with relation to them, whether inspection, surveillance, interference, or destruction.

An interesting and useful analysis of threats to space assets is contained in a 1997 Center for Naval Analyses report, "Space Control Issues: Plausible Threats and Assurance Strategies,"[16] by Dr. Bruce Wald. He discusses the potential points of attack, the forms such attacks may take, and the specific vulnerabilities of various elements to each form of attack.

Wald lists four points at which a space system can be attacked: the in-space segments, the space-to-ground links (he calls them the "telemetry, timing, and control" functions), the ground segments (often located in forward areas), and the mission itself.

The space segment is broken down into the space vehicle, its payload, and its signals. Attacks on space segments can be in the form of kinetic energy ("hit-to-kill"), radiation/EMP bursts (both by nuclear weapons and other means), directed-energy weapons, signal jamming ("brute force" electronics warfare), and signal spoofing ("deceptive" electronics warfare). These have different levels of effectiveness against different components of the space segment.

Similarly, attacks on the space-to-ground links can be directed against physical facilities, against the telemetry downlink, and against the command uplink. The ground segments, more numerous and often more exposed than the main command and control system, have similar susceptibilities to attack, plus the added threat of what Wald calls "Cyberwar." Wald defines "Cyberwar" as the "denial of service attacks as well as deception and usurpation," perhaps through sabotage, special operations, or flaws in the network protection software.

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16 Wald, Bruce. "Space Control Issues: Plausible Threats and Assurance Strategies." Center for Naval Analyses, CAB/January 1997, Annotated Briefing, Alexandria, VA.

Lastly, there are “mission attacks,” which Wald writes “include diplomatic interference with the ability of a nation to acquire space services from others.” He notes that since the United States has most or all the resources it already needs, “it is less likely to be successfully attacked by these methods than it is to employ them.” (One example was the USSR’s attempt in the mid-1980s to get Chile to deny the United States access to Mataveri Airport on Easter Island for space shuttle aborts on missions from California, which would have seriously constrained the kinds of polar orbits the shuttle could reach.) Further, he continues, “Even when the targeted country has acquired capabilities, diplomatic and political pressures can sometimes constrain the overt use of these capabilities.” In particular, he notes that “US use of space is constrained by several treaties, and to some extent by world and domestic political opinion.”

Next, Wald assesses the rationale that could lead a party to undertake an attack on space assets. He lists five criteria for the assumed-to-be rational decision making process: effectiveness, controllability, affordability, safety, and covertness.

- “Effectiveness” is the likelihood of achieving the desired effect
- “Controllability” is the ability to make short-notice attacks with precise, predictable, and preferably reversible effects
- “Affordability” is the party’s ability to pay for the desired capabilities
- “Safety” is the likelihood the attack will not bring devastating retaliation
- “Covertness” is the ability to conceal the fact of the attack or the identity of the attacker

Wald’s analysis suggests that no destructive (or even disabling) attack on a US-owned space segment is “safe,” although other analysts are far less certain that an attack on a piece of space hardware would necessarily lead to US military counterstrikes elsewhere (this is not a technical issue in any case). But he did conclude that “soft kill” of broadcast services is not only much safer, but potentially “quite effective.”

Balancing all criteria against all threatened components of a space system, Wald concludes that the most plausible threats are jamming and cyberwar. He writes: “Both are affordable, controllable, and relatively safe. Jamming is likely to be quite effective, and cyberwar can be effective if access is possible and other defenses are weak.” Jamming broadcasts, especially from an elevated site, is effective, particularly against GPS and UHF communications in general. Jamming payloads is also affordable, siting is easy because of relatively large terrestrial footprints, and effective against most communications and imaging satellites. Jamming uplinks, and wider aspects of cyberwar, are also affordable, effective against unprepared targets, and also “deniable” (covert usurpation may be possible).

Moderately plausible threats include physical attack on ground nodes (an intentionally ambiguous origin of the attack may forestall retaliation), electronics warfare against ground nodes from nearby access, and political, diplomatic, and economic attacks on the mission.

Wald concludes that in the current absence of a peer competitor, “destructive attacks on space segments are considered implausible.” He bases this on the lack of safety from retaliation and on the expense.

However, other analysts take a much less sanguine view about the vulnerabilities of US space assets to physical attack.

Writing in “Space Policy” in 1995, Allen Thomson[17] noted that the use of space assets in the Gulf War “has prompted states which might find themselves in conflict with the USA in the future to develop countermeasures against US space-based reconnaissance.”

The first step is to develop an effective space surveillance and space object identification capability. Technological advances in sensors and information systems mean that these capabilities do not require a country to match the existing US and Russian space tracking networks. The United States does not release orbital data for US active low-orbit military vehicles, but much of it is available from amateur groups via the Internet. When supplemented by deliberate visual observations from around the world (perhaps at embassies, or at sea), and by telescope-mounted CCD sensors (which can observe satellites even in daylight), this data can provide useful initial targeting

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17 Thompson, Allen, “Space Policy.” February 1995. Vol. 11, No. 1, pp. 19–30.

information. It is even conceivable that players planning an ASAT mission would utilize existing US radar sensors (or even commercial TV broadcasts) in a bistatic mode, such as surreptitiously piggybacking on the NAVSPASUR radar fence.

Additional information for identification of objects can be obtained from short-exposure CCD imaging through fast-tracking telescopes, which can provide resolution of 30–100 cm in low earth orbit. Development of adaptive optics systems, possibly in conjunction with legitimate astronomical research projects, would improve resolution even further. Within a decade, optical interferometry will allow many countries to link distant telescopes and provide imaging resolution as good as 10 cm even out to GEO.

Once a target is identified and its position predicted, an attack can be made with fairly small (by current standards) missiles. The ability to carry a few hundred kilograms to a few hundred kilometers with reasonable accuracy is a capability that dozens of countries and even some non-governmental groups already have or will have over the next decade.

Thomson stresses the rapid commercial progress in electronic and electro-optical devices for the civilian marketplace, and their potential application to ASAT functions. He writes: “The crucial part of direct ascent ASAT systems—the terminal engagement guidance and fuzing mechanisms—is dependent on the same very rapidly and proliferating technologies mentioned above, with the same implications for US planners. Moreover, the low cost of the boosters needed, the probable low cost of the associated guidance mechanisms, and the independence from fixed launch facilities makes it likely that an aspiring ASAT power will think in terms of multiple engagements against a single target, possibly using salvos of ASATs fired from different locations over time.” Such capabilities could be acquired quickly, concealed successfully, and then utilized without warning, Thomson fears.

The last threat to the function of space systems—and perhaps the most serious one, because it already has been occasionally effective—is simply the short-sightedness of potential users. The most sophisticated satellite in the world is a waste of metal and plastic if its services are not properly utilized. It could be functioning perfectly yet ultimately fail in its mission if potential users fail to exploit it.

There are a wide variety of reasons why a space system's services could be inadequately exploited. Perhaps the potential users are simply uncomfortable with the technology and are uncertain how to rate the service's accuracy and reliability. Perhaps potential users are skeptical of the system's availability when really needed. Often a system's best capabilities are realized and developed in real time when end-users have operational control, but if they are treated merely as passive recipients of services, their creative inputs may be overlooked. Or perhaps some player deliberately casts doubts on the system's products via a disinformation or cyberwar campaign.

That last possibility brings us out of the realm of technology and squarely into the realm where efficient space power related exploitation of space systems remains most uncertain and most brittle: the human element.

People

To understand the awesome power of the socio-political constraint on exercising space power, simply consider the question of nuclear power—for heat, electricity, or propulsion—on space vehicles. At the beginning of the Space Age, it was unanimously considered obvious and inevitable that nuclear power plants and nuclear engines would quickly become the mainstay of space operations, both civil and military. Yet it didn't happen, and current cultural conditions show it is unlikely to happen for a long time to come.

The difficulties were not technological but social and political, in that "nuclear" became—both on Earth's surface and in space—a term unavoidably associated with "explosion." How and why that happened is a topic for another thesis, but the fact that it happened is undeniable.

It is not merely the marginalized handful of anti-nuclear activists picketing a space launch in Florida, or of mainstream environmental lobbying groups throwing roadblocks in front of space nuclear projects using criteria that if fairly applied would also rule out all alternative power sources as well. It's the entrenched nervousness of national decision makers, made gun shy by decades of pressure from activist cadres, that under existing conditions have in practice imposed an across-the-board ban on what otherwise would have been some very attractive—and very safe—technologies for space applications.

For the sake of opening future options, such socio-political constraints need to be countered on their own terms, through education, outreach, and research.

Other constraints are internal to the space community. So far, the experience base for exercising space power is extremely limited. People who are responsible for gaining maximum advantage from these significant national space investments have a lot of routine space operations experience but have rarely if ever confronted deliberate deception or hostile intentions. So it is a formidable challenge to accumulate and retain and access the usable lessons for space power application.

The International Environment

A user's "space power" does not exist in isolation. The exercise of space power is influenced by many external factors, ranging from enhancement through trans-national alliances to constraints by international treaties.

Applying analogies with past international agreements concerning the high seas and Antarctica, diplomats and "space lawyers" have attempted to establish a legal regime for human activity in space. Furthermore, building on a long tradition of 20th Century arms control agreements, diplomats have specifically excluded certain weapons-related activities (although they rarely made the hardware itself illegal). The result is a series of treaties which constrain both space-related activities on Earth as well as activities in space.

As is familiar to any serious student of previous international treaties dealing with technological questions, treaties usually persist long after the technological assumptions or specific crises behind them have become obsolete. Thus the reinterpretation of ambiguous wording based on unanticipated technical developments can lead to the existence of a set of "shadow treaties" which diverge from the original in different directions depending on the interpretations and intentions of the different parties involved. Because of the rapidity of revolutionary change in space activities, treaties can age extremely quickly and can become ambiguous and asymmetrically restrictive within only a decade or two.

In addition, current in-force treaties affecting space activities reflect the prevailing situation at the time of their development, a bipolar and antagonistic international climate. Major metamorphosis has already begun towards a multi-polar environment with shifting and often obscure interests. How well the old treaties "fit"—or can be made to appear to "fit"—the new and very different situation is bound to baffle space planners for decades to come.

One value of international treaties to the exercise of space power lies in their ability to modify behavior of potential competitors and adversaries so as to allow concentration of energies on the most promising lines of effort. Other international agreements merely regularize the allocation of limited space resources, such as geosynchronous positions or radio frequencies, and provide administrative remedies to compel compliance. International treaties also serve domestic political purposes, such as attempting to "lock in" certain public policies for as long as possible.

But in general, long-term reliance on treaties to control behavior in space is problematical due to the still unresolved incompatibility between a discipline based on precedent (law) and an unprecedented activity in which most earthside analogies are misleading (space). And whereas maritime law developed only after many, many centuries of maritime activity, space law is being set in place often prior to the very activities it is intended to govern. Since space lawyers have no special talents in prognostication, their guesses are no better than those of other space experts, with one exception: when their guesses (expressed as treaties) are off base, their work threatens to distort what otherwise would have been the natural development of space activities.

As an example of the dangerous inadequacies of imposing earthside legal regimes on space, consider the simplest question of boundaries. Even after decades of space activities, there is still no legal definition of where "space" begins and national sovereignty ends.

Although maritime national boundaries tended to originally be defined by the range of naval gunfire, the ability of several nations to attack low-orbit objects has not led to an extension of national sovereignty to those altitudes. However, some states are now expressing an interest in limiting space activities above their territories. France has stated that commercial satellite owners should not take pictures of France for customers other than the French government. It has declared that satellites are potentially subject to French law if they can be viewed from French territory. This follows decades of debate over whether images of territory within any particular nation can be released to a third party without that nation's approval—and the US has recently endorsed that principle regarding commercial space-based imagery of Israel. In a similar vein, several Eurasian nations have objected to "cultural aggression" from Western-owned television satellites whose signals can be picked up accidentally in nearby nations, but no serious calls for in-space counteractions have yet been made.

Originally by precedent, and now by long habit, the de facto limit of sovereignty is based on a physical feature of orbital flight; it is considered to be below the altitude of the lowest possible short-term stable orbit (about 160 km), while being above the altitude of the highest aircraft and balloons (about 30 km). For numerical aesthetics, a figure of exactly 100 km has long been discussed but not officially accepted. The USAF, for example, uses 80 km as the altitude required for the award of the "Astronaut Rating." Soviet delegates to the United Nations repeatedly called for a figure of "110 km or less." During ascent to orbit, NASA's space shuttles complete their main engine burn at an altitude of about 84 km, and NASA uses 400,000 ft (122 km) to define "entry interface" when returning shuttles first begin to encounter aerodynamic forces. Descending space shuttles have passed above other nations (such as Canada) at altitudes of 80 km or less without asking permission.

While most commentators postulate an unrestricted right of orbital overflight and activities above this still-undefined boundary, there have been some other attempts to partially extend national sovereignty higher. For example, ownership of particular longitude bands of the geosynchronous arc, where commercial communications satellites can be stationed, has been assigned segment by segment to nations 40,000 km directly below. In 1983, a touring Russian space official floated a suggestion that "only satellites have the legal right to overfly other nations, but this imposes certain restrictions on their activities." This "Ulan Bator Doctrine" (the location of the speech) was scrupulously ignored by everyone else and the Soviets never suggested it again.

Attempts at establishing a legal regime for space began very soon after the first space flights. The first major international agreement on space activities was the so-called Outer Space Treaty of 1967, signed by representatives of the United States and some 90 other countries (expanded to over 100 by the adherence of the Soviet successor states). Outer space activities were to be subject to international law. The exploration and use of outer space is to be carried out for "benefit and in interests of all countries" and shall be "the province of all mankind."

According to the treaty, the use of space for peaceful purposes and the passage through space and across celestial bodies must be free from interference. Both the emptiness of space and the natural bodies it contains cannot be subjected to the sovereignty of any country. On the other hand, the man-made objects in space are the property of the country which paid for them, and are the responsibility of the country which registered them or whose government authorized their launch by commercial entities. Furthermore, space is open to exploration and peaceful exploitation by all countries.

Warlike activities are forbidden in space and on celestial bodies, save in self-defense or the defense of allies. Military personnel and military-use satellites are not warlike in and of themselves; data collection by military satellites is legal under the treaty. However, the Moon and other celestial bodies are to be used "exclusively for peaceful purposes." Adherents to the treaty agree not to place nuclear weapons or other "Weapons of Mass Destruction" in earth orbit (although the treaty does not ban the passage of nuclear weapons through space to some other destination), or station them elsewhere in space or on celestial bodies.

States conducting activities in outer space must notify the United Nations, the public, and the scientific community of the nature, location and results of such activities. However, there were no prescribed penalties for a failure to report or for providing wrong information. Finally, the treaty requires that all activities that "would cause potentially harmful interference" with other nations' activities in outer space or on celestial bodies be immediately reported to the United Nations.

In a 1994 survey of arms control treaties, "Jane's Strategic Weapons Systems" gave this assessment of the 1967 treaty, "The treaty was rapidly agreed to, with little or no argument, but this was largely due to the absence of definitions for the constraints that it imposed. It does not, for example, define "weapons of mass destruction" (which is, however, defined elsewhere), "peaceful purposes," or even "outer space." Later in the text, it is stated that "such ambiguities are common in treaties, which rely more on their intentions of good will than on substance to achieve their aims."

A good example of how even the most explicit and clear treaty requirements can be reduced to uselessness is the reaction of space lawyers and diplomats to the USSR's Fractional Orbit Bombardment System (FOBS) in the late 1960s. Notwithstanding the treaty prohibition against placing weapons of mass destruction into orbit around Earth, the Soviet system was designed to do exactly that. By using a low orbital altitude instead of the high lob of a typical ICBM non-orbital flight path, the thermonuclear warhead could hug the curvature of the planet and approach its target from any direction to a much closer range before detection (if ever) by radar.

The Soviets simply lied about the test program, calling the objects "Kosmos" scientific satellites. American treaty specialists went through excruciating gyrations in reinterpreting what had looked like clear-cut meanings of precise words, in order to excuse the Soviet activities as not being in violation of the treaty or at least not demonstrating clear intent to violate the treaty whenever convenient.

It was argued that the objects were never "in orbit" because they did not complete one revolution (a full orbit of Earth) before firing braking rockets and heading back to the surface. This was a deliberate ad hoc alteration of the original meaning of the technically unambiguous term "in orbit." Even the Soviets knew the FOBS had been "in orbit" because they had given each weapon test a counterfeit cover name of a "Kosmos" scientific satellite, reserved ONLY for objects which are “in orbit.” Furthermore, the FOBS warheads followed a flight path very similar to that used by Yuri Gagarin when in 1961, he became the first human in orbit around the Earth even though he, too, did not complete one FULL revolution around the Earth.

Such examples of ex post facto alteration of space treaty terms in order to justify practically any actual activities create a justified level of cynicism and distrust of these measures, in that the very same clauses seem to restrict the US side far more than they restrict other sides.

Various US / USSR strategic arms limitation treaties prohibit each side from interfering with the “national technical means of verification” of the other side. This is in order to allow each side to use its resources, such as reconnaissance satellites, to verify the compliance of the other side with the treaties. However, the United States also assumes that the application of space assets for other military purposes is not similarly protected, making them legitimate targets in the event of limited conflict. Nor do the treaties protect third-party observation satellites. It would be an interesting exercise to see if the United States, France, or any other country wanted to temporarily declare certain geographic regions as “no spy zones.” All unsanctioned observation satellites over a declared “no spy zone” might be subjected to ground-based laser illumination at levels high enough to damage active optical systems, but not powerful enough to damage a spacecraft’s outer surfaces. The status of such a threat in terms of space law is almost ambiguous enough to require a precedent to establish or forbid the practice.

The US Congress has imposed certain constraints on the testing of space systems as part of an ongoing process of evaluating compliance with existing space law, or negotiating new treaties or new interpretations. Recently, Congress passed a limited-duration restriction on the testing of the Mid Infrared Advanced Chemical Laser (MIRACL) and its optical system against any object in space. In the mid-1980s, Congress had invoked several constraints on US testing of antisatellite weapons, under the interpretation that the USSR had declared a moratorium on testing its own “killer-satellite.” The authenticity of the ambiguous Soviet pledge, however, was dubious at best, since Prime Minister Yuriy Andropov’s actual promise was that the “USSR would never be the first to introduce weapons into outer space.” This was promised even though years of testing of Soviet killer-satellite systems had already done exactly that. The official Soviet position was that such tests had never taken place, and therefore, there was nothing the USSR had already done in space that it would have to stop doing. Andropov’s pledge was useless as a real constraint on the USSR, but very useful in eliciting an asymmetrical constraint on the United States.

Brief descriptions of other space-related treaties are found in Appendix 2 to this chapter. Even the briefest scan of that text shows that it doesn’t require a space lawyer to see that these treaties leave certain questions unanswered and fail to address circumstances unforeseen at the time of their drafting.

For example: If the citizens of a number of countries jointly own a satellite, which state is responsible for it? This is a particularly difficult question to answer in a case when two or more of the possessors’ countries would be at war.

Would the deployment of means to track and destroy space debris or to remove errant or defunct satellites violate the ABM Treaty?

Some governments allied to the United States have stated that they would not consider an attack on American satellites to be an attack on the United States. Do such declarations free the United States from reciprocal obligations? Given the right to defend allies with space-based systems enunciated in the Outer Space Treaty, do such declarations prevent the United States from taking such defensive actions?

If a third-party-owned satellite is used to provide intelligence to one of two belligerents, could that be considered an act of war? If that satellite performed other beneficent functions such as environmental monitoring or weather forecasting, could its beneficiaries consider an attack on that space platform to be an attack on their national interests?

When and why is it in the interest of nations to make and abide by such treaties, and as deemed necessary, withdraw from such treaties (with or without notice)? In one way, it is easy to answer these questions according to an old Roman proverb: “Salus rei publicae supremus lex est”—“the health of the republic is the supreme law.” In other words, regardless of treaties or rules, governments will do whatever they can to preserve the sovereignty and well being of the state they rule.[18]

However, as the American entries into the War of 1812 and World War I illustrate, when the leaders of a state do whatever they must to win a war for survival, they can provoke neutral states into joining the conflict against them. Given the growing importance of space systems for economic, national security and environmental purposes, damaging or destroying them could trigger widespread violence on Earth.

And as analysis has indicated, the players who may comprise the greatest threat to the exercise of US space power in the next decade or two (in particular, the most likely source of attacks on US space systems) are not and never have been involved in the big-power treaty process. Whatever the emotional "feel-good" value of the treaty process, it appears increasingly irrelevant to short- and mid-range US security interests.

The conclusion from Jane's 1994 report on treaties may be an appropriate last word: "The evidence appears to be that the public feels that treaties are, of themselves, good things because they bring nations together, if only to talk. At the same time, students of the treaty process appear correct in their analyses that agreements are sometimes militarily counterproductive. This leaves, as residual value, the contentment that the treaty process itself brings; as this relates a forum of understanding, it may be sufficient to justify the effort involved."

Summary

Clearly, the exercise of space power is not purely a technology-limited question. That is, just because it is feasible or even desirable to do something does not mean that a spacefaring nation will actually do it. Factors of cost—primarily launch cost but payload cost and operations cost as well—dominate initial planning. The robustness of

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18 Sullivan, Dr. Brian R. March 1998. *Tomorrow the Stars.* (Working title of a draft for US Space Command.

a proposed system against threats, natural, accidental, and deliberate, must also be considered. Lastly, the human element, both the skills of the system's operators and the social, political, and diplomatic milieu in which they must perform, can often be a limiting factor in attaining the maximum benefits of the potential capabilities of space systems.

Thus a strategy for enhancing a nation's space power, and for maximizing the efficiency with which that nation can exploit its space advantages, must include a wide array of developments. Improving technological capabilities is at the core of such a strategy, but it is not sufficient by itself. Finding adequate funds for unavoidable expenses while seeking ways to reduce space operations cost is critical. Understanding and forestalling threats to the missions are critical. And sustaining a supportive cultural environment and a sympathetic (or at least not antithetic) legal environment are both critical as well.

Only when a complete and cohesive national understanding of the mutual interdependence of these factors is in place can a country fully reap the benefits of space power.

Appendix 1 to Chapter 3

A Discussion of Spacelift

Note: This appendix provides a basic discussion of spacelift. It is meant to provide the nonexpert with enough of an understanding of future spacelift options to understand the potential of new technologies. It provides a background to better understand the argument in Chapter 3 about the current bottleneck of spacelift.

Will Space Always be so Expensive?

One of the key features of spaceflight and of spacecraft has already been described: high cost. This is the primary inhibitor of expanded commercial, private, and even governmental activities in space.

Some of this cost is understandable in terms of unavoidable requirements for quality, and some of the costs can be attributed to inadequate insight regarding "sub-optimizing" parts of the overall problem without realizing the higher costs imposed on other unconsidered aspects of the entire system.

Another often-overlooked cost driver is the requirement for ultra-high reliability. In practice, if achieving 95% reliability costs a given amount, it may cost an equal amount to increase reliability to 99%, and equal amount more to increase it to, say 99.8%. Consequently, for certain missions, buying three times as many 95% vehicles as 99.8% vehicles (or even ten times as many 70% reliability vehicles) may be a bargain IF the launch costs weren't so intimidating.

The expense of getting into space and operating there has up until now provided a threshold over which only Earth's richest and most serious actors can cross. This "high entry cost" has kept out of space many other players whose presence would at the very least complicate, and at worst endanger, current activities. This threshold appears to be rapidly lowering, and would-be new players are lining up. Of course, while the threshold is lowering, launch cost has remained relatively static.

Getting into space has been done the same way for so long that for many people there's only one conceivable way: fuel-burning rockets. But let's take a minute to examine underlying principles.

Rockets use the Newtonian "action-reaction" effect to push themselves in a desired direction. The higher the exhaust velocity, the greater the "specific impulse" (and efficiency) of the engine, and the less total fraction of propellant is needed for a given space mission. At present, more than 90% of the weight of a space launch vehicle consists of the propellant to bring an object into orbit. Depending on the desired final orbit, the actual payload consists of only 2–4% of the vehicle's liftoff weight.

To date, this "reaction mass" has been expelled almost exclusively in the form of expanding combustion products created by actually burning something in a specially-shaped rocket chamber (one known exception is a small cold-gas jet used for vehicle pointing). However, a number of alternate approaches are technically feasible. The material to be expelled could be super-heated by an onboard nuclear power unit, or by the detonation of small nuclear explosives, or by energy projected from the ground into the thrust chamber. Or it could be expelled with electrostatic charges (ion drive). For low-thrust deep space systems, the mass could quite literally be thrown overboard in a fast-moving chain of magnetically levitated buckets. These and other promising technologies will be researched in coming years.

"Specific impulse" can be calculated as the exhaust velocity divided by the acceleration of gravity, or it can be calculated as proportional to the rocket chamber temperature divided by the molecular weight of the exhaust products (the "reaction mass"). Without the necessity of memorizing these equations, it's enough to know that "as-fast-as-possible" and "as-hot-as-possible" are good things, along with using propellants whose combustion products are "as-light-as-possible."

Solid-fuel boosters have specific impulses of 200 to 300 seconds, and liquid fueled engines can have 300 to 350 seconds (for storable propellants) and up to 450 seconds (for liquid hydrogen fuel).

Nuclear engines developed in the 1960s had specific impulses in the 800–1,000 seconds range and advanced designs could reach 2,000 to 4,000 seconds. Low-thrust but highly efficient ion engines have specific impulses in the 5,000 to 10,000 seconds range but are only useful for very long duration missions.

More revolutionary non-thrusting propulsion systems have been proposed using kilometers-long space tethers to transfer momentum between vehicles (as happened by accident on a shuttle flight when the tether snapped, flinging an Italian instrument package into a higher orbit). Wide, lightweight "solar sails" could exploit the pressure of reflected sunlight (caused by bounced-off photons, NOT the "solar wind" of charged particles) or distant laser beams for gradually building up to a very impressive speed. For high-G-tolerant payloads, cannon launch from Earth's surface followed by mid-air snagging by rotating space tethers is an intriguing concept.

For the next decade or two, however, we probably will continue to use old-fashioned rockets. But even in this situation, there are a variety of options and trade-offs open to designers. One deals with expendable versus reusable systems. Another is concerned with single stage versus multi-stage designs. A third design issue weighs the advantages of winged versus ballistic structures.

The expendable versus reusable debate has seen a lot of overblown argumentation and hype, especially of the "miracle cure" and "sub-optimization" varieties. Harsh cost assessments show that up until now it has been cheaper to build a rocket, use it for ten minutes during launch, forget about it, and then build another one for the next launch—despite the negative image of "throwing away a fifty million dollar rocket." This has been because adding the equipment needed to recover launch vehicle components may cost so much in weight and volume that the effective payload capacity of the vehicle is reduced significantly or vanishes altogether. Furthermore, reusable systems such as the Space Shuttle require so much servicing between missions that it overwhelms any savings in hardware acquisition (and the main engines are indeed expensive—mainly because they have to be reusable). However, the political appeal of "reusability"—especially if processing time can be driven down by an order of magnitude—remains high, even though most reductions in prelaunch processing for a reusable system would also as easily lower the cost of preparations for an expendable system.

Reduction in prelaunch processing is a promising approach to achieving modest reductions in launch costs, and this is being pursued both for existing vehicles and for new vehicles. Newer booster designs, which include components optimized not for weight, power, and cost, but for ease of servicing, may be able to cut launch costs in half over the next decade.

Rocket staging, a concept that goes back to medieval fireworks designers, is the trick that allowed space booster designers to evade the need for impossible "mass fractions" of fuel to payload ratios. Early in the ascent to orbit, you want high thrust from compact fuels and engines. As you gain speed and lessened drag, you want high efficiency but don't worry as much about volume or thrust. Because each phase of the launch has its own priorities, a multi-stage rocket has each stage employ specific structural designs optimized for their particular flight phases. Early stages are easier to recover and reuse because of lower maximum speeds and altitudes.

Although building everything into one single piece to facilitate recovery and reuse—the Single-Stage-to-Orbit, or SSTO, philosophy—has been a goal of space designers for years, many other space experts seriously question whether it is achievable, necessary, or even desirable. The US Government is currently developing experimental vehicles to explore the technology and economics of this approach. Meanwhile, in the United States and Europe, a number of innovative (and risky) private developmental efforts are aimed at the more achievable "fully reusable" sub-orbital systems that can either carry passengers or eject small rocket stages for the final push into orbit. Within 5–10 years, there will be enough flight experience—and a full range of failures and frustrations—to seriously reconsider whether an SSTO vehicle should be attempted.

Winged versus ballistic designs have also been grounds for vigorous debate. Owed in part to the Air Force concept of aerospace developed in the 1950s, notions of winged craft able to operate in both air and space mediums have been and continue to be entertained by many. Competition between the two schools of thought can be traced back at least as early as 1952. Then, in response to advances in ballistic missile and rocket research airplanes, the National Advisory Committee for Aeronautics (NACA), first proposed a high altitude, hypersonic system that eventually operated under the auspices of the X-15 NASA program, a decade later.

The advantages to winged craft essentially lie in their ability to optimize aerodynamics within the confines of the Earth's atmosphere for access to and from space to include, ideally, a runway takeoff and landing. To date, however, only limited aspects of this concept have been demonstrated. This includes the ability of a Space Shuttle-type vehicle to glide to landing from orbit, and an ability to access space by piggybacking an aircraft as is the case with Pegasus rocket launches. Attempts at a fully capable "spaceplane" such as the National Aerospace Plane (NASP) have been aborted due to technical obstacles. In lieu of the limited success of winged spacecraft and their relatively high cost, ballistic missile technology proponents argue that the linking of space to air flight is misguided and further consideration of winged vehicle designs is, at best, unnecessary.

One other advantage to a winged vehicle—to any design with a high lift-to-drag ratio—is its ability to steer far out of plane during descent from orbit to Earth's surface. While the conical Apollo and Soyuz vehicles could achieve cross ranges of 50 to 100 km, the winged Space Shuttle routinely reaches airfields more than 1,000 km to the left or right of its orbital track. Advanced re-entry vehicles have been tested with cross range capabilities more than twice that.

This capability becomes highly significant when a descending vehicle needs to have access to essentially any point on the Earth's surface. During the course of a satellite's 90-minute revolution, the Earth's surface can rotate as much as 2,200 km below the satellite's path. The amount of rotation is significantly reduced as one moves away from the equator, so that the spacecraft's orbital inclination can be designed to provide multiple nearby passes of specific targets, e.g. suitable runways for landing. Consequently, an entry vehicle requiring flexible targeting also requires significant lift so that it can bridge the off-to-the-side distance to its desired landing point.

Thus, regarding realistic expectations of future launch costs, it's important to focus on the real goal: lowering the costs of getting services from space vehicles. Lowering launch costs is certainly one obvious approach, but the overall purpose is to carry finite-lifetime functional hardware, not just dead weight. If the weight of that functional hardware can be reduced, or if its lifetime can be extended, the net gains on operational capabilities are equally profitable as is reducing gross launch costs.

This means that an absolute reduction in launch costs could allow a significant reduction in required payload reliability (and consequent unit cost), leading to a large constellation providing the desired services with greatly enhanced robustness.

Nor is cost the only driver in shopping for launch services. Commercial (and government) customers also must consider other features connected with prelaunch and ascent payload environment (i.e., cleanliness, security, loads and vibration), with responsiveness, reliability, reserve capacity (surge), etc.

Lastly, some government and private entities have found a cheap "back door" into orbit by exploiting a feature of existing large launch vehicles, the occasional availability of excess capability. For missions involving payloads weighing in the several ton range and higher, there is often "spare performance capability" that can be made available for "piggyback" payloads in the tens to hundreds of kilograms range. For many "micro-satellites," launching costs would be reasonable even when paying the full rate, but because they can be inserted onto rockets that otherwise would carry inert ballast or have empty corners, the actual cost to reach orbit can be as low as zero. The key enabling feature here is making the payload small enough and responsive enough when opportunities arise.

So in summary, the high cost of launching objects into orbit is a major feature—often the dominating feature—of modern space operations. Depending on the requirements and launch vehicle used, costs vary between US$10,000 and US$30,000 per kilogram of payload. There has been no measurable improvement in the past 20 years.

Reducing launch costs is now specifically called out in America's national space policy.[19] Within this directive, DoD and NASA are directed to develop short- and medium-term approaches respectively. The military-led effort is to make use of more efficient expendable launches, while NASA pursues reusable launch vehicle (RLV)

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19 National Science and Technology Council. September 1996. *National Space Policy*. Washington, DC.

demonstrations. Both initiatives are to be funded in concert with industry which can then benefit from the commercial application of their efforts. The goal of the military-led Enhanced Expendable Launch Vehicle will be to lower launch costs from approximately $20,000/kg by 25% to 50% beginning in 2001. This, in essence, will allow the US launch industry to approach the quoted costs of various Russian, French, and Chinese carriers (which are also getting lower).

The goal of NASA's RLV program is to demonstrate the technology necessary to attain launch costs of approximately $2,000/kg (a 90% reduction over current values) through a series of experimental craft aimed at producing a SSTO launch vehicle. This plan, in fact, harks back to the X-30A or the NASP program. NASP was begun in 1987 as a combination hypersonic air/spacecraft scheduled to demonstrate SSTO flight by 1999. But the program was canceled in 1994 due to the realization that its multiple technologies, including large scale supersonic combustion ramjet (scramjet) engines, were not mature enough to be flight tested in an integrated airframe. In its place NASA, has evolved several separate programs designed to demonstrate various aspects of this integrated approach to space launch: the Hyper-X, X-33, and X-34 demonstrators.

The NASA RLV program is not the only entrant in the RLV race, however. Several completely commercial ventures have emerged recently hoping to capture a share of the proliferating low earth orbit market driven by various communications consortia. These schemes include such innovative solutions as aircraft-assisted launch, mid-flight refueling, and rotary landing systems.

Cheaper rockets are not the only options. Marginal but measurable improvements in launch cost can also be achieved by finding and exploiting "short cuts" on space trajectories. Two notable innovations in 1998 illustrate how this approach can still be surprisingly fruitful: one involved moving the launch vehicle to the equator and the other involved hurling the payload past the moon to take advantage of the moon's gravitational field.

The Earth's eastward spin (nearly 1,600 km/hr at the equator, decreasing by a factor of the cosine of the latitude) can provide a valuable velocity bonus for rockets launched generally eastwards. This alone is a motivation to launch from as near the equator as you can place your rocket. But for payloads headed for geostationary orbits, there is a second bonus: eliminating the need for making a sharp turn from their usually highly-inclined transfer orbit into the equatorial final orbit, saves a lot of fuel at one of the most expensive phases of the mission, near its end.

Using the highly-automated launch processing design of the Ukrainian “Zenit” rocket, the Boeing-led “Sea Launch” corporation built an ocean-going launch platform to bring the booster and its payload to the equatorial Pacific Ocean, near Christmas Island. By launching due east, the system used both the Earth’s spin to the maximum, and also minimized the normally expensive orbital plane change maneuver. As a result, the booster could place twice the weight into the final orbit, as it would have done from its normal launch site in Central Asia.

Another commercial communications satellite, trapped in its high-inclination transfer orbit by the failure of the booster’s last stage, was successfully maneuvered into the proper equatorial orbit in mid-1998 by a bold, innovative flight plan. Using onboard fuel reserves, the payload was pushed farther out into space, until it twice passed the Moon at an angle planned so that the payload’s orbit was twisted by lunar gravity to more closely match Earth’s equatorial plane. Then most of the remaining onboard fuel was used to slow the payload down into the originally desired 24-hour orbit. The lunar swing-by was so successful that some space experts now expect that future routine launchings from far-northern sites (mostly Russian ones) will prefer to use the lunar option to save fuel on the long (but cheap) road to geosynchronous orbit.

Looking further ahead, launch technologies that would go well beyond the present goal of $2,000 / kg are also being explored. NASA’s Highly Reusable Space Transportation (HRST) study is currently focusing on concepts and technologies that could achieve another order of magnitude decrease, to $200 / kg of payload.

One such concept being studied, the rocket-based combined cycle (RBCC) is a modification to the aforementioned NASP design. Instead of relying primarily on air-breathing engines to boost the craft to near-orbit altitude and speed, the RBCC would combine air-breathing and rocket propulsion systems into a single multi-mode engine.

Technologies that could contribute to such a system include the hypersonic waverider which would make use of the lift properties of supersonic shockwaves; pulse detonation engines that make use of tubes that are periodically filled with fuel and oxygen and then ignited to generate a pulsed thrust; and the maglifter catapult which would provide launch assist through the use of magnetic levitation.

These technologies will become available in the years and decades ahead, through evolutionary advances in technological capabilities. The possibility of revolutionary breakthroughs in transportation cannot be excluded, especially in such a high-tech-intensive theater as space operations. While it may prove feasible for other nations to build "cheaper" rockets, due to locally depressed labor costs, it should be the long-range goal of the United States to always build "better" rockets and eventually be the first to build the vehicles that will make rockets obsolete.

Appendix 2 to Chapter 3

A Discussion of Applicable Space Treaties

Note: This appendix provides a basic discussion of some of the treaties that are applicable to US space planning, beyond the 1967 Outer Space Treaty discussed in the chapter itself. It is meant to provide the non-expert with enough of an understanding of existing international agreements to understand the limitations and potential of current agreements. The reader is also asked to understand that treaties are those agreements that are confirmed by the US Senate. Treaties thus become equal to Federal law and are binding upon individual US citizens. Other agreements bind the US Government to some degree, but not individual US citizens.

Limited Test Ban Treaty (1963)

Over 110 nations, including the United States, former USSR and Great Britain, have signed this treaty. France and China have not signed. This treaty prohibits nuclear explosions in the atmosphere, outer space or underwater, and prohibits parties to the treaty from causing or participating in nuclear weapon explosions in any of these environments. Specifically, the treaty was aimed at limiting the spread of radioactive material from nuclear tests. The treaty review in "Jane's Strategic Weapons Systems" offered the opinion that this treaty "has little intrinsic merit" except the historical footnote that a wider treaty foundered on the issue of on-site inspections, which the Soviets wished to severely constrain.

Rescue and Return of Astronauts and Return of Objects from outer Space (1968)

Over 83 nations, including the United States and former USSR, are parties to this treaty. It requires parties to render emergency aid to the personnel of spacecraft landing in their territory and to render assistance. In the only known instance of an emergency landing in another country, in 1975, after a Soyuz launch abort dropped two

Soviet cosmonauts across the border in Mongolia, the Soviets didn't even bother to invoke the treaty, they just ignored the border and retrieved the crew and the spacecraft.

Astronauts arriving at another nation's territory (including off-Earth manned facilities) are to be promptly returned to their home nation. Astronauts/cosmonauts cannot be kept as hostages nor imprisoned for territorial border violations. Interestingly, this requirement for automatic return to the country of origin excludes the wishes of the astronauts themselves—no appeals for political asylum on space flight!

The agreement also called on all signatories to recover and return space objects and component parts, a requirement that overlooked the country of origin's interest in denying ownership so as to avoid admitting liability for damages. In practice, most fallen space objects are retained by the finders and are not returned to the state of origin, since there is no enforcement mechanism for this legal requirement.

ABM Treaty between the United States and the Union of Soviet Socialist Republics (USSR) (1972)

This treaty covers ABM systems designed to counter strategic ballistic missiles. It limits ABM systems and requires that parties will not use deliberate concealment to impede verification (there are other potential techniques to impede verification not addressed by the treaty). There is to be no development, testing, or deployment of ABM systems or components that are sea-based, air-based, space-based, or mobile land-based. The parties agree not to give missiles, launchers or radars, other than ABM missiles, launchers or radars, the capabilities to counter strategic ballistic missiles and not to test them "in an ABM mode."

In terms of space power, the ABM Treaty of 1972 forbids the development, testing or deployment of space-based ABM systems. By general agreement, although not according to any definitive interpretation, the ABM Treaty is considered to ban the deployment of any components of an ABM system on the Moon as well.

However, the treaty does contain several loopholes that have resulted from the development of new technologies over the quarter century since the treaty was signed. The ABM Treaty permits space-based sensors that can track ICBM warheads so long as such sensors cannot communicate directly with an interceptor and cannot by themselves provide all the data required for a successful intercept.

However, as noted in “Jane’s Strategic Weapons Systems” (1994), “the ABM treaty has proved more resilient to interpretative attack because of the way in which it was written. Rather than specify everything which is to be allowed, as is generally the style of the arms limitation treaties, it bans everything and then lists exceptions; the effect of this is that new approaches and technologies are automatically excluded.”

Liability for Damage Caused by Space Objects (1972)

Over 76 nations, including the United States and the former USSR, are parties to this treaty. It specifies that the launching state is liable for compensation for damages caused by its space objects, on the ground or in outer space, based on showing of fault. The damages are to be based “on principles of international law, justice, and equity” to restore damaged material or locations to their original position or condition. The claims are to be presented through diplomatic channels.

When the Soviet Union’s Kosmos-954 nuclear-powered satellite fell over western Canada in 1978, the Canadians billed the USSR for the cleanup expenses. Pursuant to the treaty, Moscow did in fact pay Canada about half of its claim.

Registration of Objects Launched into Outer Space (1975)

Over 39 nations, including the United States and the former USSR, are parties to this treaty. Each launching state must establish and maintain its own system of registry of space objects. Launches must be reported to the United Nations which maintains a master registry and provides free and open access to all inquirers. This applies to component parts of space objects and launch vehicles.

The USSR with one exception (a booster test that unexpectedly placed some upper stage debris in low orbit) has scrupulously abided by the treaty in terms of providing operational orbital elements. The United States has regularly evaded treaty intent by providing only initial orbital elements, not final operational data, for active military missions, with frequent errors and occasional omissions. Both the USSR and the United States provide meaningless or even misleading descriptions of the purpose of many satellites. Without any enforcement provisions, the treaty depends entirely on the voluntary compliance of registering states, and everyone seems to have gotten used to the charade of misleading information in defiance of the treaty's original intent.

Bogota Declaration (1976)

Eight countries through which the geographic equator passes signed the Bogota Declaration: Brazil, Colombia, Ecuador, Indonesia, Congo, Kenya, Uganda, and Zaire. Their representatives met and signed a declaration which stated that geostationary orbit is a scarce natural asset that is not part of outer space. Instead, they declared that the geostationary orbit arc above each country is the sovereign territory of the country. The declaration also stated that such sovereign rights are in the best interest of all countries and all mankind, not just the most developed countries. It finishes by stating that the geostationary arc above the oceans are part of the common heritage of all mankind and should be exploited to the benefit of all mankind. Although the arguments made in the Bogota Declaration have been discussed almost annually for the last twenty years in the United Nations' "Committee on the Peaceful Uses of Outer Space," they have not received any legal standing. Nevertheless, since the declaration was signed, additional equatorial countries have made claims of ownership to their own overhead geostationary arcs.

Moon Treaty (1979)

This controversial treaty never went into effect but illustrates many of the major objections the developed countries have for the "common heritage" argument. Crafted under the auspices of the United Nations' "Committee on the Peaceful Uses of Outer Space," it states that the Moon and its natural resources are the "common heritage"—in essence, the legal property—of all mankind (with a United Nations department presumably collecting fees for use). It proposed the establishment of an international regime to ensure "equitable sharing" (not otherwise defined) and management of the lunar resources. Although initially the Carter Administration was inclined to accept the treaty, campaigns by private space enthusiasts energized a political alliance which prevented signature by the United States. The Soviet Union also declined to sign the treaty, and although seven non-spacefaring nations did sign it, it never went into force. The fatal objections centered on the image of a United Nations department assessing the value of a lunar resource such as water ice, and then levying a usage tax on spacefaring nations which utilize the resource.

Despite the failure of the Moon Treaty, it can be predicted that when industrial exploitation of lunar resources is about to become practical, the issue will be raised again. A powerful precedent will be the "Law of the Sea Convention," which entered into force in 1994. The Law of the Sea Convention was not signed by the United States although it has US acquiescence—the treaty is supported by many Senators and Representatives, the US Navy, US commercial interests, and oceanographic researchers. It establishes an "International Seabed Authority" to govern the commercial exploitation of seafloor resources. Earlier US objections to the "Law of the Sea" centered on its deleterious effect on property rights, but several provisions were modified, and there were also shifts in US interests, so a formal US signature is widely expected. Since analogous US interests regarding lunar resources are still unclear, it is premature to create any binding international authority over such activities—but the time will come when the issue returns.

4

Space Power in a National Context

To what ends does a nation wield "space power?" What specific benefits does a nation accrue from possessing and exploiting elements of "space power?"

At what levels does a nation exercise "space power?" What are the imaginable ranges of actions, from lowest to highest, for applying "space power?"

These fundamental questions can teach as a great deal about "space power" in the context of national power.

Simple and obvious answers often rely on circular definitions and self-evident truths. More profound and fundamental answers remain elusive. This remains a serious problem in developing a comprehensive theory of space power.

For example, the impressively insightful 1998 RAND report, *SPACE: Emerging Options for National Power,* describes what are called "space-related national security objectives." They are:

- Preserving freedom of, access to, and use of space
- Maintaining the US economic, political, military, and technological position
- Deterring / defeating threats to US interests
- Preventing the spread of weapons of mass destruction to space
- Enhancing global partnerships with other spacefaring nations

But are these true "objectives" or only "strategies" aimed toward attaining unstated objectives? Can we peel the onion layer by layer and recognize when we have reached the core? Each one will be examined to see if it reflects a true national objective.

The first item is certainly desirable, but only insofar as it makes other unspecified objectives possible. It enables the conduct of space operations whose nature is not defined here, so it is not an ultimate objective, only a means towards such objectives.

The second item appears to be a good end objective, but it is passive, conservative, and defensive. Experience with space operations shows this to be a shortsighted approach. Besides, the use of the word "position" still reeks of earthside analogies, which all too easily can mislead our thinking about space.

The third item is "obviously true," but upon closer examination, is empty. It is a "self-defining requirement" that cannot be measured, since a "threat" is something to "deter," but neither the concept of "threat" or of the value of "deterrence" is made clear.

The fourth item may be an objective based on personal philosophical or religious motivations, and it is explicitly called for in the 1967 Outer Space Treaty, but at best it is a temporary strategy toward some other unspecified end, not an end in itself.

The same is true for the fifth item. It may be "nice" to accomplish this goal, but unless this accomplishment contributes to genuine US national security concerns, it is at best merely one of many strategies, and at worst it is a distraction from the satisfaction of true objectives.

The RAND Report's treatment of these five objectives indicates that the authors agree that they are intermediate steps toward final unstated goals. They are strategies, and may contribute to useful operational concepts. But they are not—nor are they presented as—the ultimate "WHY" of space power.

Why Exercise Space Power?

As the bulk of space activities shifts towards the commercial sector, the most obvious answer to the question of "Why?" is probably also the correct answer: nowadays most players in space are there to make money. They engage in activities to produce goods and services, which attract paying customers. They require a certain level of service reliability in order to maintain market share and meet contractual obligations.

Meanwhile, national governments engage in space activities for other fundamental reasons. The first is certainly national security, which applies both to earthside security and also to protection of national assets anywhere. A second application is for traditional government support services that are depended on by other government agencies and by the private sector as well. A third application is the development, exploitation, and protection of advanced technologies that can be expected to provide significant enhancement of national military and industrial capabilities. Lastly, governments engage in space activities as expressions of national character and for the impression such projects make on their own population and on the world, impressions which often translate directly into measurable diplomatic and commercial advantages.

Even commercial entities sometimes perform space activities for public relations (several corporations have paid Russian cosmonauts to videotape themselves using specific products, or in one case, actually inflating and deploying a clearly trade-marked bottle-shaped balloon during a space walk). The same motivations could apply to other non-governmental players who would engage in space activities to “make a point” or just to show off their existence.

A country thus needs “space power” to protect existing national capabilities that involve space. This can involve physically protecting the resources which provide those services, either through negotiation, or through hardware features of the assets, or through preventative actions vis-a-vis potential threats. It also can involve assuring replacement capabilities, either through being able to reconstitute the threatened assets in a timely fashion, or through finding alternate means of performing the services.

The other side of the same coin is to use “space power” to be able to deny these kinds of space-related capabilities to other players, as needed, either temporarily or permanently. For example, discouraging other players from developing stand-alone capabilities by making them dependent on US capabilities is an effective means of ensuring that, at desired moments, the other players do not possess those capabilities (navigation services come to mind, as well as communications and earth observation capabilities).

"Space power" also is intimately involved with national technological standing relative to other entities. The concept of "spin-off" has been advanced to explain the value of space technologies. Central to the argument is the assertion that moneys spent on developing space technologies tend to accelerate the progress of national technical capabilities, with wide-ranging industrial benefits. No matter how valid the concept of "spin off" may or may not be, it is widely accepted around the world that a certain level of space spending is a "good investment" in the nation's (or even the corporation's) future.

This power is thus exercised by the deliberate development of advanced space-related technologies, often without clear-cut, near-term applications. These technologies must then be protected in order to exclusively exploit the advantages accruing from possession of them. Lastly, as the technologies inevitably age, they can be shared with other players both as a reward system and also as a way to lock other research efforts into dependency on US leads.

The United States can exercise "space power" to influence research directions in other nations. A good example of this is the International Space Station project, which despite the controversy over delays (in particular, the failure of the Russians to deliver their promised contributions), has succeeded in creating an international space research and development effort which is channeled in directions advantageous to the United States. It has also been a diplomatic success, in that each of the partner nations has come to regard its role in the overall project, and its relationship with the United States, as more important than any other potential role with other players on other projects beyond the oversight of the United States.

To the degree that the entire world respects US science and technology in general, and its space capabilities in particular, the expenditures on interplanetary probes, space telescopes, and human space flight have also created international circumstances very much in favor of the United States. These directly translate into commercial and diplomatic benefits. "Space power" thus creates new opportunities for national power.

Continuums of the Application of Space Power

These strategies can be carried over a wide range of imaginable levels, from weakly to strongly, from narrowly to broadly. Theorists have usually treated the question of choosing space power options as if it were a continuum of degree of intensity, ranging from a very hands-off drift to a very activist interventionist imposition of US will. While this is initially simplistic (as we shall see, there are several variables whose "gain" can be adjusted to satisfy national goals), it does allow the creation of a range of scenarios for space power application. By examining several different approaches, perhaps we can better understand what value such analysis offers us in understanding the nature of space power in a national context.

In the previously mentioned 1998 RAND study ("Space: Emerging Options for National Power"), the continuum of strategy options for military space policy ranged from "Minimal" to "Enhanced" to "Aerospace Force."[20] Differences were characterized primarily in organizational terms, not in terms of actual goals of the strategies, as follows: "In the Minimalist option, the military use of spacepower is highly dependent on external relationships and partnerships. Integration with other military operations depends on organizations outside the military chain of command. This strategy option is largely the outcome of budgetary constraints and technological advances in other sectors, thus leading to the US military owning only those systems that perform unique and/or time critical national security functions and leasing everything else from the commercial sector. In the Enhanced strategy option, the military use of space power is highly integrated with other forms of military power. External relationships and partnerships are important but are not critical to core military capabilities. In the Aerospace Force option, military space power is exercised separately from other military forces. Actual military operations are most likely joint and combined and may use external relationships, but this is not required."

20 Johnson, Dana J., Scott Pace, and C. Bryan Gabbard. 1998. *SPACE: Emerging Options for National Power.* RAND, United States.

The 1994 PhD. thesis by Major Peter Hays, "Struggling Towards Space Doctrine," described four "schools" of space doctrine, first described by Lupton in "On Space War." From least to most activist, they are labeled "Sanctuary," "Survivability," "Control," and "High Ground." In this continuum of doctrines, the primary value and functions of military space forces begins with the mere enhancement of strategic stability and the facilitation of arms control. Then limited force enhancement is added to make the next school. The control of space and the delivery of significant force enhancement to terrestrial forces follow that. The continuum culminates with systems for ballistic missile defense and other weapons systems which can have decisive impact on terrestrial conflicts.

In the Hays continuum, the characteristics of space systems begins with limited numbers of fragile systems in vulnerable orbits, optimized to serve as National Technical Means of Verification. The increasing presence of such features as redundancy, hardening, on-orbit spares, maneuver capabilities, less vulnerable orbits, stealth, robust reconstitution capability, defense, and convoy describes the progression up the other levels. The level of conflict capability also increases, from a very limited (or nonexistent) capability, to limited ground force enhancement with graceful degradation of in-space assets, to a level of defending friendly space systems and denying unfriendly use of space, to the highest level of decisive space-to-space and space-to-earth force application. In this analysis, location in the continuum depends on the degree of capability for force application.

Of course, other factors can be used to define a continuum. To understand the nature of this range of options better, let us consider in detail the following four possible scenarios, which range from most active to most passive. They were developed by Dr. Brian Sullivan[21] and concentrate on diplomatic postures rather than actual operations. His four options can be referred to as "Strong Pursuit of Unilateral Advantage," "Sponsorship of Collective Agreement," "Expand Cold War Alliances," and "More of the Same Old Drift." In this continuum,

21 Sullivan, Dr. Brian R. March 1998. *Tomorrow the Stars.* (Working title of a draft for US Space Command.)

the intensity level starts at the top and then declines, a trend opposite to that in the RAND and Hays models.

Option One is a strong US Government pursuit of a vigorous set of unilateral national space policies of benefit to the United States. It is a "Go it alone" plan where the United States unabashedly acts as the world's premier Space Player.

This option offers a number of attractions. With the end of the Cold War and the absence of any country or even any coalition that can rival American power—a situation almost certain to endure for at least a decade, perhaps much longer—the United States is largely free to focus its energies on pursuing goals based on purely national self-interest. Rather than rely on sentiment, tradition or outmoded national security constructs, the US Government and the American people could make an objective examination of national courses of action and choose the one judged best. Some choices could result in a radical break with previous defense and foreign policies, yet serve American interests very well indeed.

Such a policy would require close cooperation between industry and government and well-informed coordination of defense policy in support of the range of private and public goals being pursued. This policy would involve:

- A degree of increased government regulation

- An "industrial policy" and a national educational policy to promote the development of technologies deemed crucial to the national well-being and the supply of the necessary scientists, engineers, technicians and skilled labor

- The direct assistance of national intelligence agencies to private corporations

- A possible, although not large, increase in defense spending

- Far greater exchanges of information and coordination among government agencies, including United States Space Command and NASA

- And a frequent check by the national leadership to ensure that the "trinity" of government, military and people was holding firmly together in pursuit of national objectives

Certainly as a by-product of such efforts, the problem of the vulnerability of American space systems would be energetically addressed and solved by a variety of defensive and potentially offensive measures. For example, the United States could renegotiate the ABM Treaty to allow for the deployment of antiballistic missile weapons in space or, failing such diplomatic efforts, unilaterally abrogate the treaty and proceed on the basis of national self-interest.

Under this option, the government would supervise commercial space activities, and control scientific and military endeavors. But its policing and regulatory functions would be carried out along national, not international, lines. However, it's possible that the provisions of the Posse Comitatus Act might be understood to prohibit the US Air Force (specifically the Air Force Space Command, the largest service component of the United States Space Command) from policing space. Of course, Congress could amend the law or create a separate US Space Force, which would escape the law's strictures. (The law applies to the US Army and probably to its offspring, the US Air Force, but possibly not to the US Navy or Marine Corps, and arguably not to a unified command such as the United States Space Command.) However, for constitutional reasons, it would be far better to create the space equivalent of the US Coast Guard to enforce laws and promote safety in space.

The potential drawbacks of such a policy are fairly obvious. The United States might come to be perceived as a global menace and, as a result, encourage the formation of an anti-American alliance system. Conversely, isolationism, always a strong current in American thinking, might revive. This could bring with it all the attendant mistakes of American foreign policy practiced in the period between the two World Wars. Much of the world cultural influence the United States gains from presently pursuing a more idealistic set of policies would evaporate.

This could result not merely in the United States finding itself in a much more hostile international environment. The American entertainment, broadcasting and communications industries could be dealt a heavy blow if the American way of life and its values came to be more widely regarded with disdain, contempt, or fear. There is no way to know for certain, but the immediate economic and national security gains derived from such a policy might be more than offset by the long-range global disabilities the United States could suffer.

Option Two would be American sponsorship of a collective agreement to assume responsibility for space activities. This group would represent an American-led "club" to enforce space control.

This policy would involve American sponsorship of an international treaty, a NATO initiative or an agreement among the members of the Western alliance to assume collective responsibility for certain space activities. American commercial space activities would not fall under additional national supervision.

US military space activities could remain entirely national or selected portions might come under NATO command and be NATO funded. A wider military space alliance seems implausible at present. Police and regulatory responsibilities in space could be assumed by some international agency for the reasons given above. The space coalition could develop a broad civil and criminal law code governing space activities. After approval and adoption by the alliance, adherence could be opened to any state wishing to accept the protections and obligations of the code. The burdens of policing space and of introducing police weapons into space and preventing illegal activities would fall on the group, not on the United States alone.

If nuclear-powered rockets proved the best method to explore the deeper reaches of the solar system, the group could share the responsibility and address the inevitable protests that such an innovation would entail. The United States might preserve NASA yet also sponsor an ESA-like agency based on far wider membership, whose members could share the burden of highly expensive space ventures.

Recall that the major reason President Bush's 1989 proposal to establish a permanent base on the Moon, send an expedition to Mars and begin "the permanent settlement of space," was rejected. The reason given for rejection was the Office of Management and Budget and the Government Accounting Office both estimated the combined cost of such endeavors in the area of $400–$500 billion. These figures may have been vastly inflated by political opponents of such projects, since more reliable costing estimates put such projects much more on the scale of the 1960's Apollo program, or about $80 billion in current dollars. But even NASA's later scaled-back plans for a manned expedition to Mars call for launching a minimum of one million pounds into space, and at present launch costs, the transportation price alone would fall in the range of $10–$20 billion. Despite the end to budget deficits and the prospect of surpluses, Congress has continued to refuse the approval of such expenditures.

Faced with the "sticker shock" of the more grandiose space projects, some observers have argued that only an international consortium—drawing on private as well as government contributions—might make such heroic endeavors politically and economically possible. But other observers, even those sympathetic to the diplomatic value of international space cooperation, have expressed skepticism about the alleged time and money savings of large international projects. Certainly the recent experience with the International Space Station shows that early promises of saving billions of dollars and gaining years of service were naive at best.

Since the United States adheres to the Outer Space Treaty, thus rejecting claims by any state or corporation to sovereignty or ownership of what lies beyond the Earth, the insistence on a purely national civil space program is an invitation to diplomatic disputes. So long as the American Government rejects the legitimacy of selling real estate on the Moon, mining Mars for private profit or claiming an asteroid Columbus-style, some observers argue that it seems increasingly pointless to continue NASA as a national institution. It has also been argued that with the end of the Cold War and the indisputable fact of American global predominance, the United States no longer has much need for the prestige of spectacular national feats in space. There certainly are many worthy endeavors to pursue in space. But even for the wealthy United States, the costs of some remain prohibitive, at least psychologically and politically. Certainly the United States can retain robust national space forces. But the responsibilities of policing orbital and, eventually, international space, as well as the burdens and costs of exploring the solar system seem best assumed by one or another international body.

Option Three is to expand and enhance the Cold War alliance system to take control of space activities. This could occur in concert with greater political integration of the component nations, or conceivably as an independent trend.

The third alternative national policy lies near the opposite end of the spectrum of feasible national policies from unilateralism. In essence, it would involve a deliberate and carefully calibrated cession of some aspects of national sovereignty in the short term, with the expectation of gaining permanent superpower status in the long run. The preservation of such power, however, would be in the context of an international federation formed from the Western alliance in somewhat the manner that the European Union is being transformed into a European federation.

Historians note that alliances generally do not survive the threat that led to their creation. In that regard, the healthy endurance of the Western alliance formed in 1941–1942, revived as a result of the Soviet threat in 1949–1950 and preserved after the collapse of the USSR in 1989–1991, so far represents a striking historical anomaly. There are a few other examples of such a phenomenon, including the preservation of the anti-Persian alliance of the Greek city-states as the Delian League (or the Athenian Empire, if one prefers) in the fifth century BC. Other attempts, such as the effort to maintain the anti-Napoleonic alliance as the Congress System after 1815, have usually collapsed within a decade or less.

The enduring strength of the Western alliance is an asset too precious to squander. But for it to survive, many argue that the United States must reduce its leadership role to no more than “first among equals” now and gradually assume the position of a truly equal partner with the EU/European NATO group of nations and Japan over the next few decades.

Again, historians note that no superpower has survived as such forever. Nor can the United States expect to do so. But if the United States deliberately chooses to be “the last superpower” and slowly—perhaps over a century or even longer—coalesces with its allies into a great world federation, then its power could endure as long as the human race does. Admittedly, American power would survive the way that of the Republic of Texas or the Republic of California has done. But this seems highly preferable to the fate of Athens, Rome, the Hapsburg Empire or the Soviet Union.

One great advantage of such a policy could emerge in its earliest stages. The West could form a Western space agency. If one adds together the present GDPs of the EU member states, the non-EU members of NATO, the three new NATO candidates (Poland, Hungary and the Czech Republic), Japan, South Korea, Australia and New Zealand—that is, the core members of the Western Cold War alliance and the recent additions—the total comes to about 180% of American GDP. Other states that might be considered reliable allies of the United States—Egypt, Israel, South Africa, Thailand, Singapore, the Philippines, Taiwan, Mexico and Argentina—have a combined GDP over 20% of that of the United States. If these countries combined an equivalent percentage of their national wealth that the United States devoted to NASA (a rather tiny .2%), it would come to about $30 billion. If all the national space agencies of these countries received annual budgets equal to .2% of GDP and combined them with NASA's, it would total about $45 billion. If such funds were focused annually on coordinated unitary programs of space exploration and scientific research, the results would probably be spectacular.

The same advantages would accrue in commercial, military and, especially, police-regulatory space activities. Space industries would not have to be overly regulated. But international mergers of companies within the alliance would produce great economies of scale, particularly in concentrated research and development. Common funding of a united military space program would make the alliance unchallengeable in space, in case of war. But perhaps the greatest benefit would come from the formation of an alliance police-regulatory organization. Treaties and laws are of little use without force backing them. Attempts by the United States to enforce treaties relating to space unilaterally and, even more so, to introduce weapons into space to carry out police duties would undoubtedly provoke widespread protests. This would be particularly true in cases when such American policing was aimed at the lunar or planetary endeavors or the space platforms of foreign companies. An international force would not be subject to the same opprobrium. Furthermore, as another benefit of an international military space force, the problem of the vulnerability of satellites might be largely solved. An attack on any space platform of the alliance would be an attack on all. Active response or reprisal would not be seen as the bullying or irresponsible actions of the United States. Instead, it would be viewed as the legitimate and just reaction of most of the international spacefaring community.

The disadvantages of this policy option would arise mainly from the resistance of many Americans (as well as citizens of other nations) to such a surrender of national sovereignty. The political foundations for public acceptance of such a course would have to be laid carefully and long in advance. Even then, official suggestions that such a policy was under consideration would provoke widespread anger in many parts of American society. It may be that even if such an option could be logically demonstrated to be the best of those presented, it would remain impractical for nonrational reasons. Perhaps such a policy might be considered at some time in the future. But it does appear infeasible for at least the next several decades.

Option Four is to continue our present somewhat uncertain course, drifting with neither guide star nor rudder, carried by the winds and currents and by initiatives of non-governmental players. What decisions must we still make; what decisions can be deferred; what decisions will “make themselves” in the absence of deliberate choices?

With this policy option commercial space activities would be largely free from government control. However, the government would control scientific and military activities, while police-regulatory activities in space would largely be a responsibility of the space industry.

Thus, space platform vulnerability would become a problem for the American space industry to solve. One advantage of this approach is that the challenge might then be addressed in the most cost-effective manner possible, due to the functioning of free market forces. Presumably—and this is a big “if”—space firms would rapidly recognize the danger to their already great and rapidly growing investments and take vigorous measures to shield and harden the satellites they produce.

On a broader level, such corporations would function within the various treaties governing outer space in a pragmatic manner. Considering the huge costs of space systems, American and foreign companies would avoid actions that might damage each other's assets. Competition would be limited by mutually beneficial cooperation, with a certain degree of added supervision exercised by governments and possibly by the United Nations. The pressure of public opinion and the need to enjoy good public relations would be relied on to create additional motivations for good behavior.

At the same time, the American Government could continue a fairly ambitious civil space program through a NASA funded at far higher levels than any other national space agency. Given the increasing importance of space systems to national security, military space programs could expect annual budgets that might rise as high as $40 billion in current dollars.

The disadvantages of this option would arise from a possible clash between private and public interests. For all the incentives to behave reasonably in space, the lure of profit or the temptation to do in a rival might prompt illegal or treaty-prohibited commercial activities in space. Such behavior could push the United States into an international dispute or even conflict in somewhat the same trivial way that Britain and Spain got entangled in the "War of Jenkin's Ear" in 1739. (A war caused by the popular belief in commercialism in both countries and fanned by religious hatred.) Brian Sullivan reminds us of the beginning day of the war. As British Prime Minister Robert Walpole commented when bellicose London crowds hailed the declaration of hostilities: "They are ringing the bells now, they will soon be wringing their hands.")

In addition, even a well-funded military space program might be hard pressed to defend a gigantic American-owned space network based on an architecture designed in ignorance or disregard of military considerations. More than the concerns of foreign governments, the pressure exerted by American space firms against the development, let alone the deployment, of even purely defensive weapons in space, could severely hobble American space forces. A truly nightmarish situation could arise in which every aspect of American life depended on space systems but the military found itself stretched hopelessly beyond its capacity to defend them. The challenges the US armed forces faced in the Pacific in the December 1941–May 1942 period would seem trivial in comparison.

Discussion and Conclusion

The divergent appearances of these three continuums—and others—suggests that all of the constituent factors of "space power" have yet to be unambiguously defined. Clearly it is not a linear problem, but a multidimensional one, albeit a system of variables with an interconnecting pattern of binding constraints. Analysts must describe how these features are interrelated before they can produce a credible, useful model of "space power" in the national context.

Certainly there is a wide range of possible intensities in terms of implementing command structure (RAND), or of capability of force application (Hayes), or degree of international coordination (Sullivan). There are similar wide ranges in other aspects of space power. Examples of such range is the availability of high-resolution ground imagery, the degree of surveillance of other space assets matched with the degree of concealment of one's own assets, or of the fraction of space effort to be spent on "show-off" projects such as exploration and human flight.

Because "space power" has so many dimensions, it is wielded piecemeal by a wide variety of domestic players. Their interplay—both alliances, dependencies, competitions, and even occasional antagonisms—has evolved through practice, relying on changing laws, personalities, and traditions. Since opportunities in space are so often unpredictable and uncontrollable, this chaotic (some would say anarchistic) arrangement has proven remarkably resilient and responsive. But it is too much to hope for that the United States can continue to rely on such accidental and uncoordinated applications of "Space Power" in the next century.

5

A Theory of Space Power: The Influence of Space Power upon the History of the Future[22]

After more than a century of research and four decades of actual practice, the notion of space flight has entered the realm of mature use. As with all successful technical novelties, this maturation process can be distilled into essentially four phases.[23]

The first phase was discovery, or the actual research that results in the fielding of a prototype that displays some heretofore unseen quality. On a space timeline, this would correspond roughly to the era beginning in the late 19th Century with Konstantin Tsiolkovsky's technical essays on artificial earth satellites, and continuing through the rocket testing of Robert Goddard in the 1920s and 1930s.

The next phase consists of sorting out various proposals in which the new technology may be applied. For our purposes, this would correspond to a period beginning in the late 1930s with the German Wehrmacht's adaptation of rockets to power V-2 missiles, and continuing through the Cold War as the two superpowers gradually concentrated on uses such as earth observation, communications, positioning, timing, as well as scientific space exploration.

The third phase of technological maturity is one of acceptance, whereby the use of a technology is no longer regarded as a novelty.

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22 Gray, Dr. Colin S. 1996. *Comparative Strategy*. Chapter 15. The inspiration for the chapter and the wording for the phrase is based upon Dr. Gray's article.

23 Sterling, Bruce. 1992. *The Hacker Crackdown*. New York, NY: Bantam Books.

This would correspond to the point at which space flight and its related activities exist today. It is no longer the exclusive domain of a pair of world superpowers. Significant strides in the realm of space have now been made by a number of countries and commercial ventures. As satellite dishes continue to appear upon rooftops to access broadcast movie channels and establish high-speed connections to the Internet, the absorption of space services as an indispensable facet of our everyday lives becomes inevitable. It is already difficult to imagine daily life without satellite-relayed pagers, precise time and location information, accurate wide area reports as the basis for weather forecasts, or communications from any location.

The final phase of technological utility—that of ubiquitous use—occurs when the technology filters down through all levels of society. Devices such as the telephone and television represent two such technologies, becoming so pervasive in today's home as to be regarded as simply another piece of furniture. Though space utility has yet to reach this final phase of maturity, it is not too difficult to envision its vague shape at some point within the next century. Space-based communications and location services are already appearing, and space mining, space tourism, space-based manufacturing, as well as the first tentative steps towards space colonization all appear to be well within the realm of possibility and probably represent conservative guesses regarding the use of space in the 21st Century.

As space activities begin to mature, a general public recognition of their increasing importance has begun. The United States and other national governments have come to view their indigenous space industries as increasingly vital economic and political assets. The international community—under UN auspices—is debating statutes and regulations which may, in turn, require enforcement. And, with the demise of the struggle for dominance between the United States and the Soviet Union, the world now perceives an opportunity to make decisions absent the rationale of a bipolar balance of power.

As a result of this increased prominence, many in the professional space community have expressed the need for a comprehensive theory of space power akin to the strategic theories expressed by Mahan, Corbett, and others for sea power, or Douhet, Mitchell, et al., pertaining to the notion of air power. These space power proponents cite the influence of the theories of Mahan as the impetus and justification for the acquisition of navies by several nations at the beginning of the 20th Century. Likewise, the reasoning of Mitchell, Trenchard, and Douhet, proved instrumental in shaping the air forces of the United States, Great Britain, Germany, Italy, and Japan in the 1920s and 1930s. At an historical crossroads, many argue that spacefaring nations find themselves in need of a similar overarching theory against which to plan their national programs and regulate their industries.

In their rush to illustrate the ascendancy of space in military and national matters, many space enthusiasts have attempted to make their point through analogy—most often to air flight. This is only natural as it represents the evolution of a facet of 20th Century national power military analysts are most familiar with. The relatively short span in which flying machines were developed, tested, and refined for increasingly sophisticated use, combined with their position in recent history, makes air flight a ready model for comparison. Furthermore, ongoing military debate regarding the optimal uses of and organizational issues pertaining to space are reminiscent of those of air power in the first half of this century.

In these arguments, today's space environment is often compared to the air environment immediately following World War I. However, this comparison fails in many regards. Unlike its air predecessor of the 1920s and 1930s, there have been no warriors in space; there have been no weapons fired from space against terrestrial targets; and, there have been no space-to-space engagements. What exists instead are numerous unmanned sensors and communications relays that have become the key to forces operating in the media of land, sea, and air. Other than the commands to keep a craft in a desirable orbit, there exists little other control over space assets by US military space organizations.

The reason for this state of affairs—though distasteful to space advocates—is simply the relative immaturity of the technology, systems, and concepts of employment. Rather than comparing space to the post-World War I state of air warfare, a better analogy would move the timeline back approximately 30 to 40 years—to an era prior to powered flight when balloons served as the sole method of air transport. Though quite limited when compared to powered flight, ballooning did, in fact, find some limited military utility during the 19th Century in the American Civil War[24] and Franco-Prussian War.

This analogy, too, is lacking in some regards, but does hold up in several important areas of comparison. Not unlike today's satellites, balloons served as a very constricted model of the utility of an emerging medium. For instance, balloons exhibited a limited ability to maneuver, being always at the mercy of wind and weather. Speed and direction changes could only be affected by a skilled balloonist altering his altitude, thereby making use of varying wind currents. Satellites also are at the mercy of the elements—namely the Earth's gravity and solar weather. Only skilled operators who make use of orbital mechanics to change position and speed achieve limited maneuvering of present day satellites.

Well before the invention of powered, maneuverable aircraft, science fiction writers, scientists, and engineers of the 19th Century ventured predictions of the future of aviation operations, often with remarkable foresight. Jules Verne and Otto Lilienthal both projected the use of powered air vehicles for commerce and war, though neither was ever to see such an aircraft.[25] Current science fiction writers, scientists, and engineers also envision maneuverable craft enabled with the power to free themselves from the constraints of the gravitational fields of Earth, and the physical effects of solar weather.

But, how far removed are they from such spacecraft? And, how close are their predictions to the actual employment of future spacecraft? Is it worthwhile to hazard such forward looking guesses at this point in history? Or is the attempt likely to serve as an amusing historical anecdote? These questions are obviously unanswerable at present, but they may explain the reluctance of many to attempt a comprehensive, strategic theory of space power.

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24 Professor Thaddeus Lowe, an advocate for the use of tethered balloons to conduct military reconnaissance, was placed in charge of a newly authorized US Army Balloon Corps in 1862, after demonstrating their utility to President Lincoln.

25 Though Lilienthal's hang gliders were a major design source for early Wright brothers' models, he died in 1896 after stalling and crashing to the ground while gliding. Some speculate that, had Lilienthal avoided this accident, he might very well have succeeded in becoming the first person to demonstrate powered flight.

An oft-stated view within the US military—most prominently within the Air Force—holds that the Persian Gulf War represents the first space war. Others, less numerous, contend this distinction belongs to the Cold War. But both claims are dubious. Though replete with examples of space support for terrestrial forces, these conflicts were devoid of confrontation in space. It is doubtful that history will remember either as space wars. This distinction likely awaits a clash between roughly equal competitors, one of whom suffers from a decided disadvantage in space support. Such a lopsided advantage may tempt the disadvantaged side to take the offensive in space. Or, quite possibly, the world may begin to learn the tenets of space power as a result of a nihilistic attack on all its low earth orbiting assets by a desperate state or group. Whatever the case, past space operations are unlikely to serve as a future model.

Further caution is advisable. Given the relative infancy of military space systems and the pitfalls of projecting current capabilities into the future, we must also take care to remember that the study of war is not an empirical science and that no single warfare theory—whether it focuses on land, sea, or air—can stand as an enduring truth. Rather, it is like all hypotheses: attempting to explain circumstances based upon observations at given moments in time. And, though many warfare theories contain fragments that continue to prove worthwhile, the body of work invariably loses relevance as it is removed from its historical context. What this says, then, is that the utility of any warfare theory is mostly confined to a near-term future. It is then subsumed by other, more currently relevant hypotheses that retain the applicable pieces of the predecessor, while discarding the others that have outlived their usefulness.

Nevertheless, it is worth a try. Just because current space operations and the tenets derived from them are too limited to be of much use to space warriors 50 to 100 years from now is no reason that we should fail to try to derive near-term benefits over the next 10 to 20. In other words, the fear of appearing historically naive is not a valid reason for refraining from development of a space power theory. The previous 40 years of space experience, along with near-term technological and political trends, can and should serve as a basis for the advancement of a strategic theory. The impact of our national space program, both civil and military, has after all, been immense. The personal computer, live television, worldwide 24-hour news, precision weapons, and hurricane warning are just a very few of the estimated 307,000 secondary applications from space systems development and use.[26] Warfare has been changed (as has espionage) through information gathered and transmitted by space systems, which has profoundly impacted matters both military and diplomatic. Hence, a strategic theory on space power, as it relates to national security at the dawn of the 21st Century, is clearly not only achievable, but highly desirable.

Truths and Beliefs

The primary attribute of current space systems lies in their extensive view of the Earth. Ability to service large areas from a distance of less than a thousand kilometers for most low-earth systems is the key ingredient for stationing the vast majority of systems in space. It is difficult to identify a unique space-based application, since almost all could be and have been accomplished either terrestrially or within the confines of Earth's atmosphere (counterexamples include geodetic measurements of Earth's gravity anomalies, and platforms needing constant sunlight). Communications, navigation, and surveillance are all functions whose origins are earthbound, and are only projected into space because it is more efficient or cost effective to do so. It is this extended area—virtually global in nature—that not only represents space power's most valuable asset, but also sets it apart from all other forms of power. While all other forms of power are effectively regional, space power allows worldwide access in time spans measured in minutes as opposed to hours and days.

A corollary to this attribute is that a space vehicle is in sight of vast areas of Earth's surface. This means that electromagnetic radiation—signals, beacons, or high-energy beamed attacks)—can access the vehicle. The vehicle can also be observed and its orbit measured for future applications of this knowledge.

26 National Aeronautics and Space Administration, NASA Facts, August 1995, document FS-JSC-95(08)-004.

The most exploitable aspect of this worldwide view is that of information transfer, and to a lesser extent, information gathering. As with many other aspects of the information revolution, space enterprises will lead to national power in ways otherwise impossible to obtain. These include the benefits of space activities that we now engage in, those that we can reasonably predict, and many, many others that we cannot fathom. Among the benefits to citizens of the future, the greatest may lie in the prospect that our knowledge and the rate at which we assimilate that knowledge will continue to increase: knowledge of our planet, knowledge of our solar system, knowledge of our origins, and that of the universe. Information and knowledge derived from information can and will prove vital to improving our lives and our national stature.

The emergence of a commercial space industry that owns and operates a growing majority of space systems signals a maturity in space power previously lacking. As opposed to the days of the Cold War, space power now includes all aspects of commercial, civil, and military activities. In this regard, it has come to resemble its predecessors of land, sea, and air power. Like the other mediums of national power, military and civil craft are greatly outnumbered by commercial vehicles—many of indeterminate national allegiance—although each has a "flag" denoting some legal responsibility. Together they contribute to national power just as commercial, civil, and military aviation constitutes the sum of a nation's air power.

For this reason, any useful theory of space power must take this commercial aspect into account. A national power theory based solely upon military-exclusive generalities and tenets would be foolish in any case and especially inappropriate in the emerging space operations cast of characters. Although the military establishment continues to exert a significant influence over the nation's space policy, space remains unarmed. And, irrespective of any change in this state of affairs, military systems are likely to constitute only a fraction of future space activity. It will be the commercial manufacturers, owners, operators, and users who will contribute the larger, if less clearly perceptible, aspects of space power.

Specific steps can be taken to enhance survivability of commercial systems upon which military forces may rely in a confrontation (the harder a target is to attack successfully, the less the temptation to attack it). Nuclear hardening of a subset of commercial satellites, perhaps funded by the military, would be similar in principle to previous arrangements with merchant shipping and commercial airlines. Emergency access to a subset of commercial space services might also be worth arranging and paying for. At the very least, coordination and consultations must be widespread to avoid further widening of cultural gaps between the commercial and military cultures of space power.

Commercial industry's influence on space power further complicates the already formidable task of deriving a formula for national space power—particularly regarding US space power. As the mantle of space power provider is passed to commercial entities, it appears likely that the owners, manufacturers, and users are all likely to be increasingly internationalized. Some argue that this will elevate such consortia beyond the power of sovereign governments; others contend it will result in global influence akin to that of traditional nation states. Since commercial space services and products can be purchased by anyone, it is likely that a common level of space support will soon be available to the citizens of all nations, including their armies. The United States could thus find itself engaged in a confrontation or even a conflict without its traditional advantage in space support, unless it had prepared innovative ways to perform selective denial functions on these assets.

Space exists as a distinct medium. This notion, at first glance, might seem to be intuitive or of little import. However, operational concepts derived over the last forty years have served to obscure and hinder this concept. Specifically, attempts to combine space and air operations—the aerospace philosophy—have served to retard development of space doctrine. We are coming to realize that space operations require a radically different application of the laws of physics as are commonly understood on Earth, and are at times counter-intuitive to our notions of motion and speed. An unshakable insistence on envisioning spacecraft as little more than rocket propelled aircraft is testimony to our inability to divorce space from Earth.

Access to the medium of space has already changed the conventional terrestrial concepts of area, volume, and time. This fact will only become more pronounced as humans and their instrumentalities venture farther into space. The unique attributes of space operations clearly differentiate space power from other mediums of national power, but can only do so if we cease clinging to notions influenced by earthbound prejudices. Until then, space power will continue to be hamstrung by doctrine that owes more to US military organizational maneuvering than rational formulation. The basis of space power is an understanding and use of astrophysics, not aeronautics. For the near term, this will require a sound usage and further understanding of orbital mechanics. For the longer term, it may require complete severance from even this vestige of Earth's influence.

Space power, alone, is insufficient to control the outcome of terrestrial conflict or ensure the attainment of terrestrial political objectives. For the next several decades, the control of space, or even war in space, is important only in that it is important to terrestrial events. Space power must be combined with its emerging sibling, information power, and the older, purely terrestrial, expressions of national power such as air, sea, and land power to successfully influence the actions of competing nations. By recognizing this limitation at the outset, space power can avoid many of the difficulties confronted by those who embraced the early claims of sea and air power theories. They believed that single-minded pursuit of a specific arm of national power could overcome other deficiencies if only properly understood—a belief that some air power proponents continue to espouse even today. Through recognition of national power as the synergistic sum of all its components, a space power theory can avoid overstatement and overconfidence, both of which can prove costly in confrontations. A theory that begins with erroneous premises, will lead to faulty doctrine, which may result in failure in the battlespace and on the battlefields of the future. A theory with a lack of respect for other forms of national power can lead to a misdirection of national assets that can prove disastrous.

Space power has developed, for the most part, without human presence in space, making it unique among other forms of national power. Humans have been physically distant from the vast majority of space operations, including almost all military missions. Technology (both artificial intelligence and teleoperations) has substituted for a human crew in space, providing instead, a virtual presence through a connection to terrestrial control sites.

This physical absence may, in fact, help to explain a general reluctance to lend credence to notions such as space doctrine, space forces, or space power itself. Without the presence of humans in space, the tendency is to view space capabilities as essentially terrestrial with a small, albeit critical, adjunct in orbit. It is difficult to envision sailors who do not sail, and airmen who do not fly. It is equally difficult to attribute the term “spacemen” to those who never set foot in space—perhaps a better term for space operations people is “orbiters,” since that is what their systems do most. And yet humans ARE present “in spirit” aboard their remote emissaries in terms of the attributes most vital to successful space operations: observation and recognition, evaluation and decision, flexibility and innovation.

As with sea and air power, several tenets of space power may be gleaned in forming the basis of an overall theory. Though, here too, we have to make a disclaimer of “from our vantage point in history,” for certainly future circumstances can overcome what today seems intuitive. These tenets are, in fact, derivatives of the attributes of space power listed above and are, therefore, as susceptible to the mutations of time as have been their precursors. Nevertheless, they do provide a foundation from which we may build an outline of the attributes a nation must possess in order to capitalize on space systems as a form of national power.

Technological competence is required to become a space power, and conversely, technological benefits are derived from being a space power. In practicable terms, a strong space industry and a strong educational and laboratory system is required to form a vanguard civil space program and powerful military space capability. As a result, a properly organized and efficiently aimed space industry enhances national wealth. A belief in space technology as a catalyst for overall technological growth—and therefore wealth—is, in fact, often cited as a rationale for many national space programs. Though it does appear that competence in space technology is reflected in overall technological ability, this is a classical “chicken or the egg?” paradox. Technological competence is certainly a prerequisite for beginning a national space program. However, a continuing space program (as long as it is properly designed since some space activities are far more efficient in generating wealth than others) also generates many technology "spin-offs" that lead to general technology improvement. Thus, it would seem that, to the degree that one leads in wise use of space technology, one tends to lead in other technologies. This is not to rule out the need to keep close track of other national space technologies both as a means of assessing their long-range intentions and as a source of additional good ideas for domestic application.

As with earthbound media, the weaponization of space is inevitable, though the manner and timing are not at all predictable. In the near term, US policy will strive to keep space a weapons-free sanctuary, as the United States is the primary beneficiary of such a condition. And, should the United States find it necessary to arm itself in space, it will require some time to untangle itself from the self-imposed constraints erected during the Cold War. At some point in the future, however, the international system of sovereign states and the nature of mankind will combine to cause a state to put a weapon into orbit. The key event may be a perceived need to deploy a defense against ballistic missiles. Other reasoning, based upon a different set of cultural biases, may also lead to the deployment of space weapons. One can imagine that some reasons can be developed for deploying weapons systems beyond the Moon. For example, Dr. Sullivan believed that the development of antimatter for weapons, or for other uses, would have to be kept far from the Earth, perhaps beyond Mars. When warfare moves to space, many orbital locations will prove to be advantageous, including some that use the Moon's gravitational field.

At some time in the future, the physical presence of humans in space will be necessary to provide greater situational awareness. Humans have and will continue to possess a keener ability to sense, evaluate, and adapt to unexpected phenomena than machinery. This is an important attribute in any case, but especially so as spacecraft begin to venture farther from Earth where electromagnetic signal round-trip times stretch from seconds to minutes to even hours. Because of the relative narrow view of sensors that are, of necessity, specialized in their functions, unmanned missions must be pre-programmed to search for and categorize what their programmers have determined to be the likely events they will encounter. Anything outside this realm could be missed, ignored, misinterpreted, or cause for system shutdown due to undefined variables. Also, humans are uniquely able to provide the flexible prioritization in decision making necessary to best manage any situation, whether that job is tasking sensors or maneuvering the spacecraft.

Situational awareness in space is a key to successful application of space power. This means knowing not just where everything is in space and where they are going, but also knowing where they could go if desired, what they are doing, what they are seeing, and what they are relaying to their operators. The United States should enhance its own level of space situational awareness, while taking measures to reduce the situational awareness of potential adversaries so that the United States can exploit that uncertainty and ignorance. The latter principle involves both keeping accurate information away from those who might use it against us, but also camouflaging and masquerading information. To the extent that the level of detailed technical and operational knowledge of the public is degraded by this policy, this may be regrettable but culturally it has proven acceptable.

Control of space is the linchpin upon which a nation's space power depends. As the portion of space containing useful earth orbits becomes predominantly populated with commercial space assets, the country with the largest capital base for such commercial endeavors will, by default, assume a proportionally dominant share of the power accrued from such enterprises. In the near-term, the only individual nation with such an extensive capital base will continue to be the United States. Assured access to space, space-based services, and space-derived products will become of critical import to the US public and policy makers. Control of space and access to space, as a result, will be a non-negotiable issue.

Space operations have been and continue to be extremely capital intensive. Exploration of our planet, the land, the sea, and aerial flight, was often conducted within the means of individual or group wealth, with occasional appeals to royal or republican treasuries. Space has required the wealth of nations—and large nations with large budgets, at that. Only recently have corporations formed consortia to reap potential profits by investing their combined wealth. There is speculation that technologies to more efficiently access space may yet reduce the high cost of doing business there in the near future. It may not.

Scientific research and exploration pays off. Far from being an expression of idle curiosity, exploration and research have proven themselves to be the engine of technological advances, even breakthroughs. They enhance both national industrial capabilities and cultural attitudes toward space. The NASA program on "Origins," seeking data on the origin of life and the possibility of life on other worlds, may look useless in military terms, but that's like the infamous quotation, "How many divisions does the Pope have?" Such research has both the moral authority to create power, and also has a track record of providing the eventual means of generating such power.

There will be wild cards. The British physicist Haldane wrote in the 1930s, "I suspect that the universe is not only queerer than we imagine, it is queerer than we CAN imagine." For space power more than any other current aspect of human activities, the unexpected must be expected. Administrative structures must be in place, and minds must be sufficiently flexible, to detect, recognize, and move quickly to exploit or counteract these surprises. We're talking here about "blue sky" and beyond eventualities, low probability but high impact developments—perhaps development of anti-gravity or inertia-less propulsion, perhaps the capability to easily see neutrinos (and hence to be able to locate every nuclear device on our planet), perhaps energy-sinks and "force fields" which would open physical access to the interiors of planets and even stars, perhaps detection of traces or extraterrestrial civilizations, or contact with representatives of them. Since by definition those with the greatest impact may be those which catch us most by surprise, the best prediction is that these wild cards will be "none of the above," but wilder. The only recipe for Haldane's warning is to stretch our imaginations now and every day of our lives.

Attributes of a Spacefaring Nation

Several basic traits are shared by most spacefaring nations: geographical size and location, national wealth, an extensive and well-educated population, existing national power, a popular appetite for technology, and political will. Of these, it's hard, and perhaps impossible, to determine which is most important—except that at the most basic level, space power can be conceived as a combination of all the quantitative factors multiplied by the qualitative factor of will.

Exceptions to all these traits can be found among today's spacefaring nations, and what appears to have proven most important in one case can be found wanting in another. Japan and France, two countries that occupy the second tier of the world's space powers, are both moderately sized in geographic area, though both rank among the world's wealthiest. Other countries with large populations and landmass, such as India and Brazil, have achieved space programs that are best described as nascent. Israel, which has neither large land area, population, nor GDP, has nevertheless succeeded in becoming a modest spacefaring nation.

The difficulty would appear to lie in the fact that each of these attributes does not exist in isolation from the others. Various traits are inextricably tied together so that no single one can be said to be an overriding factor. For instance, the geographical size and natural resources of the United States have provided an excellent foundation for the creation of the wealth of this nation. Its wealth, population, and geographical isolation enabled the country to emerge from World War II as one of two preeminent world powers. And, as such, the United States had an existing infrastructure and political impetus to commit to an undertaking of great magnitude as was the space race with its Soviet nemesis. The current result of all these intertwined factors is unquestionable space hegemony.

Certainly large countries—as measured by area and population—have an advantage in attaining space powers status. Of the world's largest and most populous countries, Russia and the United States are preeminent space powers with a third and fourth, China and the European Union, potentially emerging as others sometime early in the 21st Century.

As with other forms of national power, space operations are facilitated by national territory. At the dawn of the 20th Century, Mahan[27] specified the extent of a nation's territory as a necessary

27 Mahan, Alfred Thayer. 1890. *The Influence of Sea Power Upon History, 1660–1783.* Boston, MA: Little, Brown & Co.

attribute for maintaining status as a sea power. In his view, Great Britain was an adequate territorial base, while Venice—despite a glorious history of naval success and a culture attuned to the sea—was not. Similarly, countries that occupy large terrestrial territories have an advantage in that they can site their space launch ranges and satellite control nodes within their national territories. Countries with overseas possessions have an equivalent capability, if the possessions are scattered about the globe.

Another geographical attribute of space powers—taking into account current launch technology—is the presence of a coastal or sparsely populated area, such as forest, steppe, or desert. This enables launch sites to be situated so that debris and failed launches avoid densely populated areas. In addition, a spaceport must not only afford an area to accommodate downrange dangers, but ideally, one in an optimal launch direction. Satellites are often launched towards the East to take advantage of the speed of the Earth's eastward rotation. Thus, a launch site whose safety zone lies in this direction may accommodate heavier payloads than one whose does not.

There are other advantages among spaceports. For instance, a nation with territory that straddles the equator or near to it, has a decided edge in launches to geostationary orbits. Not only is the Earth's rotational speed greater at the equator, but less rocket fuel is used since the expensive out-of-plane maneuver to reach an equatorial orbit is greatly reduced, even eliminated. For example, a Zenit booster launched from the equator can place twice as much payload into geostationary orbit as one launched from Baykonur. Sites such as Alcantara in Brazil, the European launch site at Kourou, French Guinea, and the Indian launch sites all benefit greatly from their equatorial geography. Current consideration of Cape York, Australia, as a prospective launch site is based upon its near equatorial location. Other proposals for utilizing the benefits of equatorial launches include mobile sea launch operations.

Some projects seek to circumvent this dilemma altogether by substituting large low earth orbiting constellations (requiring near-polar orbits for full coverage) in lieu of geosynchronous satellites. As other methods of launch become practicable, it is likely spaceports closer to payload construction plants or return payload processing sites will become the most advantageous. However, as long as weight continues to equate to tens of thousands of dollars per kilogram, equatorial launch sites will retain their advantage.

Large countries are also likely to have large populations, and within that population, a large number of highly educated people able to perform the technical work necessary for space systems development. Whether by free choice or through selection, engineering schools as well as mathematics, physics, chemistry, metallurgy, and computer science programs must be sufficiently robust to support a national space program. The dream of space is rooted in educated minds, and space programs are the provinces of the technologically educated. Perhaps more importantly, however, there must be others whose motivation lies solely with attaining knowledge of space and space systems. It is these individuals who are invariably the catalyst for a successful program. They are the visionaries whose single-minded drive allows them to overcome bureaucratic inertia, apathy, and the waxing and waning of support any national program must endure.

Wealthy countries also attract skilled immigrants, many of whom seek out the most challenging professions, including space technology. Five to ten percent of civilian space workers, including astronauts, are foreign born, and their contribution in both technical and cultural terms is spectacular.

As with any great national endeavor, in the end it is the role of the state that is of paramount importance. A national culture must be flexible enough in political, economic, and religious values to permit—if not promote—the challenging of science and engineering standards. In such a national culture, educational institutions must strive to encourage innovation and irreverent attitudes towards the perceived scientific and engineering truths of the past. Information must flow swiftly and widely. In the large, well-funded, national laboratories of a space power, subordinates must be allowed to freely state new scientific truths as they are discovered. Management must not be allowed to reshape fact. There are lessons from history about the consequences of ignoring this principle. In the former Soviet Union, the national space program was greatly burdened by additional costs incurred as a result of excessive secrecy, paranoid compartmentalization and a bureaucratic penchant for substituting political edit for truth.

And we need the "fringe," those at or beyond the boundaries of accepted thinking. Space power, like air and sea power before it, cannot grow without the input of those who challenge the assumptions of the culture and its leaders. Bright minds, free to explore and learn, are a prerequisite—including those considered eccentric, even crackpot. Space power cannot advance merely from classic cookbook applications of current engineering knowledge. As with any innovative endeavor, many of those who served as pioneers in the development of space systems were dismissed as "weird" in their thinking. The culture of a nation must be able to accommodate many different intellectual approaches to the challenge of defining space power and exploring the means to exercise and retain space power. Those cultures and nations that have not understood this necessity for the free exchange of information and the challenging of known facts, have now fallen behind. As a consequence, we can expect the cultures of successful space powers of the 21st Century to be relatively open by today's standards.

Large populations can also be beneficial in that they tend to generate large national revenues—an attribute that may be as important a factor as geographical size and population. Provided that a certain portion of these revenues are discretionary and can be freed from other governmental expenditures, a wealthy nation will be able to afford the large development costs of a space program. As with many governmental programs, a national space effort seeks, at least in part, to justify such expenditures, not only as the necessary cost of national power, but as an economical investment in the future. Such claims appear to rest upon safe ground; few analysts doubt that space enterprises will bring great wealth. Given this foresight, those countries that invest the most can expect to reap the most. To this end, the United States should feel fairly secure in that its investment in space is already huge. Others, though making similar investments in terms of percentage of their annual expenditures, pale in comparison in absolute terms.

Large populations also provide a potential market for space-related services and products. This market potential can stimulate commercial investment in space technology, as is now the case within the United States, and in limited form elsewhere in the world. The benefits of direct economic advantage and spin-offs that will, in turn, revolutionize other fields of economic growth will enrich spacefaring nations. This belief is so widely held that the United Nations Committee on the Peaceful Uses of Outer Space annually discusses how to ensure that others benefit from the growing treasure chest of space results.

What are we then left with, in our examination of these necessary attributes of a spacefaring nation? Certainly size—both geographic and in populace—are important though not critical, if the case of Israel is considered. A well-educated population is also needed, however, the Chinese, who have yet to produce a Nobel laureate, are nevertheless well on their way to becoming a future space power. Wealth must necessarily be considered. But, in terms of absolute wealth, the Soviets lagged far behind the United States and still managed to field a comparable space program. Also, though the Indian and Chinese states are not usually considered to be among the world's wealthiest, they have afforded entry into the space community. What then, if anything, can we say that could qualify as a maxim in a state's drive to attain space power? Probably, only that: a state's drive to attain space power.

When all layers are peeled away, what is left is a state's political will. In the absence of absolute wealth, as well as bureaucratic and technical inefficiencies, it was the political will of the Soviet Union to commit a disproportionate share of their national resources that enabled them to keep pace with the United States. It is also the policy in China, which views itself as the once and future "Middle Kingdom," where national will is responsible for an ascending space program in the midst of a myriad of competing national interests. And, most tellingly, it is the political backing of Israel's space program that has enabled that country to overcome the apparent obstacles to becoming a full-fledged member of the space community.

Interestingly it is this very attribute—political will—that makes the European space endeavor so enigmatic. In combination, Europe has population, education, wealth, size, and suitable launch sites. And, it appears, only in combination does it have a future as a space power.

However, it is questionable whether a combined political will can be found to drive the machinery of a space program comparable to that of the United States and the erstwhile Soviet Union. France, Britain, and Italy, all had ambitious national space programs in the early 1960s; however, only France has carried that impetus through to the present—maintaining an aggressive space program both within the European Space Agency and nationally. Every other European national space program has essentially become a supporting player to ESA and, in essence, to France. Furthermore, having recently experienced national budgetary constraints due to the rising costs of social programs and labor, there are serious doubts that the French can continue to finance their space program at present levels. Future plans for a European military space program, centered about an already under-funded French program, are equally uncertain.

An outgrowth of national will is the development of a cohesive space development strategy that avoids the worst features of endless bureaucratic infighting and freebooting commercial bloodletting. Centralized control is not desirable, but some sort of coherent entity must operate to resolve disputes, set policy, break ties, and act as an advocate for space power in the halls of government. Whether this is a "National Space Council" or an activist department elsewhere in the Executive Branch, experience has shown there is a beneficial role for such a player.

The Exercise of Space Power for National Security

The history of mankind has proven time and again that anything which enhances the power of an individual or group—be it political, economic, or military strength—will be coveted by others. It follows then, that any prudent consideration of national power must include the resources to protect it from those who would seek to turn it to their own advantage. If the United States, or any other spacefaring nation, wishes to retain its national space power, it must necessarily protect its interests in space. The term most commonly used for expressing this need is space control, derived from Mahan's notion of sea power and sea control. This notion—no matter its designation—is the primary principle of the exercise of space power.

A basic tenet of space control is a requirement that all elements of space power, whether orbital or terrestrial, be protected. Also, should confrontation become inevitable, then it is vital to be able to disrupt or deny some elements of opposing space power. This does not imply that third party states or groups will be barred from space activities, nor will they be required to obtain the permission or acquiescence of the spacefaring nation exercising space control. Space control is, rather, akin to concepts for air and sea control. It is exercised less by the active use of military forces than subtle pressures, including the possibility of military action.

Space control, as practiced during the Cold War, was defined as the use of space by one's self and friends, combined with planning for terrestrial actions to deny a potential adversary the exploitation of space systems. This view of space control will likely change with the events and politics of the 21st Century as coalition forces become the rule and international commercial consortia come to dominate many of the space services once the province of militaries.

As mentioned, the protection required and provided by the concept of space control must be applied to all space assets upon which a spacefaring nation relies. Due to the ascendancy of commercial enterprises in space, this will come to include a large number of commercial orbital and terrestrial assets as well as the assets owned by our international friends and allies. Protection will remain primarily a passive function as the threat of hostile actions against spacecraft and terrestrial facilities itself remains passive.

Additionally, a spacefaring nation must become adept in the related concept of information control. The most feasible threat against space power will likely continue to be the blocking of, or introduction of error into, the information streams from and through space, including those necessary to conduct space operations.[28]

As an adjunct to protection, survivability must also be integrated into the elements of space power, whether by protection or through redundancy. Physical security of terrestrial facilities, while not

28 See *Space Control Issues in the Post-Cold-War Era* (Bruce Wald, Gary A. Federici, Linton Brooks, Center for Naval Analysis, Research Memorandum CRM 96-83, November 1996) for a more detailed analysis concerning the most likely threats to space systems.

unimportant, can often be accomplished by auspicious siting within the boundaries of the spacefaring nation. For instance, as launch sites are nearly always located within national territory, physical access to space can be assured, barring terrorist attack or invasion. Tracking stations and certain control nodes are often not, however, providing an adversary with a potential point of disruption. Advances in satellite control and tracking through the use of satellite cross-linking may circumvent this deficiency by redirecting a constellation's signaling over national territory. Such a mechanism is hardly foolproof, though, as the accessing of information to and from space is more easily tampered with by reason of its route through the Earth's atmosphere.

For the most part, survivability of orbital spacecraft continues to be based largely upon a consideration of odds. Though satellites may be protected against radiation associated with a nuclear detonation at a relatively small increase in component cost and weight, near earth satellite owners have been loath to accommodate even this small increase due to the additional costs of launch and the negligible chance of nuclear hazard during the life of the satellite. Should near-earth radiation levels change, this additional protection would, no doubt, be added very quickly.

The ease by which satellites in low earth orbit have been tracked by many groups of interested amateurs, illustrates a different problem concerning the certainty of orbital periods. Easily tracked satellites are, by default, easily targeted. This state of affairs will be mitigated somewhat by the advent of large, commercial, low earth orbiting systems that will complicate satellite tracking by increasing the number of objects in view at any given moment. Another mitigating factor is the current discussion of replacing larger satellites with smaller, more numerous "microsats." Given the increased number of satellites near the Earth, survivability could be further enhanced through the ability to freely maneuver, hiding in the vastness of space and among other objects in earth orbit.[29] Such maneuverability would greatly complicate the calculations of those who would wish to track a particular satellite. To counter satellite maneuverability, an

29 Though almost all satellites today possess some such ability (for most, a minimal capability), large or numerous changes are too expensive in terms of satellite lifetime.

adversary would be required to develop a very robust, widely situated, and very precise space surveillance system to successfully attack a particular satellite, or type of satellite.

This leads to another vital component of space control: the ability to gain visibility over operations in space. As with any attempt at management, particularly as it pertains to the military concept of the battlefield, knowledge of all applicable variables is absolutely vital. It follows then that no nation, or group of nations, can hope to achieve space control without knowledge of the environment. If one can't see other spacecraft, man-made debris, or pieces of the cosmos hurtling by, one can't assess, warn, dodge, protect, or attack.

Thus, surveillance of space emerges as the key element of space control, enabling the other facets of protection and denial. This is, in actuality, a declaration that controlling one's destiny in space hinges upon an ability to detect what is happening in real time, as it happens. Until the point when we can truly watch over satellites, we must place our faith in the good intentions of others.

Though precise, real-time knowledge of a satellite's position could prove to be a daunting task should someone truly wish to hide in space, everyday space control could be more easily effected simply by patterning it after aspects of air traffic control. Both surveillance and survivability could be greatly enhanced by requiring satellites to report their own position as do aircraft.[30] However, given such an analogy to air, the problem arises: who then assumes the mantle of space traffic control? Would it default to the United States by virtue of its standing as owner of the world's most extensive existing surveillance network? Or would there be objections to hegemony over such a vital function? Would there be a competition? Or, more likely, would such an executive agency fall under the auspices of the United Nations in the same fashion that flight beyond national airspace does under the International Civil Aviation Organization (ICAO)?

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30 Unlike aircraft, however, which cease to fly when they malfunction, spacecraft remain aloft (albeit in a gradually decaying orbit), presenting an uncontrollable hazard to the remaining space traffic.

As the space environment matures and corresponding doctrine evolves, space control will necessarily become a facet of any spacefaring nation's space policy, particularly as space becomes important to the economy and national security of those nations. However, like any effort to exert a nation's will, space control will be most effective when all avenues of influence are employed.

The exercise of space control is more than the muscle and bulk of a dominant spacefaring nation. It will require diplomacy as well as a believable, coercive capability. It will require national autonomy, as well as economic cooperation and true partnerships. Effective space control must provide the freedom to allow consortia to lead the way, the freedom to allow others to develop different methods and approaches, and the freedom to accept new ideas. Space control accepts the presence of others, while reserving the ability to checkmate threats.

And in the end, history teaches that the fullest exploitation of space power, as with other forms of national power, ultimately rests on the willingness to use force. That is a topic for its own chapter.

6

Warfare in Space

Some moral philosophers argue that space exploration was "born in sin," and that the original "rocket scientists" had blood on their hands or were accessories in conspiracy to commit mass murder. In such a view, this far-from-immaculate conception of space travel consequently taints all subsequent activities based on the original evil.

The "rocket's red glare" was that of weapons attacking the United States, the same Congreve-style rockets used by the British to torch non-combatant Copenhagen, Denmark. The first rocket which actually reached outer space was the German A-4, which in 1944, as the V-2 weapon, killed thousands of people in London and elsewhere and cost thousands of more lives in the slave-labor factories. And the mainstay boosters of much of today's Russian and American space program—the Soyuzes, Protons, and Tsiklons, the Titans, Thors, and Atlases, were originally designed and built to kill millions of civilians in a nuclear exchange.

Opposing this condemnation are arguments both philosophical and practical. First, the Nazi V-2 program severely damaged the Third Reich's war-making capability, consuming a third of Germany's fuel alcohol production and major portions of other critical technologies that might instead have gone into jets, tanks, or other far more efficient killing machines. Without the V-2 program, the result may well have been that the war in Europe would have lasted months longer, another million people may have died, and the first city atomic bombed may have been Hamburg, not Hiroshima. Secondly, the intercontinental thermonuclear missile weapons introduced in the late 1950s seem to have accomplished what millennia of preachers had failed to do—make major wars "unthinkable" and hence obsolete. Thus there are no moral or philosophical grounds for which space engineers need be at all apologetic, especially after the inspirational conversion of such "swords" into the plowshares of today's space exploration.

The issue of space and war, of "weapons in space," or of weapons designed for use in space, is a highly volatile one. There have been both emotional and cynical arguments, appeals to optimism and pessimism, and mutually conflicting interpretations of historical lessons. Few advocates of either extreme can be expected to change their minds, but national policy will be swayed by the most practical and soundly reasoned arguments.

After all, the sanctuary of space has already been transgressed, not merely for passive military applications, but also for surface-to-surface weapons in transit, and the archaic but effective Soviet killer-satellite system. Guns have been in space for a long time and are probably there as you read these words; they were in the survival kits of Mercury, Gemini, and Apollo astronauts and are currently in the survival kits of cosmonauts (though not shuttle astronauts). While in theory they are accessible in flight, they have never been used in space and threaten nobody in space. But they are there, needing only a requirement or a mission to set new precedents of space law and space conflict.

Predicting Space Combat

There are four basic approaches to predicting future human events: extrapolation from current trends, intuition, the use of analogies and an appreciation of what cannot change. None can offer more than crude approximations of the shape of things to come. Each suffers from serious drawbacks as a forecasting device. The truth is that no human being possesses the gift of prophecy and any accuracy in such matters is little more than fortuitous.

However, human nature seems immutable. By knowing the standard range of reactions that individuals and groups display in different situations and relating that understanding to such stable factors as scientific laws, accurate historical information, and the practical limits of technological change, it is possible to make a number of educated guesses about events a few decades hence. Combining such guesses with the first three forecasting methods mentioned previously is the closest one can come to a rational approximation of what may happen.

The truth is that, while neither a human being nor even a large group of highly educated human beings can know what is going to happen, people and governments can only make plans as if they do enjoy a degree of the true prophet's vision. However, looming over all frail human attempts to part the veil of the future is the reality that history is full of surprises.

National security and military planning largely function along the lines mentioned above. Analogies can be useful, so long as the appropriate ones are chosen and not pushed too far. Dr. Brian Sullivan[31] points out that after all, history never repeats itself in a precise manner. Extrapolation from current trends also quite often proves less than ideal: if it worked, we would all be millionaires from playing the stock and commodities markets. Even the most careful and well-educated attempts at projecting the influence and pace of ongoing developments into the future have led their practitioners to wildly inaccurate conclusions.

Intuition can be amazingly precise about what is going to happen. The science fiction of Jules Verne and Arthur C. Clarke proves that. On the other hand, for every example of a person successfully intuiting the course of coming events, there seem to be at least a thousand glaring failures. Witness the failures of the hunches, visions, dreams, and gut feelings of Nostradamus, Benedict Arnold, Father Divine, Elizabeth Claire Prophet, Saddam Hussein, and all those who bet their farms on pork belly futures. With these caveats firmly in mind, let us consider the possible nature of aspects of space warfare in the 21st Century.

The following observations may or may not prove relevant to the possible shape of future warfare and the applications of military space power in future conflicts. Their relevance heavily depends on correctly identifying the most important factors which will affect armed conflict in the 21st Century and on the degree to which military history might "repeat itself," although only in a very rough fashion.

31 Sullivan, Dr. Brian R. 1998. *Tomorrow the Stars.* (Working title of a draft for US Space Command.)

History is not shaped by any single factor or even by a few major perpetual influences. It is molded by a myriad of such factors, even though some may be a good deal more important than others. This is as true for military history as it is for the history of any other human activity.

This means that the "history of the future," to use a paradoxical phrase, will be no more the result of any single factor than has been true for the past or the present. Nonetheless, in hazarding the following picture of the future of warfare, heavy reliance will be placed on a relatively narrow band of possible developments to make forecasts about the whole range of activities that constitute war.

The Debate Concerning Weapons in Space

Weapons for use in space, stationed in space, have been discussed since before space exploration began. The most common ideas were hopelessly ill conceived, crippled by forced analogies with terrestrial history. For decades, since there were so few good ideas and sound arguments for space weapons, it was easy enough to assume that there never would be, and that space should remain weapons-free forever.

The impetus of recent reconsideration of this question is chiefly an awareness of the increasing importance of space to the conduct of US military operations. Moreover, there is also a growing recognition by the general public of the overall economic importance of space systems, given the emergence of civil applications and a commercial space market. Hence, some have seized an opportunity in which to trot out an old formerly discredited concept that has long been regarded as taboo, one that essentially runs counter to the US stance as it has been espoused practically since the advent of space flight.

But as already stressed, there are no constant truths or eternal policies for space. Rather, the rapidly changing space operations environment demands that former assumptions always be subjected to profound reassessments when situations change.

To Arm or Not to Arm?

At its core, the notion of weapons in space is one that pits military pragmatists against idealistic futurists. Or, put another way, it is a conflict between those that espouse the immutable nature of human beings against those that believe they are slowly, but definitely and irreversibly, moving toward an era of greater cooperation and unity; it is the idealists versus realists, the political hawks versus the doves, and it is an argument probably as old as humanity.

Space-based weapons proponents take as their argument the historical proof that, wherever there has been advantage and profit, there followed efforts to usurp it. Where caravans plied their trade over the Silk Road, they did so under a series of tributes and constant threat of plunder. As sailing ships constituted the vital link to trade centuries later, piracy, often state-sponsored, was common. Attacks on commerce were not always rational, they sometimes were designed to harm the parent societies. So as space enterprises look to gain commercial advantages, there too will emerge entities seeking to capture or spoil what part of the profits they can.

More important to space weapons proponents is the recognition of the medium as an emerging linchpin for the threat and application of force and of the conduct of war. As such, the ability to negate US space systems offers a key to success for would-be enemies. The fear is that, as US forces increasingly come to rely on space, its potential to serve as its Achilles Heel increases.

The logic essentially boils down to the belief that weapons in space are an inevitability. Since weaponization of space is inevitable, the United States, as the country with the historical opportunity to be the first to field them, would be foolish not to do so. And, should it not afford itself of the opportunity, it will likely find itself held hostage to the state that does.

This argument,[32] however, also finds opposition in history, for although it is true that national policy evolves to accommodate prevailing conditions, it is also a creature of its past. Arguments for the shifting of US policy regarding weapons in space often omit the underlying reasons for its existence. Forgotten—or conveniently

32 Much of this section is derived from Lt. Col. Bruce M. Deblois' article in the Winter '98 *AirPower Journal*, Vol. XII, No. 4, "Space Sanctuary" A Viable National Strategy." Lt. Col. Deblois would disagree with my conclusion, but he does a very good job of developing the logic trail for both sides of the argument.

ignored—is the reality that the current US space weapons policy was not foisted upon the United States by the United Nations. Neither was the current policy imposed at the urging of allies, nor was the current policy adopted at the insistence of our erstwhile Cold War nemesis. Rather, it was, and remains, a policy entirely of our own making, with our own interests and benefits as the primary motivators.

The current US stance against the fielding of space-based weapons is the result of decisions made during the Cold War, based on a belief in the USSR's ability to counter them, and on their ultimate destabilizing effect on carefully wrought nuclear relations. Though this policy was later hedged somewhat during the pursuit of the Strategic Defense Initiative, the popular view of space as a sanctuary, is one carefully crafted by the United States.

And, while it is true that America now enjoys a position of space hegemony, it is only as a result of the recent demise of an adversary of equal stature. For the United States to change the rules of the game, simply because it can, may be viewed, by governments and citizenry alike, as needlessly provocative. In a world now comprised of global trade organizations, multinational coalitions, and cooperative UN security relations, the necessity to single-handedly extend the boundaries of warfare by the world's lone superpower may be politically indefensible.

Space sanctity proponents, on the other hand, couch their arguments on the basis of various movements toward the goal of a global polity. They take heart from the rhetoric of UN treaties and resolutions regarding the use of space as well as the current reluctance of nations to field space-based weapons. This state of affairs results more from the strategic military concerns of superpowers than noble-minded bureaucrats. The essence of the belief in space sanctity is a contention that the medium, due to its sheer enormity, is a logical unifying element for mankind.

Supporters of the sanctity of space also point to the sanctuary status that Antarctica currently enjoys. The inference is that, if the global community puts its mind to it, such stances can and do succeed. However, this example suffers from the absence of the crucial criteria that drives national acquisition: strategic military and economic value, which is a deficit the space surrounding our planet does not suffer from.

Oddly, the organizational unification likely to most influence the politics for space sanctity is not governmental, but corporate. As the world political structure becomes increasingly democratic and a global capital market increasingly drives the financial well being of the population, state wealth and economic assets will be increasingly hard to define.

The most striking example of this comes from the wholly derived, erstwhile US asset of the Internet. Now occupying a truly global expanse, and interconnecting a dizzying and continually expanding array of users, the system represents the ultimate blurring of boundaries that is quickly overtaking traditional commerce. The United States is only now beginning to discover the enormous difficulty of defining national assets and protecting them within such a complex, far-flung system. As the ownership of more and more business becomes multinational, servicing an increasingly global customer base, a single nation's pursuit or protection of gain continues to lose relevance.

Regardless of their rational premise, however, arguments for the exclusion of weapons in space are nevertheless doomed to fail against the irrationality that is human conflict. Arguments pertaining to the incorrigible nature of humanity have a rationality of their own. And, in a circular type of logic, the argument for fielding space-based weapons becomes self-justifying. The need to place weapons in space as a defense against weapons in space begets the scenario from which the original contention was based. Against this paradox, those who support the sanctity of space have no recourse. As a result, despite every conceivable argument that can be thrown against it, the simple historical inevitability of war, warfare, and arms cannot be overthrown.

A Prognostication

It is almost certain that sometime early in the 21st Century, the fielding of space-based weapons will occur under the auspices of defense, in much the same manner as the nuclear weapon buildup that occurred within the latter half of the 20th. And, like nuclear weapons, once fielded, there will be no reversing course. This too is an historical lesson of warfare. As the world now grapples with the proliferation of nuclear weapons that were once the province of superpowers, so too will it see the initial weaponization of space be followed by increasingly sophisticated armaments as proliferation occurs there as well. A sobering thought is the prospect that as launch costs go down per unit of mass, the opportunity for other actors to put weapons into orbit about the Earth will go up.

Given this prediction, what nation or military force would shun the opportunity to prepare itself for the inevitable? And, if one's charter is the control of space, as is the US Defense Department's, how can you be expected to enthusiastically deny yourself the means to more competently conduct your mission? The directive to "ensure freedom of action in space and, if directed, deny such freedom of action to adversaries"[33] clearly conjures images of space weapons. Although the caveat "consistent with treaty obligations," somewhat blurs this directive, the statement nevertheless maintains the effect of an open-ended clause under which the placing of weapons in space is virtually assured.

Having said this, however, the means by which the placement of space-based weapons will likely occur is under a second US space policy directive—that of ballistic missile defense. It is under this rubric that the United States is most likely to act unilaterally, although a more probable scenario will see overtures to include US allies in fielding such a system. This could preempt any political umbrage from most of the world's influential nations while positioning the United States as a guarantor of defense from a universally acclaimed threat. It would also serve to discourage allies from fielding other systems in the same fashion that the Global Positioning System (GPS) succeeded in forestalling the fielding of rival navigation and timing systems.[34] Additionally, this could also serve as a mechanism for the pooling of resources of the United States and its allies: an action that presently enables them to dwarf the remainder of global military spending. The result would be the unlikely fielding of a peer system for a generation.

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33 *National Security Space Guidelines*. National Space Policy, Office of the President, National Science and Technology Council, September 1996, Para 6(g).

34 The notable exception being the Soviet Global Navigation Satellite System (GLONASS) launched beginning in 1982; four years after the initial GPS launch.

Regardless of the dual usage inherent in such a system, its assured success lies in the fact it appeals directly to the euphemism under which war resides, that of national defense. The notion of a protective space shield for America’s troops and general population has already generated significant public discussion during the funding of the Strategic Defense Initiative (much of the public is apparently under the impression that such a shield already exists). Any other nation, facing a realistic threat to national survival which passes through space would consider a protective defensive shield, and would not shy away from basing all or part of that defense in space, if that were the most effective location.

This is hardly the outcome hoped for by proponents for space sanctuary. It does, however, move the issue toward the realm of a unified, semi-global agreement.

Although it is doubtful the United States could be induced to relinquish control of such a system, there is some precedent for globally extending the use of a US-developed military space system. As noted, a strategic concern for providing service to allies through a US-financed, satellite-based, positioning system included forestalling the production of a competing system. Once operational, the recognition of its overall utility for civil purposes provided the impetus to extend the system to maritime and aviation agencies five years later. And, as it has further migrated to the commercial marketplace, the result has been near ubiquitous use throughout the world.

Although the extension of protection from a US weapons constellation clearly has its limits, the point is that there is precedence for a shared-use system. And, with regard to proliferation concerns, such a shared system continues to answer certain US strategic interests.

Though this analogy holds out some hope for the cooperative use of a space-based defensive weapon system, the nature of weapons differs greatly from that of a passive system such as GPS. This is because the benign, defensive nature of a ballistic missile killer is not the only facet of such a system—it also has inherent offensive capability against satellites.

This will give rise to two practical effects: the first will be an innate capacity for the control of space from space; the second will be the eventual acquisition of a like capability by other would-be world players. While nations might be content to rely upon a US military system for ballistic missile protection, they are unlikely to long tolerate a de facto US control of space. For the same reasons our allies and other nations possess a separate nuclear capability, they will also desire space-based weapons. Prudence, pride, and individual concerns will drive countries to field their own systems.

The Use of Space Weapons

Once in place, the use of space-based weapons, unlike nuclear weapons, will likely be unreserved, at least in their initial incarnation. This is in view of several factors. The first lies with their probable targets, low-earth-orbiting satellites, which are a relatively vulnerable prey whose remoteness and lack of human presence make them excellent candidates for preemptive strike. Lacking the stigma of the loss of life resulting from most other types of attack, the destruction of a satellite carries far less risk of earthbound retaliation. Popular sentiment—at least throughout the industrialized world—does not equate the loss of life against the loss of machinery, no matter how vital.

The second factor lies in the disproportionate loss of war-making capability such a strike could inflict upon an adversary. Due to their vantage point, global reach, and station-keeping qualities, space systems enable system characteristics that would be expensive, if not impossible, to replicate by terrestrial systems if lost. Even if only LEO systems were lost, the combination of terrestrial and GEO systems required to replace LEO systems would be nearly as expensive. Thus, the side suffering a preemptive strike is faced with a very narrow set of options. A counter-attack in space could be launched, provided the attacker has not greatly limited his ability to do so. This would deprive the attacker of his vital space systems and provide a more level playing field for the conduct of an earthbound war. Or, a proportionate earthbound attack could be carried out that would deprive the attacker of enough non-space capability to compensate for his space advantage.

Either option would likely prove difficult to effect in the wake of a no-notice opening engagement. The employment of space weapons for counterattack, provided they survive an opening salvo, will likely be limited by the destruction of supporting space-based communications, surveillance, and targeting systems. Unless there is a marked increase in system redundancy and replenishment capability, this equates to an initial and continued deficit of space support. Alternately, the conduct of massive earthbound operations is equally problematic due to its perceived escalation of the conflict.

A possible third solution might take its cue from the nuclear strategy of assured mutual destruction. By pre-targeting an adversary's critical space systems, a nation could deter a first strike through an implied mutual destruction of each side's space assets. The problem with this strategy lies in the guaranteed operation of a nation's space-based weaponry. To make this strategy a viable threat, the delivery of a crippling counterattack must appear to be certain. Unlike the nuclear scenario of the Cold War, the warning time of an attack in space would be greatly reduced and the redundancy of space-based counterattack systems would be limited. Augmenting space-based weapons, however, with ground-to-space and air-to-space weapons would function as a type of antisatellite triad in much the same way that a nuclear triad continues to serve as the cornerstone of US nuclear strategy. But this analogy to nuclear deterrence also suffers from the inability of space warfare to provide the ultimate trump card that a nuclear threat does. Absent the force-wide destruction that nuclear weapons promise, an adversary might willingly choose to eliminate space assets from the battlefield, perceiving himself to be disadvantaged in that arena.

A further complication of the issue of space warfare is concern regarding the contamination of space resulting from physical destruction of a satellite. Depending upon the destructive force used to annihilate a satellite, the resulting debris from the breakup of a number of systems, would entail a risk of rendering certain orbits useless. In this respect the analogy with nuclear weapons is appropriate. Here too, the use of weapons has the potential to corrupt the physical environment long after the conclusion of any conflict, leaving behind a bitter legacy.

To mitigate this effect, a space weapon must function in a more benign fashion by neutralizing a target without physical fragmentation. A weapon that would blind a satellite's optics through the use of laser technology is one such candidate. Another might direct an alternate focused source, such as microwaves, to simply overheat a satellite's internal components. To counter such attacks, the owner of a satellite could include an explosive package. Then, if an attack on the satellite was proven, the owner could blow up the satellite, providing the command circuitry survived the initial attack.

However, once again, a precedent within US Cold War nuclear strategy can serve to illustrate some of the ramifications inherent in this line of reasoning. The enhanced radiation weapon (ERV), or neutron bomb, was based upon a similar premise of preserving the use of the battlefield while effectively negating an adversary's systems.[35] First proposed in the early 1960s, the weapon produced a relatively small blast, greatly reduced radioactive fallout, and increased killing power through the release of neutrons. By localizing destruction, limiting battlefield contamination, and maximizing the killing zone, the practical effect was to spare equipment and structures while eliminating the personnel within them. Intended for tactical use in the defense of Western Europe, production commenced in the mid-1970s. Public debate within the United States quickly escalated over the ethical implications of such a device. But, more to the point, European allies viewed the weapon as less of a deterrent than offering a more palatable means for conducting nuclear war in Europe. Eventually, in the face of strong opposition, the United States abandoned plans to deploy the weapon.

Although many argued otherwise, the neutron bomb almost certainly represented an increased likelihood for the use of nuclear weapons. Aside from its stigma as a nuclear weapon, the neutron bomb contained features that moved it closer to the realm of traditional military weaponry. Its destructive power could be more precisely directed over military targets rather than creating a large, collateral swath over adjacent civilian population centers. The battlefield would remain inhabitable, minus large scale fallout of

35 In this case, through the killing of personnel manning those systems.

fissile material. Protected conventional operations could, at least in theory, proceed in conjunction with their use.

Likewise, the presence of space weapons, which can be employed without fear of orbital debris, will result in the increased likelihood of their use. Without the fear of contaminating space to the detriment of future operations, the use of such weapons loses its remaining constraint outside of strategic warfare considerations. And, without that constraint, the possibility of a preemptive strike in space will become all too likely. The strategic military gain, system vulnerability, and detachment from an earthbound public's concerns, will combine to render space a target much too tempting to pass over.

Final Caveat

Yogi Berra is quoted as having said that predicting is hard to do, particularly about the future. The development of a strategic theory of space power is in a formative stage. We, the United States, all spacefaring nations, mankind, do need an underlying theory from which we can proceed to develop policy. We need some foundation philosophy from which to start. We have accumulated some small cache of facts from conducting space operations for forty years. We have the accumulated insight of 4,000 years of human history.

This and the previous chapter has attempted to lay out some of the attributes, truths, and beliefs about the exercise of space power for national security, up to and including the application of force. We have also attempted to frame some of the debates of the late 20th Century about space activities in the context of national security.

Space power is real and it is extremely relevant to national security. It must be protected like all other important and valuable assets. At some time, weapons will be placed in space, when the need for them is irrefutable: this may be merely a domestic political need. In light of all this, what should the United States, or another spacefaring country, do to gain or maintain status as the world's premier space power? That is the subject of the next and final chapter.

7

Epilogue: Directions for the Future

The purpose of this work has been to illustrate why space power has become inseparable from all other forms of terrestrial power, and to assert that both by itself, and in conjunction with other forms of terrestrial influence and power, space power is necessary for the maintenance of national power.

But even provided that this argument has been successfully advanced, there remain two important, unanswered questions. First, how does a spacefaring nation attain or (in the case of the United States) maintain preeminence in space? And secondly, how does a space power use that strength for national purposes?

After all, Mahan insisted that preeminence on the sea rested upon a nation's acquisition and maintenance of a large, concentrated battle fleet. Douhet prescribed a large air force of "Battle Planes" or bombers to gain, or maintain, dominance of the air. What then is the hardware blueprint for space superiority? It is not yet weapons, nor is it any particular type of spacecraft, or any specified space-related system. For the time being, it is probably as simple as assured access. The definition of space power in the first chapter of this book is a good prescription for the near term, but time will change this prescription.

As with much of the previous discussion regarding space power, what follows focuses primarily on the United States and pertains to the current state of its national politics and economy. Most of this discussion may be applied, however, to other existing or would-be spacefaring nations as it is (1) general in nature, and (2) represents an environment that is increasingly being seen throughout the world. That is, the democratization of national politics and the merging of national economies into a global infrastructure. For this reason, it is reasonable to assume that a future or aspiring space power will likely face many of the same concerns regarding national debate, organizational matters, economic realities, and global restrictions, that the United States faces today.

As the world's premier space power, the current preeminence the United States enjoys is due to something less than the realization of a master plan. Rather, it is more a matter of serendipity, in combination with several well-thought-out policies.

And, though its space power is unquestionable, there is great danger in the present position of the United States. That danger comes not in the form of an adversary or even competition, but rather self-contentment and self-congratulation. One of the primary reasons for the United States' present comfortable situation is the rigorous competition furnished by the Soviet Union, which provided the impetus for developing a sophisticated US space capability (bluntly, the USSR kept the US space industry "running scared" for decades). The Soviet Union has since dropped from the race, leaving its successor, Russia, to cope with an unaffordably huge space industrial base but without sufficient funds to maintain full use of its capacity.

How Can We Decide What We Must Do?

Space has been described previously in this work as an arena much more volatile and unstable than any previously known medium. Space technologies and designs have proven to be more short-lived than those of the early years of aviation. This means that policy decisions, no matter how well based upon sound reasoning, are quickly outdated, yet tend to remain in effect through bureaucratic inertia.

This means that flexibility, innovation and open-mindedness are required not only from the scientists, engineers, and technicians involved in the space program, but others as well. Government policy makers, legislators, and judges must also be made to understand that yesterday's solutions may be incorrect for today's emerging technologies.

Perhaps even more importantly, there must be an understanding that space is the wrong arena to be accommodating and willing to let nonparticipants have an important role in the development of law and policy. The impediments caused by once innocent passage in space treaties described previously are proof of the pace of change. Enthusiasm for today's, or even tomorrow's, solutions must be tempered with the knowledge that tomorrow's wrong choice was the one that seemed so obviously correct yesterday. Yet decisions cannot be avoided, and a slow, cautious approach may be as wrong a policy of space activity as may be a headlong rush.

Like the language and policies of space treaties, prescriptions for action are likely to soon become so outmoded as to be of little other than historical value in just a decade or so. Also, they are all too often prescriptions exclusively for government, which neglect the fact that though government must necessarily be part the environment that supports national space power, it is no longer the sole actor nor, perhaps, even the most important.

A list of prescribed actions would then have to include all of the contributors to space power and national security, which have been discussed in preceding chapters.

Not too long ago, an operational antisatellite capability once seemed to be an absolute requirement for the United States to counter a militaristic use of space systems by the Soviet Union. Today, a robust research program may suffice to meet a threat not currently manifest in space. This brings us back once again to the central point of this discussion. If lists and formulas make little sense, what then must a nation do to gain or maintain preeminence in space?

To begin with, there must be an understanding that space is more than a place to stage spectacularly entertaining events. We must construct a national consensus about space exploitation and about exploration for curiosity and for future exploitation. Space is a medium that requires serious, methodical exploration to develop the details of commercially beneficial discoveries.

Exploration must also include those activities that lead to a better understanding of the history of the universe, our solar system, and the development of life on our planet. By exercising the knowledge we gain from space, we do more than satiate our curiosity or provide fulfillment on some aesthetic plane; we acquire the tools that enable us to achieve a better standard of living for the people of our nation, of our civilization, and of our planet. The expansion of space power by the United States and other nations will provide new technologies, new knowledge, new services, and eventually new resources as we extend our reach farther into our solar system.

The exploitation of space was, is, and will continue to be a vigorous undertaking. A country wishing to gain or maintain status as a space power must first demonstrate a willingness to commit to a space program and then follow that effort through thereafter. In the case of the United States, the major efforts of its first decade in space have been followed by relatively modest undertakings. The result has been modest achievement, especially when viewed from the heady days of early space development. Moon bases, manned missions to Mars, as well as an orbiting space station, were all envisioned to have been accomplished by the end of this century, but none came to pass. The small portion of national wealth being spent by the United States government on civil space activities today is apparently the minimum necessary to sustain modest growth.

It is always tempting to look at our current set of contemporary problems and try to put all of our efforts and treasure into mitigating poverty or disease. But those problems need time, more than attention and money, to come up with workable solutions. Investment in the future is also required.

History provides the object lesson of the Chinese "Treasure Fleet," immense ocean-going vessels which in the early 14th Century explored what would later be called the "East Indies," visited northern Australia, and crossed the Indian Ocean to the east coast of Africa. But back home, Chinese society never found anything worth buying from foreign barbarians, and government funding of the voyages was slashed. Instead, China diverted its resources to domestic needs such as canal construction and "ever-full" granaries, while the ships—with ocean going travel a capital offense—rotted in their harbors. A century later, Portuguese mariners, inferior to the Chinese in every sea-going skill except boldness, retraced the abandoned routes in the opposite direction, reached China, and began a centuries-long tragic confrontation between East and West.

What will we pass on to generations after us—rotting, rusty spaceships, or a bold legacy? History tells us that there is no short term fix to social ills and economic inequality. However, we can give our descendants a culture, a regulatory philosophy, and an economic infrastructure attuned to the potential of space exploitation. It will require the constant awareness, a sense that space is the future, the kind of emotional ownership that the Phoenicians, the Venetians or Victorian British are reported to have felt about the sea.

The investment required of space powers is much more than money, the real investment is an educated concern by those who understand national power and create the intellectual atmosphere to nourish the required policies. The onus is not on government officials, it is on us.

So government space programs are not the answer to how to maintain the US lead in space. In the absence of an obvious national security threat, the government will scale back national security budgets and noncritical exploratory efforts. So much is already promised to entitlement programs that little is left to invest in research and new procurement in defense and for NASA.

Industry is thus free to step to the front. It appears certain that profit will flow to innovative space solutions. With the expansion of satellite technology and applications, private capital and enterprise may become integral ingredients in international operations in space.

For example, solar power satellites may augment other public utility installations. Large space structures and space stations may constitute the skeleton, but the heart of future space operations has to be the industrialization of space, i.e., satellite applications, metallurgy, pharmaceuticals, energy, and resources from space. The industrialization of space will result in mining operations on the Moon and the asteroids, which may lead to the colonization of space. The imagination of minds who want to sell their wares to our fantasies may lead us eventually beyond the horizon of time into a future we cannot foretell.

Anticipated profits will cause a great increase in the number of commercially owned space systems, requiring government planning to protect and control commerce. Depending on the strategies and the implementation systems selected for the regulation of commerce, additional capabilities for international coercion may also become available. For example, an ability to deny access to some small terrestrial regions by commercial earth resource imaging satellites has use in commerce regulation and international relations. The ability to refuel or bring satellites back to Earth includes the ability to inspect satellites, and to disable or seize non-cooperative assets. Many space technology experts have envisioned a greater role for the space-related contribution to national security. Without some stimuli, the technological level of national space power that now seems technologically possible, will not be achieved until sometime in the future. Without funding for further research, promising technologies will remain future possibilities.

If industry must innovate and cause the changes we expect to increase space power, then governments must provide an environment for private innovation. Governments should take a look at the treaties, agreements and regulations in effect and determine how best to protect and yet manage this most volatile of mediums.

In particular, it seems that a fitting task for governments is the growing amount of debris at low earth orbit. Another task that will require governmental action is the requirement to set up some traffic control type of organization for earth orbits. This is not yet a crisis at the end of the 20th Century, but the addition of hundreds of more satellites, the launch vehicles to put them into orbit, and the limits of the radio frequency spectrum require innovation and regulation. Governments must also carefully consider the types of international treaties and regulations being proposed. The task is to foster an environment that allows rapid, yet safe exploitation of the technologies and the opportunities of space.

Our commercial and government programs must have the freedom to fail. Modern management techniques of risk assessment, risk avoidance, and risk mitigation have provided space programs that have been, on the whole, very safe and very reliable. There is a reasonable expectation that safety and reliability can remain high. However, failure is a also good teacher.

This is not to encourage reckless behavior, or to deliberately seek danger in space by following shortsighted strategies. After all, nothing new is learned from the stupid mistakes, like cleaning rags in the fuel system of a launcher, or mis-programming an upper stage. Decades of space activities have provided volumes and volumes of "lessons" which must be more efficiently transferred from those who paid for them to those who may avoid having to pay again, if they're smart enough.

Currently the cost associated with loss of life in space is politically very high. Yet this is only a temporary phase, when annual human flights into space can be counted on one's fingers. As access to space widens and traffic increases vastly, space accidents—even space fatalities—will transition from occasions for national mourning, to shocking news on par with an airliner crash, and ultimately to sad but quickly-forgotten tidings such as a skydiving accident or a military helicopter crash. To the extent that space activity becomes "ordinary," the public will come to view these accidents as acceptable losses.

There will be other kinds of losses, many involving money, sometimes a great deal of money (a higher level of mature space operations will be achieved when some space firms go bankrupt—before then, they were all being too cautious). Risk avoidance also avoids revolutionary innovations; risk prevention usually results in extra cost. Great rewards are often snatched from great risk.

There needs to be a tolerance for failure in our space activities. The ability of humans to err is well known. Making each mission less costly is one way to avoid some of the pain of failure. Failures will surely happen. The technologies of space weapons, of space exploration, of other forms of space launch, will result in some sort of success after failure. Learning will result; success will surely follow. We just don't know the form of the success.

An understanding that failure teaches is desired. This understanding will lead to a national sense of ease about failure. The shortsighted, quarterly profit sheet approach is not the correct model. The modern world is, in some respects, the product of the European Age of Discovery and the Industrial Revolution. The Europeans discovered that the world was larger than Europe through a series of adventures and mistakes. The world is richer for their mixed record of success.

National security is another matter. All spacefaring national governments want to preserve their access to space. Those countries without a space program or space industry of their own want to receive the benefits of on-demand space services. In conflict situations, the tendency for each side to deny space support to the other side could threaten space access for all countries.

The United States and other major spacefaring nations should study the intended and unintended consequences of such actions. Weaponizing space will make space war the inevitable spillover of terrestrial conflict. The United States should use its influence within the United Nations to sponsor discussion of the adoption of voluntary limits on space-based weapons. Since some types of weapons could have more than one use, the discussion should include means to prevent the use of space-based weapons, if ever deployed, against terrestrial targets.

Such voluntary limits will not prevent the eventual weaponization of space, but it could delay weaponization by some significant period. Any delay of time when conflicts move into space works to the benefit of spacefaring nations. Unlike previous strategic theories, the building of a space battle fleet is not the first priority of space power. The use of space, and the protection of that use, is the primary directive. Eventually, weapons will be on orbit around the celestial bodies of our solar system. We must be ready with practical, working designs and the will power to protect space for our national security.

To effectively practice space control, the United States must develop the capability to know what information all satellites supporting military operations are collecting, and to whom it is being provided. This requirement is related to US concerns regarding information operations. In addition, the military must develop, along with the national policy community, a strategy for space control in time of crisis, tension, and war. This strategy should include planning to use capabilities that deny an adversary the use of space-related assets including satellites. Experience gained in war and other hostile environments, as well as the study of space operations and warfare in general, suggests that a “clean sweep” over the shortest possible time may provide sufficient “shock effect” to prevent the start of terrestrial hostilities, or at a minimum, provide the United States and its allies a significant edge in terrestrial hostilities.

The United States must plan for and rehearse military actions in space. Military space commands need innovative leadership and freedom to experiment. Through experimentation and gaming, the military can develop the strategies and tactics to win if hostilities require warfare in space. Military action in space must be routine to the military to be effective. It must be thought out, rehearsed, intuitive, and instinctive. Operational experience with weapons systems is required before operational employment doctrines can be perfected. The military must prepare by establishing the routine well before the threat forces the United States to arm its space forces.

It seems most likely that weapons will be put in orbit for one of two reasons. First, it will be because some other state has or is about to put weapons in orbit. The asymmetric advantage of a state with space-based weapons is enhanced by the apparent acceleration of the scale of time in space. The second reason is far more likely. It will be in keeping with self-defense.

The proliferation of weapons of mass destruction and ballistic missiles will drive some portions of national self-defense systems to space to gain an edge in time, and thus, effectiveness. It would seem that such an inherently sensible system could be shared with allies. Is it time to consider a Supreme Allied Commander—Space? Yet, it is well before such a command is needed, our allies might opine that we are merely being too aggressive and that we are attempting of gain their support for something they believe to be necessary. Early discussions and organizations to take our closest military alliances beyond terrestrial boundaries may enhance the appearance of a combined determination to jointly resist the use of WMD for terrorist causes.

Such an organization could discuss the problems of debris propagation in low earth orbits and could be the agency of choice if a means to lessen the quantity of debris were developed and fielded. Likewise, a combined military command might be the logical operator of the supporting sensors, management displays, and communications for an orbital control agency, perhaps under UN auspices. Among the alliance of advanced states, only the United States has a military space command at present. Would the addition of allied members to the policy process make them better partners in the future?

Educators in the United States have done a great job of exciting students about space subjects. Almost every major university has some type of space-related curriculum. Primary and secondary teachers excite their students about science by using space systems and scientific discoveries as teaching tools. Spacefaring nations and those who would benefit from space-based services send their students to schools in the United States.

This student and educator interest is one of the more sure proofs of the value of space power. There seems to be a consensus, based upon instinct, that space, and its sibling, information technologies, will be very important to the future. However, reality often lags expectation and imagination. It is this cold dose of reality that ends interest for many eager students. The impact of Sputnik upon the US educational system resulted in an increase of science studies and science degrees. Not only space will benefit from a successful revitalization of wide interest in the sciences and mathematics—not only for the handful of students who will enter technical careers, but for the broad mass of future citizens who will be voters and customers relative to space issues.

For the United States in particular, space power can be maintained if the dream of the founding fathers is maintained. Americans need a dream. We have an opinion of ourselves as providing a responsive and honest government: government of, by and for the people. We see ourselves as an example for the rest of humankind to follow. We enjoy freedom; life, liberty and the pursuit of happiness. We developed our West, kept the Western Hemisphere free of new imperialism, and led the fight against the succession of totalitarian regimes that appeared in the 20th Century.

For the majority of us, our parents and forebears came across oceans to settle this country, enduring great hardships. Many more new Americans are crossing oceans or deserts to be part of this country. As the descendants and heirs of those adventurous people, it is only fitting that we should fulfill their heritage by continuing the expansion of our species into space.

In 1893, a young history professor from the University of Wisconsin named Frederick Jackson Turner delivered the last talk of an evening session at the annual conference of the American Historical

Association. In seeking to explain so much that we all find commendable about American culture—the egalitarian democracy, individualism, and spirit of innovation—Turner's insight centered on the existence of the Western Frontier.

"To the frontier the American intellect owes its striking characteristics," Turner asserted. "That coarseness of strength combined with acuteness and inquisitiveness; that practical, inventive turn of mind, quick to find expedients; that masterful grasp of material things, lacking in the artistic but powerful to effect great ends; that restless, nervous energy; that dominant individualism, working for good and evil, and withal that buoyancy and exuberance that comes from freedom—these are the traits of the frontier, or traits called out elsewhere because of the existence of the frontier."

Turner continued, "For a moment, at the frontier, the bonds of custom are broken and unrestraint is triumphant. There is not tabula rasa. The stubborn American environment is there with its imperious summons to accept its conditions; the inherited ways of doing things are also there; and yet, in spite of the environment, and in spite of custom, each frontier did indeed furnish a new opportunity, a gate of escape from the bondage of the past; and freshness, and confidence, and scorn of older society, impatience of its restraints and its ideas, and indifference to its lessons, have accompanied the frontier."

"What the Mediterranean Sea was to the Greeks, breaking the bonds of custom, offering new experiences, calling out new institutions and activities, that, and more, the ever retreating frontier has been to the United States directly, and to the nations of Europe more remotely. And now, four centuries from the discovery of America, at the end of a hundred years of life under the Constitution, the frontier has gone..."

Frontier cultural influences still echoed in American society for several more generations, but some observers now bemoan their weakening influence and seek to explain current US social ills to be a consequence of the loss of the frontier. On the Internet Web Page of the "Mars Society," a private group that advocates human settlement of the planet Mars, they put it this way: "Currently we see around us an ever more apparent loss of vigor of American society: increasing fixity of the power structure and bureaucratization of all levels of society;

impotence of political institutions to carry off great projects; the cancerous proliferation of regulations affecting all aspects of public, private and commercial life; the spread of irrationalism; the banalization of popular culture; the loss of willingness by individuals to take risks, to fend for themselves or think for themselves; economic stagnation and decline; the deceleration of the rate of technological innovation and a loss of belief in the idea of progress itself. Everywhere you look, the writing is on the wall.

"Without a frontier from which to breathe life, the spirit that gave rise to the progressive humanistic culture that America for the past several centuries has offered to the world is fading. The issue is not just one of national loss—human progress needs a vanguard, and no replacement is in sight.

"The creation of a new frontier thus presents itself as America's and humanity's greatest social need. Nothing is more important: Apply what palliatives you will, without a frontier to grow in, not only American society, but the entire global civilization based upon Western enlightenment values of humanism, reason, science, and progress will die."

Perhaps the space enthusiasts overstate the stakes, but maybe not. History teaches that there is no inherent advantage—geographic, ethnic, philosophical—that guarantees future success to any nation, except by the exercise of successful cultural patterns. Every generation needs to evaluate its parent culture's history, identify and extract the traits responsible for success, modify them as modern conditions require, and then apply them with the same energy and passion that former generations did.

We have the great gift of yet another period when our nation is not threatened; and our world is free from opposing coalitions with great global capabilities. We can use this period to take our nation and our fellow men into the greatest adventure that our species has ever embarked upon. The United States can lead, protect, and help the rest of mankind to move into space. It is particularly fitting that a country comprised of people from all over the globe assumes that role. This is a manifest destiny worthy of dreamers and poets, warriors and conquerors.

In his last book, *Pale Blue Dot*, Carl Sagan presents an emotional argument that our species must venture into the vast realm of space to establish a spacefaring civilization. While acknowledging the very high costs that are involved in manned spaceflight, Sagan states that our very survival as a species depends on colonizing outer space. Astronomers have already identified dozens of asteroids that might someday smash into Earth. Undoubtedly, many more remain undetected. In Sagan's opinion, the only way to avert inevitable catastrophe is for mankind to establish a permanent human presence in space. He compares humans to the planets that roam the night sky, as he says that humans will too wander through space. We will wander space because we possess a compulsion to explore, and space provides a truly infinite prospect of new directions to explore.

Sagan's vision is part science and part emotion. He hoped that the exploration of space would unify humankind. We propose that mankind follow the United States and our allies into this new sea, set with jeweled stars. If we lead, we can be both strong and caring. If we step back, it may be to the detriment of more than our country.

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