GPS Vulnerabilities

Lieutenant Colonel Thomas K. Adams, US Army, Retired

For centuries explorers have navigated by fixed stars. Today our increasingly expeditionary military navigates by orbiting emitters. Satellites enable flexible communication and precise navigation that were unimaginable a generation ago. Space-based technologies reach down into everyday military business so much that interrupted service immediately and fundamentally degrades operations. Adams describes various threats to US satellites, systems that use their signals and a military that depends on falling stars.

THE US ARMED FORCES' 21st-century combat plan is based on Joint Vision 2020, an extension of Joint Vision 2010's conceptual template that is reflected in the US Army Chief of Staff's Army Transformation Program, the Marine Corps' Sea Dragon programs and various service statements, policies and other implementing plans. All of these are part of a seminal effort to leverage information-age technologies in a lethal, agile and rapidly deployable 21st-century force.[1] Equally, they all depend heavily on information technology and space-based capabilities.

Joint Vision 2010 states the need for "space and information superiority . . . to accomplish the assigned tasks."[2] The same philosophy is reflected in various posture statements and other service-peculiar policy documents. In his recent posture statement before Congress, General Henry H. Shelton, Chairman, Joint Chiefs of Staff, repeatedly referred to the importance of space-based technologies and information for the US Armed Forces.[3]

The vision statements, implementing programs and policy statements are built on two foundation blocks—information systems and space-based resources. Together they lead to the "information dominance" that is key to the entire enterprise.[4] Unfortunately, the inescapable interrelationship between the two creates serious vulnerabilities that could destroy military forces.

A Double-Edged Sword

Like most recent force-modernization efforts, most of Army After Next (AAN) and Army XXI technologies will come from commercial-sector research rather than Department of Defense (DOD)-sponsored research and development. Major General Robert Scales, a key architect of the AAN program, says about 40 percent of the dollars spent 25 years ago on telecommunications research and development came from DOD. In Fiscal Year 2000, DOD provided about 2 percent of the funds spent on developing information-age technologies.[5]

During a National Defense Industrial Association conference on the future force, Scales remarked, "Like it or not, the advantage we are going to gain in the future over a potential major competitor is going to come from the commercial sector. We ought to just step back, relax and be prepared to exploit it. In many ways, too much emphasis on military specific research . . . may very well work to our disadvantage."[6]

Dual use is not a ground-breaking innovation; it is a long-term trend. The United States has never owned a freestanding, solely military industrial base. Most military equipment is off-the-shelf commercial equipment painted olive drab. The American Expeditionary Force took commercial trucks right off the assembly line to France in 1917. The famous C-47 World War II transport aircraft was a green-painted cargo version of the Douglas DC-3 airliner. Artillery officers discovered hand-held Hewlett-Packard calculators early on, but the first small computers purchased by the US Army were ordinary Apple IIe's in a "militarized" box. The best-known example is probably the military use of thousands of off-the-shelf commercial Grid Positioning System receivers during the Gulf War.

DOD directed research and development in areas of particular defense interest until about 1965. Since then, especially after the Cold War, the trend has accelerated away from DOD-led research.[7]

Dual Use and Vulnerabilities

Before entering the 21st century dependent on space-based systems and commercially developed information-technology based systems, the US military must understand its capabilities, limitations and vulnerabilities. Dual-use and off-the-shelf technologies offer real advantages and are especially cost effective. However, they have serious disadvantages:

- Dual use means that both civilian and military users employ the same technology. Technology training, documentation and product improvements are also available to potential adversaries.
- Off-the-shelf merchandise provides civilian and military users with nearly identical systems. Systems designed to operate in a much less stringent peacetime environment could be chosen rather than those designed for combat.
- States, political movements and individuals can obtain current military technology without costly research, development, manufacture, training capacity or espionage.

Dual-use and off-the-shelf policies can give various entities much of the military capacity formerly reserved to the great powers.

A Case Study

Built at a cost of $21 billion, the Global Positioning System (GPS) consists of an orbiting constellation of small artificial satellites, called NAVSTAR, which give receivers accurate altitude and geographic positioning information. Originally, the system was to be exclusively military, but in 1980, the US government transformed it into a free, globally available system. The system is now undergoing a long-term, billion-dollar improvement and upgrade.[8]

The US Air Force invests more than $600 million annually for tracking commercial trucking, and airline and merchant marine navigation. Commercial aviation and private pilots—including drug smugglers—use the GPS Standard Positioning Service.

During the Gulf War, GPS gave a major advantage to coalition forces, allowing tanks and aircraft to navigate Iraq's unmarked deserts. GPS was an unqualified success and quickly became central to a revolution in military affairs. Most US military aircraft now use GPS, and the US Army uses almost 100,000 GPS units. Eventually, every major precision-guided munition will target using GPS navigation.[9] In addition to combat uses, the US military uses GPS for routine activities ranging from surveying and civil engineering to base infrastructure applications.

GPS, which provides accurate positioning to within 100 meters, is free to anyone with a receiver, including actual and potential US adversaries. For instance, on 1 March 2000, Iran Aircraft Manufacturing Industries announced that two new variants of its Ababil unmanned air vehicle will use on-board GPS navigation.

Dual use includes technologies that both military forces and civilians can use. This US Air Force investment (plus $600 million in annual operating expenses) is used for tracking commercial trucking and airline and merchant marine navigation. Commercial aviation and private pilots—including drug smugglers—use the GPS Standard Positioning Service. The US Federal Aviation Administration (FAA) and its Canadian counterpart are also planning to use GPS throughout the North American Air Traffic Control System using the Wide Area Augmentation System, a GPS system with 1- to 3-meter accuracy. Since the FAA also intends to broadcast GPS corrections via geostationary satellites, worldwide airlines will likely take advantage of this highly accurate system for normal en route navigation, collision avoidance

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and airport ground navigation. In fact, the FAA would like to make GPS the only navigation system for commercial air traffic.[10]

Despite this, the United States and its allies had hoped to retain access to 10-meter accuracy through selective availability encoding, also known as the Precision Positioning Service. This navigational edge was expected to help the US military conduct 21st-century warfare.[11] President William J. Clinton directed that selective availability be discontinued at midnight Eastern Daylight Time 1 May 2000, removing our navigational edge. According to a White House press release issued the same day, discontinuing use of selective availability would improve the GPS accuracy for civilian users from within 100 meters (about 300 feet) to within 20 meters (about 60 feet). In many cases, real-world users realized even better accuracy. This performance boost enabled GPS to serve various civilian activities—land, sea, air and space—where it previously could not.

This effect offers highly accurate GPS positioning to anyone who wants to use it for military purposes. For example, an ordinary executive-class jet with an automatic pilot slewed to GPS signals can become a rudimentary long-range cruise missile simply by filling the interior with explosives and an impact detonator and sending it to its target. Improved GPS would ensure that the missile would strike within 20 meters of the desired point.

In theory, GPS could still give the United States and its allies a navigational advantage by preserving an ability to "tweak," or adjust, GPS signals to focus the effect on adversaries without adversely affecting friendly forces.[12] Adjusting signals is always problematic since the "local area" is likely to be large, and any tweaking is likely to affect friendly military GPS near the target area as well as enemy ones. In any case, it would be dangerous to exercise this capability since it could also affect uninvolved civilian traffic such as ships or airlines.

The National Academy of Science and the National Academy of Public Administration are advancing the concept of internationalism, calling GPS an emerging de facto international utility. This notion only complicates the situation because the idea of serving as a utility assumes some obligation to assure service to users. Furthermore, upgraded GPS performance is expected to accelerate its worldwide business, government and individual use. Signal tweaking would likely raise protests from many civilian users.

GPS Signals Jammed During Tank Trials

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Based on 6 August 2000 reports in *The Sunday Times* of London, Agence France-Presse and the 25 September 2000 *Elevtheros Tipos*, Athens

The highly accurate Global Positioning System (GPS) supports modern ground forces as they move and shoot. Maps and compasses stay in cases as digitized forces quickly use GPS to determine their location and the enemy's. Although map-reading skills atrophy, few worry that GPS may suddenly provide erroneous information or cease working. Still, US Army equipment has already faced attacks on GPS functions—by allies.

In August 2000 the Greek government sponsored a tank competition at Litokhoro to determine the Greek army's next tank—a deal worth $1.4 billion for 250 tanks. Competitors included the British Challenger 2E, the US M1A1 Abrams, the German Leopard 2A5 and the French Leclerc. During the trials, the British and US tanks had navigation problems despite using multiple GPS satellites to determine their positions precisely. After the embarrassing performance, officials discovered that the GPS satellites were being jammed—by a French security agency. Less than a foot high, the jammers transmitted stronger signals than satellites on the same frequency. The jammers were reportedly hidden on the firing range and remotely activated as US and British tanks were tested.

Greek defense officials found the jamming episode rather amusing and discounted the associated technical problems. The threat remains: if an ally can create such havoc during a test, what effect could hostile GPS jamming have during combat?

US Army

On the "fragile battlefield" of the future, GPS-dependent operations could be adversely affected by diminutive jammers scattered by helicopters, UAVs, aircraft and easily manufactured mine-scattering devices similar to the US Army's ground-emplacement mine-scattering system (*above*). A number of inexpensive jammer/spoofers, orbiting in cheap UAVs over a "digitized" force, could randomly degrade operations.

Well-designed military receivers are, to some degree, jam resistant because jamming them would require a 100-watt jammer to disrupt it from 20 kilometers away. However, jammers are inexpensive and simple to build, and even a large, crude one can fit comfortably in a pickup truck. Expendable hockey puck-size jammers already exist and can be scattered from aircraft. . . . A jammer/spoofer that can render GPS receivers inaccurate within a 10-mile radius can be built for less than $400 from parts available at retail stores.

Interference—Intentional and Otherwise

Jamming is quite simple, both in principle and in practice. Almost anyone who is interested can do it. Jamming only becomes difficult when the user wants to limit the effect to a narrow, specific range of frequencies over a great distance. Such a power and focus is important to high-tech users who depend on their own electronic systems. A less sophisticated user who wishes only to deny an adversary's capability has no reason for concern. Careful planning could allow a low-tech adversary to conduct electronic countermeasures—such as jamming—and wreak havoc on a high-tech opponent while the low-tech force uses relatively crude electronics such as frequency-modulated radios at short ranges.

The Defense Science Board and the National Research Council confirm that GPS jamming poses a real threat.[13] David E. Lewis, Magnavox Electronic Systems Company, quoted the Defense Science Board's November 1993 Tactical Air Warfare study, "Current GPS receivers are vulnerable to jamming in acquisition mode at very long ranges from low-power jammers and will lose track at moderate range for reasonable jammer threats."[14] Lewis states that a 100-watt jammer can affect a standard military GPS receiver, such as a precision-guided munition would carry, as far away as 600 miles (or line-of-sight distance, whichever is less) during initial GPS acquisition. Even when the missile has acquired the GPS signal and is using it to track its progress to the target, such tracking could be interrupted within 28 miles of the jammer.

Commercial television, very high-frequency transmitters, aeronautical satellite communications and Mobile Satellite System terminals can also degrade GPS signals, and natural occurrences can cause interference that would pose distinct problems for users, including the military.[15] Designers were aware that GPS signal interference was possible but faced a basic problem—placing weight in orbit is costly. To reduce costs and extend operating life, GPS satellites were designed to produce weak signals; only a few milliwatts. The decision makes good engineering sense but, unfortunately, makes GPS signals easy to jam.

Former Assistant Deputy Undersecretary of Defense for Strategic Aeronautical and Theater Nuclear Systems, Dr. Stanley B. Alterman, stated that a 1-watt (cellular phone-size) jammer located 60 kilometers away (line of sight) can prevent a good commercial GPS receiver from acquiring Navigation Satellite Timing and Ranging (NAVSTAR) signals.

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Hugh Blanchard suggests that a GPS jammer/spoofer that can render GPS receivers inaccurate within a 10-mile radius can be built for less than $400 from parts available at retail stores. A number of inexpensive jammer/spoofers, orbiting in cheap unmanned aerial vehicles (UAVs) over a "digitized" force, could randomly make US self-location and force-tracking capabilities unreliable. Blanchard adds that placing such devices throughout probable target areas would enable an enemy to misguide US precision-guided weapons aimed at enemy centers of gravity. This would certainly create a ripple effect through the Army, causing confusion, fratricide, hits on unintended targets and civilian casualties.[17]

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This results in what Alterman refers to as a "fragile battlefield" where GPS-dependent operations could be easily stymied. Developing affordable antijamming concepts such as nulling antennas and cancellation electronics would counter threats. Alterman further explains that future electronic combat will also require "GPS jammer location and targeting systems, as well as our own GPS jammers (howitzer-launched or mounted on UAVs or helicopters)." He urges improvements in "GPS designs for signal acquisition, an ability for weapons systems to lock-on before launch and low-cost Inertial Navigation System integration. Auxiliary terminal sensors and even battlefield pseudolite augmentation must be strongly considered in jamming scenarios."[18]

The military cannot meet key requirements to improve resistance to intentional and unintentional interference (including a higher-power GPS signal) until currently planned Block III satellites are in orbit sometime after 2010. Unfortunately, it is much easier to increase an earth-bound jammer's output than it is to raise an orbiting transmitter's designed signal strength.

Falling Stars

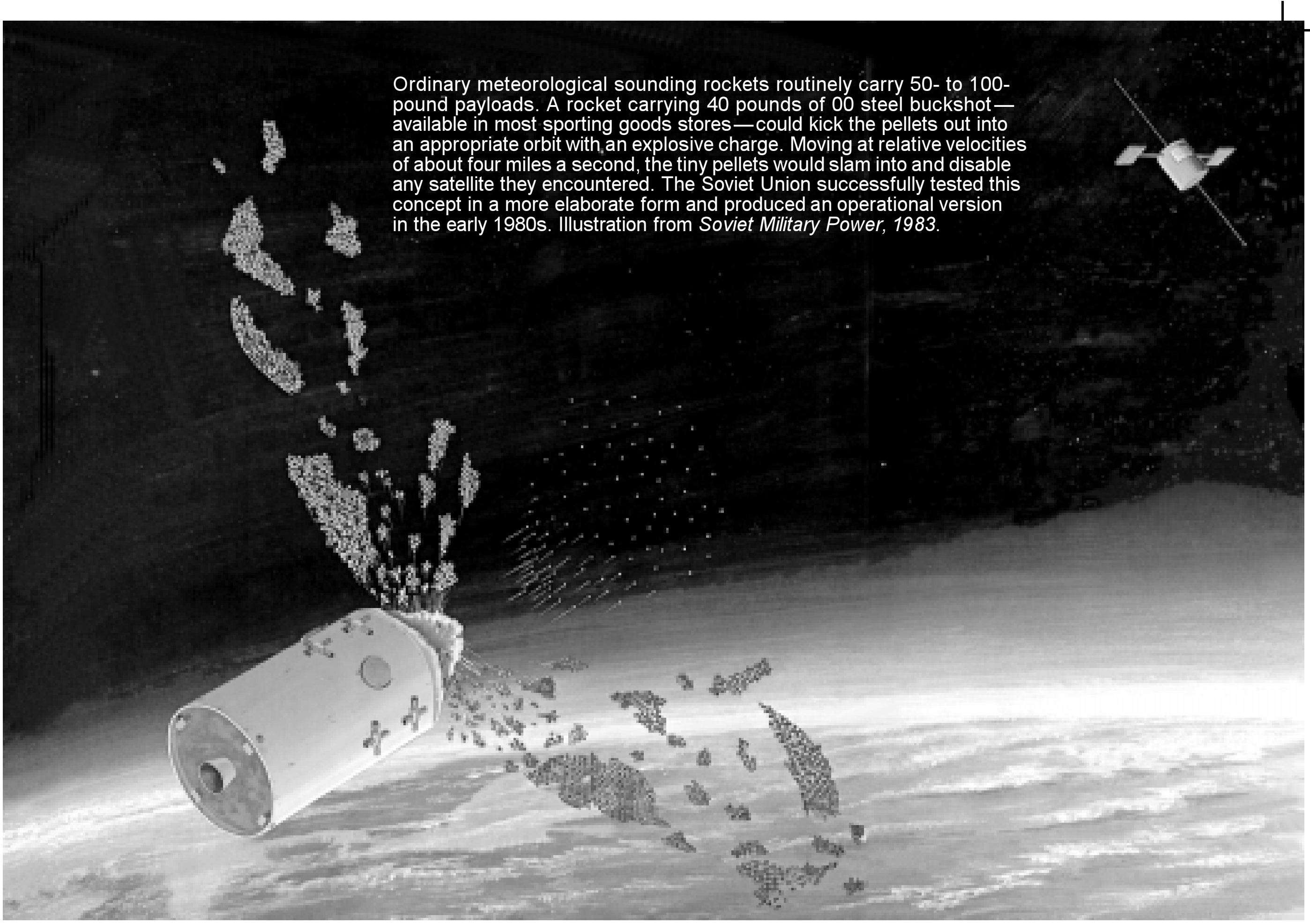
The electronic details of GPS are completely irrelevant unless the satellites remain in orbit. The National Reconnaissance Office convened a futures study panel that found "the future security of the nation depends on its ability to conduct surveillance from space."[19] That space got a little more crowded on Monday, 31 August 1998. According to the Harvard-Smithsonian Center for Astrophysics, North Korea launched a satellite that failed to enter orbit when the rocket's third stage malfunctioned. During the same month three highly sophisticated vehicles from "major powers" failed to launch.

North Korea's launcher was apparently cobbled together from a Nodong 2 missile as the first stage with an adapted Scud as the second stage. The third (orbital) stage was probably a small solid motor. This Rube Goldberg contraption narrowly missed placing North Korea among the space powers. North Korea media called the satellite "one more fruit of the independent national economy, a product of 100 percent local technology and local effort."[20] While the purity of this pedigree is doubtful, the consequences of the feat are not.

A satellite could bring North Korea much closer to sending payloads into orbit for reconnaissance, communications and navigation. These nice-to-have capabilities are not crucial to North Korea's terrestrial aspirations. Such a satellite could offer the ability to launch crude attacks on satellite systems.

Space-based systems are militarily important to the United States for all large-scale operations. The US philosophy has been to orbit a few very expensive (up to $1.2 billion each) satellites with longevity and maximum capability. US military operations depend increasingly on a few, very expensive, difficult-to-replace orbiting systems, making it unlikely that there are many "orbiting spares."

Any US adversary could place a crude antisatellite system in orbit relatively cheaply. A US reply in kind is impossible because the belligerent would not have any significant orbiting systems or related ground-based infrastructure. It is impossible to take out their "eyes in the sky" because they do not have any.



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The US Space Command currently does not have an operational antisatellite weapon. Other powers can because they are not hamstrung by international legal issues and do not need sophisticated, discriminating weapons.[21] It is not difficult to reach at least low-earth orbit with ordinary meteorological sounding rockets that carry 50- to 100-pound payloads.[22] If a rocket could carry 40 pounds of 00 steel buckshot—available in most sporting goods stores—it could kick the pellets out into an appropriate orbit with an explosive charge. Moving at relative velocities of about four miles a second, the tiny pellets would slam into and disable any satellite they encountered.[23]

If an attacker wonders where to find such satellites, help is available. Off-the-shelf telescopes, sensors and software, including computer-directed telescopes, are now so cheap and powerful that amateur skywatchers can, and do, track and photograph orbiting spacecraft, including a number of US scientific, military and intelligence-gathering vehicles.[24]

Defending the Indefensible

Can an orbiting satellite be protected? Some already are. Satellites can be hardened (armored) or enhanced to maneuver away from attacks. Unfortunately, armor adds weight and degrades satellite capability. The space shuttle has been used to launch satellites, but it is slow, public, extremely expensive and vulnerable. Some satellite parts, such as the solar panels on the GPS birds, cannot be armored. Perhaps adding more maneuvering fuel could allow detection of attacks in time to move the target. This raises the weight-versus-capability issue again and also means the satellite would be useless while it is out of its assigned orbit.

The effectiveness of these defense measures is limited; an attacker could increase his satellite lethality simply by using ball bearings instead of buckshot and attacking twice. Suppose the attacker has a little better lift capacity and is less fussy. Orbiting a thousand pounds of gravel could sweep parts of near-Earth space like a broom and provide history's most spectacular meteor shower as millions of tiny rocks,

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bits of $500-million satellites and plans for information dominance all begin the long slide to earth.[25]

Of the options being explored, the best defense method against such an attack is probably to orbit dormant spares that can be activated when needed. Of course the spares would still be expensive, complicated and relatively inexpensive to defeat.

The time needed for countries such as China, India, Japan or North Korea to acquire significant space-denial capabilities is rapidly becoming less than the time the United States needs to replace existing satellites. During the Falklands War, the Soviet Union launched 29 small satellites within 69 days. In contrast, the United States took 113 days to replace a defense weather satellite after an emergency.[26]

A practical solution can possibly be found in a proposal now under study to use small-size, optico-electronic, radar and electronic reconnaissance satellites that can be quickly manufactured and launched by light booster rockets during crises. These satellites will conduct reconnaissance with worse resolution than current methods. However, this is only a partial solution since it does not solve the problem of other satellites used for communications and navigation.[27] Whatever their ultimate form, solutions to space vulnerabilities must enable the US military's information dominance.

NOTES

1. The Joint Chiefs of Staff, *Joint Vision 2020* (Washington, DC: US Government Printing Office, June 2000), 1; and Department of the Army, "Army Releases Army Vision 2010" (Washington, DC: Office of the Chief, Public Affairs, 15 November 1996).
2. Ibid., 23; and Avery V. Allison Jr., "The State of the US Army and Space Operations," Strategy Research Project, US Army War College, Carlisle Barracks, PA, 1998.
3. GEN Henry H. Shelton, "Posture Statement of General Henry H. Shelton, USA, Chairman of the Joint Chiefs of Staff Before the 106th Congress Committee on Armed Services, United States Senate, 8 February 2000," <www.dtic.mil/jcs/core/Posture00.html>; and MAJ Henry G. Franke, "An Evolving Joint Space Campaign and the Army's Role" (Fort Leavenworth, KS: US Army Command and General Staff College, School of Advanced Military Studies, 1996), 77-78.
4. *Joint Vision 2020*, 10-11; and Defense Science Board, *Report of the Defense Science Board Task Force on Information Warfare—Defense (IW-D)* (Washington, DC: US Department of Defense, Office of the Under Secretary of Defense for Acquisition and Technology, November 1996), hereinafter referred to as *IW-D*.
5. MG Robert Scales' remarks are courtesy of the US Army War College Public Affairs Office, Carlisle Barracks, PA, June 2000.
6. Ibid.
7. Michael Hirsh, "The Great Technology Giveaway?" *Foreign Affairs* (September/October 1998), 2-9 and 3.
8. Elliott D. Kaplan, ed., *Understanding GPS: Principles and Applications* (Boston: Artech House, 1996); and Alfred Leick, *GPS Satellite Surveying*, 2d ed. (New York: John Wiley & Sons) 1995. An excellent presentation by Peter H. Dana of the Department of Geography, University of Texas at Austin, "Global Positioning System Overview," <www.colorado.edu/geography/gcraft/notes/gps/gps_f.html>.
9. Stanley B. Alterman, "GPS Dependence: A Fragile Vision for US Battlefield Dominance," *Journal of Electronic Defense* (September 1995).
10. Ibid.
11. Stephen M. Hardy, "Will the GPS Lose Its Way?" *Journal of Electronic Defense* (September 1995).
12. Alterman.
13. *IW-D*.
14. Hardy.
15. Ibid.
16. Alterman.
17. Hugh V. Blanchard, personal correspondence between the author, 2 November 1998. Blanchard is a retired US Army officer with an interagency background in electronic warfare, electronic communications and data security.
18. Alterman.
19. National Reconnaissance Office, Final Report to the Director, "Defining the Future of the NRO for the 21st Century," Executive Summary (Washington, DC: National Reconnaissance Office, 26 August 1996), 1; and US Army Training and Doctrine Command (TRADOC) Pamphlet 525-60, *Operational Concept for Space Support to Land Force Operations* (Fort Monroe, VA: Headquarters, TRADOC, 1 November 1994).
20. Comments from US sources imply that a third-stage burn was observed, but nothing was spotted on radar, suggesting that the satellite fell into the Pacific Ocean instead of reaching orbit; Personal correspondence from Dr. Jonathan MacDowell, Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts, 4 September 1998.
21. US Space Command, "U.S. Space Command" Brochure (Peterson Air Force Base, CO: US Space Command, 1997), 11. The US Army Space Command controls Army ballistic missile defense (BMD)/anti-satellite (ASAT) capability but lacks operational systems. President William J. Clinton vetoed an Army program to provide an emergency ASAT capacity with a kinetic energy anti-satellite (KE-ASAT) that Boeing Space Systems was developing. See Bill Gertz, "Yeltsin Letter Reveals Antisatellite Weapons," *The Washington Times* (7 November 1997). The nearest term US ASAT system is the existing mid-infrared advanced chemical laser (MIRACL) located at White Sands Missile Range, New Mexico. Originally a Strategic Defense Institute project, the laser is being adapted to use against satellites. The former Soviet Union is also believed to have constructed, tested and flown some ASAT devices in the late 1960s. China does not have a publicly identified, dedicated ASAT effort. Existing Chinese launch capabilities could provide the basis for rapidly developing such a system. See Federation of American Scientists, "Space Defense," <www.fas.org/spp/military/program/asat/overview.htm>.
22. Harry G. Stien, *Confrontation in Space* (Englewood Cliffs, NJ: Prentice-Hall, 1981), 82.
23. The Korea Aerospace Research Institute (KARI) has a sounding rocket that reaches low-Earth orbit using the two-stage solid-fuel Keyboard Send/Receive-II sounding rocket. The Anhueng launch site in Ch'ungch'ong Namdo province has publicly announced four launches.
24. Leonard David, "New Software Enables Amateurs to Track Satellites," *Space News* (August 1996), 8. A crude tracking program for nonmilitary satellites is available at <www.liftoff.msfc.nasa.gov/RealTime/JTrack/>. NASA tracks objects in near-Earth space that are larger than a few inches and has proposed a system to track one-half inch objects at 18,000 to 23,000 miles.
25. Sounding rockets do not go into low-Earth orbit; they go to the same altitudes as low-Earth orbits. Altitudes are quite different. Most sounding rockets, such as South Korea's, cannot put anything into orbit, but they can put something at zero velocity at low orbital altitudes such as an explosive fragmentation device, which still has anti-satellite potential. Gravel and ball bearings put into orbit are much more dangerous because they stay there a few days and scrub the entire low-Earth orbit. Using sounding rockets puts the material there for 10 minutes or so and wipes out one specific satellite rather than everything in that orbit. Using explosive charges to further propel the material, however, can add considerably to this performance.
26. MAJ Jeffrey L. Caton, "We Can Reduce Satellite Vulnerability," Research Paper (Maxwell Air Force Base, AL: Air University Press, 1994). Also interesting in this connection is "Convergence of Space Sectors — A New Symbiosis" an address by General Howell M. Estes III, US Space Command, at the 1998 National Space Symposium, Colorado Springs, CO, 9 April 1998.
27. Lt Col A. Andronov and Sr Lt R. Shevrov, "American Overhead Visual Reconnaissance Systems" *Zarubezhnoye Voyennoye Obozreniye* (*Foreign Military Review*) (1995), 37-42.

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