

Space Weapons

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Crossing the U.S. Rubicon

In the next decade, planned U.S. military activities in outer space will cross several important thresholds. By 2008 the U.S. Missile Defense Agency intends to deploy a test bed of space-based kinetic-energy kill vehicles (KKVs) to destroy high-speed collision test targets that mimic nuclear-armed reentry vehicles in the mid-course of their arc through space. In early 2006 a Missile Defense Agency satellite experiment, NFIRE, is planned to attempt to intercept a rocket in or near boost phase. Beyond missile defense, these U.S. space-deployed weapons will have broad implications for the entire space sector. Because a KKV designed to intercept missiles could also function as an antisatellite weapon (ASAT) and as a means to deny other countries' access to space, U.S. adversaries might feel compelled to develop means to counter these and other U.S. space weapons with their own systems based in space or on the ground.

In light of these impending developments, this article examines the possible roles for space weapons in addition to missile defense—for protecting satellites, controlling space, and projecting force—in terms of capabilities and cost.¹ Our analysis is intended to help policymakers in the executive and legislative branches to make more fully informed decisions about missile defense and related near-term U.S. military activities in space, taking into account implica-

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1. To further understand these concerns and opportunities, the Council on Foreign Relations in 2002–03 convened a Study Group on Space Weapons composed of military and civilian experts, co-chaired by Bruce DeBlois and Richard Garwin, and staffed by Jeremy Marwell and Scott Kemp. The three sessions of that study group in Washington, D.C., together with three public forums, helped to inform this article.

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tions for the civil and military space sectors, including the space systems that currently support the U.S. military.

Methodologically, this article reviews the potential utility of space weapons by comparing them with other means to accomplish the same tasks—for instance, in force projection, we compare the lethality, access, and prompt response times of space-based and terrestrial means. In essence, the article provides a first-order cost-benefit analysis for space weapons, considering existing means as a baseline. Any proposed space weapon that can compete in function and cost with nonspace and nonweapon alternatives should be examined by future policymakers in light of broader issues such as proliferation of counterspace capability, civil and commercial impact, political appropriateness, and international relations.² Advocates of systems failing these basic technological and economic tests (which we apply below to the leading-candidate space weapon systems) may face a heightened burden of proof in advancing their cause.

At the same time, the United States should seriously consider the gains to national security to be found in an international regime banning space weapons and should work to encourage other states to join a regime opposing the deployment of space weapons, although the details of such considerations are beyond the scope of this article.³

This article proceeds in five parts. First, it surveys existing literature and policy, setting our cost-benefit approach in the context of other philosophical and theoretical analyses. Second, it examines leading-candidate space weapons for the task of protecting U.S. satellites, concluding that in all but the most nar-

2. These considerations are beyond the scope of this article.

3. Substantial attention has been given to the prospect of an arms control regime. See, for example, Philip D. O'Neill Jr., "The Development of International Law Governing the Military Use of Outer Space," and Donald L. Hafner, "Approaches to the Control of Antisatellite Weapons," both in William J. Durch, ed., *National Interests and the Military Use of Space* (Cambridge, Mass.: Ballinger, 1984), pp. 169–199 and pp. 239–270, respectively; Paul B. Stares, "Anti-Satellite Arms Control in a Broader Security Perspective," in Joseph S. Nye Jr. and James A. Schear, eds., *Seeking Stability in Space: Anti-Satellite Weapons and the Evolving Space Regime* (Washington, D.C.: Aspen Strategy Group, 1987), pp. 109–124; and Walter Slocombe, "Approaches to an ASAT Treaty," in Bhupendra Jasani, ed., *Space Weapons—The Arms Control Dilemma* (London: Taylor and Francis, for the Stockholm International Peace Research Institute, 1984), pp. 145–155; and Paul B. Stares, "Rules of the Road for Space Operations," in Barry Blechman, ed., *Technology and the Limitation of International Conflict* (Washington, D.C.: Johns Hopkins Foreign Policy Institute, 1989), pp. 99–116. For more modern approaches, see Rebecca Johnson, "Multilateral Approaches to Preventing the Weaponization of Space," *Disarmament Diplomacy*, No. 56 (April 2001) pp. 8–16; and Philip E. Coyle and John B. Rhineland, "Drawing the Line: The Path to Controlling Weapons in Space," *Disarmament Diplomacy*, No. 66 (September 2002), pp. 3–7.

rowly tailored circumstances, space weapons either are not suited to the threats currently facing the United States in space or are outpaced by terrestrial alternatives. Third, the article considers space weapons as a tool for denying adversaries the use of space, finding that terrestrial and nondestructive techniques (rather than destructive antisatellite weapons) will most effectively maximize U.S. security—in space and in conventional conflicts. Fourth, the article considers space weapons for force projection against time-critical and denied-access targets, concluding that terrestrial methods of force projection will dominate systems such as space-based lasers and long-rod penetrators.

Finally, the article considers space weapons for long-range ballistic missile defense of the United States, concluding that although space weapons are attractive and perhaps uniquely capable in theory, in practice they suffer from enormous deployment costs and crippling vulnerability to cheap, readily accessible countermeasures. The article closes with our net judgment that the foreseeable costs of space weapons outweigh their benefits, and therefore the United States should delay the deployment of weapons in space or the creation of dedicated antisatellite capability.

Existing Literature

In each of our three areas to be examined—defense of U.S. satellites, control of space, and projection of force—this article builds on existing literature and policy guidance. The most significant official source is the January 2001 *Report of the Commission to Assess United States National Security Space Management and Organization*.⁴ In addition to recommendations on organizing the U.S. government for space activities, this report contains substantive observations and recommendations about space weaponry, the vulnerability of U.S. military space assets, and the need to deny adversaries the use of space in a conventional war; further it implies the need for force projection with the deployment of weapons in space. Memorably, it invokes the specter of a “Space Pearl Harbor” that might deny the United States its essential military support systems.

These considerations are not new. An extensive article in this journal in 1986 introduced, characterized, and analyzed satellites and antisatellite systems and

4. *Report of the Commission to Assess United States National Security Space Management and Organization*, January 11, 2001, <http://www.defenselink.mil/pubs/space20010111.html>, pp. 7–10. Until a few days before its publication, this commission was chaired by then-Defense Secretary-to-be Donald Rumsfeld.

laid out some dynamics of competition between them.⁵ In recent years, the question of weapons in space has become more urgent for the United States, in view of the prospective developments mentioned above, as well as U.S. abrogation of the 1972 Antiballistic Missile (ABM) treaty under President George W. Bush in 2002. Previously, the ABM treaty had barred the placement of not only missile defense components (such as radars) in space but also of space-based weapons (such as conventional KKV's or perhaps space-based lasers [SBLs]⁶) intended to intercept warheads or rockets.

In the area of force projection from space, a RAND report from 2002 analyzes three much-discussed elements of space power projection: space-based lasers, long-rod penetrators, and the common aero vehicle (CAV).⁷ The RAND report treats at length the potential of SBLs for intercepting and destroying missiles in boost phase (boost-phase intercept). Similarly, a recent report of a study group of the American Physical Society (APS) is devoted to boost-phase intercept, analyzing space-based hit-to-kill interceptors and ground- and sea-based interceptors with similar kill vehicles. The APS study group, however, regarded SBLs as beyond its ten-year time horizon and therefore did not consider them.⁸ Other technical studies have assessed the capabilities of space weapons and their countermeasures.⁹ Given the Bush administration's keen interest in missile defense, and the potentially unique capability of SBLs and space-based interceptors (SBIs) for boost-phase defense against launches from the interior of

5. Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," *International Security*, Vol. 10, No. 4 (Spring 1986), pp. 46–98.

6. Both KKV's and space-based lasers are well known from the earliest days of the Strategic Defense Initiative, announced by President Ronald Reagan in his White House "Address to the Nation on the Defense Budget," March 23, 1983.

7. Bob Preston, Dana J. Johnson, Sean Edwards, Michael Miller, and Calvin Shipbaugh, *Space Weapons, Earth Wars*, MR-1209 (Washington, D.C.: RAND, June 2002), <http://www.rand.org/publications/MR/MR1209/>.

8. American Physical Society Study Group, "Report of the APS Study Group on Boost-Phase Intercept Systems for National Missile Defense," *Reviews of Modern Physics*, Vol. 76, S1-S424 (2004); also available at http://www.aps.org/public_affairs/popa/reports/nmd03.html.

9. On the capabilities of space weapons, see Dean A. Wilkening, "Space-based Weapons," in Durch, *National Interests and the Military Use of Space*, pp. 135–167; Patrick J. Friel, "Space-Based Ballistic Missile Defense: An Overview of the Technical Issues," in Keith B. Payne, ed., *Laser Weapons in Space: Policy and Doctrine* (Boulder, Colo.: Westview, 1983), pp. 17–35; and William L. Spacy II, *Does the United States Need Space-Based Weapons?* (Maxwell Air Force Base, Ala.: Air University Press, 1999). On space weapons countermeasures, see, for example, U.S. Congress Office of Technology Assessment, *Anti-Satellite Weapons, Countermeasures, Arms Control* (1985), reprinted in Congressional Office of Technology Assessment, *Strategic Defenses* (Princeton, N.J.: Princeton University Press, 1986); Michael M. May, "Safeguarding Our Space Assets," in Nye and Schear, *Seeking Stability in Space*, pp. 71–85; and George F. Jelen, "Space System Vulnerabilities and Countermeasures," in Durch, *National Interests and the Military Use of Space*, pp. 89–112.

a large country such as Russia or China, this article includes a section on the capabilities of SBLs, their alternatives, and countermeasures, as well as on the vulnerability of the orbiting SBL weapons themselves.

The space weapons debate began in earnest in the late 1960s, after the United States and the Soviet Union tested their first antisatellite systems in 1959 and 1968 respectively.¹⁰ Much of the literature generated during the Cold War was colored by questions of nuclear deterrence and the possibility of a U.S.-Soviet arms race in space.¹¹ This article begins to update the existing literature beyond a bipolar Cold War world to include, for example, considerations of asymmetric threats and “rogue states.”

As to current schools of thought about space weaponization, we adopt the typology set forth in Karl Mueller’s “Totem and Taboo,” which categorizes existing policy views on space weaponization into six groups.¹² Opponents of space weaponization, Mueller argues, can be classified as “idealists” (opposing the spread of weapons into any new realm, including space¹³), “internationalists” (opposing the spread of weapons due to their destabilizing effects on international security¹⁴), and “nationalists” (opposing the spread of weapons because it would weaken U.S. power relative to the rest of the world¹⁵). Weapons advocates, in turn, can be characterized as “space racers” (because space weaponization is inevitable, the United States should be first¹⁶), “space

10. Bhupendra Jasani, ed., *Space Weapons and International Security* (Oxford: Oxford University Press, for the Stockholm International Peace Research Institute, 1987); and Jasani, *Space Weapons—The Arms Control Dilemma*.

11. See, for example, Thomas Karas, “Military Satellites and War-Fighting Doctrines,” in Jasani, *Space Weapons—The Arms Control Dilemma*, pp. 43–55; Nye and Shear, *Seeking Stability in Space*; and Paul B. Stares, *Space and National Security* (Washington, D.C.: Brookings, 1987).

12. Karl P. Mueller, “Totem and Taboo: Depolarizing the Space Weaponization Debate,” *Astropolitics*, Vol. 1, No. 1 (Spring 2003), pp. 4–28. Mueller cautions, however, that “these categories are ideal types, and are not mutually exclusive: it is entirely possible, and even commonplace, for individuals in the real world to hold beliefs that fall into more than one of these camps.” *Ibid.*, p. 6.

13. Bruce M. DeBlois, “Space Sanctuary: A Viable National Strategy,” *Airpower Journal*, Vol. 12, No. 4 (Winter 1998), pp. 41–57; and Bruce M. DeBlois, “The Advent of Space Weapons,” *Astropolitics*, Vol. 1, No. 1 (Spring 2003), pp. 29–53.

14. See, for example, Donald L. Hafner, “Averting a Brobdingnagian Skeet Shoot: Arms Control Measures for Anti-Satellite Weapons,” *International Security*, Vol. 5, No. 3 (Winter 1980/81), pp. 41–60; and Jozef Scheffers, “Why Anti-Satellite Warfare Should Be Prohibited,” in Jasani, *Space Weapons and International Security*, pp. 77–82.

15. Karl P. Mueller, “Space Weapons and U.S. Security: The Dangers of Fortifying the High Frontier,” paper presented at the annual meeting of the American Political Science Association, Boston, Massachusetts, September 6, 1998; David W. Ziegler, *Safe Heavens: Military Strategy and Space Sanctuary Thought* (Maxwell Air Force Base, Ala.: Air University Press, 1998); and Charles S. Robb, “Star Wars II,” *Washington Quarterly*, Vol. 22, No. 1 (Winter 1999), pp. 81–86.

16. The 2001 Space Commission report uses this, among others, to argue for space weapons development. See also Karl P. Mueller, “Is the Weaponization of Space Inevitable?” paper presented at the annual convention of the International Studies Association, New Orleans, Louisiana, March 27,

controllers” (the military utility of space is so great that the benefits to the United States of weaponization outweigh its costs¹⁷), and “space hegemonists” (space will become the ultimate, and decisive, battleground of the future—the “ultimate high ground” for the United States to seize¹⁸). The approach taken in this article spans that of “nationalist” and “space controller,” focusing on cost-benefit analysis from a U.S. perspective.¹⁹

Analysis of Leading-Candidate Space Weapons

The analysis below—an initial litmus test for space weapons—focuses on the three roles for leading-candidate space weapons as proposed by advocates: defending U.S. satellites, preventing the hostile use of space by others (“space control”), and using space as a base for U.S. force projection. We further address space-based weapons for missile defense, and we assume in any case that nonweapon elements of missile defense (e.g., radars or satellites that function as radars) are to be deployed in space, as well as the full suite of nonweapon space assets that currently support U.S. military capabilities.

ROLE #1: PROTECTING U.S. SATELLITES

In 2001 the Rumsfeld Space Commission warned that the United States would be an attractive candidate for a “Space Pearl Harbor”—a devastating surprise attack against critical U.S. space systems.²⁰ Although risks to individual satellites vary by function and orbital location, generalized threats to U.S. space capabilities are listed here roughly in order of decreasing likelihood²¹: (1) denial

2002; and Uri Ra’anan and Robert L. Pfaltzgraff Jr., eds., *International Security Dimensions of Space* (Hamden, Conn.: Archon, 1984).

17. See, for example, William J. Perry, Brent Scowcroft, Joseph S. Nye Jr., and James A. Schear, “Anti-Satellite Weapons and U.S. Military Space Policy: An Introduction,” in Nye and Schear, *Seeking Stability in Space*, pp. 1–28.

18. See, for example, Keith B. Payne, ed., *Laser Weapons in Space: Policy and Doctrine* (Boulder, Colo.: Westview, 1983); *New World Vistas: Air and Space Power for the 21st Century*, Space Applications Volume (Washington, D.C.: United States Air Force Scientific Advisory Board, 1995); Sen. Bob Smith, “The Challenge of Space Power,” *Airpower Journal*, Vol. 13, No. 1 (Spring 1999), pp. 32–40; Everett C. Dolman, *Astropolitik: Classical Geopolitics in the Space Age* (London: Frank Cass, 2001); Simon P. Worden, “Space Control in the 21st Century,” in Peter L. Hays, James M. Smith, Alan R. Van Tassel, and Guy M. Walsh, eds., *Spacepower for a New Millennium* (New York: McGraw-Hill, 2000), pp. 225–238.

19. Broader conceptions of cost and benefit—such as international political opposition to U.S. space weapons—are beyond the scope of this article.

20. Executive Summary, *Report of the Commission to Assess United States National Security Space Management and Organization*, p. 15.

21. Threats to U.S. space systems have been assessed, in a nonclassified setting, in some detail. See, for instance, Tom Wilson, “Threats to United States Space Capabilities,” paper prepared for

and deception (e.g., camouflage, smoke screens, and scheduling of ground operations when U.S. satellite imagery resources are not available); (2) electronic warfare (e.g., jamming satellite signals and inserting false commands); (3) physical attacks on satellite ground stations; (4) dazzling or blinding of satellite sensors; (5) pellet-cloud attacks on low-orbit imaging satellites; (6) attacks in space by microsatellites; (7) hit-to-kill antisatellite weapons; and (8) high-altitude nuclear explosions.

Techniques available to protect U.S. satellite capabilities include advanced technical means to overcome denial and deception, radiation hardening and shielding, command and data encryption, antijamming measures, and limited orbital maneuvering. These safeguards, however, are neither sufficient nor universally employed. For example, no commercial satellites and perhaps no military satellites are known to have the ability to detect electromagnetic or physical attacks in space.²² More generally, the quality of available information about what is going on in space—so-called space situational awareness—is currently one of the United States' most urgent space security shortcomings. (In principle, improvements in U.S. space situational awareness would be welcomed both at home and abroad—because many other countries rely on U.S. space tracking data for their own peaceful space activities.)

Below, we discuss technical approaches potentially available to the United States to mitigate the above threats. Also important are diplomatic agreements and treaties that could provide disincentives to potential adversaries (in large part by legitimizing U.S. use of force in response to violations of the agreements), while offering an important measure of security that would extend to others as well.²³ To the extent that U.S. space-based military support capability is essential, preservation of these capabilities must engage U.S. nonspace forces and include action against an adversary's nonspace assets.

DENIAL AND DECEPTION, GROUND-STATION ATTACKS, AND HIGH-ALTITUDE NUCLEAR EXPLOSIONS. The development of space weapons would not significantly mitigate three of the generalized threats to U.S. space capabilities mentioned

the Commission to Assess United States National Security Space Management and Organization, <https://www.space.gov/commission/support-docs/article05.pdf>; and U.S. Army, "Threats and Countermeasures," *Army Space Reference Text*, July 1993, http://www.fas.org/spp/military/docops/army/ref_text/chap08.htm, chap. 8.

22. Benjamin S. Lambeth, *Mastering the Ultimate High Ground: Next Steps in the Military Uses of Space* (Santa Monica, Calif.: RAND, June 2003), <http://www.rand.org/publications/MR/MR1649/MR1649.pdf>, p. 104.

23. See, for example, Johnson, "Multilateral Approaches to Preventing the Weaponization of Space," pp. 8–16; and Rebecca Johnson, "Security without Weapons in Space: Challenges and Options" (Geneva, Switzerland: Disarmament Forum, UN Institute for Disarmament Research, March 2003), pp. 53–65.

above: denial and deception, attacks on ground stations, and high-altitude nuclear explosions. To counter an adversary's denial and deception techniques, for example, the United States might seek to employ multiple, redundant satellite and unmanned aerial vehicle (UAV) sensing channels; avoid detection of its reconnaissance satellites; and improve analysis of currently available imagery. Evidently, orbiting weapons cannot prevent physical attack on satellite ground infrastructure; more effective counters are familiar security techniques such as physical surveillance, fences, guards, and back-up systems. A high-altitude nuclear explosion, and its resulting bands of persistent, damaging beta radiation, would require shielding (to reduce the radiation dose) and, in some cases, hardening (to increase tolerance of semiconductor circuitry to radiation) of satellites in potentially vulnerable orbits. Technological means to proactively depopulate the trapped electrons from the Van Allen belts—such as the orbiting of lead or uranium foil to scatter and disperse the electrons into the atmosphere—are possible but in their infancy.

ELECTRONIC WARFARE. Neither would space weapons easily resolve the oft-cited threat of electromagnetic jamming—unsuccessfully employed against U.S. Global Positioning Satellite (GPS) systems in Iraq. In time of war, as demonstrated in Iraq, ground- or air-launched munitions (in some cases guided by the enemy jammer's own signals) can be a direct and effective countermeasure to ground-based jamming.²⁴ In the face of more persistent jamming, ground- or air-deployed pseudosatellites, so-called pseudolites, could boost GPS and other satellite signals in a local area. For example, an unmanned aerial vehicle transmitting GPS signals from an altitude of 20 kilometers (60,000 feet) would provide 10,000 times the received signal strength on Earth as a GPS satellite with equivalent transmission energy. Such augmentation would reduce by a factor of 100 the effective radius of a GPS jammer—or, conversely, increase by a factor of 10,000 the power required to jam the original area, a significant improvement insofar as robustness is concerned. Furthermore, a GPS transmitter on an unmanned aerial vehicle could radiate ten times the power of a GPS satellite, rendering hostile jamming efforts more difficult by a further factor of 10.

Neither "hacking" (unauthorized intrusion into satellite control networks), "spoofing" (fake instructions to a satellite), nor ground-based jamming of command links could be significantly mitigated by space weapons. A space mine closely accompanying a U.S. satellite easily jam its command link. Destructive attack on the little jammer could readily provoke an instantaneous and auto-

24. Robert Wall, "The Next Space War," *Aviation Week & Space Technology*, July 28, 2003, p. 27.

matic destruction of the jammed satellite, limiting the utility of such a protective space weapon once the space mine was in place.

SENSOR BLINDING OR DAZZLING. We distinguish “blinding” from “dazzling,” using the former for permanent damage and the latter for momentary disabling. Such a threat is not unprecedented; in 1997 the United States tested a low-power laser from White Sands, New Mexico, against an orbiting U.S. Air Force satellite, temporarily blinding it.²⁵ A similar system located in an adversary’s remote or denied-access territory might damage a U.S. surveillance satellite in a matter of seconds, depending on details of the imaging system. Short-pulse lasers can do damage in less than a millionth of a second. As described by Ashton Carter, the destruction of a nonimaging satellite by laser heating is difficult at ranges to geosynchronous earth orbit and could be prevented by modest shields; the sensitive focal plane of an imaging satellite operating at far lower altitudes, however, may suffer damage at laser powers smaller by a factor of 1 million or more.²⁶

Physically destroying a ground-based laser site before damage could be done to a U.S. satellite would be nearly impossible, even with space weapons. At the speed of light—300,000 kilometers per second (km/s)—a laser’s propagation from Earth to space is essentially instantaneous, although it would take minutes or seconds to aim the laser in addition to whatever “burn time” was necessary for destructive effect once the laser had focused on its target.²⁷

As a defense, airplanes or cruise missiles would take hours or days to act, and intercontinental ballistic missiles, or ICBMs (assuming the needed accuracy could be achieved) up to forty-five minutes. But even a kinetic-energy weapon (such as a long-rod projectile) stationed in orbit would require some tens of minutes to arrive at a suitable orbital position, and five minutes to fall from a typical altitude of 450 kilometers.

Only a constellation of space-based lasers could respond with necessary promptness and global reach; the ground-based hostile laser system, however,

25. John Donnelly, “Laser of 30 Watts Blinded Satellite 300 Miles High,” *Defense Week*, December 8, 1997, p. 1.

26. Carter, “Satellites and Anti-Satellites,” p. 76.

27. Atmospheric distortion creates substantial beam spreading of a ground-based laser at orbital altitudes. For instance, at the near-infrared wavelength of 1 μm , a mirror $D = 2$ m diameter would produce a spot $D_0 = 0.5$ m diameter at a distance of 1,000 km in the absence of atmospheric effects. Atmospheric refractive disturbances with a typical scale of $r_0 = 15$ cm would spread the spot to some $D_0(D/r_0) = 7$ m diameter, reducing the heat input to a surface by a factor near 180. Correction of this effect with adaptive optics (“rubber mirrors”) is technologically more difficult than the use of adaptive optics in improving the capabilities of ground telescopes to image the heavens. Space-based lasers do not have to contend with beam spread due to atmospheric distortion.

could be outfitted with protective measures without concern for weight (unlike orbiting satellites), affording at least enough protection for the system to disable a U.S. target satellite. A single enemy ground-based laser could destroy only satellites within its line of sight, and the time necessary for other satellites to move into view would allow the United States time to target the site with conventional weapons, if its precise location were known. Consequently, an adversary would need multiple ground-based lasers or significant ground-based laser mobility to destroy many U.S. space assets.

A potential solution to this problem would be satellite self-protection. Reconnaissance satellites and other vulnerable systems could be outfitted with physical shields to protect optics and sensitive electronics upon detection of high-intensity laser light. Detection of the low-power aiming phase of the ground-based lasers would give time for closing a shutter to eliminate the exquisite vulnerability of the satellite's focal plane. If deployed promptly, a thin metal shield (a parasol) could provide substantial protection against a megawatt-class laser.²⁸ The point is that space weapons are not an effective response to this threat, while strictly defensive measures and terrestrial weapons and retaliation may be.

MICROSATELLITES, PELLET-CLOUD ATTACKS, AND ANTISATELLITE WEAPONS. Advocates of U.S. space weapons suggest that such systems could be an effective defense against microsatellite space mines or antisatellite projectile weapons.²⁹ These types of threats are an emerging technological reality. China, for instance, tested a nonmaneuvering civilian microsatellite capability in conjunction with the British Surrey Space Center in 2001. In January 2003 the U.S. Air Force openly demonstrated its XSS-10 microsatellite, which repeatedly maneuvered to within 35 meters of a target to take photographs³⁰; a shotgun could have destroyed a satellite from such a range. In addition, almost any mid-course missile defense system could threaten satellites, which are more fragile and more predictable (and therefore easier to hit) than ballistic missile warheads.

28. Specifically, a heated surface can radiate no more than 57 kW/m^2 at a temperature of $1,000^\circ\text{K}$, with the radiation increasing as T^4 . To radiate 300 kW/m^2 from an insulated parasol would thus require a surface temperature of at least 1570°K . The parasol might be built of tungsten foil with a melting point of $3,695^\circ\text{K}$. Such protection might increase total satellite system costs by a few percent.

29. Wilson, "Threats to United States Space Capabilities," section entitled "Self-Defense or Escort Defensive Capability."

30. Craig Covault, "USAF Technology Satellite Plays Tag with GPS Delta," *Aviation Week & Space Technology*, February 3, 2003, p. 39.

Some U.S. experts have proposed “bodyguard” or escort satellites—a group of armed satellites surrounding a valuable U.S. system—as a possible defense.³¹ But there are hazards even in a successful intercept. A collision with a multi-kilogram incoming satellite or projectile weapon traveling at 10 kilometers per second would have the equivalent destructive power of ten times that amount of TNT; a close-in intercept may deal a fatal collateral blow to the satellite intended to be protected.

Avoiding space debris from the intercept of an incoming kill vehicle imposes substantial requirements on the self-defense interceptors based near a satellite. To intercept even at a distance of 1 kilometer would require an escort interceptor flight time of 3 seconds for an escort accelerating at twenty times the acceleration of gravity—200 meters per second-squared. This is well within the state of the art, and such an interceptor would need to devote only about 30 percent of its mass to rocket fuel. Interceptor launch would need to occur while a KKV approaching at 10 kilometers per second was still 30 kilometers away. But providing even one minute of warning, for instance, would require detecting an incoming microsatellite and determining its hostile intent at a distance of 600 kilometers. While existing ground-based tracking systems can track small space-borne objects in orbit with the requisite accuracy, they do not provide the necessary near-real-time data to determine intent.³²

A constellation of space-based lasers could be considered for defense against debris-like antisatellite weapons, for instance, pellets or gravel that might be delivered to low earth orbit (LEO) altitude by a Scud-derived missile such as North Korea’s Nodong or Pakistan’s Ghauri.³³ Such a weapon would be launched by a U.S. adversary at precisely the right time to arrive at (but not in) low earth orbit coincident in place and time with a U.S. satellite. For an in-plane intercept, timing the intercept would be eased by having the rocket reach maximum altitude (and therefore zero vertical velocity) at the satellite’s orbital height, with the lethal 300-kilogram pellet payload cloud (of a gross payload of about 1 ton) remaining for almost 30 seconds centered within 100 meters of its quarry’s expected altitude. If the orbiting satellite has a vulnerable area of 10 m² to the encounter with a 1-gram pellet (capable of ejecting about

31. Tom Wilson finds that an escort defense system would increase the total system cost by between 20 and 40 percent of the total satellite cost. See Wilson, “Threats to United States Space Capabilities.”

32. Jeremy Singer, “U.S. Developing Ground-Based Systems to Counter Satellites,” *Space News International*, June 30, 2003, p. 6.

33. See Federation of American Scientists, “North Korean Missiles: Nodong,” <http://www.fas.org/nuke/guide/dprk/missile/nd-1.htm>; and Federation of American Scientists, “Pakistan Missiles: Ghauri,” <http://www.fas.org/nuke/guide/pakistan/missile/hatf-5.htm>.

1,000 grams of metal from a massive plate) at more than 7 km/s, one can estimate the kill probability of such a pellet warhead. We assume that the unmodified Scud-D (Nodong)³⁴ has a circular error probable³⁵ of 1.5 kilometers at a range of 1,000 kilometers, corresponding to a velocity error of 3 m/s. It will reach 500-kilometer altitude if fired near vertically, with a time of about 350 seconds. If a GPS receiver and a set of small thrusters are added to the rocket, or to a separating fore body, and most of the necessary velocity corrections are made in 50 seconds after rocket burnout at 110 seconds, then a few kilograms of hydrazine (in simple thrusters that provide a specific impulse of 200 seconds) could in this way bring the payload to the desired point in space within about 10-meter accuracy. The GPS-guided bomb (i.e., the Joint Direct Attack Munition [JDAM])—of which thousands were used in Iraq in 2003—achieves few-meter accuracy.

Even advanced space weapons could not defeat a Nodong pellet-cloud attack, given the timing of rocket ignition and pellet-cloud formation. After launch, a Nodong rocket fires for about 110 seconds. Because the rocket may be below the clouds for 30 seconds or more of its trajectory, the chances of detection, tracking, and interception by a space-based laser (whose beam would not penetrate cloud cover) would be reduced. Furthermore, Nodongs can easily be hardened against a laser attack, are cheap and plentiful compared to SBLs, and can choose to fire when SBLs are most distant.

On the other hand, Whipple Bumpers, a set of passive barriers deployed around a satellite in space, could reduce a satellite's particular vulnerability to Nodong intercept. Deploying bumpers only in front of the satellite would minimize the extra mass and the added system cost.

The cost and limited effectiveness of a weapon-based satellite defense must be weighed against those of alternative approaches. In particular, the use of redundant backup systems with equal or greater capabilities in a theater of conflict, while not providing physical protection, would reduce an adversary's motivation to attack (if it was known that such an attack would have no effect), and in any case would reduce the adverse effects. Although accepting the inherent physical vulnerabilities of expensive and vital U.S. satellites is undesirable politically, and Whipple Bumpers add cost and may limit flexibility, a defense by redundancy is preferable to a weapons-based solution with a known low probability of success.

For example, UAVs do, and could further, augment or substitute for U.S. sat-

34. See *ibid.*

35. Circular error probable is the radius of a circle within which half the weapons strike.

elite reconnaissance assets, achieving equivalent imaging resolution by scaling the size of optics. The limiting resolution of a 2-meter satellite mirror in 300-kilometer orbit could be replicated by a 20-centimeter mirror on a UAV at an altitude of 30 kilometers. For distant targets, say at 100 kilometers, a 50-centimeter-diameter mirror would allow the UAV to match a satellite's resolution. Using multiple UAVs would mitigate the drastically reduced field of regard resulting from operation at lower airborne altitudes; this approach is particularly effective in the important case in which adversary interests and hence U.S. resources are concentrated in a localized theater of operations. Stealthy UAVs may be required for survival against capable air defenses.

IN SUM: PROTECTING U.S. SATELLITES. Space weapons are generally not good at protecting satellites' capabilities. In those cases where space weapons might play a unique or contributing role—in opposing microsatellite attack and hit-to-kill antisatellite weapons—terrestrial or passive approaches match or exceed their utility. In the case of microsatellites and bodyguards, one might commit to deploying (in the spirit of Jonathan Swift) "smaller still to bite 'em." In such an arms race, the vulnerability inherent in the cost of existing and future U.S. high-capability satellites in low earth orbit outweighs any competitive advantages of superior U.S. space resources (e.g., in building advanced bodyguard microsatellites).

Cost, long development cycles, and vulnerability suggest that space weapons are not—except perhaps in the most narrowly defined of circumstances—a satellite defense of first resort. Instead, the United States should develop redundant, terrestrial back-up systems, thereby reducing its dependence on satellites while ensuring the capabilities those satellites provide in a localized theater of conflict. High-power pseudolites on the ground and on UAVs could provide GPS, remote sensing, communications, and other satellite signals in a theater of operations, eliminating most of the benefit to theater adversaries intent upon attacking U.S. satellites. An adversary state or terrorist might still attack a valuable satellite not for military benefit but to damage the reputation of the United States; the solution to this problem seems to lie in the promise of retaliation against a state actor or a state aiding terrorists in such an act.

ROLE #2: COUNTERING ADVERSARIES IN SPACE: SPACE CONTROL

Recent conflicts such as those in Afghanistan and Iraq have left no doubt about the military advantages conferred by space-based communications, reconnaissance, intelligence, and navigation systems. Perhaps as a result, U.S. allies and adversaries alike are now developing indigenous space-based military support

capabilities that could significantly augment the threat to U.S. forces. Other countries contract with U.S. firms or international consortia for communications and imagery services. It is unlikely that the United States will be able to prevent these developments. Accordingly, military planners see the ability to deny adversaries the hostile use of space—analogueous to securing air superiority in a ground campaign—as a crucial component of twenty-first-century warfare.

Ensuring U.S. and allied freedom of action in space and, when necessary, denying an adversary that freedom is sometimes referred to as “space control.” If approved and funded by Congress, space control programs could include space surveillance, satellite jamming, spoofing, dazzling, disabling of ground stations, or using microsatellites to block an adversary satellite’s field of view or to spot-jam transmissions. Currently, U.S. space-control capabilities include surveillance, jamming, and (at least in theory) the ability to attack ground stations and use ground-based lasers to dazzle or blind satellite sensors.

Techniques for denying an adversary the use of space—so-called offensive counterspace—are, in theory, the very ones that an adversary might use to threaten U.S. space systems: denial and deception, electronic warfare, attacks on ground stations, microsatellites or space mines, and ground-based projectile antisatellite weapons. As such, offensive counterspace is a double-edged sword: any technique the United States develops or employs (or maintains the right to employ) against others might proliferate and be employed in return. True, powerful SBLs may be beyond the capability of many adversaries, but adequate denial of U.S. capabilities might be achieved by pellet-cloud attack against satellites in LEO and with microsatellites (space mines) against satellites in geosynchronous or other orbits. The United States must balance the potential advantages of offensive counterspace against the possibility of increasing risks to its own high-value systems.

DESTRUCTIVE ANTISATELLITE WEAPONS. Physical destruction of an adversary’s satellites—for instance, by a space mine or antisatellite weapon—is an oft-discussed and politically controversial counterspace technique. There is little doubt of U.S. capability in this field, for instance, through the use of one of the interceptors now deployed in Alaska and California by the Missile Defense Agency for use against a few long-range missiles directed against U.S. territory. The effectiveness of such interceptors against nuclear warheads launched by long-range missiles is minimal, however, in view of the antisimulation and decoys an adversary is likely to use in any attack on the United States. (“Antisimulation” is the technique of reducing the cost of effective decoys by dress-

ing the warhead to mimic a cheap decoy—for instance, by putting the warhead in an aluminized plastic balloon.) Yet satellites cannot employ such protective techniques and continue to accomplish their mission. Later, space-based missile-defense interceptors would have antisatellite capability. Some U.S. military space analysts have acknowledged the undesirable consequences of physical attacks on adversaries in space—notably, the potential for uncontrolled escalation and increased quantities of hazardous space debris. As one such analyst commented, space debris is essentially an “unguided, hypervelocity kinetic-energy weapon.”³⁶ Because the United States owns a significant majority of the world’s satellites, it would suffer disproportionately from any increase in the amount of space debris.

Space debris is already a serious concern that would be intensified by the testing or use of explosive weapons in space or, for that matter, of hit-to-kill intercept of satellites.³⁷ Recognizing the dangers of orbital pollution, most of the international space community have implemented strict (but voluntary) regulations for the safe disposition of spent boosters and other space trash.³⁸ Nonetheless, U.S. Space Command currently tracks nearly 10,000 objects in orbit, ranging in size from several centimeters to many meters, only about 600 of which are operational satellites. Low earth orbits are to some degree self-cleaning, due to atmospheric drag; however, objects in higher orbits linger for decades or millennia. Concern for debris is evident in measures taken thus far by the Missile Defense Agency to minimize the overall amount of debris in space by testing its KKV intercept on downward trajectories of suborbital targets, at low altitude. A collision or explosion at a given altitude cannot produce debris in orbit above that altitude; so a test at an altitude for which the drag-induced debris decay is short does not produce an enduring debris problem. And if a collision takes place in LEO at an altitude 200 kilometers above the short-decay altitude, only that debris from the satellite that maintains orbital speed to some accuracy, and is not emitted at a significant angle below or above the horizontal, can remain in orbit. Specifically, with the Earth radius of some 6,400 kilometers, tests at 200 kilometers above the decay altitude can

36. Lambeth, “Mastering the Ultimate High Ground,” p. 111; and Lt. Gen. Roger G. DeKok and Bob Preston, “Acquisition of Space Power for a New Millennium,” in Hays et al., *Spacepower for a New Millennium*, p. 85.

37. Commission on Engineering and Technical Systems, National Research Council, *Orbital Debris: A Technical Analysis* (Washington, D.C.: National Academy Press, 1995), p. 161.

38. Inter-Agency Space Debris Coordination Committee, National Aeronautics and Space Administration, “IADC Space Debris Mitigation Guidelines,” IADC-02-01, October 15, 2002, http://www.orbitaldebris.jsc.nasa.gov/library/IADC_Space_Debris_Mitigation_Guidelines_Oct02.pdf.

yield orbital debris fragments only from those particles that are emitted within about two degrees of the horizontal and with no more speed loss than about 200 meters per second.

In sum, space debris is a concern, but can be mitigated by careful planning.

FLEXIBLE NEGATION. “Flexible negation” is bureau-speak for the tactical denial of an adversary’s space capabilities rather than their destruction or permanent damage. Such techniques could involve physically nondestructive methods such as selective jamming of satellite data links or the denial of GPS signals in a theater of conflict, as well as exotic methods such as micro-satellite-deployed screens to temporarily block satellite lines of sight or communications.

Nondestructive flexible negation techniques might find acceptance in rules or agreements guiding conduct in space. Even a unilateral declaration by the United States might help to protect satellites from destruction. Although the fact that negation is “flexible” would be cold comfort to an adversary in the heat of battle (eliminating any benefit to the United States from employing reversible means), such techniques might find good use for low-intensity conflicts.

The U.S. Global Positioning System provides a useful example of a successful U.S. flexible counterspace activity. Beginning in 1983, the United States made GPS signals available to civilian users worldwide only after deliberately degrading their accuracy, a policy known as “selective availability,” intended to prevent GPS from being used in conflict against the United States.

In May 2000, however, the United States removed the restraint on accuracy for all civilian users worldwide, improving GPS’s accuracy tenfold. This change—credited with catalyzing the commercial and civilian adoption of GPS worldwide—was apparently made possible by the availability of localized jamming techniques for denying the use of GPS to U.S. adversaries in a theater of conflict. On September 17, 2001, in response to speculation that the September 11 terrorist attacks on the World Trade Center and Pentagon might prompt a return to degraded GPS signals, the United States confirmed that it had no intent ever again to impose selective availability.³⁹

NON-U.S. INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE FROM SPACE. Experts often cite the emerging capability of other states to use space for intelligence, surveillance, and reconnaissance as a strong motivator for U.S.

39. See Special Notice, September 17, 2001, <http://www.igeb.gov/sa.shtml>.

counterspace programs. For example, the problems posed by high-resolution commercial remote sensing have resulted in a complex debate between national security and economic interests in the United States and abroad.⁴⁰ Although the threat of an adversary using remote sensing in a future conflict—say for detecting U.S. aircraft carrier battle groups at sea—must be countered, most remote sensing resources are devoted to legitimate, peaceful applications, including land-use management, scientific research, and weather prediction.

Furthermore, the United States already possesses a significant number of non-satellite-destructive techniques for mitigating risks from space-based intelligence, surveillance, and reconnaissance systems, including: denial and deception, attacks on enemy ground stations, jamming, spoofing, dazzling of enemy satellites, and (for friendly countries) government oversight and “shutter control” arrangements to restrain the use of space-based intelligence during times of crisis. Military analysts have also suggested the use of microsatellites to temporarily disrupt satellite control links, spot-jam, or block satellite lines of sight.

Techniques for denying an adversary’s satellite reconnaissance, however, beg the question of whether to do so in the first place. In a recent space war game, U.S. commanders found that preemptively destroying or denying an opponent’s space-based information assets could lead to rapid escalation into full-scale war, even triggering nuclear weapon use. As one “enemy commander” commented: “[If] I don’t know what’s going on, I have no choice but to hit everything, using everything I have.”⁴¹ Thus mutual transparency—that is, choosing not to deny an adversary’s situational awareness—may in some circumstances enhance U.S. security, as reflected in Cold War agreements and practice protecting U.S. and Soviet reconnaissance satellites and their overflight rights.⁴²

IN SUM: COUNTERSPACE. Although the ability to deny adversaries the hostile use of space is critical for U.S. national security, the United States must be heedful of its unique vulnerability as the country with the most to lose in

40. Peter L. Hays, *United States Military Space: Into the Twenty-first Century* (Maxwell Air Force Base, Ala.: U.S. Air Force Institute for National Security Studies, Air University Press, September 2002), pp. 124–130.

41. Quoted in William B. Scott, “Wargames Zero In on Knotty Milspace Issues,” *Aviation Week & Space Technology*, January 29, 2001, p. 52.

42. See, for example, “Treaty between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems,” <http://www.state.gov/www/global/arms/treaties/abm/abm2.html>, art. 12, par. 2: “Each Party undertakes not to interfere with the national technical means of verification of the other Party operating in accordance with paragraph 1 of this Article.”

space. In addition to requiring careful management to mitigate the proliferation of space debris, deploying physically destructive antisatellite weapons risks subjecting the United States to a disproportionate tit-for-tat.

Instead, the United States should choose a counterspace strategy that maximizes the security of its own satellites—one that relies on nondestructive techniques to minimize threats from competitors' space systems and exploits U.S. strengths in nondestructive technological innovation (e.g., in developing flexible negation techniques). For protecting U.S. military and civilian space systems, the United States should focus on collective security measures, the success of which will depend on deterring attacks through the promise of retaliation against ground and political (but not space) assets. For denying adversaries the hostile use of space, the United States should focus on capabilities to jam satellite uplinks or downlinks, measures to attack essential ground stations, and the development of negation techniques such as obscuring satellite lines of sight through screens in space.⁴³ It may also be possible to use eventual U.S. capabilities for boost-phase intercept to destroy some antisatellite weapon launchers in powered flight—especially from small states of interest, such as North Korea.

If the United States maintains nondestructive flexible negation capabilities in space, other states may ask how they can be assured that these will not be used for simple destruction. And if the capacity for destruction exists, how can these skeptics be dissuaded from deploying their own nominally nondestructive negation systems (e.g., close-in jammers) that they could fit expressly with destructive means? This would set up an unstable confrontation in space—one particularly vulnerable to the initiation of war through accident, misunderstanding, or the action of a third party given the persistent difficulties of even the most sophisticated space powers of real-time space situational awareness. A mutual confidence-building regime accompanying nondestructive flexible negation systems would therefore need to be supplemented by multilateral agreements on space.

ROLE #3: SPACE AS THE ULTIMATE HIGH GROUND?

Among proposed uses of outer space, force projection is perhaps the most militarily alluring and politically provocative. At the center of the debate is the question of how—in terms of response time, global reach, accuracy, and

43. See, for instance, Richard L. Garwin, "Space Weapons: Not Yet," presentation at Pugwash Workshop on Preserving the Non-Weaponization of Space, Castellón de la Plana, Spain, May 22–24, 2003, <http://www.fas.org/rlg/030522-space.pdf>.

lethality—the United States will project military power around the globe in future conflicts. Enthusiasts have long argued that space is the dominant theater for military operations, with potentially decisive effects on terrestrial conflicts; the United States, they warn, neglects such capabilities at its peril.⁴⁴ On the other hand, the prospect of weapons in orbit—poised to strike anywhere on the globe at any time—has elicited vigorous opposition, both in the United States and abroad.⁴⁵ We judge that it is the space-based military support capabilities that are essential and that must be preserved by force, by political and diplomatic means, and by nonspace redundancy. Space weapons, paradoxically, seem more likely to imperil than to protect these important systems and undermine overall U.S. military capability.

Advocates claim that space weapons may offer a unique capability to strike two types of military targets: those that are time critical (e.g., mobile Scud missiles or biological weapons laboratories) or those that are denied access (e.g., geographically remote, protected by air defenses, or hardened and deeply buried). As the recent conflict in Iraq demonstrates, both of these issues stand to play a central role in twenty-first-century warfare.

Given the likelihood that time-critical and denied-access targets will continue to factor prominently in U.S. national security, decisions must be made about how best to meet these objectives within the constraints of a finite defense budget. Such calculations require an understanding, where possible, of existing capabilities and feasible adaptations thereto; future requirements; and proposed new weapon systems, in terms of technical feasibility, overall desirability, and cost. Although, as stated above, a comprehensive cost-benefit analysis is beyond the scope of this article, the sections below outline some of the basic physical principles and economic realities of the systems in question.

TIME-CRITICAL TARGETS. Recent U.S. military operations in Afghanistan and Iraq have demonstrated the growing importance of rapid intelligence and response cycles for identifying and targeting mobile, low-profile objectives such as small groups of (or even individual) military personnel. It should be noted that over the past decade the Pentagon has significantly accelerated U.S. military response times without the use of space weapons. The amount of time necessary to identify and strike a target shrank from twenty-four hours in Op-

44. Hays et al., *Spacepower for a New Millennium*, p. 3.

45. See, for example, Neil Mackay, "Revealed: U.S. Plan to 'Own' Space," *Sunday Herald*, June 22, 2003, p. 21; Julian Borger, "U.S. Planning Global-Reach Missiles: Allies Not Required," *Guardian Weekly*, July 3–July 9, 2003, p. 1; and Loring Wirbel, "Unilateralism Goes to Space," *Electronic Engineering Times*, May 19, 2003, p. 18.

eration Desert Storm to forty-five minutes in Afghanistan to some eleven minutes most recently in Iraq. U.S. Air Force Chief of Staff John Jumper has stated his desire to decrease response times still further, to one minute or less.⁴⁶ With such short U.S. response times, decisionmaking, rather than technology, may be the limiting factor (i.e., response times of less than a minute are of diminishing value if good decisions—e.g., the determination of hostile intent—cannot be made in such a short time frame). But there are instances (and there will be more) in which the decision has been made, as in the case of the few-second response required to intercept an ICBM fired from a known hostile nuclear launch site.

If a manned expedition was required, and in the absence of forward-deployed forces, U.S. response times would be far slower than one minute. According to some sources, medium-weight army brigades require some ninety-six hours between call-up and deployment, navy carrier battle groups up to ninety-six hours to reach striking distance of a target, and air expeditionary forces forty-eight hours or more to launch attacks.⁴⁷ Ballistic missiles launched from the continental United States could strike targets anywhere in the world in less than forty-five minutes; although such weapons have not been designed or procured for conventional (i.e., nonnuclear) warfare, U.S. Strategic Command has called for such a capability.

Some defense strategists argue that the United States should pursue new strike capabilities that could reach anywhere in the world from U.S. territory in less than ninety minutes.⁴⁸ With the exception of ballistic missiles and forward-deployed forces (which face significant practical, economic, and political barriers), space systems alone possess the vantage point and positioning necessary for rapid global response. But U.S. satellites do not currently have any ability to employ or project direct force from orbit.

Whether a ninety-minute goal is essential or even useful, it is instructive to compare the potential responsiveness of proposed space systems, such as long-range penetrators and space-based lasers, with existing (and future) conventional capabilities such as submarine-launched missiles.

46. Rich Tuttle, "New Tactics: Fast-Paced Technology in the Air and on the Ground Opens Doors in Iraqi Freedom," *Aviation Week & Space Technology*, June 9, 2003, pp. 50–51.

47. Matt Bille and Rusty Lorenz, "Requirements for a Conventional Prompt Global Strike Capability," National Defense Industrial Association, Missile and Rockets Symposium, May 2001, <http://www.dtic.mil/ndia/2001missiles/bille.pdf>.

48. See U.S. Space Command, *Long Range Plan*, April 1998, <http://fas.org/spp/military/docops/usspac/lrp/toc.htm>, chap. 6.

Long-Rod Penetrators. One commonly discussed tool for global power projection would be to deliver projectile weapons from orbit. Long tungsten or uranium rods, falling vertically from orbit, would deliver enormous destructive force on impact.⁴⁹ To achieve the equivalent energy of high explosive used in bombs or missiles, however, the rods would need to fall at some 3 km/s, requiring an initial altitude of 460 kilometers and a fall time of five minutes. Dropping the rods from geosynchronous orbit would produce ten times this energy density but require a fall time of almost six hours. This fact—that greater destructive energy requires higher altitudes and longer fall times—is a consequence of the constraint that the rods “fall” to their targets without maneuver or guidance.

Although (assuming equivalent intelligence and tasking cycles) the nearest orbiting rods could in theory reach ground targets fifteen to thirty minutes faster than the most distant ICBM (with a maximum flight time of some forty-five minutes), the cost of space weapons would be many times greater. Overall system cost would be dominated by the price of putting rods—and their fuel—in orbit and later canceling their orbital velocity so that they would drop back to Earth. For a single 100-kilogram rod and its required 3 tons of rocket fuel in a 450-kilometer low earth orbit, assuming typical launch costs of \$22,000 per kilogram, the launch costs alone would total some \$66 million.

To guarantee that a single target (located near the equator, to take the easiest case) could be attacked at will and not only when a single orbiting rod happened to pass overhead, a distributed constellation of some forty rods would be necessary, with total system launch costs of some \$8 billion.⁵⁰ By contrast, the United States already possesses hundreds of surplus ICBMs (flight time less than forty-five minutes), cruise missiles (response time of minutes to hours, depending on their range to target) at some \$600,000 per unit, and JDAM precision-guided bombs (response time of minutes to hours, again depending on forward deployment and range) at some \$15,000 per bomb. Of

49. Extensive analysis of such “mass on target,” “kinetic energy,” and “long-rod penetrator” weapons is provided in Preston et al., *Space Weapons, Earth Wars*, pp. 131–171. A striking and limiting assumption of this analysis is that the reentry into the atmosphere must be ballistic and that “for accuracy” the trajectory must be within 30° of the vertical so that the rod falls and does not fly. The consequence of these assumptions is a far more costly system and less accuracy than would be achieved otherwise.

50. Wang Ting, “Analysis of the Feasibility of Long-Rod Penetrator Orbital Dynamics,” personal communication, Beijing University of Aeronautics and Astronautics, July 2004. To achieve no more than an additional ten-minute response time, on-orbit propulsion would be required for each rod capable of reaching 3 km/s. Each rod would need a rocket on-orbit three times its mass, driving up the total system launch cost to some \$66 million (per rod) × 40 (rods) × 3 (mass of rockets), or \$8 billion.

course, it is necessary also to factor in a share of the cost of the multipurpose aircraft deployment to carry these munitions. In addition, submarine-launched ballistic missiles could be fitted with nonnuclear warheads, with attendant shorter flight times from the nearest submarine.

An equivalent destructive effect to dropping rods from geosynchronous orbit could be achieved by placing them (or conventional explosives) on theater-range ballistic missiles, thereby avoiding the cost and difficulty of orbital mechanics altogether. A ballistic missile with range in excess of 900 kilometers provides a reentry speed of more than 3 km/s. To achieve 3 km/s for a short-range missile, the rod could be accelerated by a solid-rocket motor in approximately 10 seconds as it approaches the target. The cost of such a system would be on the order of \$100,000, in addition to whatever terminal guidance system was necessary (although this latter component would surely be no greater for a ballistic missile than for an orbiting projectile).

The Navy Special Programs Office has proposed and initiated work in collaboration with the U.S. Army on a submarine-launched intermediate-range ballistic missile (SLIRBM). This would be launched from one of the guided missile (former Trident) submarines. The guided missile submarine could carry pods of three SLIRBMs in eight of its launch tubes. With a flight time of ten minutes to 2,500-kilometer range, the SLIRBM would carry a GPS receiver supplemented by an inertial navigation system like that of the JDAM bomb. It could maneuver during atmospheric reentry and might be equipped for much more substantial maneuver to provide flexible approach to the target. The GPS target coordinates could be changed in flight, and attack on valuable moving targets might be launched while a UAV was imaging and relaying the actual scene to strike headquarters. One reentry package considered for the SLIRBM is the TACMS-P, which delivers a penetrating warhead at near optimum speed for earth penetration.⁵¹ It would be fitted with GPS guidance.

Any U.S. proposal to introduce nonnuclear ICBMs or SLIRBMs into operational force structures might face political opposition on several grounds. In the public consciousness, ICBMs are still associated—whether rationally or not—with Cold War visions of “bolt-from-the-blue” attacks and nuclear war.⁵² Other Cold War fixtures previously deployed for nuclear weapons, however,

51. Michael Padilla, “Sandia Tests Conventional Weapon Created to Penetrate Hardened, Buried Targets,” *Sandia Lab News*, Vol. 56, No. 9 (April 30, 2004), http://www.sandia.gov/LABNews/LN04-30-04/key04-30-04_stories.html#tacms.

52. See Preston et al., *Space Weapons, Earth Wars*, p. 170, arguing that “ICBM trajectories would be more economical for this class of weapon than space basing if confusion with nuclear-armed missiles can be avoided.”

notably the B-52 and B-2 bombers and air-launched cruise missiles, have been successfully integrated into conventional warfare without serious political opposition at home or abroad. Furthermore, voices from the international community make clear that the same taboo associated with “bolt-from-the-blue” ICBMs would also be conferred on similarly “bolt-from-the-blue” space weapon systems, so an argument against the use of ICBMs in conventional roles does not validate space weapons. In any case we must address realities, not taboos. Most nations will not know that a missile has been launched; those that do might be forewarned that the payload is nonnuclear.

Contrary to the conventional wisdom regarding long-rod penetrators from space, unguided reentry would not have useful accuracy for a nonnuclear warhead. Rather, GPS measurements up to the time of plasma sheath formation, which prevents the reception of GPS signals, combined with the type of inertial navigation system on the JDAM bomb, will suffice to guide the rod to the GPS coordinates of the target, achieving the few-meter accuracy typical of JDAMs. Maneuver can be accomplished by “jet flap” interaction with the hypersonic flow field or by shift in the center of mass of the rod. In this way, much of the 7.4 km/s orbital velocity in LEO can be preserved to impact, and only modest retro-rocket fuel need be on board for prompt reentry—say 2 km/s velocity change, in contrast with 7 km/s to stop the rod in orbit so that it can fall.

Space-based Lasers. Another weapon proposed for fast response times is the space-based laser.⁵³ A constellation of high-powered, orbiting lasers of the appropriate wavelength to penetrate the Earth’s atmosphere could attack terrestrial targets over a range of some 3,000 kilometers. Propagating at the speed of light, the laser beam would reach its target almost instantaneously—in about 0.01 seconds.

Space-based lasers, however, face significant operational barriers. Because the satellite would move with respect to a fixed point on Earth, continuously covering strategically important regions (in clear weather) would require a constellation of several dozen lasers. The lasers would be effective only against a narrow class of targets, such as combustibles, aircraft canopies, and thin-skinned storage tanks. Common military objectives such as bunkers, armored vehicles, and buildings would be basically immune to laser attack. Rudimentary shielding by smoke screens, ablative cork coatings, or even pools of water can provide a substantial and cheap defense for nearly any target. Fur-

53. This discussion draws on *ibid.*, app. A, pp. 109–130.

thermore, space-based lasers could not attack targets under cloud cover—on average 30–40 percent of the Earth’s surface and some 70 percent of the time in parts of Germany or North Korea.

Space-based lasers would be enormously expensive. For a typical proposed laser system at an altitude of 3,000 kilometers, a target protected by 3 centimeters of cork could withstand about twenty minutes of laser burn time before its surface would be exposed to laser heat.⁵⁴ With the orbiting laser consuming fuel at a rate of some 9 kilograms per second, a single twenty-minute “shot” would use 11 tons of fuel. The cost of putting this fuel in orbit would be some \$240 million per target.⁵⁵ At a lower orbit for the lasers, say 1,000 kilometers, allowing a range of 1,500 kilometers, the necessary lasing time per target would drop to five minutes. Fuel costs would fall to \$60 million per target, although a greater number of lasers would then be required to achieve the same terrestrial coverage.

By comparison, a single Tomahawk cruise missile costs some \$600,000, could attack heavily armored and nonflammable targets, would not be affected by clouds, and would be expended only when needed. Nearly the entire surface of the Earth, including North Korea, most of the Middle East, and more than half of China (including its principal industrialized regions), is reachable by Tomahawk Block III cruise missiles.⁵⁶ Launched from outside the 12-nautical-mile territorial limit, cruise missiles would have a flight time of several hours.

Although early selective strike will continue to be an important component of U.S. military capabilities, in light of such cost-equivalent comparisons of a few-dozen space-based, limited-use lasers and a virtual armada of multiuse cruise missiles, even enthusiasts admit that space-based lasers would be a specialist, “leading-edge” tool for attacking a narrow class of targets. They would not replace conventional military means.⁵⁷ The open question is whether mar-

54. This calculation assumes zero loss through the Earth’s atmosphere, a perfect 3-meter mirror, and laser power output of 3 megawatts (MW) in the 3.8-micron DF band producing roughly 200 MJm⁻² energy over the course of twenty minutes.

55. One commonly used estimate for launch cost to LEO is approximately \$10,000 per pound, or \$22,000 per kilogram. See National Aeronautics and Space Administration, fact sheet, “NASA’s Space Launch Initiative: Expanding Access to the Space Frontier,” <http://www1.msfc.nasa.gov/NEWSROOM/background/facts/slisumm.html>. Although for the shuttle this estimate is certainly low, it is a reasonable measure of the cost to orbit using existing large expendable boosters. At 3 kg/s fuel flow per MW of laser output, this figure gives a baseline cost of about \$20 million for the fuel for 100 seconds of 3 MW laser operation.

56. “Cruise Missiles: Proven Capability Should Affect Aircraft and Force Structure Requirements,” GAO/NSIAD-95-116 (Washington D.C.: U.S. General Accounting Office, 1995).

57. Everett C. Dolman, “Inherent Assumptions in the Responsive Space Debate,” paper presented at the National Security and Space Workshop, Naval War College, Newport, Rhode Island, March

ginally increasing the vulnerability of targets susceptible to laser attack (while factoring in the likelihood and low cost of effective countermeasures) is worth the time, effort, and political fallout associated with building a U.S. space-based laser constellation.

DENIED-ACCESS TARGETS. Military analysts predict that the United States will face increasingly robust threats to its ability to access and dominate future theaters of conflict (i.e., to attack targets in those regions). “Denied-access” threats are expected to include basing and overflight problems, anti-aircraft systems, and the deterrent effect of an adversary’s weapons of mass destruction (WMD). The 2001 Quadrennial Defense Review acknowledges the need to address this threat as one of six operational goals for the future development of the U.S. Armed Forces, citing the requirement of “projecting and sustaining U.S. forces in distant anti-access or area-denial environments and defeating anti-access and area-denial threats.”⁵⁸

Recent operations in the Persian Gulf, Kosovo, Afghanistan, and Iraq have demonstrated the importance of establishing and maintaining air superiority. Advocates argue that space weapons would reinforce U.S. battlespace access by enhancing the ability to destroy denied-access threats such as anti-aircraft facilities (including those deep in enemy territory), WMD, and ballistic missile sites. The SLIRBM would be an accurate, quick-response weapon for this purpose, with flexible payload capability.

Space-based Lasers for Defense against Ballistic Missiles. Space-based lasers have been proposed for boost-phase ballistic missile defense, potentially both a denied-access and time-sensitive threat. As intercept would occur at a high altitude, the laser beam would not need to penetrate the Earth’s atmosphere or to correct for beam broadening from dynamically changing atmospheric conditions. But even given the greater relative susceptibility of booster missiles compared to warheads in their reentry vehicles, the laser system would face many of the obstacles discussed above, including the logistical challenges of launching, orbital storage, and refueling, as well as the launch cost of the needed tons of laser fuel. Boost-phase intercept via SBL was beyond the ten-year horizon of the APS Study Group, so we lack the detailed technical analysis analogous to that provided in their report for space-based interceptors. The 2002 RAND re-

1, 2003; and Everett C. Dolman, *Pure Strategy: Power and Policy in the Space and Information Age* (London: Frank Cass, forthcoming).

58. Office of the Secretary of Defense, *Quadrennial Defense Review Report*, September 30, 2001, <http://www.defenselink.mil/pubs/qdr2001.pdf>, p. 30.

port mentioned earlier, however, provides insight into the requirements and capability of an SBL constellation.⁵⁹

Here we examine the number of lasers necessary to defend the United States against a “rogue state” ICBM threat, in this case, four or five missiles launched simultaneously from North Korea. Under highly favorable assumptions, approximately twelve lasers at altitude 3,367 kilometers would be necessary to destroy a cluster of four missiles.⁶⁰ Because the constellation would move relative to a fixed point on Earth, its overall missile defense capability would at times be greater—about six targets. An adversary capable of building ballistic missiles, however, would surely take advantage of the predictable fluctuations of the constellation’s capability, choosing the moment of launch to correspond with the lasers’ minimum coverage. Figure 1 shows the RAND calculations of this case.

Restricting the calculation to more readily achievable laser technology increases the number of required lasers and therefore overall system cost. For example, a constellation of 120 lasers in 550-kilometer orbit, with 10-meter diameter optics, and 1-megawatt power output would be needed to destroy three boosters.⁶¹ These results are for boost-phase intercept, on the assumption that the nuclear warheads once separated from their rocket boosters would be accompanied by decoys sufficiently numerous and effective to preclude attack by the SBL. It might be more productive to use a less-capable SBL constellation to support a ground-based midcourse missile-defense system by “popping balloon decoys,” but that case is yet to be made in the face of feasible counter-measures.

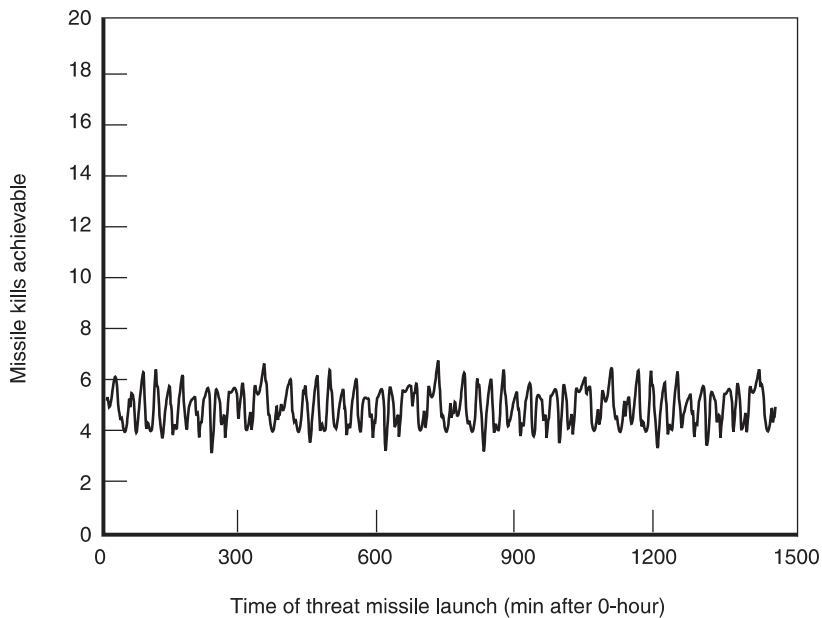
The problem with SBL for missile defense is not the ineffectiveness of an ultimate system, if it can be developed and judged worthy of deployment.

59. Preston et al., *Space Weapons, Earth Wars*, pp. 109–130.

60. Ibid., app. A, “Space-Based Directed-Energy Weapons,” p. 120, Fig. A.8. This assumes hydrogen-fluoride laser power of 35 MW, optical aperture diameter of 10 meters, and orbital altitude of 3,367 kilometers. The target can be engaged at 15-kilometer altitude and burns out in 180 seconds at an altitude of 248 kilometers. For comparison, see Richard L. Garwin, “How Many Orbiting Lasers for Boost-Phase Intercept?” *Nature*, Vol. 315, No. 23 (May 1985), pp. 286–290. This calculation assumes an effective surface area of 164 square megameters, a flat Earth, and maintenance of the laser constellation without coverage gaps. The present calculation is a modification of Cold War context assessments that showed that a 25 MW hydrogen fluoride laser with a 10-meter-diameter mirror in a 3,000-kilometer orbit could destroy a missile booster with hardness 200 MJ/m² in 6.7 seconds, assuming perfect laser pointing and optical performance. For the large number of attacking (Soviet) missiles assumed in this calculation, 251 lasers were necessary to counter 1,400 missiles launched simultaneously in a launch clustered in space and time—the most stressing of possible cases.

61. Preston et al., *Space Weapons, Earth Wars*, Fig. A.9.

Figure 1. Space-based-Laser Kill Capacity, Higher-Altitude Constellation



SOURCE: Bob Preston, Dana J. Johnson, Sean Edwards, Michael Miller, and Calvin Shipbaugh, *Space Weapons, Earth Wars*, MR-1209 (Washington, D.C.: RAND, June 2002), <http://www.rand.org/publications/MR/MR1209/>, Fig. A.8. Reproduced with permission of David Egner, director of external communications, RAND, July 6, 2004.

Rather it is the system's susceptibility to being overwhelmed by large numbers of missiles and the vulnerability of the enormously expensive SBLs to low-cost and relatively low-technology attack—by pellet clouds in LEO and space mines.

Space-based Lasers for Force Projection. Using a space-based laser constellation to attack ground targets would face the logistical and cost barriers described in the time-critical targets section above. Furthermore, any target valuable enough to be protected by air defenses or other denied-access techniques could be fitted with laser countermeasures, including flatbed diffuse reflectors of titanium oxide or other material, ablative shields such as cork or more advanced

ablative materials, dyed water that would absorb energy by boiling,⁶² or low-technology countermeasures such as smoke or fog generators. Naturally, while projected to be inexpensive, the costs of such countermeasures must be considered.

The Spaceplane and Common Aero Vehicles. To address future denied-access threats, U.S. military space doctrine includes proposals for a “spaceplane,” a reusable, unmanned space vehicle providing responsive, launch-on-demand global force enhancement and projection.⁶³ The proposed spaceplane would be armed with a common aero vehicle, a (proposed) small, low-cost, precision-guided missile capable of delivering conventional munitions against an assortment of targets. The CAV would protect its munitions during hypersonic reentry and then dispense them with the same accuracy as if they had been dropped from an aircraft (but with the greater global reach of the orbital spaceplane and without need to obtain overflight permission, as the CAVs would reenter controlled airspace only over the target country). Furthermore, advocates claim that the “spaceplane” will be less internationally provocative because space power projection, like airpower, could be extended when required, and withdrawn when the crisis subsided.

As proposed, a CAV could operate against fixed or mobile targets identified by surveillance data from another platform or, for instance, by laser target designation. CAVs are advocated for use against hard and deeply buried land targets, naval bases and surface combatants, massed forces, mobile targets, air bases, and military and civilian infrastructure, to name a few examples.⁶⁴ Proponents emphasize the advantages of striking from space: global reach from the continental United States, the ability to hit a target anywhere in the world in less than ninety minutes, a means of bypassing denial-of-access air defenses, the lack of a costly “logistics tail,” and eliminating risks to pilots or support staff.⁶⁵

Although the technological and financial validity of such forecasts is the

62. One kilogram of water can absorb two MJ of energy, so a 25 MW laser would boil 10 kilograms of water per second or 1 ton in 100 seconds.

63. Graham Warwick, “USAF Targets 2h Strike Capability,” *Flight International* (Surrey, U.K.: Reed Business, July 8, 2003), p. 6; and ONE TEAM, “The Military Space Plane: Providing Transformational and Responsive Global Precision Striking Power” (Peterson Air Force Base, Colo.: January 2002), http://www.spaceref.com/docs/DOD/military_spaceplane_utility.pdf.

64. Office of the National Security Space Architect, “National Security Space Roadmap” (Washington, D.C.: Office of the Secretary of Defense, U.S. Department of Defense, July 12, 1999), <http://www.fas.org/spp/military/program/nssrm/initiatives/cavmsp.htm>.

65. See Larry G. Sills, “Space-Based Global Strike: Understanding Strategic and Military Implica-

subject of considerable contention, some analysts foresee the development of a functional two-stage-to-orbit space operations vehicle demonstrator within five to ten years.⁶⁶ But even assuming this optimistic timeline, the spaceplane would face the significant logistical barriers and expense of launch, orbital dynamics, and reentry, as compared to nonorbiting alternatives such as unmanned aerial vehicles, cruise missiles, ICBMs, or SLIRBMs.

Alternatives to the Spaceplane and CAVs. Unmanned combat aerial vehicles (UCAVs), which have enjoyed considerable success in recent operations in Afghanistan and Iraq, present one alternative approach to attacking denied-access targets. Against robust air defenses and distant targets, UCAVs offer the important advantage of not risking the life of a human pilot. Several UCAV models are already operational or under development:

- The \$2 million Predator can perform sortie missions up to 563 kilometers from base, loitering over a target for twelve hours and carrying a 318-kilogram payload at altitudes up to 12,200 meters. (The updated “hunter killer” Predator B, at a cost of some \$4 million, is to carry a 1360-kilogram payload at higher cruising speeds.)⁶⁷
- The Global Hawk has maximum round-trip and one-way ranges of 2,400 and 14,000 nautical miles, respectively, with an endurance time of forty-two hours, payload limit of 890 kilograms, and ceiling of 20,000 meters.⁶⁸ It is expected to cost some \$10–\$20 million, not including the ground station.
- The X-45 UCAV (currently under development by the Defense Advanced Research Projects Agency) is expected to carry a 1,500-kilogram payload at medium-to-high altitudes at high subsonic speeds, with a sortie range of 1,300 nautical miles.⁶⁹

tions,” Occasional Paper No. 24 (Maxwell Air Force Base, Ala.: Center for Strategy and Technology, Air War College, August 2001), pp. 7–17, 21; and Terry Torraca, “Space Meets Sand at Lucky Sentinel,” *Military Review*, Vol. 8, No. 6 (November–December 2001), p. 55.

66. For example, the X-40a and X-37 projects are planned second-stage devices capable of fulfilling the Space Operations Vehicle Requirements. Testing of the X-37 is scheduled for 2006. See National Aeronautics and Space Administration, “X-37 Demonstrator to Test Future Launch Technologies in Orbit and Reentry Environment,” <http://www1.msfc.nasa.gov/NEWSROOM/background/facts/x37facts2.html>.

67. David A. Fulghum, “Predator’s Progress,” *Aviation Week & Space Technology*, March 3, 2003, pp. 48–50; and David A. Fulghum, “Predator B to Increase Lethality of UAV Fleet,” *Aviation Week & Space Technology*, November 11, 2002 p. 34.

68. National Aeronautics and Space Administration, “NASA Wallops Flight Facility Unmanned Aerial Vehicles,” <http://uav.wff.nasa.gov/>.

69. “Joint Unmanned Combat Air Systems: J-UCAS Overview,” <http://www.darpa.mil/j-ucas/index.htm>.

Some UCAVs, such as the X-45, are being explicitly designed to defeat enemy air defenses and clear the way for manned aircraft or missiles. The X-45 might also be used for distant force projection, though with relatively slow response (i.e., flight) times of tens of hours. The Global Hawk, with a one-way range of 14,000 nautical miles, could access any point on Earth from a base in the continental United States.⁷⁰ The next-generation Predator B is expected to be capable of significant destructive effect, armed with payloads such as the Joint Direct Standoff Weapon, 500-pound JDAM, 250-pound small-diameter bomb, radar-guided AIM-120 advanced medium-range air-to-air missile, and AIM-9 infrared air-to-air missile.⁷¹

As discussed above, ballistic missiles could provide an affordable (as the United States already possesses a significant surplus), quick-response, and effective near-term alternative to space-based force projection.⁷² Although during the Cold War, hundreds of nuclear-armed ICBMs would have been overkill in destroying an entire country, many thousands of nonnuclear warheads might now be required in even a modest war. If, however, one assumes that space weapons are only for exceptional, “leading edge” targets, then a comparable number of ground-based intercontinental force-projection weapons would have greater capability and responsiveness. Note, in particular, that the long flight time of a UCAV does not imply a similarly long response time to targets of opportunity. If there are many targets to be struck, a steady UCAV presence would be maintained, and targets dynamically tasked by data link to the closest UCAV carrying the proper munitions.

Both nuclear and conventional ground-launched ballistic missiles (and cruise missiles) with ranges of 500 to 5,500 kilometers are banned (for only the United States and Russia) by the Intermediate-Range Nuclear Forces Treaty of 1987, limiting potential platforms to ground-launched ICBMs, aircraft, and submarine-launched ballistic missiles of assorted ranges.

If the existing accuracy of ICBMs, approximately 100 meters, is not adequate

70. National Aeronautics and Space Administration, “NASA Wallops Flight Facility Unmanned Aerial Vehicles Database.” Note that without a destination base at which to land, any flight of such great length would result in the loss of the aircraft.

71. David A. Fulghum, “Predator B to Increase Lethality of UAV Fleet,” *Aviation Week & Space Technology*, November 11, 2002, p. 34.

72. Agence France-Presse, “Pentagon Considering the Use of Conventionally-Armed ICBMs,” *Space Daily*, July 17, 2002; William B. Scott, “Rapid Response,” *Aviation Week & Space Technology*, April 7, 2003, pp. 68–70; and Dagobert Brito, Bruce Bueno de Mesquita, and Michael D. Intriligator, “The Case for Submarine Launched Non-Nuclear Ballistic Missiles,” January 2002, http://www.rice.edu/projects/baker/Pubs/facstudies/Sub_paper2002.pdf.

for precision nonnuclear strike requirements, improvements are possible. Ballistic missiles could be reconfigured to have slower reentry speeds and enhanced terminal guidance systems using GPS or laser designation, improving missile accuracy to the few-meter circular error probable or better achieved by JDAM bombs or cruise missiles.⁷³ Ballistic missiles could be armed with a variety of munitions, including a solid-tipped penetrator payload used as a kinetic energy weapon (effective against hardened targets and shallow bunkers or tunnels if their locations were precisely known); traditional bombs; or non-lethal payloads such as hardening foam, irritating gas, foul-smelling liquid, or an electronics-disabling electromagnetic pulse weapon.⁷⁴

Cruise missiles, as discussed above, could also attack denied-access targets, with speeds in excess of 550 miles per hour and a maximum range of some 1,350 nautical miles. Next-generation Tactical Tomahawks will feature two-way satellite communication, allowing commanders to dynamically retask missiles in-flight to various preprogrammed alternatives or any GPS-designated coordinate. Navy Tomahawks, for example, can carry a range of conventional warheads, including 1,000-pound-class unitary bombs, smaller 700-pound warheads, or a “bomblets” dispenser, capable of deploying munitions in up to three locations. These munitions could be air-burst, detonated on impact, or delay fused for greater depth penetration.⁷⁵

The original U.S. Air Force cruise missiles (ALCM-B, intended to carry nuclear payloads) had a unit cost of about \$1 million, with an additional \$160,000 for adaptation to conventional blast or fragmentation payloads. Upgrading existing Block II missiles to use precision GPS navigation costs approximately \$435,000 per missile, and Block IV Navy Tomahawk missiles cost \$600,000 each.⁷⁶

IN SUM: GLOBAL FORCE PROJECTION. Global rapid and denied-access force projection is possible and will happen without the development of space weapons, through adaptations to existing systems. Except for the unique capability that might be contributed by space-based lasers for a small class of

73. Federation of American Scientists, “Ballistic Missiles Basics,” <http://fas.org/nuke/intro/missiles/basics.htm>.

74. Jamie G. Varni, Gregory M. Powers, Dan S. Crawford, Craig E. Jordan, and Douglass L. Kendall, “Space Operations: Through the Looking Glass,” *Air Force 2025* (Maxwell Air Force Base, Ala.: Air War College, 1996), <http://www.au.af.mil/au/2025/volume3/chap14/vol3ch14.pdf>, p. 36.

75. United States Navy, “Fact File: Tomahawk@Cruise Missile,” <http://www.chinfo.navy.mil/navpalib/factfile/missiles/wep-toma.html>.

76. United States Air Force, fact sheet, http://www.af.mil/news/factsheets/AGM_86B_C_Missiles.html; United States Navy, “Fact File: Tomahawk@Cruise Missile”; and Federation of American Scientists, “AGM-86C/D Conventional Air Launched Cruise Missile,” <http://www.fas.org/man/dod-101/sys/smart/agm-86c.htm>.

targets, terrestrial methods of force projection appear to be superior to space weapons systems, if they were to become a reality at some point in the future. Furthermore, space weapons will be expensive, vulnerable to countermeasures, and politically inflammatory. The question of whether to deploy space weapons, therefore, becomes a matter of marginal value added and opportunity costs. In the near term, nonspace weapons such as UAVs, cruise missiles, and ICBMs with conventional payloads will provide greater capability sooner and at lower cost.

ROLE #4: SPACE WEAPONS FOR DEFENSE AGAINST BALLISTIC MISSILES

In the first three roles for space weapons—protecting U.S. satellites, countering adversary capabilities in space, and force projection—we find little merit in comparison with more readily available terrestrial military tools and tactics. A different issue is that of defense of the United States against hostile ballistic missiles. If properly developed and widely deployed, U.S. space weapons in the form of constellations of dozens or hundreds of powerful orbiting lasers and thousands of orbiting kill vehicles would seem to have significant effectiveness against ICBMs armed with nuclear warheads launched against the continental United States (perhaps even including Alaska and Hawaii).

We have summarized some examples of SBL constellations for destroying in boost phase a few ICBMs launched simultaneously from a small region such as North Korea (or a Russian missile field). We touched only generally on the passive countermeasures that would make boost-phase intercept more difficult. These include light-weight improvements for increasing a missile's resistance to laser beams and rotating the missile during boost to limit temperature rise by spreading the heat over a belt on the booster. An adversary might also choose to deliver nuclear weapons by short-range missile from a ship 20 to 100 kilometers from U.S. shores, which would be much simpler than ICBM delivery and could potentially draw on a large number of Scud missiles of 300-kilometer range. The report of the Commission to Assess the Ballistic Missile Threat to the United States (to be distinguished from the 2001 Space Commission) states: "Sea launch of shorter range ballistic missiles is another possibility. This could enable a country to pose a direct territorial threat to the U.S. sooner than it could by waiting to develop an ICBM for launch from its own territory."⁷⁷ The short burn time and low burnout altitude of the Scud make

77. "Executive Summary of the Report of the Commission to Assess the Ballistic Missile Threat to the United States," 104th Cong., 2d sess., July 15, 1998, <http://www.fas.org/irp/threat/missile/rumsfeld/toc.htm>.

it largely immune to SBL beams. In addition to these passive counters, we have stressed the vulnerability of the enormous and costly SBLs to destruction, especially by space mines.

Space-based interceptors were analyzed in depth by the APS Study Group, whose members included long-time engineering experts on rockets and defenses. The APS group refined existing techniques for bringing the rocket-propelled interceptor's kinetic-kill vehicle into collision with the booster while it is still firing, such that its calculations represent an optimistic picture of the system's capability. Nonetheless, the group found that mass constraints (driven by the cost of putting material in orbit) undermined any inherent advantages the space-based interceptors might have enjoyed in terms of global reach and exo-atmospheric maneuverability.

In sum, the APS study estimates the United States would need some 10,000 tons of material in orbit to deal with the simultaneous launch of five ICBMs from a compact area, and that with only one or sometimes two interceptors per ICBM launch. At \$22 million per ton of mass launched into LEO, this would amount to some \$220 billion for launch costs alone.

For boost-phase intercept, the APS analysis demonstrates that small interceptors (of mass 1,300 kilograms) sometimes proposed for sea-based boost-phase intercept (in the case of North Korea) would not be effective. The study does not preclude, however, the effectiveness of ground- and sea-based high-speed interceptors of some 14-ton launch weight.⁷⁸ Ten ground-based interceptors could provide the same capability as some 8,000 space-based interceptors to counter a clustered launch of five ICBMs. The main point of the APS analysis in comparing SBI to ground-based interceptors is that presence in orbit provides no utility unless the KKV of the SBI is given similar "reachout" and "divert" capability to that needed for a ground-based interceptor.

The APS study shows that to have years of orbital life without drag-makeup propulsion, SBI would need to be based on orbits of 500-kilometer altitude or more. Because ICBMs burn out at about 200-kilometer altitude, the SBI would need not only reach-out but also substantial "reach-down" capability, adding to the mass to be placed on orbit. To reduce the reach-down propulsion requirement, the APS optimization includes an advanced drag-makeup propulsion system and its fuel.

It is well established, however, that it would be trivial to destroy the

78. Richard L. Garwin, "Cooperative Ballistic Missile Defense," November 17, 1999, <http://fas.org/rlg/991117.htm>.

SBIs one by one as the constellation is being built. In contrast to attacks on large, very costly LEO satellites, 1-ton SBI satellites would best be attacked at leisure with a small, low-performance ground-based KKV interceptor, aided by ground-based laser or radar at the planned intercept site.⁷⁹ This intercept is feasible now, but the question is one of incentive and resolve: which nation or combination of nations would have sufficient interest to object to and destroy U.S. SBIs, which would be in orbit in violation of no existing law? At the very least, existing international law would require the state responsible for the destruction of SBIs to repay the United States the cost of the SBI and its launch.⁸⁰

IN SUM: BALLISTIC MISSILE DEFENSE. Space-based weapons for defense of the United States against long-range ballistic missiles armed with nuclear warheads would be ineffective in the midcourse phase, if the nuclear warheads in antisimulation balloons were accompanied by many indistinguishable balloon decoys. Space-based lasers and space-based interceptors are attractive concepts for boost-phase intercept of long-burn-duration liquid-fueled ICBMs, but entail large costs to offset a few ICBMs that might be launched simultaneously from a small area. The SBL provides a billion-dollar target for a small space mine, while the SBI is vulnerable to space mines or, more specifically, to destruction by low-performance ground-based KKV as the constellation is being deployed.

Recommendations and Conclusions

Based on the above analysis of three proposed uses of space weapons—the protection of U.S. satellites, denial of the hostile use of space to adversaries, and global force projection—we find that the utility of space is limited by three main factors: high cost, considerable susceptibility to countermeasures, and the availability of cheaper, more effective alternatives.

The fourth potential role of space weapons—boost-phase missile defense implemented by space-based lasers and space-based interceptors—would in principle be part of a broader program designed to reduce the vulnerability of the United States to nuclear attack. We have noted, however, that states with modest nuclear and missile capabilities have better options than ICBMs carry-

79. Richard L. Garwin, "Brilliant Pebbles Won't Do," *Nature*, July 5, 1990, p. 21.

80. "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies," 1967, <http://www.oosa.unvienna.org/SpaceLaw/outersptxt.htm>, art. 7.

ing nuclear weapons. The deployment of SBLs and SBIs would ultimately provide unique capability against states with large territorial expanse—Russia and China. But these two states have extensive capabilities in space themselves. The deployment of SBLs would surely be countered by the equally legal deployment of space mines. That would be feasible but less affordable for countering a system of thousands of SBIs, and the question is whether the cheaper and surer destruction of these SBIs one by one in peacetime would be undertaken.

Moving from description and analysis, we offer with some hesitation a policy prescription, without the details and evaluation (on, e.g., political, bureaucratic, legal, and diplomatic issues) that would be needed to constitute a compelling argument and a detailed program. An aggressive campaign to prevent the deployment of weapons by other nations might best be implemented as a U.S. commitment not to be the first to deploy or test space weapons or to further test destructive antisatellite weapons. A unilateral U.S. declaration should be supported by a U.S. initiative to codify such a rule, first by parallel unilateral declarations and then perhaps a formal treaty. A treaty would have the added benefit of legitimizing the use of sanctions or force against actions that would imperil the satellites of any state.

The 2001 Rumsfeld Space Commission report recognizes that the well-being and security of the United States, its allies, and partners depend on the promotion and protection of the peaceful use of outer space. In considering the development of its military doctrine for the century ahead, the United States is faced with a decision of significant proportion: how to establish a secure international environment in outer space that will protect U.S. interests, as well as those of its allies and future generations.

A regime that effectively prohibits the deployment of space weapons and the use of destructive ASAT before they can destroy U.S. or other satellites would be a smart, hard-nosed investment in U.S. national security, but would require U.S. leadership. By sacrificing relatively unattractive technical and military options, the United States could move to protect its valuable scientific, civil, and commercial space systems while ensuring the security of crucial U.S. military assets—and the dominant systems and capabilities they enable. Such an approach, more than incidentally, would pay dividends for the entire international space-faring community.