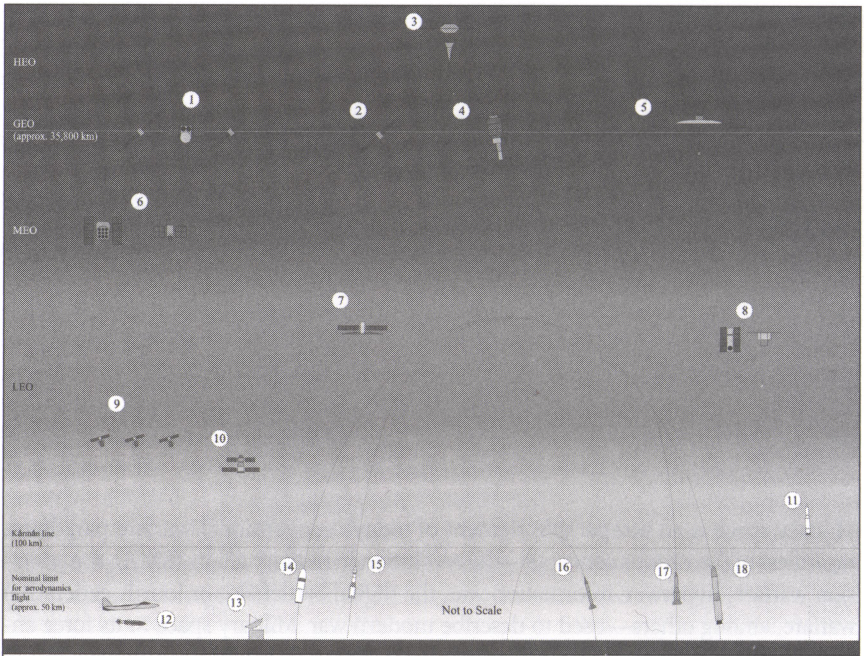
CHAPTER 2

Military Space and Force Enhancement

Military space is an inseparable element of today's conventional warfare paradigm, regardless of the various concepts—the revolution in military affairs (RMA), the precision warfare, hyperwar, information war, the digital battlefield, or fourth-generation warfare, among others—used to describe modern war. Military space in its force enhancement role is arguably the foundation of America's military supremacy in the information age. Satellites have become the enabling technology for much of the precision, agility, and speed that has allowed the U.S. military to subdue those clinging to the old paradigm of industrial-age warfare. The significance of military space capabilities and U.S. space power in today's conventional warfare paradigm has its foundation in the classic theories of war by Clausewitz and Sun Tzu—the use of space to mitigate "fog and friction of war" and to fulfill the imperative to "know thy enemy and know thyself." Further underscoring the place of space in military matters has been the steady investment by allies, peer competitors, and those outright hostile to the United States to both emulate its space capabilities and counter its space power.

The Origins of Space Force Enhancement

In order to understand the significance of space in contemporary warfare, it is useful to examine briefly the evolution of warfare relative to technology over the past century. Warfare has always reflected the technology of the time. Industrial-age warfare followed from the Industrial Revolution of the 19th century in which industrial procedures and production were applied to warfare as evident in World War I. As industrial technology contributed significantly to the four-year stalemate and high level of casualties on the western front, so subsequent technological developments within the industrial mode of mass production (the assembly line) saw the return of mobility and maneuver in World War II. Blitzkrieg, or



1. Military Communications Satellites: NATO IV(1991), US DSCS-3 (1982), UK Skynet 4A (1990)	2. Contracted Commercial GEO Communications Satellite
3. Soviet Molniya-1T Communication Satellite (1970)	4. US Defense Support Program (DSP) Satellite Block 14 (1989)
5. US Trumpet/Mentor ELINT Satellite (2003)	6. Global Positioning Constellations: US Navstar Block IIR (2005), Russian Glonass (1981)
7. Canadian Radarsat-2 Radar Imaging Satellite (2007)	8. Digital Imaging Satellites: US KH-11 (1976), Commercial Ikonos (1999)
9. Commercial Iridium LEO Communications Satellite Constellation (1997)	10. Chinese Manned Dual Civil/Military Space Program (1999)
11. Chinese SC-19 Ground Launched Direct Ascent ASAT experiment (2007)	12. US JDAMS GPS Guided Bomb (1997)
13. Satellite Downlink Jammer: US Counter Communication System (2004), Russian made GPS Jammers used by Iraq in 2003	14. US Trident D5 SLBM (1990)
15. US Ground Based Interceptor (2005)	16. Scud/R-11 derived SRBM in use by various rouge nations.
17. Soviet/Russian ABM-3/SH-11 “Gorgon” (1980’s)	18. Russian Topol M ICBM (1997)

Figure 2.1 Present Military Space

lighting war, brought together armor, artillery, and aircraft via wireless radio to create a swift and powerful expression of combined arms. World War II also saw the beginning of the atomic or nuclear age where nuclear weapons became the primary focus of military matters for the following decades of the cold war. It was in the final decade of the cold war that emerging technologies, the microchip and computer network, put in place the foundation of the contemporary age of warfare, initially conceptualized as a revolution in military affairs (RMA). Though space technology has been around since the atomic age, with its own contending technological era known as the space age, it is in the information age that space has become an integral part of warfare.

The focused nature of information-age warfare contrasts with the mass destruction of nuclear warfare. Nuclear reactions release vastly greater amounts of energy than the most powerful of conventional chemical reactions. For this reason, the yield or explosive power of nuclear weapons is given in units of tons of the common chemical explosive trinitrotoluene (TNT). Due to the intricacies of nuclear physics, the first nuclear devices were in the kiloton (kt), or thousands of tons of TNT, range. The nuclear weapons that devastated Hiroshima and Nagasaki were 15 kilotons[1] and 22 kilotons,[2] respectively. With advanced nuclear weapon design techniques, such as mixing fission and fusion nuclear reactions in the same weapon, the yield of nuclear weapons was increased to ludicrous levels of destructive power, expressed in millions of tons of TNT—megatons. The realities of mass destruction drove strategy development in what was to be the centerpiece of the cold war superpower military relationship.

During the cold war, national security for the United States revolved around the many problems of facing another nuclear-armed superpower, the Soviet Union. The realities of the nuclear age led for the most part to the patterns of nuclear deterrence, and the well-known concept of mutually assured destruction (MAD). Essentially, in a MAD relationship in which both parties possessed the capacity to destroy the other even after a preemptive first strike by either one, the likely consequences of a large-scale nuclear exchange would have been an unacceptable amount of damage to all participants—mutual suicide. Thus, the MAD scenario produced a situation where there was severe disincentive to provoke a nuclear war. In effect, nuclear weapons produced nuclear deterrence as a war-prevention strategy.

Under the rational-actor model, one expects that a prerequisite for superpower status is some measure of rationality, so the consequence of the MAD scenario is arguably a stable nuclear standoff. The devastating consequences of nuclear warfare constrained the actions of the participants in the confrontation between the cold war superpowers. Even conventional warfare directly between nuclear-armed countries was a difficult proposition due to fears of it spiraling out of control, and these fears extended to regional and proxy wars beyond the central front in Europe. In the present day, even with reduced stockpiles of nuclear weapons and the emerging missile defense capability to defend against a limited ICBM strike, the potential devastation of nuclear weapons still tempers relations between nuclear-armed adversaries. Relatively recent nuclear powers, India and Pakistan, have cited the calming effect that their small nuclear arsenals have brought to their turbulent relations since independence.[3]

Providing a bridge between conventional warfare and the world of nuclear Armageddon was the tactical nuclear weapon—a nuclear weapon meant to be used against fielded forces, not strategic targets such as population and industrial centers or other strategic nuclear weapons. The rational for tactical nuclear weapons is simple—relative cost. Based on destruction per weapon, nuclear warheads are a relatively inexpensive means of waging war. Aside from an all-out nuclear exchange, the cold war had the potential to go hot in the form of mass-mechanized maneuver warfare across the central plains of Europe. The cliché scenario involved East Bloc armor and mechanized infantry pouring through the Fulda Gap, invading West Germany and beyond. The massive superiority in the number of tanks held by the Soviet Union lent credibility to this threat. To counter the Soviet superiority in numbers, the battlefield nuclear weapon option became desirable for quite some time. Though not always appreciated, nuclear weapons in some sense made up for the perceived gap in conventional forces needed to defend Europe from Soviet aggression. As a result, the United States, its allies, and NATO adopted a strategic policy of nuclear first use to bolster their deterrent postures.

As part of the Western view of deterrence (and not just against nuclear attack), the reason to be nuclear armed was to dissuade the Communist world from attacking the West. The resultant ambiguity over when nuclear weapons would be used was part of maintaining a credible deterrent. Deterrence would have failed if the other side had felt it could get away with a strictly conventional war. Years after the collapse of the Soviet Union, the rational for maintaining the nuclear deterrent and ambiguity over when it would be used, though diminished, remains, at least in latent form.

The history of the space age and the military use of space, as discussed in the Introduction, were intertwined with the atomic age and the cold war. Most of the successful space launchers of the era were converted nuclear delivery missiles. To this day versions of Sergei Korolev's R-7 missile continue to reliably launch payloads, including wealthy space tourists, into orbit. The space race itself was an outlet for cold war tensions—a place for each superpower to demonstrate technological prowess to reassure allies, win converts to the cause, and rattle the saber. In addition to demonstrating each superpower's skill to deliver payloads, the space environment was used in support of nuclear deterrence. The high vantage point of space was used for early warning systems meant to prevent surprise attack. Communication satellites contributed to the redundant links between command authorities and deployed nuclear forces. Orbiting reconnaissance satellites gave each superpower an idea of the other's capabilities, including the potency of the other's nuclear forces, which dispelled any misconceptions about the credibility of each other's nuclear capabilities. Though comparatively limited in numbers and capability, space systems were extensively used in support of nuclear deterrence, hence the superpower conflict that shaped practically all international and military matters of the cold war era.

While the bomb was the mainstream in military matters, the guided weapon was struggling to reach acceptance. The first guided weapons were deployed in World War II. Initially, their guidance was in the form of remote control either via wires or radio command. Among the World War II–era guided bombs was also a version of the German Hs-293, which experimented with a form of television guidance.[4] Like the atomic bomb, guided weapons concepts are meant to improve a platform's ability to destroy a specific target. Atomic weapons facilitate target destruction by providing a surplus of destructive force, increasing the acceptable margin of error when it comes to hitting the bull's-eye. Guided weapons on the other hand represent an economy of force—an attempt to apply force only where needed.

Technologies linked to the rise of the information age, solid-state electronics, the integrated circuit, and the microchip, allowed the evolution of guided weapons into truly useful and, more importantly, acceptable weapons. The electronics of the early cold war were bulky, expensive, unreliable, and consumed large amounts of power. All of these factors, especially the lack of reliability, made guided weapons at best a niche weapon, and for many a waste of resources better spent on proven systems such as nuclear weapons or enlarged conventional forces for an old-fashioned mechanized war. As electronic and related computer technology developed, equipment became smaller, cheaper, and robust and consumed less power.

Guided weapons, like nuclear weapons, offered the potential to reduce the number of attackers or sorties needed to destroy specific targets. With a guided weapon, or precision guided munitions (PGMs) as they are now labeled, city-sized regions did not have to be leveled to ensure the destruction of a single target. As the accuracy and precision of guided weapons increased, the amount of destruction that was needed to destroy a target declined. In the past, bombing missions were planned around the number of aircraft needed to destroy a target. Today, bombing missions are planned around the number of targets that can be brought under precision fire by a single aircraft.

The 1991 Gulf War, Operation Desert Storm, is often presented as the first demonstration of the effectiveness of PGMs. Though the majority of munitions employed in the 1991 conflict were actually of the unguided dumb-bomb variety, the general public was captivated by video footage of PGMs hitting specific targets. In contrast to the visions of megadeath invoked by nuclear warfare, the dropping of smart bombs came to acquire an antiseptic video-game quality. War, even with PGMs, is still a horrible and painful affair, but the promise of precision targeting to minimize destruction or collateral damage and to bring swift victory acquired great political appeal as a result of Desert Storm. Increased precision gave the option of limiting destruction to only that necessary to achieve victory, sparing both warfighters and bystanders from excessive risk and harm. The previously unimagined one-sided exchange rate in favor of coalition forces over those of Saddam Hussein, where the United States and allies suffered less than 300 combat-related deaths, certainly hinted at the promise of high-tech warfare to reduce the cost of war. Rightly or wrongly, the 1991 victory against Saddam Hussein was seen as a harbinger of how PGMs would change warfare in the future.

Along with the public's fascination with PGMs, the 1991 Gulf War is also presented by some commentators as the first space war. It was in this war that the public at large, and indeed many within the military establishment, became aware of how important the U.S. investment in the military space program was to overall U.S. military power. NAVSTAR Global Positioning System (GPS) satellites allowed ground forces to find their way through the featureless desert. The opening coalition air campaign was made possible by GPS, where GPS-equipped MH-53J

Pave Low (a large Special Operations transport) helicopters led U.S. Army AH-64 Apache attack helicopters, which at the time did not posses GPS,[5] to attack Iraqi radar sites in strikes carefully timed to open passages through Iraqi airspace for en route coalition aircrafts. The Defense Support Program (DSP) early warning satellites alerted coalition forces, as well as Israel and Saudi Arabia, of attack by Iraqi modified-Scud ballistic missiles. Though the Patriot Advance Capability–2 (PAC-2) tactical missile defense system, then under development, was unsuccessful in intercepting these missiles, the superior vantage point of space for operational early warning systems was demonstrated. Since the 1991 conflict, information technology has been informed by the lessons of this war and subsequent conflicts. The development of military space technology has been transferred from the nuclear warfare paradigm to that of war in the information age.

Alongside these dominant features of information-age warfare, and especially the key enabling role played by military space, is the increasing blurring of the age-old distinction between military technology and civil/commercial technology. In many cases, it is difficult to trace the specific relationship between the development and application of technology for military versus civil/commercial purposes. As noted in chapter 1, military and civil rocket technology developed in a hand-in-glove relationship. The origins of the Internet can be traced back to U.S. military developments to ensure continued communications in the event of nuclear war. Technology developed through investments by the U.S. Defense Advanced Research Product Agency (DARPA) for military purposes have regularly found their way into the civil/commercial sector, such as the computer mouse.

Military-developed technology applied in the civil/commercial sector is known as a *spin-off* relationship. In contrast, technology developed by the civil/commercial sector that is applied to the military sector is termed a *spin-on* relationship. There is also a long history of spin-on relationships, such as the creation of the tank from the tractor and the very origins of the airplane itself. While much of the initial technology related to space was driven by military investment, once NASA was created, civil investments and resulting technology would also be exploited for military purposes. In effect, space industries and organizations continue to be leaders in developing dual-use—civil/commercial and military—technology and application. The significance of digital computing with the rise of the microchip is a classic example of dual-use. The same factors that led to information-age warfare are also at play with the broader information-age economy.

In many ways, the commercial sphere has outpaced the military in creating and adopting information technology, in part because the battlefield is a harsher environment than the corporate boardroom, and the commercial marketplace is much larger than the military one. Regardless, the exploitation of advanced civil/commercial digital technology is central to the military use of space and has enabled military forces to use civil and commercial satellites for military purposes. Indeed, it is estimated that over 80 percent of satellite use by the U.S. military in Afghanistan and Iraq is derived from the nonmilitary sector.

Military Space and Information-Age Warfare

The information age has in some ways superseded the space age, with earthly technologies such as cellular phones, undersea fiber-optic cables, and personal computers having a greater public provenance in most people's lives than satellites, space stations, and missions to the moon. Fiber optics running directly to end users and short-range cellular coverage is perfectly fine for most domestic information applications. However, these relatively fixed technologies are too confining and insecure for a true global military power. Satellite constellations are the information age's means of power projection, using the commons of space to connect platforms on a global-scale battlefield. Space systems bring the effects of information technology to parts of the world where the information infrastructure is either sparse or nonexistent. The marriage of space with information technology in military affairs has led to the concept of space force enhancement.

It is difficult to trace the specific origins of the concept of force enhancement, although it is tied directly to the development of satellite capabilities of direct value to the conduct of military operations. It is the addition of a new military purpose for space systems alongside their original primary military function to support U.S. strategic deterrence. Generically, force enhancement simply refers to capabilities that generate or facilitate a more effective and efficient application of military force. Historically, one can conceptualize a range of military activities such as training, doctrine, equipment and logistics that play a force enhancement function in support of the warfighter. In providing this support, these activities also serve a force multiplier role, which has traditionally enabled smaller forces to defeat much larger forces as seen most clearly during the imperial age of European expansion into the Americas, Africa, and Asia. Indeed, the U.S. conventional military response during the cold war was to apply technology to offset Soviet numerical superiority in numbers during the cold war, even though the United States had the capacity to match the Soviet Union in terms of numbers. In this sense, advanced technologies served a force enhancement function, even though the term itself was not applied.

The first application of space systems to enhance military operations was the employment of weather data from earth observation satellites for planning operational air missions during the war in Vietnam. Since then, the marriage of new information technologies with satellites has resulted in a dramatic expansion of the role of space systems in support of the warfighter. While the basic force enhancement functions of space systems, dedicated military and civil/commercial satellites, are not new per se, their employment in space is, and it is this newness that spawned the term *force enhancement* itself. As a result, *force enhancement* when used today almost exclusively refers to the role of space systems. Even so, the idea of force enhancement also appears under different labels. For example, U.S. Space Command's 1997 Long Range Plan to 2020 does not employ the term *force enhancement* but instead addresses it in terms of the role of space systems in support of the range of U.S. military activities as defined by the Concept for Future Joint Operations—dominant maneuver, full-dimension protection, precision engagement, focused logistics, and information superiority.[6]

Space force enhancement is the collective term given to the use of orbiting satellites or systems to enhance the abilities of terrestrial platforms and munitions. The vantage point of space, reverently labeled the highest of the high ground, is the best location for the collection and rapid distribution of information. Precision warfare is dependent on having the best possible information available. This is information not only on threats and targets, but also on one's own fielded forces and those of allies. For information to be used effectively, there must be confidence in its accuracy, and it must reach those who can use it best. Space assets provide information support to earthbound warriors and weapons, increasing effectiveness not through increased force but by better management of the application of military force. While it is possible for terrestrial and airborne systems to be substituted for some space-based assets for regional coverage, only the vantage of orbit can provide the services needed for the digital battlefield on the global scale.

Space systems not only span continents, but also organizational hierarchies. Thanks to the information technology revolution, the direct impact of space systems has a much broader audience. The military use of space has steadily become ubiquitous, forming networks that link all levels from large-scale formations and deployments down to the individual soldier, sailor, and aviator. The reach of space systems in some cases extends to that of individual munitions and in future potentially to submunitions. Just as it is the vision for some information technology companies to network every element of a business or home together, it is the vision of many within advanced militaries to network as many elements of armed force together as possible—what is known as *net-centric warfare*. Space systems, as part of joint battlespace concepts, cross the boundaries of the separate U.S. armed services. Space systems allow disparate and mobile elements such as tanks, warships, and aircraft spread across a global battlefield not only to talk to one another, but also for one platform to engage a target only seen by another.

The revolutionary capabilities bestowed by space force enhancement capabilities raises the controversial issue of military use of space extending into the realm of weaponization, as discussed in detail in the next two chapters. For now, understanding the idea of space as a weaponized domain is dependent on one's perspective on what is a space weapon. In most respects, space is not commonly conceived as a weaponized environment. Yet, ballistic missile warheads have transited through space since World War II. Even so, the brief sojourn of long-range ballistic missile/warhead flight up to orbital altitudes has not generated a belief that military use has crossed into weaponization. The first generation of missile defense capabilities, the U.S. Safeguard and Soviet Galosh systems, which employed nuclear warheads at the upper reaches of the atmosphere, were not treated as space weapons. Even today, the newest generation of U.S. missile defense capabilities, which in February 2007 destroyed a deorbiting U.S. intelligence satellite that failed to reach its planned orbit, was not viewed in space-weaponization terms.

Nor are the traits of space force enhancement and other information-age warfare concepts linked to weaponization. Nonetheless, the widespread and very open use of space systems to aid in putting steel on target has made the distinction between space weaponization and the rest of the military use of space somewhat fuzzy to say the least. Quite clearly, the question of space weaponization is not just a far-off problem hidden behind technology that exists only in the minds of scientists and science-fiction writers.

Earth Observation Sciences

Earth observation sciences are often the unsung heroes of a nation's defense. Superior knowledge of a battlefield's characteristics is often the deciding factor in victory. The characteristics of a region, its terrain and weather patterns, drive what options are available for both politicians and military commanders. Understanding the options available goes a long way in getting into the other side's head. It is always preferable to exercise the option of choosing one's battlefield and gaining tactical home-field advantage. For example, the Duke of Wellington's survey of the terrain around the village of Waterloo, and his resulting choice to fight at Waterloo, significantly contributed to Napoleon's ultimate defeat in 1815.

Since the beginning of map making, commanders and planners have been dependent upon maps for their campaigns. The flaws of maps are also telling in indicating lapses in knowledge and critical pieces of topographical information that could decide victory or defeat. Knowing the geography of an area guides the planning of a campaign, and discovering in the midst of battle a previously unknown geography often defeats planning. Knowledge of the terrain allows for speed, safety, and efficient movement. Thus, it is no surprise that many of today's survey organizations and observatories have military roots. For example, the United Kingdom's chief mapping organization, the Ordinance Survey, has a history dating back to the Napoleonic Wars and concerns over how to defend the island nation from French invasion.

Whereas in the past map making was a terrestrially restricted activity, space provides a vantage point to survey the entire earth—a necessary capability if one is projecting military power and defending and attacking on a global scale. Satellite imagery of the earth has greatly simplified the task of map making. Basic pictures of the earth, combined with elevation data from satellite-based sensors, produce on demand high-fidelity representations of the earth's physical surface. One application for this type of detailed topological data is autonomous navigation systems, such as the U.S. terrain contour matching (TERCOM) system found on cruise missiles prior to the establishment of ubiquitous satellite navigation. In the 1991 Gulf War, cruise missiles had to take the scenic route through mountainous terrain along the Iran-Iraq border to obtain geographic fixes not available in the comparatively featureless deserts found in the vicinity of most Iraqi targets. While this need to detour over land with missile visible landmarks represents a definite limitation to indirect satellite support, TERCOM and similar systems are completely autonomous and immune to jamming or loss of navigation satellites.

A more current example of the application of satellite-generated maps is the 2001 campaign to remove the Taliban regime from power in Afghanistan. Under the Taliban, Afghanistan was a closed-off country with its people kept away from the modern world and modern ideas. Unlike the West, there was no domestic demand for up-to-date road maps that could be exploited by the United States. Traditional land survey and cartographic resources for Afghanistan were limited, and the United States faced a lack of knowledge of the terrain. As a result, the United States turned to commercial satellite imagery, which had achieved some measure of commercial success in the years prior to 2001. As a function of digital transmission technology, the United States could obtain images of specific target areas constrained only by the nature of a particular imagery satellite's orbit. Moreover, depending upon orbital paths, maps could be updated periodically during the conflict. Seeking to ensure operational secrecy over the Afghanistan theater of war, the United States bought exclusive rights to all commercial imagery of the region—a step it had also taken during the Gulf War. As a result of these exclusive contracts, the United States and its allies were more than well supplied with fresh maps of Afghanistan prior to the commencement of hostilities.

The importance of satellite imagery for obtaining accurate topographical information for campaign planning and execution is a double-edged sword. Commercial imagery is available to anyone willing to pay, unless the company producing the imagery is explicitly prohibited by national law from selling such imagery to certain clients or nations. If the U.S. government had not obtained an exclusive contract to commercial earth imaging data of Afghanistan, its adversary potentially would be able to acquire such data, undermining U.S. information superiority. Commercial satellite imagery may have fallen into the hands of the Taliban and its supporters. Despite promoting a very austere form of Islam, the al-Qaeda organization, which had training camps in Afghanistan hosted under the Taliban regime, has no qualms with using technology to achieve their aims, including the possible use of commercial space technology. In addition, the media could also have potentially accessed the imagery to report on the war, thereby affecting U.S. operational secrecy. Indeed, in early 2001, commercial space imaging had been used by the media to obtain pictures of a U.S. Navy EP-3 in the middle of a Chinese airbase after a midair collision with a Chinese fighter forced it to make an emergency landing in China. U.S. contractual control of overhead images from commercial satellites also enabled the United States to provide maps of the war zone to the media without disclosing the capabilities of U.S. satellite image reconnaissance capabilities and ensure that the maps did not disclose any sensitive military information.

With computer technology there is also no reason to stop with just emulating old mapping products. To assist in visualizing the prospective battlefield, elaborate models are often constructed, complete with scale representations of the opponent's defenses. Today, through the use of computers, accurate satellite-derived topological data can be used to build virtual representations of the battlespace. These three-dimensional representations can be inserted into various military simulators providing the opportunity for low-cost, high-fidelity mission training without risking personnel or equipment. This technology has also made its way into civilian life by filtering into hobbyist flight simulations and other entertainment software.

Further information can be embedded into digital maps, including political, economic, and environmental data. Satellite-aided digital maps and tools for manipulating data are now nearly ubiquitous. Detailed maps of most of the earth's surface are not just available to government users (military and civil servants concerned with a particular piece of ground) but are now free for the taking by practically everyone with access to the World Wide Web. The Internet company Google has not only made satellite imagery available online, but has also integrated it with various mapping tools ranging from simple addresses to automated route planning and, most recently, combining the overhead imagery with links to street-level imagery. Data and integrated utilities to make use of the data are continually increasing, in part as a function of competition among Internet companies. GoogleMaps and similar free Internet mapping services, such as MapQuest, have become convenient means for individuals to locate landmarks for navigating around the city they live in. These developments, in turn, reinforce the utility of commercial products for military use.

Alongside maps, space-based imagery is vital for weather reporting. Meteorology, like cartography, has been central in human conflict. Weather, like geology, can cause grief to navigation and military enterprises, and the weather is much more prone to rapid change than geology. Weather conditions control what operations can or cannot be conducted. During the Battle of Britain, the Royal Air Force only had to sustain control of the skies over southern England long enough for seasonal weather changes to make air attacks difficult and an invasion across the English Channel impractical. On the eve of the D-Day invasion of France in June 1944, Allied planners agonized over weather conditions over the English Channel. On a smaller timescale, immediate weather conditions affect day-to-day air operations. Poor weather may delay or outright cancel operations. At sea, blundering into severe weather may be as destructive as any naval weapon short of a nuclear warhead.

Meteorological science seeks to mitigate the effects of weather by providing both long- and short-term predictions of environmental conditions. Earth orbit provides an excellent vantage point for monitoring the development and movement of weather on a regional and local scale, as most publicly evident in the release of satellite images of hurricanes as they develop and move. Weather satellites are built around various sensors meant to see weather, including optics across a wider spectrum than is visible to the human eye. Superior information on the weather, to the point of near real-time monitoring in some cases, allows for superior planning to mitigate the effects of weather.

Of importance to precision warfare, weather conditions can disrupt the operation of optically guided and laser-guided smart weapons. Despite the proliferation of GPS and millimeter wave radar guidance, laser- and optically guided weapons still have a place in a technologically sophisticated arsenal. For instance, recent improvements to the joint direct attack munitions (JDAM), commonly thought of as a GPS-guided weapon, include the addition of a laser guidance seeker to allow precision engagement of moving targets. The JDAM's laser guidance option is meant for use in clear weather. The original GPS and inertial guidance are available for use in all weather conditions where bombs may be dropped.

Space-based earth monitoring also extends beyond the surface of the earth to weather in space. For example, it is believed that ICBM guidance systems utilize data on local variations in the earth's gravity (due to imperfections of the earth from a perfect circular sphere) to enhance accuracy. Gravity and other geodesy measurements over the flight path of an ICBM, including the parts over the target country, can only be safely obtained from orbit. As a result of improved accuracy derived from satellite data, some have argued that ICBMs and submarine-launched ballistic missiles (SLBMs) could be employed as conventional, precision strike weapons. Of course, this is highly controversial because of the problems differentiating between an ICBM carrying a conventional warhead and one carrying a nuclear warhead in a situation where an adversary also possessed nuclear weapons and feared a possible disarming first strike. Indeed, such precision as enabled by space assets, whether from ICBMs, cruise missiles, or air-launched JDAMs, for example, all hold the possibility of a disarming first strike without using nuclear weapons. In effect, space systems' applications, as further discussed below, have been central to the replacement of the deterrence paradigm by the precision conventional warfare paradigm. The full strategic and political implications of this dramatic change have yet to be fully addressed and will likely be a major focus of future strategic assessment.

Surveillance, Reconnaissance, and Targeting

Military terminology distinguishes between three types of observation: the surveillance of a wide area of territory or military activity, the reconnaissance of a specific area of territory or military activity, and the targeting of specific territory or military activity for attack. In one sense, these three correlate to the concepts of strategic (surveillance), operational (reconnaissance), and tactical (targeting). In another sense, they are interrelated. Surveillance of a wide area identifies activity of operational interests on the part of the adversary and cues reconnaissance of particular threatening operational activities, which, in turn, identifies potential targets for the direction of ordinance. All three have been greatly facilitated by the highest of the high ground—space. Moreover, the continued refinement and proliferation of orbiting earth imaging capabilities has blurred somewhat the line between strategic surveillance, reconnaissance, and targeting intelligence gathering and tactical observation. In some specific niche roles, space-based sensors now have the potential to participate directly in the sensor to shoot cycle of a weapon engaging a terrestrial target. While the highest of the high ground is perhaps intuitively the best vantage point for military observers, the laws of nature governing orbiting have limited just how useful a satellite can be in engaging targets on earth. The march of technology is, however, hinting at ways to overcome nature for satellites to participate in the sensor to shoot cycle.

Objectively there is not much difference between an earth imaging satellite and an image reconnaissance satellite. Like many dual-use technologies, the separation between tool and weapon is a matter of intent. Commercial earth imaging has already proved itself for map-making applications. The fear that commercial earth imaging services may be employed by those hostile to the United States clearly underscores the reality that even limited civilian capabilities are of potential intelligence value. Even so, the capabilities of National Reconnaissance Office (NRO), the agency that runs the majority of the U.S. orbiting reconnaissance programs, are estimated to be of higher resolution than those offered on the open market.

The development of orbiting earth imaging capability has in many respects mirrored the development of consumer camera technology. Both the consumer-grade camera and the spy satellite camera are based on the same laws of physics governing optics, except the orbiting camera is on a much larger scale than the camera found on any vacationing tourist. Initial U.S. imaging reconnaissance satellites utilized photographic film cameras, just as the cameras of the era. The first of these satellites run under the CORONA program was launched in 1959. These satellites used the now fabled KeyHole (KH) designation to separate series of imaging satellite types. As film was used to record images, these satellites had to employ small reentry vehicles to return pictures to the earth, which were captured by a plane as it descended by parachute back to earth. While there is no commercial equivalent to the early film return imaging reconnaissance satellites, obsolete images from successive series of KH satellites have been released to the public domain. Starting in 1995, select images from the KH-1 series of satellites were made available. The most recent declassification of U.S. satellite imagery occurred in 2002 with the release of imagery from the KH-9 HEXAGON, or more commonly Big Bird, series of satellites.

The nature of the recording medium, film, restricted the operation of these types of satellites. As pictures taken by early KH satellites could only be obtained from the satellite with the return of the film return reentry vehicle, operators had to decide on using up the entire roll of film before commanding the film capsule to return or wasting unused film to return some critical pictures early. Film retrieval also exposed the valuable pictures to all the hazards of reentry. Finally, the quality of the images or if images were actually taken would not be known until the film was developed. Just like the roll of film inside the ordinary tourist's camera, each roll of film on the spy satellite only had one chance to produce pictures worth keeping. The limitations of film were partially mitigated by equipping KH satellites with multiple film return capsules. Starting on the later KH-4 CORONA satellites two film return capsules were carried. The final film return spy satellites, the KH-9 Big Birds had five.

Electro-optical sensors and digital computers made digital photography available first to satellites and much later to the consumer. While there remains some truth to claims that analogue film can produce a superior picture, both in the civilian world and in the national security world, digital-imaging technology does have the advantages of speed and flexibility. Instead of recording images on film, image data in digital form is readily transmitted back to ground stations. This meant that the KH-11 series of satellites, which used an electro-optical imaging system, could be designed for a much longer service life in orbit due to no longer being limited by how many pictures it could take before running out of film. Digital transmission of pictures also meant that the response time for obtaining pictures from a spy satellite was only limited by the nature of a satellite's orbit relative to the location of ground stations and whether the controllers thought it was worthwhile to use valuable propellant to adjust the orbit. Digital imaging is the enabling technology for the Hubble space telescope, which some have claimed bears a physical resemblance to KH-11.

The same orbital digital-imaging technology in conjunction with the explosive proliferation of computer technology in home and business has allowed for the viability of the commercial earth imaging as a business, although with a much lower resolution. Recent commercial imaging satellites are, however, closing the gap with their national security counterparts. In reverse direction, the militarization of cutting-edge civilian information technology opens up the possibility for the increased distribution of imagery intelligence. Once a picture is in digital form, it can be copied and distributed as needed.

While the turnaround time of today's imagery intelligence satellites is much faster than that of film, and the distribution of imagery intelligence increased, its abilities to affect the tactical battlefield are still limited by the science of orbiting and photography. The quality of pictures from a camera operating in visible wavelengths, whether in the hands of a tourist or in space, is limited by lighting. A vacationer has the option of having a flash to illuminate the subjects of low-light holiday snaps. This is not an option available to the spy satellite. A satellite-based optical camera can only take pictures when the sun is able to provide lighting and there is no cloud cover obscuring the area or target of interest. Thermal-imaging cameras allow for low-light and no-light imaging capability but still cannot penetrate some cloud cover. Synthetic aperture radar (SAR), the use of a moving radar and computer processing, allows radar to produce images of relatively high resolution and is not affected by cloud cover or lighting conditions. Canada's RadarSat I and II are prominent examples of SAR-based satellite surveillance imaging.

Ultimately, the number of operational imaging reconnaissance satellites in current use has resulted in their employment as strategic assets, instead of assets for direct targeting purposes. With the increased life span of imaging satellites for strategic purposes, not many are needed. KH-11 satellites and their near-term successors have life spans measured in years; they cost billions, and there are only a few operating in orbit. The orbits of these satellites are relatively low and therefore have a field of view that covers only a small portion of the earth's surface. If they were higher up so that the field of view covers a hemisphere, then the resolution would be so poor as to not be able to see anything of strategic significance. This, of course, can be addressed by more powerful, larger optics, but space launch capability and costs remain a severe constraint on how big a reconnaissance satellite can be lofted. Moreover, the small number of satellites means that tasking these reconnaissance assets is controlled at the highest levels. Although a component of the information revolution is to give access to lower and lower levels of an organization's hierarchy (flattening it in the process), the operational model in use today for spy satellites simply cannot fulfill this empowerment role. These imaging reconnaissance satellites are of course meant to collect strategic-level intelligence—to study ships under construction in shipyards, to catch a glimpse of a new aircraft caught out in the open, to provide before-and-after images related to deployments and movement, or, in an almost tactical, use to count parked tanks in a marshaling area.

For tactical optical intelligence, the atmospheric unmanned aerial vehicle (UAV) has seen much greater proliferation than satellites. Larger atmospheric systems are relatively cheap enough to be somewhat plentiful, which results in control being released to lower levels of the chain of command. General Atomic's Predator-B UAV, for example, embodies the whole sensor to shoot cycle by carrying its own weapons to engage directly any targets it may find as determined by its controller. Small man-portable UAVs allow infantry patrols to carry their own organic aerial surveillance, relaying imagery back to small portable computer devices. This class of micro-UAVs is cheap enough that it may be procured in such quantities to give everyone who needs one their own aerial spy. In this respect, the potential for widespread space-age satellite-derived tactical image intelligence is upstaged by information-age computer technology and robotics. Of course, UAVs are also vulnerable to a range of air defense capabilities.

Despite the proliferation of UAVs, today's reconnaissance satellites do possess operational value, and the strategic, operational, and tactical realms are converging. Not all tactical targets are small and hard to see from orbit. If a target can get the attention of a satellite in orbit, then the satellite may be used for tactical applications. The Soviet Union during the cold war launched several nuclear-powered radar satellites, RORSAT, for tracking shipping and warships, which were used, for example, to find U.S. aircraft carriers, among other purposes. In the event of war, located carriers could be attacked by long-range cruise missiles launched by aircraft, surface ships, and submarines. The Soviet (now Russian) Project 949 submarine, or "Oscar Class" in NATO coding, is noted as having satellite detection as one means to give initial targeting for its powerful antiship cruise missiles.[7] Space, through the RORSAT, was to be used by the Soviet Union as part of its sea denial strategy to counter U.S. sea power.

Early warning satellites, which are a form of reconnaissance satellite, are designed to stare at the earth for the easy-to-see signatures of a rocket in powered flight. The U.S. DSP satellites arranged in a constellation in high geosynchronous orbits provide continuous coverage of a wide band of the earth's surface. Even at these high attitudes, the bright heat signature of a long-range missile with its engines still burning is detectable. DSP was originally a strategic asset to provide early warning of Soviet ICBM attack. Since its employment in the Gulf War, it has also acquired an operational, theater role and, through the evolution of its role to cue missile defense systems, a tactical role as well.

DSP is able to detect the hot engine plume of a ballistic missile from geosynchronous orbit, allowing for a small number of satellites to provide near global coverage. It is also rumored that DSP, and its replacement, the space-based infrared-high satellites, are also able to detect hot engine plumes of a lower intensity than ballistic missiles, such as aircraft, if calibrated to do so. Regardless, less-intense target signatures require the use of more-powerful sensing technology or lower orbits. Lower orbits require more satellites to provide the same coverage. Small satellite technology is being touted as being a possible platform for providing space-based tactical surveillance.

One of the most successful tactical space force enhancement applications has been the U.S. GPS. As an omnipresent global system, the space-borne architecture for GPS is based around a relatively large constellation of 24 active NAVSTAR satellites in medium earth orbit (MEO). The GPS system, created and maintained at great cost to the United States, provides accurate navigational, positional, and timing data to anyone with a GPS receiver at no cost. Today, GPS is critical to the shipping and transport industry. Combined with digital mapping technology, GPS gives waypoint-by-waypoint directions to delivery services, taxis, emergency services, and ordinary drivers. The GPS timing signal is also used to synchronize financial transactions down to the level of the corner bank automated teller machine (ATM). The low cost of GPS receivers has also meant that new civil applications are being found on a continuous basis. For the military, the originators and custodians of the GPS system, it has become a means to victory.

GPS is based on three components: a space segment, a control segment, and a user segment. The complete space segment is the constellation of 24 NAVSTAR satellites arranged into six orbital planes in circular MEO. GPS satellites in addition to their navigation and timing payload also carry detection equipment meant to catch sight of and pinpoint above-ground nuclear explosions. The control segment for GPS, run by the U.S. military, is made up of ground stations that monitor and update GPS satellites to ensure the accuracy of timing and positioning data. Finally, the user segment is anyone or anything with a GPS receiver, ranging from a ship at sea, an aircraft, or an orbiting spacecraft to a GPS-equipped cellular phone. Each satellite continuously broadcasts position and timing information in two forms or codes—a standard positioning service (SPS) level for civilian use and the classified precise positioning service (PPS), or P-code, primarily for military use. Line-of-sight to four satellites is needed to calculate position in the three physical dimensions along with time being the fourth. The more satellites visible to a receiver, the greater is the accuracy. GPS signals, however, can be selectively degraded, which limits access in specific regions. While the United States has incentives to degrade the civilian signal in areas of military operations where adversaries might employ GPS for their military operations, the Clinton administration pledged no to do so, regardless of the situation, in part because too much economic activity depends on the availability of this service.

The accurate positional and timing information supplied by GPS is an enabler for forces on the battlefield. GPS allows unprecedented levels of coordination on the battlefield in the maneuvering of forces right down to the lowest level. Friendly, or blue force tracking (BFT) and similar systems automatically collect and report the position of the vehicle or even the soldier to which it is attached. From a composite of the positional data, a commander can have an accurate picture of friendly (equipped) forces and how they relate to each other on the battlefield. The confidence GPS gives on the location of one's own forces reduces the fog and friction inherent in the operational art of wielding a fighting force.

The basic concept of blanketing the earth in navigational information has also simplified many of the problems of autonomous flight and allowed for explosive growth in the number of PGMs. Autonomous flight, that is flight without direct human input, is a capability possessed by many UAVs, particularly in longer-range platforms. Instead of some horribly complex and expensive navigation system, a low-cost GPS receiver simply tells the robotic air vehicle where it is in time and three-dimensional space. With such data, the UAV's onboard computer logic can easily make decisions on what it has to do to get to a specific place on time. These advanced UAVs only have to be supplied with coordinates and instructions for what to do when they are achieved and the UAV can carry out its entire mission without human intervention. On August 24, 2001, a U.S. Global Hawk bearing the name *Southern Cross II*[8] landed in Australia, successfully completing a milestone autonomous flight from Edwards Air Force Base.[9]

An aerial guided weapon is essentially a UAV with a warhead. GPS guidance in cruise missiles is a lower-cost alternative to terrain matching systems, and inertial navigation systems (INS), which lose accuracy over time. The joint direct attack munition (JDAM) uses a combination of GPS and INS to achieve all-weather precision guidance. Low-cost JDAM tail kits can be attached to existing stocks of iron bombs, allowing for conversion into smart bombs. The JDAM system's circular error probability (CEP) or accuracy is given as being 5 meters when GPS is available.[10] This means that at least half the JDAMs will fall within a 5 meter radius (10 m diameter) circle around the aim point, as long as GPS is working. Without GPS, the JDAM can still function with some accuracy as INS guidance can function without external updates from GPS. However, the accuracy of INS is dependent on the quality of the position information from the point the bomb was dropped, and the time it takes the JDAM to reach its target, as INS looses accuracy with time from its last external fix. The CEP without GPS for JDAM is 30 meters with a maximum flight time of 100 seconds from release after its last external location fix.[11] The CEP difference between GPS and INS is significant, especially in relation to the amount of explosive charge needed to destroy a target and extent of collateral damage.

The political push to reduce collateral damage demands that smaller amounts of explosive are used, which in turn increases the need for accurate and precise weapons delivery. The U.S. Small Diameter Bomb (SDB) program aims to produce a 250-pound weapon guided by a combination of GPS, INS, data link, and eventually laser designator terminal guidance. This is half the weight of the smallest JDAM—the 500-pound GBU-38/B. The small size of the SDB family of weapons allows for more bombs to be carried per sortie or platform. However, less-explosive power means a smaller margin of error to achieve equivalent effects of bigger bombs. Only GPS can provide all-weather guidance with the precision needed for SDB and similar weapons to be effective.

The war against the Taliban in Afghanistan led to a somewhat curious assignment of strategic bombers, like the U.S. B-52, in a tactical close air support (CAS) role. As background, in the U.S. Air Force there has historically been internal rivalries and outright conflict between the various mission communities. Strategic bomber advocates vied with the tactical air communities for funding and influence. Within this environment, the CAS mission had to fight for survival among the fast-jet advocates and the strategic air power types. With the technology available in 2001, JDAMs and portable GPS target designators, combined with the unique situation of the Taliban having practically no air defenses, allowed all elements of offensive airpower to participate in the critical precision support of U.S. and allied forces on the ground. Strategic heavy bombers flew high overhead waiting for the call from the ground to drop GPS JDAMs on targets specified by forces on the ground. Instead of carpet-bombing an area, these precision strikes were called in by forces directly in contact with the enemy. The large bomb loads of aircraft such as cold war–built B-52s allowed these aircraft to circle overhead for hours providing CAS. Space force enhancement gave a new and important purpose for legacy systems in the respect.

Competing GPS constellations are also emerging. Despite the United States providing the world access to its own GPS as a global public good, and having committed to allowing generally reliable civilian access, the nature of the international system means that those able to set up their own GPS equivalent have a tendency to do so. The Russian GLONASS GPS program was inherited from the Soviet Union. The GLONASS constellation has been largely reconstituted after over a decade of neglect due to the lack of funding for replacement satellites. It should shortly, if not already, be able to provide full coverage. That being said, the U.S. NAVSTAR GPS constellation was incomplete during 1991's Desert Storm but is still recognized as one of the contributing factors to the U.S.-led coalition's overwhelming victory over Saddam Hussein. The European Union's soon to be launched Galileo system is another source of irritation and outright alarm for the U.S. defense establishment since it offers NAVSTAR GPS-like capability outside of their control. Chinese investment in Galileo only adds to fears that it will someday be used against U.S. interests. China, for the same reasons that Europe and Russia want their own independent GPS system, is also developing a regional navigation satellite system independent of its participation in Galileo. There are ongoing discussions and working groups between the United States, Russia, and the European Union to coordinate so that the systems' services do not inadvertently degrade services to users.

The Movement of Information

In military operations there are two realities with regard to information—the distribution of information to those who can make use of it and the nearly insatiable appetite for more and more information. Speed, agility, and precision in military operations are products of having not only the right information to make battlefield decisions, but also the rapid delivery of time-sensitive information to the decision makers. It is in meeting these realities that communication satellites play a vital role in U.S. space force enhancement. For mobile forces deployed in far-off battlefields, only communication satellites (ComSats) can provide the data links critical to information-age warfare.

In the bent-pipe communications model, the satellite is a relay point between two points on earth—the satellite being the elbow of the metaphorical communication pipeline. The bent-pipe model allows for communication beyond the horizon. Due to the spherical shape of the earth, the maximum distance that the bent-pipe model can span conceptually is limited to a hemisphere. Real-world considerations actually reduce the coverage to less than a hemisphere. Three satellites are needed to always maintain at least one above the horizon in a position so that a signal can be relayed off it. Operationally, the higher the ComSat's altitude, the greater the coverage it can provide. Geostationary orbits (GEO) give a ComSat both the necessary altitude and the added characteristic of having its position relative to a point on the equator fixed. The distance between the earth and a GEO ComSat, 35,800 kilometers at its closest point, however, means that more power is required by both the ground stations to get a legible signal up to the satellite and the satellite to rebroadcast the signal down to the destination ground station.

Sacrificing the benefits of having the ComSat in a fixed position in the sky, orbits below GEO are used to reduce transmission power requirements at the cost of reducing satellite coverage. To maintain continuous coverage, a much larger satellite constellation must be employed. From the minimum of three satellites in the GEO ComSat, a LEO satellite constellation requires dozens and in some proposals hundreds of satellites. In the civilian world, the promise of true global coverage has been outweighed by lower costs of terrestrial communication technologies, resulting in the collapse of Iridium, the first LEO ComSat industry, before it even really began. The Iridium service managed to get its constellation of 66 active satellites, plus some spares, into orbit before financial difficulties curtailed the industry as a whole. The U.S. military stepped into the financial breach, and is now a major user of the Iridium service, giving fielded forces cellular-like portability for voice, messaging, and data.

In a curious twist of technology, the long-range UAVs, which have denied satellites a major place in the near-term future of tactical reconnaissance, are themselves dependent on satellites for communications. A common characteristic of the Predator, Global Hawk, and other long-range UAVs is a hump located on the top, often emulating the shape and position of the bubble canopy found on fighter aircraft. This is the aerodynamic fairing for a satellite communication antenna. While developments in robotics were increasing the potential for autonomy, the information revolution was binding things closer together into real-time networks. Unlike pre–digital age spy planes, UAVs are capable of supplying data through satellite links to end users in near real time. Just as in the civilian world, the clients of aerial intelligence gathering have become accustomed to faster and faster service and simply cannot wait for film to be developed and copies made.

The more information a UAV is capable of gathering, the more bandwidth is needed, and hence a relatively large antenna is fitted, necessitating the prominent cockpit-like hump. As the data link between the UAV and its controllers goes two ways, these aerial spies can be rapidly retasked, giving these platforms unprecedented flexibility. Conceptually, the UAV's data link can be routed to fielded units, or to a National Command Authority, making it part of the network of systems that allows a nation to project information superiority. Without satellite communications, today's attention grabbing UAVs would be limited as an information-age platform.

Modern society is in large part defined by connectivity—the degree to which information technology (IT) binds and relates everything and everyone together. Since the 1990s, the Internet has continually connected more and more people together—a fact that has had significant societal impact. Information is power, and individuals having greater access to information means that individuals have the potential to be more powerful. In the other direction, IT allows large organizations to act with precision on the small scale. As Thomas L. Friedman puts it, "the small shall act big . . ."[12] and "the big shall act small,"[13] rules that are also applicable to the defense world. Long-range UAVs such as Predator or Global Hawk are examples of this information-age phenomenon. The imagery supplied by a Predator UAV can be simultaneously displayed to a commander or even an individual soldier in the middle of the battlefield and the commander in chief back home. It goes beyond simply sharing reconnaissance data, as IT tools allow and encourage collaboration. UAV imagery can be combined with other data to provide context to what is being viewed. The tools needed to tag collected information with user-specific notes and to share such analysis are available along the entire length of the command chain. Indeed, it can be used as a feedback mechanism via satellite links to allow those on the front to relay back information to those leading from the rear.

The corporate world has seen the benefits of global-scale collaboration on productivity, agility, and speed. Instead of working independently, business units are expected to connect together. Instead of individual computers working in solitude, they now work in networks. However, the business world rarely ventures away from the infrastructure of the globalized world. Influential former Pentagon official Thomas P. M. Barnett has suggested that the degree to which a country is connected has a large part in defining its place in the modern world, where it stands with respect to the functioning core of nations that participate in globalization and the gap of nations and failed states that have reduced contact with the globalized economy and hence are largely untouched by its benefits. Among the characteristics of the functioning core is the presence of IT infrastructure. Those that must operate in the gap, however, do not have the luxury of having a local Internet service or telecommunications provider to schedule an appointment for the installation and maintenance of service. Satellite services are the mechanism to fill the gap.

For the most part, contemporary U.S. military communication satellite programs are based around geostationary satellites. These are the satellites of the fleet satellite communications system (FLTSATCOM), Defense Satellite Communications System (DSCS), and MILSTAR systems. As in all contemporary ComSats, the primary mission systems of the military ComSats are made up of collections of transponders, the equipment necessary for the satellite to act as an active relay station based at the extreme distance of a geostationary orbit. In addition to bridging the distance of approximately 36,000 kilometers with multiple ground stations simultaneously, military ComSats include provisions for secure communications, which are certain to include encryption and counter jamming capabilities. That being said, the similarities between military and civilian telecommunications have allowed for some off-the-shelf solutions. The much delayed MILSTAR 3, formerly the Advance Extremely High Frequency (AEHF), communication satellite program is based on Lockheed Martin's A2100 satellite bus,[14] which is also in use for several commercial satellites already in orbit. Superficially, all these satellites would bear some physical resemblance; the difference would be found the payload of black boxes that each carries.

Dedicated military satellite communication systems (MILSATCOM) have become victims of their own success relative to the increasing volume of, and demand for, information. Today, reliable and plentiful satellite bandwidth essential to the movement of this information has become an increasing area of concern. Though there is work being done to increase the efficiency of data transmission through data-compression techniques, only more ComSats can ultimately solve current and future requirements. In the meantime, bandwidth (access to satellites in effect) is being purchased from commercial telecommunication companies, such as the restructured Iridium based on the large LEO ComSat constellation concept, and from operators of large traditional GEO ComSats. Of course, the level of security available on commercial ComSats is much less than for MILSATCOM, and military access to commercial capacity competes with nonmilitary users. The expenses of space have meant that ComSats launched for profit are minimally shielded and therefore may be a weak link of space force enhancement.

One consequence of information-age warfare via the rapid movement of information through satellite communications across great distances is the possibility that senior decision makers far away from the battlefield will attempt to micromanage the battle. The challenge is to combine increased connectivity, which technology proponents argue flattens hierarchies, with one of the most hierarchical forms of human interaction—the military chain of command.

As the military adopts information technology, its own lexicon has developed. One of the phrases coined to describe certain transformational concepts partially enabled by space is *network-centric warfare*—a deemphasis on individual platforms in favor of many platforms bound together to work in unison via IT. Just as the business world has seen distances and timescales effectively compress due to the influence of IT, so too has the military world. The reality of warfare today is that observation, decision to engage, and actually conducting the attack on a target does not have to occur on the same platform. Indeed, via communication satellites, these three functions do not have to occur on the same continent. The battlefield of today extends into both cyberspace, with cyberwarfare being a major concern, and into outer space with these critical space lines of communication. Network-centric warfare is more than just enhancing existing weapons, but instead becomes a new methodology for the conduct of military affairs. Among the changes is the creation in a sense of the infinite battlefield, where the battle may be carried out everywhere and anywhere. Compounding the new realties of warfare is the impact of IT on nonmilitary combatants. Mass violence on short notice with little investment is now within the grasp of many actors on the international stage.

Military Space and Three-Block War

It is somewhat misleading to suggest that the military use of space in its force enhancement role is simply the product of technology. Thinking and investments have also been informed by military requirements. As noted in the Introduction, space force enhancement in its initial days was informed by cold war military requirements centered upon the possibility of a major war in Europe, in which the Soviet conventional military superiority forced NATO and the United States to rely on the deterrent threat to use nuclear weapons. The force multiplier effect of marrying the emerging information technologies with space in the 1980s not only offered somewhat of an alternative to nuclear weapons, but also placed space force enhancement within the paradigm of interstate warfare. In so doing, it raised concerns that transforming U.S. military forces to prosecute information warfare was out of touch with the reality of the different form of war or violence in the post–cold war/911 era—the global war on terror and counterinsurgency operations a la Iraq and Afghanistan. Indeed, the chorus of criticisms of the handling of the Iraq War and insurgency by the former secretary of defense Donald Rumsfeld is partially rooted in a failed attempt to apply the information-warfare interstate paradigm to a different form of conflict.

Of course, the information revolution does not just apply to how nations conduct war, but also to how others may use violence to achieve political ends. Unconventional threats such as terrorism and criminal activity have seized greater power through the subversion of information-age technology and other implements of globalization. The terrorist attacks of September 11, 2001, demonstrated how the implements of the modern world can be used by a small group of fanatics to strike not just at the United States, but at the international system as a whole. In light of contemporary terrorism and other substate threats, military transformation and space militarization have had to adapt to remain relevant. The United States and its allies today find themselves embroiled in a global war on terror, which has seen the application of space force enhancement systems against unplanned enemies.

This environment has operational consequences for legitimate militaries designed to fight each other instead of these subnational groups. Terrorists do not generally field armies in the traditional sense, nor sail fleets of warships, nor procure squadrons of aircrafts. Essentially, they do not present targets that were in the sales brochures for military space applications in the 1990s. For U.S. and allied forces on the ground, this presents a complex situation where the level of danger can change in moments. To a large extent, this transformation of war has resulted in threats being found and fought at close quarters. This theater of operation has been described as a *three-block war* where full-scale combat, peacekeeping operations, and humanitarian aid exist simultaneously with only a city block separating each mission. Door-to-door hunts for insurgents and terrorists do not necessarily bring to mind orbiting satellites, yet these systems are part of the joint battle space that also describes today's three-block war.

The proliferation of space systems down to the level of the individual soldier has meant that space is part of the arsenal that the U.S. fields in the global war on terror. Special forces, the tip of the U.S. and allied response to the 9/11 terrorist attacks, entered hostile ground with space systems in tow. As mentioned earlier, the United States had taken steps to prevent satellite imagery from being made available to al-Qaeda and the Taliban during the early war in Afghanistan. Satellite imagery was used for both battlefield intelligence and public relations. Satellite phones allowed easy distribution of intelligence and overall two-way data flow to operators in the field. GPS helped not only with navigation and coordination of allied forces, but also with direct attack. U.S. Special Forces operators embedded with allied Afghan forces could call in satellite-guided bombs. In this respect, space militarization literally rode into war on horseback in Afghanistan.[15] Space systems demonstrated their adaptability and allowed the United States to project information superiority into a land where modern amenities were denied.

The global war on terror is a war of ideas and a war for the hearts and minds of the people in fragile and failed states. Minimizing collateral damage is important in winning such wars. Causing unnecessary harm damages the message that the United States and the international community are a force for good, stability, development, and freedom. Moreover, this is an asymmetric battlefield. The importance of minimizing casualties for the West in these conflicts generally does not apply to the adversaries—terrorists and insurgents. Indeed, maximizing civilian casualties is a tool of terrorists and insurgents to demonstrate the limitations of a government's, or international community's, ability to protect its citizens. Only careful attention to detail and precision can prevent the actions of Western forces being misconstrued into something less than scrupulous. In this regard, the high-tech form of warfare chosen by the United States and its contemporaries is well suited to the global war on terror, as this form of warfare enables a degree of precision necessary to minimize collateral damage. The use of special forces, like the use of precision guided weapons, allows for the surgical application of force. Precision is not only to fulfill the West's preference for a just war but is also cornerstone to victory in what is expected to be a long-term struggle.

Part of winning hearts and minds is found in bridging the gap between the modern world and the nations that thus far have been left behind. Communications satellites allow the information age and modern ideas to be projected into denied parts of the world. The threat posed by communications technology is recognized by certain governments on less than friendly terms with the United States by banning the possession of direct broadcast satellite television receivers and attempts to disrupt these broadcasts through electronic jamming countermeasures.

Conclusion

The emergence of space systems in a force enhancement role is one of the most significant military developments of recent times. It is the backbone in many respects of the information-age warfare paradigm. In this regard, its roots are a function of the development and application of broader information technologies, especially computing, being married to satellites, rather than any major advancements in space technologies related to launch and satellites themselves. Space offers that perch, or the highest of the high ground, from which militaries, led by the United States, can effectively and efficiently exploit these information technologies. Barriers still exist to the full exploitation of space systems in support of terrestrial military operations related to the high costs of space access, on-orbit power generation, and multispectral sensors, among others. Nonetheless, the revolutionary developments of the past two decades suggest that many of these barriers will eventually be overcome.

The significance of space for terrestrial military operations has led many in the United States to describe space today as a critical and vulnerable center of gravity. Potential military adversaries will recognize its critical nature and seek to offset the advantage it provides to U.S. military forces. Adversaries will not only seek to replicate the United States by adapting to information-age warfare, but also undertake strategies and develop capabilities to deny the use of space to U.S. military forces. The measures available to do so range from counterelectronic measures to disrupt the flow of information from and through space to direct attacks on U.S. space assets, military and commercial. In effect, the significance of space force enhancement raises the specter of war being waged in space, and this specter in turns raises demand for developing capabilities to defend space and apply force in and from space.

Notes

1. Global Security, "Historical Nuclear Weapons," http://www.globalsecurity.org/wmd/systems/nuke-list.htm.

2. Ibid.

3. Statements by former Pakistani President Pervez Musharraf and former Indian President A.P.J. Abdul Kalam in 2002 note the deterrent effect of nuclear weapons in preventing open warfare from breaking out recently between India and Pakistan.

4. Fitzsimons, Bernard, ed., et al. "Hs 293, Henschel," *The Illustrated Encyclopedia of 20th Century Weapons and Warfare,* vol. 13 (New York: Columbia House, 1978), 1375–77.

5. Max Boot, *War Made New* (New York: Gotham Books, 2007), 331.

6. U.S. Space Command, *The Long Range Plan* (Colorado Springs, CO: U.S. Space Command, 1997).

7. Norman Polmar and K. J. Moore, *Cold War Submarines* (Washington, DC: Brassey's, 2004), 278.

8. The name *Southern Cross II* is an allusion to the historic 1928 U.S. to Australia flight of the original *Southern Cross*.

9. Dr. Jim Young, Air Force Flight Test Center History Office, "Milestones in Aerospace History at Edwards AFB," August 2007, http://www.af.mil/shared/media/document/AFD-080123-063.pdf.

10. United States Air Force, "Factsheet: JOINT DIRECT ATTACK MUNITION GBU-31/32/38," November 2007, http://www.af.mil/factsheets/factsheet.asp?id=108.

11. Ibid.

12. Thomas L. Friedman, *The World Is Flat: A Brief History of the Twenty-first Century* (New York: Farrar, Straus and Giroux, 2005), 345.

13. Ibid, 350.

14. Peter Bond, *Jane's Space Recognition Guide* (London: Harper Collins, 2008), 216.

15. Lt. Gen. Joseph M. Cosumano Jr., United States Army, "Space Criticality to Ongoing Military Operations," *The Army Space Journal* 1, no. 2 (Spring 2002), http://www.armyspace.army.mil/spacejournal/SJ_V1N2_02_Spring.pdf.

for civilian applications can produce respectable sized craters in metal target blocks.[17]

Space-to-Surface Force Application

The debate over space weapons often hinges as much on where the weapon attacks and where the weapon is based as much as it considers its effects. Often ground-based weapons are left out of being categorized as a space weapon despite its effects occurring in space. This has allowed some degree of ambiguity for systems such as the Chinese ASAT tested in 2008, and U.S. land- and sea-based ballistic missile interceptors. Similarly weapons that transit through space fall into the same fuzzy grey area with respect to the space weapons debate. The inclusion of such systems in a comprehensive definition of space weapon then brings us to the reality that space has been directly exploited for warfare since the first Nazi V-2 entered space on its way to London. The clear cut example of a weapon that is permanently space based, in other words a weapon in orbit, brings up many technical arguments over the utility of space weapons. An examination of space-to-surface concepts highlights many of the obstacles facing near-term space weaponization, and the possible dysfunction of some concepts for so called space weapons.

In Stanley Kubrick and Arthur C. Clarke's *2001 A Space Odyssey*, an ancestor of humanity throws a bone, freshly used as a weapon against his own kind, into the air, which is tracked by the camera until the scene jumps to the near future (for the 1960s) and an orbiting nuclear weapons platform passes by. Metaphorically this represents that human nature has not changed over the millennia between prehistory and the future. With respect to space weapons, the orbiting nuclear weapons platform represents a bit of a technological dead end. Through the lens of the early cold war, the imagery of Kubrick's masterpiece makes sense; the space race is intertwined with the nuclear arms race, with the orbiting of Sputnik only a few years earlier certainly raising the specter of orbiting communist A-bombs. However, in hindsight the science of space has rendered the concept of orbiting weapons of mass destruction (WMD) as being a somewhat implausible threat.

Due to the mechanics of deorbiting a warhead an orbital surface strike platform would be uncompetitive verses ballistic missiles with respect to propulsion requirements. To be effective, there must be enough propulsion, or Delta-V, available to rapidly put a warhead on a trajectory that intersects the earth. A warhead that takes multiple orbits from launch to impact would take hours to conduct an attack exposing it to counterattack. In addition propulsion technology affects the number of platforms needed. Unless the surface strike platform is in GEO, it will only be in position to carry out an attack for a fraction of its orbit. GEO is a high orbit, which would compound the deorbiting problem. To increase the range at which an individual orbiting surface strike platform would be effective, more powerful propulsion must be attached to the warheads. This propulsion must, however, be put into orbit with the warheads, therefore increasing launch cost further. The economics of the Brilliant Pebbles constellation made of several thousand satellites was based on low cost satellite manufacture and expected low cost industrial small satellite launch. Nuclear weapons for many reasons are not low cost items, nor are they particularly light weight. Dispersing orbiting nuclear weapons into smaller and more numerous satellites worsens the problems associated with command and control. Nuclear weapons are not something that you want to lose control over. Placing nuclear weapons onto manned platforms only magnifies the already great financial burden of what is, arguably, already a questionable deterrent.

Compounding the ease at which a low orbiting satellite may be found (and attacked) it can be expected that an adversary would pay extreme attention to finding and monitoring orbiting nuclear weapons platforms. The existence of orbiting nuclear weapon strike platforms would be incentive for the deployment of ASAT systems. In a nuclear warfare mindset, ASATs would perhaps be less about securing space for ones own use, but instead neutralizing the others nuclear strike capabilities, with the consequence of perhaps a more relaxed attitude toward the use of messy kinetic energy and even nuclear ASATs. Warhead vulnerability also decreases a system's deterrent value. A vulnerable system under some nuclear strategies leads to a lower threshold for weapons use, the use-it-or-loose-it effect, which is considered destabilizing.

In comparison the terrestrial triad of nuclear weapons delivery systems, land- and sea-based missiles along with air delivered bombs and cruise missiles, offers greater survivability and flexibility for less cost. A long-range ICBM only needs enough thrust to throw its deadly payload to the desired range. The propulsion requirements of ballistic flight, even for global ranges, is significantly less than that needed to put the warheads into orbit along with the propulsion needed for rapid deorbit. The ballistic flight path of an ICBM only takes minutes to complete. On earth, missiles can be protected by building massive bunkers capable of surviving nearby nuclear detonations, or by placement on smaller mobile launch systems. Today missiles can be dispersed on railroad cars, on all-terrain trucks, and on near undetectable ballistic missile carrying submarines. Indeed the submarine launched ballistic missile is the only nuclear strike system maintained by the United Kingdom, which dispensed with bomber and ground-based ballistic missiles decades ago. Manned nuclear armed bombers provide flexibility over how an attack is conducted, including the possibility of recall. Bombers have kept up with interception technology with electronic warfare, stealth and standoff cruise missiles.

All of the nuclear delivery methods employed by the United States and the Soviet Union (now Russia) overlap to ensure survivability against a first strike. The nuclear triad is not a quartet because of the great cost involved with turning the orbit-to-surface concept into a credible deterrent. This of course did not stop development work from being conducted on orbiting WMD platforms; however, none have made it off the drawing board. Orbiting weapons of mass destruction are prohibited by the 1967 Outer Space Treaty, however, it would seem that by banning WMDs in orbit, not much utility was lost. Indeed it would appear that the banning of WMDs in orbit had more utility in the overall cold war struggle for public relations than it would have had it actually pursued been as a military capability.

The counterpoint to this is the Soviet deployment of WMD platforms based on the fractional bombardment (FOB) system. FOB lofted a nuclear warhead bearing missile bus into a very low orbit with the intention of warhead reentry prior to the completion of one orbit. The orbital trajectory is needed to carry the warhead halfway around the world, and if it were not for the intervention of missile bus' onboard propulsion and the air resistance present at such low orbit the FOB system would orbit the earth, in clear contravention of the 1967 OST. That being said FOB was classified by Soviet sources as an ICBM and therefore by their interpretation of the FOB system it was exempt from the 1967 OST. FOB had many of the characteristics of a long-range ICBM, not surprising as the deployed FOB was based on an ICBM. A small number of R-36-O FOB missiles were deployed briefly from 1969 to 1983.[18] The R-36-O was a variant of the R-36 heavy ICBM, which had a significantly larger payload or 'throw weight' than comparable U.S. ICBMs.

Compared to its ICBM brethren, the R-36-O only carried one warhead, compared to the many carried by the R-36 in the ICBM role. This highlights that orbiting requires more propulsion, and the need for payload to be devoted to deorbit propulsion. However, this one warhead could be launched in any direction to reach its target. The ability to deorbit at will also meant that the true target of FOB could be obscured, unlike an ICBM where the target could be reasonably estimated from its ballistic course. Moreover the FOB concept flew barely into space; minimizing the time the missile bus would be visible to ground-based sensors, and producing attack times comparable to an ICBM. Orbiting by definition gives FOB global attack range, but unlike a fully orbiting WMD platform, FOB had all the survivability benefits of a terrestrial system. In an odd way, Soviet paranoia over the U.S. space shuttle could be seen as a reflection of their own FOB deployment. With not much imagination the space shuttle program could have been viewed by the Soviets as a natural U.S. response to the R-36-O, a reusable fractional orbit bomber with a potentially larger throw weight.[19]

FOB demonstrated that while there are serious obstacles and costs associated with orbit to surface strike, these problems do not necessarily affect the whole concept of using space to apply force on the surface of the earth. While many of the problems with orbiting nuclear weapons apply to orbiting conventional surface strike weapons, many of the opportunities that FOB opened for nuclear attack, can also be applied to conventional strikes against targets on the earth. Given relatively minor advances in launch vehicle technology, the FOB concept could make use of any of the terrestrial basing methods already in use by nuclear weapons and take advantage of the benefits each has to offer avoiding the vulnerabilities of orbital basing. Suborbital bombardment beyond the already proven ballistic missile is still a strong contender for the global strike mission.

Today in the United States there is interest in developing a prompt global strike capability. The United States already has global reach via its aircraft carriers, and long-range air refueled bombers. However, these strike systems take time to get into position, and they require the consent for over flight by any country that sits between the United States and the target. Passing through space or at extremely high altitudes would allow an aerospace craft to reach easily the hypersonic speeds already used by ICBMs and launch vehicles. Long duration hypersonic cruise allows an aerospace craft to reach any point on earth from the continental United States. Flight though space, or at altitudes where sovereign airspace is debatable, avoids the need to obtain over flight permission from countries that stand in between the United States and the target. The process for obtaining permission to fly through airspace, even that of an allied nation can be as long as the actual mission itself. Moreover, allies can, and do, deny use of airspace. Candidate systems for the prompt global strike mission include land- and sea-based ballistic missiles converted to a conventional strike role, manned hypersonic bombers, sub orbital systems and even orbital systems.

ICBMs and SLBMs offer a proven solution, and are often just existing U.S. Air Force Minuteman or U.S. Navy Trident missiles with their nuclear payloads replaced by some kind of precision guided weapon. A criticism of this approach is that by using an existing nuclear warfare system, the use of a conventionally armed Minuteman or Trident missile could be misinterpreted as a U.S. nuclear attack by a third-party nuclear power otherwise not involved in the conflict, provoking a retaliatory nuclear strike against the United States. That being said, retasking existing Minuteman and Trident missiles for conventional strike, even with the cost of developing a precision reentry vehicle is currently the lowest cost option available.

The prompt global strike concept was developed in a U.S. defense establishment committed to precision attack. The common aero vehicle (CAV), or X-41 under the U.S. X-series of research aerospace craft, is part of DARPA's FALCON program. The CAV takes advantage of the atmosphere for maneuver, using aerodynamic control to make rapid and significant course changes, something impossible for an orbiting spacecraft to achieve with near term propulsion technology. Of course, the CAV is not traveling at orbital speeds, though this fact in itself only highlights that orbiting can hinder the application of space technology to surface attack. The U.S. space shuttle has already demonstrated a large cross range as it glides back to earth at hypersonic speeds. Some nuclear warhead reentry vehicles also have a bit of glide capability, but not to the degree of either the space shuttle or the proposed CAV. Once the CAV has neared its target, it is meant to release a variety of conventional guided munitions or surveillance equipment. The CAV is essentially a precision hypersonic munitions dispenser. To facilitate this role, it is hoped that the price of fielding a CAV would be comparable to that of a cruise missile.[20]

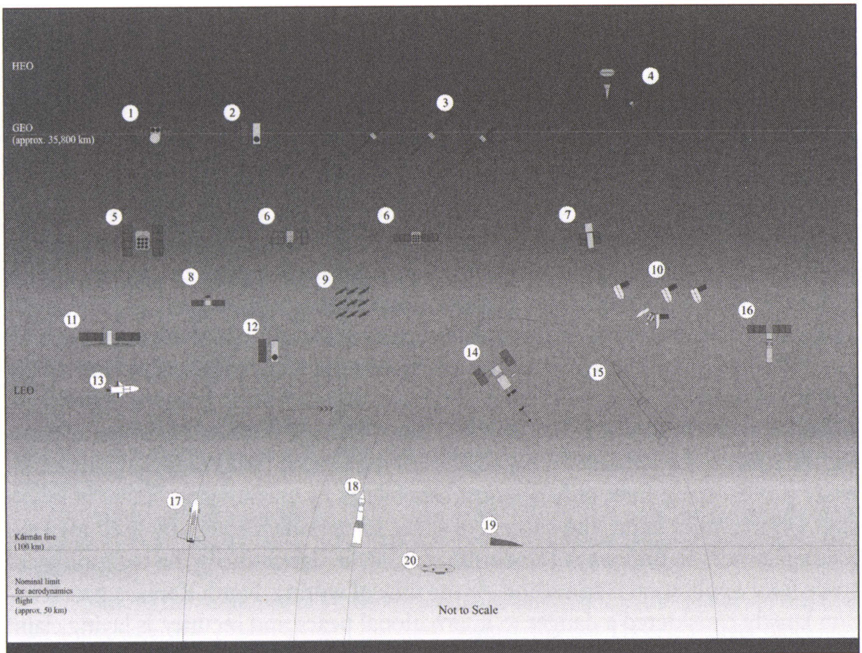
Aside from rocket powered launch vehicles and a weaponized X-37 space plane (which itself is launched by rocket power), hypersonic aircraft using the air-breathing scramjet are also suggested for boosting CAV-type munitions carriers to suborbital speeds. At the time of writing scramjets are still in the research stage, though at the very least they have been proven to function in real life under the X-43A program and the HyShot program conducted by the University of Queensland, Australia, in partnership with several international partners. Under the FALCON program is the Hypersonic Cruise Vehicle (HCV), a program to build an aircraft capable of hypersonic speeds approaching orbital velocities.[21] In contrast to the X-43A and

HyShot, the HCV will be takeoff and land from a runway, instead of being boosted by a rocket (the X-43A and its booster rocket are also air-launched from a B-52 bomber). Scramjets require boosting to high supersonic Mach numbers (approx Mach 4) to function, and part of the HCV program is the development of engine technologies that can take an aircraft from a standstill to speeds that overlap those at which a scramjet will operate. Integrating both low speed propulsion and scramjets represent a daunting challenge, and has been attempted before, notably in the defunct orbit capable X-30 program. Compared to the X-30, the goal of a global range suborbital aircraft or disposable cruise missile is much more modest.

An orbit to surface conventional strike is, however, not a completely shelved concept. There are still proponents for orbital basing. Expanding on suborbital CAV deployment, the same technology is being suggested in an orbit-based version, though in a more robust form in order to survive reentering the atmosphere at orbital speeds. The significant energy embodied by an orbit body can be converted to destructive power through the use of kinetic energy bombardment. A KE strike system can be as simple as a rod of material that can survive reentry reasonably intact (such as tungsten or depleted uranium) propelled toward the earth, with perhaps some kind of maneuvering capability to make fine adjustments to the course as it streaked through the atmosphere at nearly 25 times the speed of sound. This concept is often referred to under the 'Rods from God' nickname.

If a space transiting bomber or munitions dispenser can be developed, then the follow-on is the delivery of soldiers, the smartest of all weapons, via space. Spaceborne troop delivery is not a new concept in the United States, and has been entertained in aerospace circles for decades. Prominent among these were single stage launch vehicle concepts by engineer Philip Bono capable of hauling to anywhere on the globe hundreds of infantry plus equipment. Developed around the time of the Apollo moon landings, it only seemed natural that the next heavy lift rocket developed in the course of the space age could be used to insert a battalion to any trouble spot on earth. The space age has not developed in the manner expected in the 1960s; however, suborbital troop deployment has found new life leveraging off of the progress made toward affordable space tourism. In addition to the propulsion technologies that may allow spaceflight to fulfill the prompt global strike mission, troop insertion through space will require reliable life support. The technology needed to provide a reasonable level of safety and comfort for paying passengers will be more than sufficient for elite military forces, that routinely accept great risk.

Interest in prompt global access via space is not confined to the military. Rapid intercontinental cargo shipping via suborbital flight is today one of the usual future applications claimed by proponents of spaceflight technology development. The price and dangers of space flight remains barriers to the space delivery business plan. That being said, space tourism became a reality only a few years ago via the right combination of money and willingness to provide the service. Space borne delivery of cargo, munitions and special operations teams may very well follow in the wake of spaceflight holidays.



1. Military GEO Communication Satellite
2. GEO/HEO Early Warning Satellite Constellation
3. Contracted Commercial GEO Communication Satellite
4. Small Satellite conducting autonomous inspection of foreign satellite
5. US NavStar III GPS Constellations
6. Foreign GPS Constellations: Russian Glonass, European Galileo
7. Space Based Laser (SBL) Satellite
8. Space Based Space Surveillance
9. Small Satellite Constellation: Multi-spectral imaging, LEO Communications, ELINT
10. Orbit Based KE Missile Defense Constellation
11. Space Based Radar Ground Moving Target Surveillance and Tracking
12. LEO Early Warning Satellite Constellation
13. Autonomous Space Operations Vehicle
14. KE Strike System
15. Rouge State ICBM
16. Future Electro-optical Surveillance Satellite
17. Rapid Reaction Orbital Space Launch
18. Ground Based KE Missile Defense
19. Sub-orbital Hypersonic Strike
20. Lighter-than-Air Exploitation of Near-Space

Figure 4.2 Future Military Space

Conclusion

Cost-to-benefit is perhaps the best decider over whether specific space force application technologies are pursued into operation, and ultimately whether space militarization moves beyond the current fuzzy state of weaponization. Directly and indirectly technologies beneficial to active space force application seems to be making constant, though often inconsistent, progress. The sciences behind all the discussed space weapons concepts are sound; however, the engineering is not yet practical for many of them. Research and development costs must be weighed against a variety of factors: the threat situation, public finances, and the costs of competing space force application concepts. Promising, yet difficult technologies face competition from less capable but more within reach weapons. Not all systems are equal, and therefore some, if not most of what has been discussed may be superseded by events. However, every now and again, science fiction does become reality, and the technologies of the imagination become commonplace.

It cannot be ignored that there are political costs and benefits associates with particular technologies. How costs and benefits are weighted is a product of the politics of the time. At present there appears to be no rush to progress space force application beyond its relatively low key status. Indeed there are fears that increasing the space force application capabilities of the United States could jeopardize already proven space force enhancement capabilities by encouraging others to follow suit. On the other hand, the success of space force enhancement by itself may encourage others to find ways to neutralize it. More dangerously the technology of space force application is spreading. As the time of writing, North Korea, a pariah nation largely considered a danger to international peace and security, is laying claim to the right to have space technology along with its ambitions toward nuclear weapons. Peace it would seem is often more far off and unobtainable than some of the technologies discussed here. The technology of war in space as informed by political and strategic interests will remain a concern for some time.

Notes

1. Department of State, "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," January 27, 1967, http://www.state.gov/t/ac/trt/5181.htm.

2. Ibid.

3. Craig Covault, "Chinese Test Anti-Satellite Weapon," *Aviation Week & Space Technology,* January 17, 2007, http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/CHI01177.xml.

4. Shirley Kan, *China's Anti-Satellite Weapon Test,* Congressional Research Service Report for Congress, April 23, 2007, http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA468025&Location=U2&doc=GetTRDoc.pdf.

5. "Draft Treaty for the Prevention of Placement of Weapons in Outer Space," February 12, 2008, http://www.ln.mid.ru/brp_4.nsf/e78a48070f128a7b43256999005bcbb3/0d6e0c64d34f8cfac32573ee002d082a?OpenDocument.

6. A monopropellant is a single compound that, on command, can break down chemically releasing energy, which in turn may be used to expel the by-products of the chemical reaction generating thrust in the process.

7. A variant of the nuclear-tipped Nike Zeus was an antisatellite weapon (ASAT) program in competition with Project 437.

8. Walter L. Perry and Marc Dean Millot, *Issues from the 1997 Army After Next Winter Wargame,* http://www.rand.org/pubs/monograph_reports/MR988/.

9. Congressional Budget Office, *Alternatives for Boost-Phase Missile Defense,* July 2004, http://www.cbo.gov/doc.cfm?index=5679.

10. David S.F. Portree, "NASA, Mir Hardware Heritage," March 1995, http://ston.jsc.nasa.gov/collections/TRS/_techrep/RP1357.pdf.

11. The kinetic energy weapon portion of the now suspended XM29 individual weapon program is at its heart a Heckler and Koch G36 based selective fire rifle firing the NATO standard 5.56 mm round.

12. National Institute of Standards and Technology, "CODATA Value: Speed of Light in Vacuum," http://physics.nist.gov/cgi-bin/cuu/Value?c.

13. Raytheon, "Silent Guardian" online sales brochure, http://www.raytheon.com/capabilities/products/stellent/groups/public/documents/content/cms04_017939.pdf.

14. Ibid.

15. Carlo Kopp, "The Electromagnetic Bomb—a Weapon of Electrical Mass Destruction," *Air & Space Power Journal,* 1996, http://www.airpower.maxwell.af.mil/airchronicles/cc/apjemp.html.

16. Arms Control Association, "U.S. Test-Fires 'MIRACL' at Satellite Reigniting ASAT Weapons Debate," *Arms Control Today,* October 1997, http://www.armscontrol.org/act/1997_10/miracloct.

17. Among the memories of a different academic career, one of the authors of this book had a professor who passed around the class Engineering EM Theory, a target block from his own research work.

18. Global Security, "R-36-O / SL-X-? FOBS," http://www.globalsecurity.org/wmd/world/russia/r-36o.htm.

19. Paul A. Czysz and Claudio Bruno, *Future Spacecraft Propulsion Systems: Enabling Technologies for Space Exploration* (Berlin: Springer, 2006), 46.

20. Terry H. Phillips, *A Common Aero Vehicle (CAV) Model, Description, and Employment Guide,* January 27, 2003, http://www.dtic.mil/dticasd/sbir/sbir041/srch/af031a.doc.

21. Defense Advanced Research Projects Agency: Tactical Technology Office, "Falcon," February 18, 2008, http://www.darpa.mil/tto/programs/Falcon.htm.