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A HISTORY OF ANTI-SATELLITE PROGRAMS

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More than 5,000 satellites have been launched into orbit and more than 950 still operate today. Because these satellites provide information and other services that are increasingly critical for national security, economic vitality, and human well-being, their owners are increasingly concerned about keeping them safe—for as long as there have been satellites there have been plans for interfering with them.

The act of destroying a satellite can damage the space environment by creating dangerous amounts of space debris. What's more, the impairment or loss of an important satellite, such as one used for reconnaissance, can quickly escalate a conflict or generate other unpredictable and dangerous consequences. And short of an actual attack on a satellite, even the targeting of satellites or the construction of space-based weapons could precipitate an arms race with its own damaging and far-reaching consequences (including the diversion of economic and political resources from other pressing issues, or the hindrance of international cooperation necessary to make progress on important challenges such as nuclear non-proliferation, climate change, and terrorism).

This report briefly describes the major motivations and milestones in the development of anti-satellite (ASAT) weapons, from the years of the first satellites to today.

The Growing Importance of Satellites

In the early decades of the space age, military satellites were used primarily for communications, reconnaissance, early warning of ballistic missile launches, weather data collection, and arms control verification. While they still perform these mainly passive support functions, satellites now play a much more active role in "force enhancement" during wartime: other essential military support tasks such as secure and high-volume unsecured communications, targeting and navigation services, weather prediction, and battle assessment. These applications are pursued largely by the United States, but other countries are increasingly able to use satellites for such active military support as well. Commercial satellites have also expanded in their technical capabilities, now offering capabilities that used to be the sole province of governments, such as high-resolution imagery and secure communications.

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This widening range of services is now essential to our civilian, scientific, and economic life as well as our military operations. For example, while the NAVSTAR/Global Positioning System (GPS) satellite-based navigation system was built by the U.S. military for military purposes, it was soon recognized by President Bill Clinton as a "global utility," benefitting users around the world. Clinton therefore declared in 2000 that the United States would no longer retain the option of "selective availability"—i.e., its prerogative to intentionally degrade the GPS signal's accuracy—so that civilian and commercial users who depend on the service could count on it in the future.

Many countries have space and launch capabilities today, including more than 50 that own satellites or a large share of one. In this new era, the United States has renewed its interest in ASAT weapons, as evidenced not only by political rhetoric[1] but by development, testing, and deployment of the technology as well. China, apparently spurred by Soviet

1 The January 2001 report of the Commission to Assess United States National Security and Space Management and Organization (chaired by Donald Rumsfeld shortly before he became secretary of defense in the George W. Bush administration) specifically called for ASAT technology, stating that, "The U.S. will require means of negating satellite threats, whether temporary and reversible or physically destructive." See *http://www.defenselink.mil/pubs/space20010111.html.*

Photo: iStockphoto.com/loops7

and American ASAT and anti-ballistic-missile (ABM) technology developments in the 1970s and 1980s, began its own research on hit-to-kill technology in the 1980s. Other countries, notably India, have also expressed interest in developing ASAT weapons.

1950s–1960s
Early ASAT and Missile Defense Systems and the Outer Space Treaty

Countries recognized that satellites would have great military value even before any had been successfully launched into orbit. The advantages were made evident by early U.S. reconnaissance satellites, which were developed to maintain intelligence-gathering capability when it became clear that the Soviet Union would eventually be able to prevent American U2 spy planes from flying over its territory.[2]

Thus, the United States and the Soviet Union/Russia have followed parallel and often mutually reinforcing paths toward the militarization of space over the past 50 years. At times, both countries heavily invested in ASAT technologies, but some key diplomatic measures—and the recognition that ASAT weapons were not in either nation's best interest—slowed the drive toward deployment of such weapons. This recognition manifested itself most notably in the Outer Space Treaty (which sets basic principles by which space activities are to be conducted), U.S. congressional constraints on the funding and testing of ASAT weapons, and voluntary Russian moratoria on testing.

Both countries developed ASAT capabilities as dedicated systems and as residual capabilities of systems developed for other purposes. The United States pursued ABM/ASAT systems in part because of a perceived threat of Soviet "orbital bombardment systems,"[3] in which a weapon would be placed into orbit and then accelerated down to Earth in an attack. Because of the limitations of interceptor guidance systems at the time, early U.S. missile interceptors were tipped with megaton-class nuclear weapons—the large lethal range of such a weapon would permit a successful ABM/ASAT attack without precision guidance.

The Soviet/Russian armed forces have had ABM and space defense programs since the 1950s.[4] The Soviet Union began developing a limited missile defense system for Moscow (employing nuclear-tipped interceptors) in the 1960s, and eventually deployed the system after 1977.[5] Moscow's current missile defense system features a different design but continues to use nuclear-tipped interceptors.[6] Although such interceptors could be used against satellites, they have long been recognized as a poor ASAT option, in part because nuclear explosions in space are indiscriminate and would destroy all nearby satellites in their line of sight. In the weeks after detonation, many more satellites would be damaged by the increased radiation in low earth orbits. Use of such weapons (though not their possession) would also violate the Partial Test Ban Treaty (PTBT) of 1963.[7]

During this period the United States gradually modified its position on arms control. In the late 1950s U.S. diplomatic initiatives centered around a ban on all military activity in and through space, which the Soviet Union viewed as a ploy to slow down its superior long-range missile program. But by 1967 both nations were prepared to set out basic principles governing space activity. The United States was eager to have its space reconnaissance

2 The Soviet Union began a diplomatic effort against U.S. satellite reconnaissance by submitting a draft proposal to the United Nations Legal Subcommittee in June 1962 that states, "The use of artificial satellites for the collection of intelligence information in the territory of foreign states is incompatible with the objectives of mankind in its conquest of outer space."

3 President Lyndon Johnson announced in a 1964 speech that, "To insure that no nation will be tempted to use the reaches of space as a platform for weapons of mass destruction we began in 1962 and 1963 to develop systems capable of destroying bomb-carrying satellites." See: Stares, P.B. 1985. *The militarization of space: U.S. policy, 1945-1984.* Ithaca, NY: Cornell University Press, 95.

4 The Soviet space defense program is discussed in detail in: Johnson, N.L., and D.M. Rodvold. 1993. *Europe and Asia in space, 1993–1994*. Colorado Springs, CO: Kaman Sciences Corp., 346-348. And: Podvig, P. (ed.). 2001. *Russian strategic nuclear forces.* Cambridge, MA: MIT Press.

5 Podvig 2001, 416.

6 The United States also deployed a system using nuclear interceptors at Grand Forks, ND, in 1975, but shut it down within months because it was costly and ineffective.

7 The treaty prohibits nuclear weapons tests "or any other nuclear explosion" in the atmosphere, outer space, and underwater.

mission be seen as legitimate, and to protect itself from Soviet space weapons, while the Soviet Union had come to the conclusion that arms control in space worked to its advantage.

Despite concerns that verification would be difficult, the two superpowers signed the Outer Space Treaty (OST) that year. The OST provides that all countries are free to use space for peaceful purposes as long as they respect the interests of other space users and operate in accordance with international law. It does not explicitly prohibit deliberate attacks on satellites or prevent ASAT weapons tests that pose risks to other space users. While the OST bans orbiting nuclear weapons, it does not outlaw the possession of other kinds of space weapons.[8]

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1960s–1970s
Russia's Co-Orbital ASAT Weapon, Development of Bilateral Agreements

Russia's main and only dedicated ASAT system uses a **co-orbital** strategy, in which a weapon armed with conventional explosives is launched into the same orbit as the target satellite and moves near enough to destroy it.[9] When the target satellite's orbital plane passes over the interceptor launch site, the interceptor can be launched into the same plane. Since low-earth-orbiting satellites will only pass over a given launch site twice a day, the average wait time for an opportunity to launch such an attack would be six hours. The 1,400-kilogram Russian Co-Orbital ASAT weapon is designed to approach a satellite, guided by controllers on the ground, within one or two orbits (1.5 to 3 hours). At that time, the onboard radar system guides the interceptor to within tens of meters of the target, then detonates an explosive that damages the target with shrapnel propelled by the explosion.

The initial testing phase of the system began in 1963, and consisted of about seven close approaches or "interceptions," five of which culminated in interceptor detonations and were considered successful by western analysts,[10] confirming the system could work from orbital altitudes of 230 to 1,000 kilometers (km). After a test in December 1971 the Soviet Union apparently suspended testing and declared the system operational in February 1973.

The 1972 Treaty on the Limitation of Anti-Ballistic Missile Systems (hereafter referred to as the ABM treaty) prohibited interfering with either country's "national technical means of verification" of treaty compliance.[11] While not explicitly mentioned, U.S. reconnaissance satellites were chief among these means of verification and Soviet acceptance of these terms was viewed as a tacit confirmation of the legitimacy of such satellites.

Protections began to be formally extended to other types of satellites as well. The Accidents

8 The Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, commonly known as the Outer Space Treaty, has been signed by 100 countries (the latest being North Korea in 2009). It bans weapons of mass destruction from space and stipulates that, "The exploration and use of outer space . . . shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind . . . [and] shall be guided by the principle of co-operation and mutual assistance."

9 During testing, the Co-Orbital ASAT interceptors were launched from the Baikonur launch site in Kazakhstan using the Tsyklon-2 booster. The assumed similarity between the Tsyklon-2 and Tsyklon-3 launch pads imply that the ASAT system could also be launched from the Tsyklon-3 pads in Plesetsk, Russia, 800 km north of Moscow. The target satellites were launched from Plesetsk.

10 Detailed information about the testing program for the Soviet/Russian Co-Orbital ASAT program can be found in: Zak, A. 2008. IS anti-satellite system. Online at *http://www.russianspaceweb.com/is.html*. And: Stares, P. 1987. *Space and national security.* Washington, DC: The Brookings Institution, 85-88.

11 Online at *http://www.state.gov/t/avc/trty/101888.htm*.

Measures Agreement,[12] signed by the United States and Soviet Union in 1971, requires immediate notification to the other party if "signs of interference" with missile warning systems or their related communications facilities are detected. The Hotline Modernization Agreement,[13] signed at the same time, requires the parties "to take all possible measures" to protect the reliable operation of the U.S.-Soviet Direct Communications Link, a system that at the time included Molniya and Intelsat satellites.

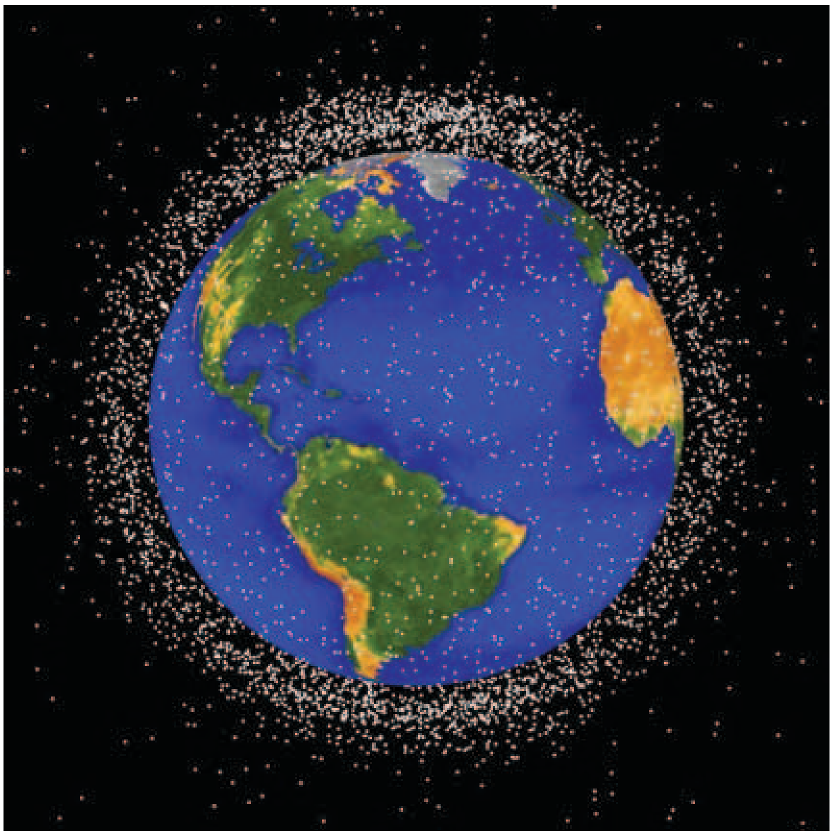

Image courtesy of NASA Orbital Debris Office

Computer-generated image of objects in low earth orbit that are currently being tracked. Only about 5 percent of these objects are functional satellites; the rest is debris. (The dots are not drawn to scale with Earth.)

The Soviet Union resumed testing of its Co-Orbital ASAT system in 1976, with four tests that year and four in 1977. These tests reportedly showed some improvements in the system, extending the altitude at which it could engage to as low as 150 km and as high as 1,600 km, and minimizing attack time by enabling the interceptor to maneuver to its target in a single orbit. Attempts to improve the sensor package with optical and infrared systems are thought to have been unsuccessful, but at the time, the system was considered ready.

From 1978 to 1982, testing of the Soviet Co-Orbital ASAT system continued at a pace of about one intercept a year, and the system remained operational until it was decommissioned in 1993. It is possible the system could be made operational again, but it has not been tested for many years.

In the mid-1970s, the aerospace trade press reported a renewed U.S. interest in anti-satellite technology—an interest largely generated by exaggerated reports of Soviet laser and particle beam ASAT/ABM technology. The U.S. Space Shuttle, which was in advanced development at the time, is rarely considered today as having had an anti-satellite capability, but the Soviet Union objected to the shuttle's ability to rendezvous with a satellite and pull the satellite into its cargo bay.

In summation, both the United States and Soviet Union appeared to be hedging their bets by engaging in anti-satellite arms control talks while also pursuing anti-satellite technology (albeit at a low level).

1980s

U.S. Strategic Defense Initiative, U.S. and Soviet Air-Launched ASAT Systems

In June 1982, the United States announced its intention to test a new-generation ASAT weapon: the Air-Launched Miniature Vehicle (ALMV), which consisted of a two-stage missile launched from an F-15 aircraft flying at high altitude. The missile would ascend to a target satellite in low earth orbit and destroy or disrupt the satellite in a high-speed collision; this "**kinetic kill**" or "**hit-to-kill**" strategy is significantly more challenging technically than the co-orbital strategy (in which the weapon approaches the satellite slowly), but it offers a number of advantages.

First, the ALMV did not place stringent requirements on when an attack could be launched. While a co-orbital ASAT weapon must be launched when

12 Agreement on Measures to Reduce the Risk of Outbreak of Nuclear War Between The United States of America and The Union of Soviet Socialist Republics; online at *http://www.state.gov/t/isn/4692.htm*.

13 Agreement Between The United States of America and The Union of Soviet Socialist Republics on Measures to Improve the U.S.A.-USSR Direct Communications Link; online at *http://www.state.gov/t/isn/4787.htm*.

the satellite's orbital plane is overhead, the range of the F-15 and ALMV allowed considerably more flexibility in which satellites could be engaged and when. Second, the time between ASAT weapon launch and target destruction was significantly reduced. The Soviet Union was reportedly developing a similar ASAT weapon around this time, to be launched from a MiG-31 aircraft, but there is no evidence this project was pursued seriously.

In the spring of 1983, President Ronald Reagan gave his "Star Wars" speech, announcing that he intended to focus U.S. resources on developing a large-scale missile defense system. The Strategic Defense Initiative (SDI) he created was expected to develop several types of space-based interceptors that would have intrinsic ASAT capabilities. Though the systems that emerged from this program are mainly ground-based, small research projects dedicated to space-based missile defense still exist.

The Soviet Union responded to the announcement of the SDI program by restarting research on its own missile defense systems. The Soviets also made diplomatic overtures, proposing a ban on space-based weapons and declaring a unilateral moratorium on ASAT weapons tests.[14]

The United States tested its ALMV system twice in 1984, launching interceptors against empty points in space, not actual orbital or suborbital targets. The first and only test against a satellite was performed in October 1985 when the aging Solwind satellite was destroyed at an altitude of 555 km. This test highlighted in a dramatic way the consequences of destructive ASAT technology: the Solwind satellite generated more than 250 pieces of persistent space debris large enough to be tracked by the surveillance capabilities of the day, as well as 800 to 900 smaller pieces (each at least 10 centimeters across). The last piece of tracked debris from this test finally fell out of orbit in 2002. Such debris, traveling at the same high orbital speeds as satellites, can damage or disable satellites with which it collides.

The U.S. Air Force intended to pursue the ALMV program vigorously, scheduling a number of tests for 1986, but in December 1985 Congress banned further testing of the system on satellites.[15] This decision was made the day after the Air Force sent two target satellites into orbit for its next round of tests. The Air Force continued to test the ALMV, but stayed within the limits of the ban by not engaging a space-borne target.

The next few years were characterized by restraint. The United States renewed its ban on ASAT weapons tests in 1986 and the Soviet Union continued to observe its voluntary moratorium. In November 1987 the White House and Congress agreed to extend the testing ban but allow it to be suspended should the Soviet Union resume its tests. The political opposition to the ALMV system appeared entrenched, and the Air Force ended the program.

The Soviet Union, while honoring its testing moratorium, continued to pursue some missile defense and ASAT research. In 1987, a Soviet attempt to launch what was reportedly an unarmed test platform for a space "battle station" aimed at negating U.S. space-based missile defense failed when the craft could not achieve orbit and fell into the Pacific Ocean. General Secretary Mikhail Gorbachev, who had been unaware of the project until shortly before this launch attempt, refused to fund the program further.[16]

1980s–1990s
U.S. MIRACL and KE-ASAT Systems, Soviet Laser ASAT System

In April 1988 Congress voted against extending the ASAT testing ban, but also rejected a $100 million request by the Department of Defense (DOD) for development of a ground-based ASAT system. The Air Force began plans for other ASAT programs, in particular a ground-based laser system.

While kinetic-kill systems such as the ALMV have certain advantages (usable in any kind of weather,

14 Soviet President Yuri Andropov said Moscow would impose a '"moratorium on such launchings for the entire period during which other countries, including the United States, will refrain from stationing in outer space anti-satellite systems of any type." See: Iams, J. 1983. Andropov says nyet to Star Wars weapons. United Press International, August 18.

15 The ALMV testing bans are included in Public Laws 99-145, 99-661, and 100-180.

16 See: Moltz, C. 2008. *The politics of space security: Strategic restraint and the pursuit of national interests.* Stanford, CA: Stanford University Press, 209.

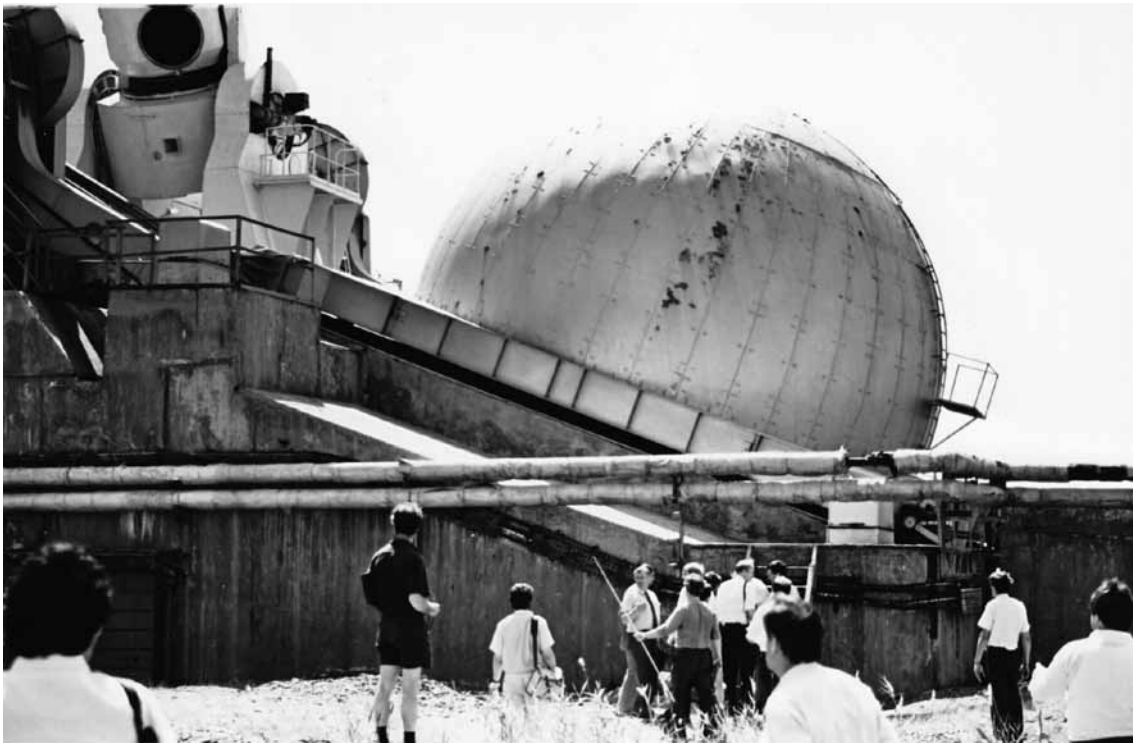

Photo courtesy of Thomas Cochran, Natural Resources Defense Council

In 1989, a U.S. delegation visits the Soviet Union's facility at Sary Shagan, a rumored site of ASAT research and development.

produce an easily observable and verifiable "kill"), they are also likely to produce significant space debris and are easily linked to the source of the attack. ASAT weapons based on **directed electromagnetic energy** (such as lasers or high-powered microwaves) are more limited in range and are vulnerable to poor weather, but produce a great deal less debris and may allow for a covert attack (or at least delayed identification of the attacker). In addition, kinetic-kill weapons are designed to destroy satellites, whereas laser weapons can attack with differing levels of intensity: low-powered lasers can merely "dazzle" (temporarily overwhelm) or "blind" (permanently damage) parts of a satellite's sensor, while high-powered lasers can disable, damage, or destroy a satellite. See the appendix for a more detailed discussion of these weapons systems.

During this period, the Navy coupled its ground-based, megawatt-class Mid-Infrared Advanced Chemical Laser (MIRACL) to the Sea Lite beam director, a large and agile mirror that can direct the MIRACL's beam, at the Army's White Sands Missile Range in New Mexico.

Intelligence reports at this time suggested that the Soviet Union had developed a working laser system that could pose a significant threat to both satellites and ballistic missiles. The Soviet Union's apparent success was given as motivation for further U.S. ASAT technology development. In an effort to provide credible information on the rumored Soviet ASAT work, in July 1989 the Natural Resources Defense Council and the Soviet Academy of Sciences arranged for a U.S. delegation to visit the likely site of this work, the Sary Shagan Laser-Ranging Facility in Kazakhstan.[17] The visiting delegation observed that the facility only hosted low-powered lasers that were struggling to track satellites on a continuous basis, and did not have any adaptive optics that would compensate for blurring of the laser beam by Earth's atmosphere—a crucial technology for any laser ASAT system meant to target the body of a satellite.

Following the revelation that the Soviet laser system posed no significant threat to satellites, Congress included bans on testing the MIRACL laser against an object in space in its defense

17 See: *Science & Global Security*. 1989. A visit to Sary Shagan and Kyshtym. 1(1-2):165.

appropriations bills for 1991 through 1995.[18] The ban on testing the MIRACL laser against space targets lapsed in 1996, and in October 1997 the Air Force commissioned a test using the MIRACL laser and Sea Lite beam director to illuminate a satellite orbiting at an altitude of 420 km. Both the MIRACL laser, which was damaged during the test, and a lower-power (30-watt) laser primarily intended for system alignment and satellite tracking were used. Results of the test are classified, but the DOD did report that the system tracked and illuminated the satellite, and the lower-power laser either temporarily dazzled or damaged the satellite's sensor.[19] Though the Pentagon described the test as defensive (i.e., designed to learn about the vulnerability of U.S. satellites to laser attack), Russian officials expressed concern about the system's offensive capabilities and whether it violated the ABM treaty,[20] and formally requested negotiations on an ASAT weapons ban.

The U.S. Army began speeding up plans for its own ground-based ASAT system, the kinetic-energy ASAT (KE-ASAT)[21] program, during this period. The DOD formally terminated the program in 1993 but Congress resurrected it in 1996, adding $30 million of unrequested funds to its budget, followed by another $50 million in 1997—which President Clinton vetoed—and $37.5 million in 1998.

Despite governmental reviews that said the program was in disarray,[22] Congress authorized an additional $7.5 million in 2000 and $3 million in 2001. No funding was included in the FY 2003 budget and the program's strongest congressional advocate, Senator Robert Smith of New Hampshire, was not reelected in 2002. There appeared to be scant interest in the program outside the Army, and officials from the Air Force—which has primary responsibility for operating military satellites—were openly critical of the program, stating that the risks of damaging friendly space assets with debris generated by the KE-ASAT outweighed its usefulness.[23]

What capabilities from this generation of U.S. ASAT systems remain?

- **ALMV:** Testing of this system was never completed. Air Force officials have expressed a disinclination toward using destructive, debris-generating ASAT weapons, and even DOD advisors in favor of developing ASAT capabilities view weapons like the ALMV as a last resort.[24] Although the Air Force has traditionally been the armed service most involved and interested in ASAT technology, it has not expressed interest in reviving this particular program and has not tested the system against orbiting targets since 1985.
- **KE-ASAT:** As the DOD recommended, the Army and its contractor Boeing continued integration work and environmental compliance tests on three kill vehicles that were to be placed in storage. Program officials believed the George W. Bush administration might be more supportive of the program than the Clinton administration, but acknowledged that there would likely be significant political opposition to flight tests.[25] If they could secure money and support for two flight tests, officials said the system could be readied for deployment within three years—despite the fact that two of the three completed

18 The MIRACL laser testing bans are included in Public Laws 101-510, 102-190, 102-484, 103-160, and 103-337.

19 See: Donnelly, J. 1997. Laser of 30 watts blinded satellite 300 miles high. *Defense Week*, December 8, 1.

20 Russian Foreign Ministry spokesman Gennadi Tarasov stated, "The question arises of how compatible such work is with progress achieved on joint measures to ensure compliance with the ABM treaty. . . . The creation of anti-satellite weapons could sharply change the strategic situation." See: Richter, P. 1997. Russia issues warning after U.S. laser test. *Los Angeles Time*s, October 7, 5.

21 Program number PE 0603892D.

22 See: U.S. General Accounting Office. 2000. *KE-ASAT program review.* Report GAO-01-228R. Washington, DC. December 5.

23 See: Gildea, K. 2001. Space Command chief questions value of KE-ASAT. *Defense Daily*, March 29.

24 A report by the Defense Science Board states, "The task force notes that the authority to employ systems for the 'physical' destruction of an adversary's satellite is not likely when other 'reversible' means for accomplishing the objective are at hand. Only under the condition where the permanent removal of an adversary's space mission capability is in the national interest would the United States destroy a space system, and only then when directed by the National Command Authority." See: Hsu, E. 2000. Science board urges development of anti-satellite capabilities. *Inside Missile Defense*, April 5.

25 See: Gildea, K. 2002. Possible funding boost in FY '04 budget could lead to KE-ASAT flight test. *Defense Daily*, December 17.

kill vehicles had already been dismantled for use in other projects.[26]

- **MIRACL:** This system has not been tested on a satellite since 1997. Although the Army has occasionally fired the laser for routine power tests and continued to improve its ability to use large mirrors for satellite tracking, the MIRACL program has steadily lost financial support. In the late 2000s, the Army drastically reduced its budget for the High Energy Laser Test Facility (HELTF) that serves as MIRACL's home, and proposed mothballing the MIRACL laser itself. At press time, the FY12 HELTF budgetary support documents did not list any MIRACL activities.

In 2011, reports surfaced that a decades-old Russian airplane-based laser ASAT system may have been granted new life.[27] It is unclear what state of repair this system is in, but it is unlikely to be capable of anything more than dazzling or partially blinding the sensors of observation satellites.

2000s
Renewed U.S. Interest in Space-based Weapons and ASAT Capabilities

In the early 2000s, the U.S. government adopted a more aggressive approach to space security and control, drafting documents that envisioned a restructuring of military commands and the development and deployment of ASAT weapons and space-based weapons.[28] In June 2002, the United States unilaterally withdrew from the ABM treaty.

The armed forces and defense agencies were directed to focus and reorganize their space control efforts, and underwent a number of bureaucratic changes. Though no new large-scale ASAT weapon initiatives were funded in the unclassified budget, the United States deployed a satellite jamming system, fielded ground-based midcourse missile defense interceptors (which have the ability to target most low-earth-orbiting satellites), and proposed a space-based missile defense "test bed" that would likely have had residual ASAT capability.

Russia, the only former Soviet republic to retain a government space program, continued to be invested in space, although its military launches decreased while its commercial launches increased. The Russians began considering cooperating with the United States on aspects of missile defense, and both nations continued to respect the ASAT weapons-testing moratorium until the United States destroyed a satellite during a 2008 test.

Development of New Capabilities

The George W. Bush administration increased funding for, and widened the scope of, research and development of space-relevant technologies including improved tracking of space objects, new launch and propulsion technologies, and lightweight sensors and kill vehicles. High-energy laser technology also received a large funding increase; supporting projects included techniques for propagating laser radiation through the atmosphere while tracking a satellite, and decreasing system weight to improve the feasibility of transporting the laser by airplane or launching it into space.

Development of traditional satellite components continued to emphasize smaller size and lighter weight, and the ability to rendezvous closely with other spacecraft without guidance from the ground. While this technology can serve nonintrusive or defensive purposes, it could also enable the development of space mines (small craft that could follow a target satellite then maneuver close enough to either disrupt or destroy it).

Producing deployable offensive or defensive systems using these technologies would take a number of years once an explicit political decision was made to do so. The Bush administration appeared to have high ambitions for such systems, but ultimately gave

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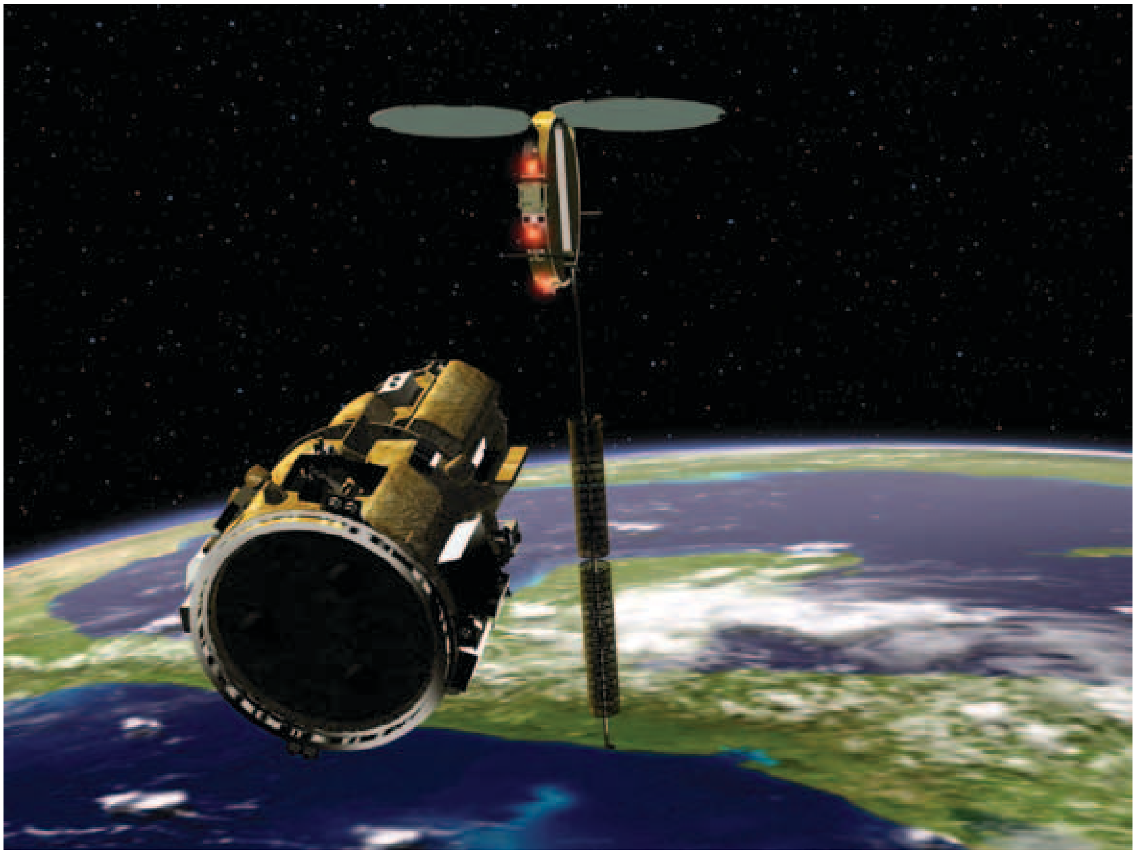
26 See: Hsu, E. 2003. Program officials trying to rebuild support for Army KE-ASAT system. *Inside Missile Defense*, March 5.

27 Podvig, P. 2011. Is Russia reviving an old laser ASAT project? Russian Nuclear Forces blog, May 27. Online at *http://russianforces.org/blog/2011/05/is_russia_reviving_an_old_lase.shtml*.

28 See, for example: Andrews, D.P., et al. 2001. *Report of the Commission to Assess United States National Security Space Management and Organization*. January 11. Online at *http://www.dod.gov/pubs/spaceabout.html*, accessed April 25, 2011. And: Air Force Space Command. 2003. *Strategic master plan: FY06 and beyond*. October 1. Online at *http://www.space-library.com/0312AFSPC_SMP_StrategicMasterPlan.pdf*, accessed April 25, 2011.

Image courtesy of NASA Kennedy Space Center



An artist's conception of the Demonstration for Autonomous Rendezvous Technology (DART) spacecraft as it approaches the Multiple Paths, Beyond-Line-of-Sight Communications (MUBLCOM) satellite.

precedence to other economic and military priorities. The following is a summary of the readiness of these technologies at the current time; see the appendix for a more detailed discussion about the technologies themselves.

Satellite jamming—interfering with radio communications between a satellite and users on the ground—can be attempted with either the uplink (ground-to-satellite transfer of data to be broadcast) or the downlink (satellite-to-ground data transfer), which are more vulnerable than the command-and-control link between ground stations and satellites. In the case of downlinks, the attacker would not actually be interfering with the satellite but with the reception of satellite signals by terrestrial devices.

Both the United States and Russia likely have jamming capabilities that are effective out to geosynchronous orbit, especially against nonmilitary targets, which are relatively unprotected from such attacks. In 2002, the United States deployed the ground-based Counter Communications System, but little is publicly known about the specific capabilities of this or any other system.

Because nonmilitary communications satellites are used by a wide variety of parties, they are likely to be designed with ease of access in mind, rather than protection against interference. The great majority of interference with satellite communications is unintentional, due to factors such as poorly trained operators, but state actors have intentionally jammed foreign satellite broadcasts into their territories a number of times,[29] and non-state actors have jammed commercial communications as well.[30]

Maneuvering satellites—satellites that could approach and potentially touch target satellites without the target's cooperation—could be the basis for

29 In 2003, Iran used a jamming device located in Cuba to block American transmissions from the Telstar-12 satellite into Iran. See: Haeri, S. 2003. Cuba blows the whistle on Iranian jamming. *Asia Times*, August 22. Iran also jammed an Intelsat satellite broadcasting into Iran between 2009 and 2010. See: Baker, L. 2010. EU ministers warn Iran on satellite jamming. Reuters, March 22.

30 The Falun Gong reportedly jammed a Hong Kong-based satellite and broadcast its own message in 2004. See: Xinhua. 2004. Falun Gong hijacks HK satellite. November 22.

ASAT weapons capable of causing temporary or permanent damage using a number of methods. These methods could be low-tech, non-explosive, and not produce debris.

A number of civilian and military actors are developing close-proximity maneuvering technology. For example, the NASA Demonstration for Autonomous Rendezvous Technology (DART) program launched a satellite in 2005 on a short mission to approach a target satellite without assistance from ground personnel. The mission failed when the DART satellite collided with its target.[31] The Air Force, reportedly having more success with its Experimental Satellite System 11 (XSS-11) program, has been developing "rendezvous and proximity operations, autonomous mission planning, as well as other enabling space technologies."[32]

A number of other countries and organizations including Russia, Japan, China, and the European Space Agency have autonomous rendezvous and close-proximity capabilities in various stages of development.

Ground-based lasers can interfere with satellite sensors or damage a satellite's body. Low-powered lasers can dazzle the sensors of high-resolution reconnaissance satellites, inhibiting observation of regions that are kilometers in size. At higher powers, lasers trained on a satellite's sensor can partially blind the satellite by damaging relatively small sections of the sensor. High-powered lasers

An adaptive optics system at the Starfire Optical Range (Kirtland Air Force Base, NM) relies on lasers to help compensate for distortion created by light traveling through the atmosphere, whether that light is incoming (from celestial objects) or outgoing (in the form of laser beams fired from the ground).

Photo courtesy of Directed Energy Directorate, U.S. Air Force

31 See: NASA. 2006. Overview of the DART mishap investigation results. May 15. Online at *http://www.nasa.gov/pdf/148072main_DART_mishap_overview.pdf*, accessed May 1, 2011.

32 See: Air Force Research Laboratories Space Vehicles Directorate. 2005. XSS-11 micro satellite. December. Online at *http://www.kirtland.af.mil/shared/media/document/AFD-070404-108.pdf*.

may also be able to damage a satellite's structure or cause it to overheat if the beam can be held on the satellite long enough.

While ground-based laser ASAT systems do have operational drawbacks, research into relevant technologies likely still continues in the United States and other countries. For example, an Air Force research program at the Starfire Optical Range pairs a large mirror able to track rapidly moving objects (like satellites) with an adaptive optics system that compensates for the atmospheric distortion experienced by an outgoing laser beam. This technology is exactly what would be needed for a ground-based laser ASAT weapon. In fiscal years 2004 to 2007, the program's stated objective was to "Perform atmospheric compensation/beam control experiments for applications including antisatellite weapons, relay mirror systems, satellite tests and diagnostics, and high-resolution satellite imaging." When pressed on the use of the system as an ASAT weapon, however, the Air Force claims that the technology has no specific purpose.

In 2006, reports surfaced that China had illuminated a U.S. satellite with a ground-based laser, perhaps more than once. While the details and purpose of the incidents were unclear, it is certain that China (and many other countries) have the capability to track satellites using low-power ground-based lasers, since this practice is the basis of laser ranging (bouncing laser signals off a cooperating satellite to make precise measurements of Earth's gravitational field, the movements of continental plates, etc.).[33] The International Satellite Laser Ranging effort consists of 40 stations in 23 countries performing such measurements on a set of approximately 30 dedicated, cooperative satellites; this equipment could be used—without permission—to illuminate satellites that are not part of the network.

X-37B space plane. The concept of a "space plane"—a craft that can return from orbit and land autonomously on a runway—has been under development in different forms for many years in the United States, with research shifting back and forth between civil and military oversight. In April 2010, the Air Force launched a prototype, the X-37B, which stayed in orbit for the better part of a year. A second prototype was launched in March 2011.

Because the Air Force has declined to discuss the program's budget publicly or provide a detailed explanation of its objectives, some observers have inferred that the X-37B has a specialized military purpose and is perhaps an ASAT or space-based weapon testbed. However, the space plane is not particularly well suited to these missions compared with other alternatives.[34] Because it requires extra structure such as wings and heat shielding to withstand the rigors of re-entry, the space plane is significantly heavier than it would be if it were not designed to return to Earth. This extra mass makes the space plane more expensive to launch and more difficult to maneuver in space. Other systems that do not require a return to Earth can be used to accomplish ASAT-related tasks such as carrying payloads into orbit, maneuvering in space, rendezvousing with satellites, and releasing multiple payloads—at a much lower cost.

ASAT Capabilities of U.S. Missile Defense Systems

Because missile defense systems are intended to destroy ballistic missile warheads, which travel at speeds and altitudes comparable to those of satellites, such systems also have ASAT capabilities. Furthermore, while these systems might not prove effective against ballistic missiles (because of countermeasures deployed by the missiles, etc.), they could be far more effective against satellites.[35]

In many ways, attacking satellites is an easier task. Satellites travel in predictable orbits that ground facilities can accurately determine. An attacker could plan the time of the attack in advance, and would be able to take as many shots as necessary to destroy the target, without having to deal with the same

33 See: Butt, Y. 2009. Effects of Chinese laser ranging on imaging satellites. *Science and Global Security* 17:20–35.

34 For a more detailed analysis, see Grego, L. 2010. Upcoming X-37B test: What can a "space plane" do? All Things Nuclear blog, April 15. Online at *http://allthingsnuclear.org/post/523923159/upcoming-x-37b-test-what-can-a-space-plane-do.*

35 For a more detailed account, see: Wright, D., and L. Grego. 2003. Anti-satellite capabilities of planned US missile defense systems. *Disarmament Diplomacy* 68: December 2002–January 2003. Online at *http://www.acronym.org.uk/dd/dd68/68op02.htm*.

Photo courtesy of Missile Defense Agency

An Aegis SM-3 ballistic missile interceptor is launched from the U.S.S. Hopper. A similar missile was used to destroy a nonresponsive U.S. satellite in 2009.

countermeasures a midcourse missile defense system would face.

The Ground-based Midcourse Defense (GMD) interceptors deployed at Fort Greely in central Alaska and at Vandenberg Air Force Base in California each consist of a three-stage rocket booster that carries a kill vehicle into space. The kill vehicle, which is intended to intercept its target above the atmosphere, carries its own fuel for maneuvering as well as an infrared sensor. The sensor allows the interceptor to home in on the target and destroy it by direct impact. If launched against satellites in low earth orbit, the interceptor could use some of its fuel to reach out laterally over thousands of kilometers, allowing it to hit satellites in orbits that do not pass directly over the launch site—placing a large fraction of satellites in low earth orbit within range of the GMD interceptors.

In February 2008, the United States demonstrated the ASAT capability of its Aegis sea-based missile defense system by destroying a nonresponsive U.S. satellite at an altitude of 240 km. U.S. officials said this task required a software modification, but other countries may assume this change could readily be made again to give any Aegis interceptor the ability to intercept other satellites. Officials also stated that the U.S. GMD and Terminal High Altitude Area Defense (THAAD) interceptors have similar capabilities.

The Aegis missile defense system may also give other countries ASAT capabilities. For example, Aegis interceptor technology is being co-developed and operated by Japan, and the United States is expected to eventually sell the system to several European countries and South Korea.

The U.S. Airborne Laser (ABL) program, whose goal is to create a megawatt-class laser small enough to be carried in an aircraft and powerful enough to destroy missiles during their boost phase, could also be used to attack and damage satellites at low altitudes. Since the ABL would be fired at missiles above the aircraft carrying the laser, it would also be able to fire upward at satellites.

As with ballistic missile interceptors, the ABL may be more useful in an ASAT role, due to the aircraft's vulnerability to attack and the possible use of countermeasures such as protective coatings on the missiles, which could thwart the laser.[36] Since the aircraft does not have a fixed location on the earth, it would be able to move to a location optimal for attacking a specific satellite at a given time. However, in late 2011, the Missile Defense Agency announced it would be shuttering the program.[37]

36 For a detailed technical analysis of the ABL, see: Stupl, J., and G. Neuneck. 2010. Assessment of long range laser weapon engagements: The case of the Airborne Laser. *Science and Global Security* 18:1–60.

37 See: Butler, A. 2011. Lights out for the Airborne Laser. *Aviation Week*, December 2.

2000s
China's Direct-Ascent ASAT Weapon

In January 2007, China used a mobile ground-based missile to launch a homing vehicle that destroyed one of its aging weather satellites via direct impact.[38] This destructive ASAT test, the first by any country in 20 years, caused a great deal of international concern because it created more persistent debris than any previous event in space. China had been developing this "hit-to-kill" technology since the 1980s as both an ASAT weapon and ballistic missile defense, and it also likely provided the basis for China's first ballistic missile defense test in January 2010. Since that test was conducted against a suborbital target, it left little if any persistent orbital debris.

Because missile defense systems are intended to destroy ballistic missile warheads, which travel at speeds and altitudes comparable to those of satellites, such systems also have ASAT capabilities.

2000s
India's ASAT Weapon Ambitions

In a January 2010 televised press briefing, the director-general of India's Defence Research and Development Organisation announced that India was developing a hit-to-kill ASAT system based on a laser sensor and exo-atmospheric kill vehicle originally planned for ballistic missile defense purposes.[39]

2000s
Diplomatic Efforts

The prevention of an arms race in outer space (PAROS) has long been on the agenda of the Conference on Disarmament (CD), the primary international body through which arms control treaties are negotiated. An ad hoc working group on PAROS was established in 1985 and continued to meet through 1994, though it made little progress. Because of the consensus rules guiding the CD, all participating states need to agree on its program of work, and since 1996, the CD has been unable to reconvene any of its ad hoc groups or to begin formal discussions or negotiations on any subject.

PAROS has also been a goal of the United Nations General Assembly. Each year since 1983, its First Committee has passed a resolution affirming efforts to achieve PAROS—despite the United States' eight separate "no" votes (most recently from 2005 to 2008) and abstentions on every other vote.

In 2006, the United States added a provision to its National Space Policy opposing the development of any new legal regimes or other mechanisms that would restrict U.S. access to or use of space, including any arms control proposals that would impinge on military space acquisitions or operations. Such categorical rejection of international efforts to address space security issues, however, runs counter to U.S. interests: by forgoing the possibility of new mutually agreed-upon rules or constraints, the United States limits its options rather than keeping them open. Without constraints on ASAT weapons, for example, threats to satellites will continue to proliferate and mature, leading to less predictability and stability in crises and forcing the United States to expend more effort in securing satellites.

In 2008, Russia and China presented to the CD a draft Treaty on the Prevention of the Placement of Weapons in Outer Space[40] based on elements from a working paper originally presented in 2002. The treaty would place important limits on the use of ASAT weapons, but offers little to slow their development or deployment.

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38 For more detail, see: Kulacki, G., and J.G. Lewis. 2008. Understanding China's antisatellite test. *Nonproliferation Review* 15(2).

39 See: de Selding, P.B. 2010. India developing anti-satellite spacecraft. Space.com. January 11. Online at *http://www.space.com/7764-india-developing-anti-satellite-spacecraft.html*, accessed May 1, 2011.

40 The full text of the treaty can be accessed at *http://www.reachingcriticalwill.org/political/cd/papers08/1session/Feb12%20Draft%20PPWT.pdf*.

The draft EU Code of Conduct provides a good starting point for developing norms about how responsible space users should act. It represents a modest step forward in improving the safety of space operations and protecting the space environment, as well as setting the reasonable expectation that space assets should not be a target of aggression.

Signatories of the treaty would agree:

- Not to place weapons of any kind in orbit
- Not to resort to the threat or use of force against space objects
- Not to encourage or assist other states in participating in such activities

The major omissions in the treaty include:

- No prohibition on developing, testing, and deploying ground-based ASAT weapons
- No restriction on dual-use satellites that could serve as weapons
- No provision for verification

The proposal was not well received by the United States, which offered a critique but no counter-proposal.[41]

The Obama administration, as stated in its National Space Policy of June 2010, indicated greater openness to diplomatic processes at the CD and elsewhere:

> *The United States will pursue bilateral and multilateral transparency and confidence-building measures to encourage responsible actions in, and the peaceful use of, space. The United States will consider proposals and concepts for arms control measures if they are equitable, effectively verifiable, and enhance the national security of the United States and its allies.*

While this policy dropped the categorical opposition to arms control proposals that characterized the 2006 policy, it did not suggest the United States would take an active leadership role in drafting and submitting proposals. In line with this weak support for negotiated agreements, the U.S. deputy assistant secretary for arms control, verification, and compliance stated that the United States continued to support a "nonnegotiating" discussion at the CD should a program of work be adopted.

In lieu of formal treaty processes, various groups have attempted to create non-binding, voluntary practices to improve space security, such as the Stimson Center's Code of Conduct for Responsible Space-Faring Nations.[42] Voluntary agreements are sometimes easier to negotiate and less constraining, but formal legal agreements have the important benefit of being binding and more durable than informal agreements. They can also include more extensive and effective verification mechanisms, and often establish a body with the legal authority and resources to resolve disputes.

In 2010, the European Union developed a draft Code of Conduct for Outer Space Activities[43] and began consulting with potential signatories, who would be responsible for preventing harmful interference with space objects and refraining from intentional damage to satellites (except to prevent debris or for reasons of self-defense or safety). Development and deployment of ASAT weapons would not be constrained, but their use would be prohibited except under the circumstances mentioned above.

The draft EU Code of Conduct provides a good starting point for developing norms about how responsible space users should act. It represents a modest step forward in improving the safety of space operations and protecting the space environment, as well as setting the reasonable expectation that space assets should not be a target of aggression. In January 2012, the United States announced that in lieu of signing the EU code, it would work with the European Union and other nations to develop an International Code of Conduct for Outer Space Activities.

41 The text of the U.S. critique can be accessed at *http://www.reachingcriticalwill.org/political/cd/papers08/3session/CD1847.pdf*.

42 See *http://www.stimson.org/books-reports/a-code-of-conduct-for-responsible-space-faring-nations*.

43 See *http://register.consilium.europa.eu/pdf/en/10/st14/st14455.en10.pdf*.

Appendix: ASAT Technologies

This appendix provides a more detailed description of some of the ASAT technologies discussed above, including specific advantages and disadvantages.[44]

Satellite Jamming

Because the equipment required for jamming is so similar to legitimate satellite communications equipment, jamming is not particularly demanding technically. To jam a downlink signal from a GPS satellite, for example, one must simply be able to produce a similar signal with sufficient intensity to overwhelm the legitimate signal. Since GPS satellites orbit at an altitude of about 20,000 km, the ground-based jammer has a decided advantage because it is much closer to the downlink signal's destination (ground-based receivers), and no interference with the satellite itself is required. Of course, the location of the jammer would quickly be revealed, opening it up to counterattack.

Jamming a satellite's uplink signal is more complicated, as the attacker does not have the distance advantage that a downlink jammer has, and must know the direction and receiving frequency of the targeted satellite transponder in order to overwhelm the signal. Since communications satellites have a number of users, all operating at different frequencies, the attacker needs to know which frequency to target—or use enough power to jam a range of frequencies (and risk jamming other users unintentionally). As mentioned earlier, the command-and-control uplink for satellites is well protected in all cases (though if the computer providing command and control is connected to the Internet, a hacker may be able to gain control of the satellite without interfering with the link itself).

Jamming attacks have the advantages of being relatively difficult to attribute compared with other ASAT technologies, do not add debris to the space environment, and are temporary and reversible. However, it can be difficult for the attacker to confirm the success of such attacks.

Techniques exist to counter jamming, such as encryption and rapid, unpredictable frequency changes, but these can reduce the rate at which information is communicated.

Maneuvering Satellites

A satellite that could approach a target satellite closely, without the target's cooperation, may have some advantages as an ASAT weapon. The weapon it uses would not necessarily require technical sophistication or long range or large mass, and it could produce no debris. A small maneuvering satellite could also be relatively covert. For example, a small ASAT weapon's presence could be disguised by launching it along with a legitimate satellite instead of by itself. Because it would not rely on high relative speeds to inflict damage, it could slowly maneuver into place near its target. Such a weapon could be placed into orbit at any time, avoiding concerns about the ability to launch promptly in a crisis (due to factors such as poor weather or suppression of launch capabilities by another nation).

On the other hand, if these objects are identified as ASAT weapons they would be vulnerable to attack. And because satellite reliability degrades over time, the owner of such weapons will have decreasing confidence in their performance after they have been placed in orbit.

Ground-based Lasers

Directed-energy weapons using laser beams have a number of desirable characteristics for an attacker: the energy reaches its target rapidly (at the speed of light), and can be adjusted to produce either temporary, reversible effects or permanent, debilitating damage. In terms of disadvantages, directed-energy weapons can only reach targets in their line of sight (unless relay mirrors are used), and satellites can be defended effectively from them using simple shields of reflective, absorptive, or conductive material.

Lasers are particularly useful for directed-energy attacks because they can emit a large amount of

44 For even more technical detail, see: Wright, D., L. Grego, and L. Gronlund. 2005. *The physics of space security: A reference manual.* Cambridge, MA: American Academy of Arts and Sciences.

energy in a narrow beam and a narrow band of frequencies. In principle, this should allow the attacker to direct energy toward the ideal spot on a satellite—and at the proper frequency—for inflicting damage; in practice, however, the frequencies that can be used are constrained by the available technology and other considerations such as the need (with ground-based lasers) to choose a frequency that can penetrate the atmosphere.

A laser ASAT system also requires a tracking and pointing system. A movable mirror, for example, can be used both to focus the beam and direct it toward the satellite.

Remote-sensing satellites that take high-resolution images of the ground have strategic and tactical importance that makes them attractive targets for ASAT weapons. Temporarily interfering with the sensor a satellite uses for such imaging is called **dazzling**. Just as a satellite's receiver can be overwhelmed by a jamming signal, a satellite's optical sensor can be overwhelmed by a light source brighter than what it is trying to view.

Dazzling can be achieved with low-power lasers that are widely available commercially.[45] However, the mere ability to generate a low-power beam does not necessarily mean an attacker can stop a satellite from viewing objects on the ground. Because imaging satellites typically carry multiple detectors and filters, an attacker wanting to dazzle large sections of every detector must know the frequency band of each filter, and have a laser operating within each of these bands. The attacking lasers would also need to be in the field of view of the satellite sensor being targeted.

At sufficiently high intensities, laser light can permanently damage an imaging satellite's sensor—damage referred to here as **partial blinding**, since such an attack will damage only a portion of the sensor. Like dazzling, a blinding attack would need to be mounted from within the sensor's field of view; unlike dazzling, however, the laser only needs to be within the field of view for a short time. The power needed for partial blinding is higher than for dazzling and depends on the size of the tracking mirror used, but commercial lasers are capable of damaging sections of a detector tens of meters across. A high-power laser can also disable a satellite if the beam can be held on the satellite long enough to cause overheating or structural damage.

Lasers become larger and more complicated as their power increases, since they require large power supplies, cooling, and, in some cases, exhaust systems. The MIRACL laser, for example, is fueled by a chemical reaction similar to what occurs in rocket engines, and requires the support of a large facility. Building an ASAT weapon from a high-powered laser also requires mirrors and other optics able to handle these high power levels, and a ground-based system must compensate for atmospheric effects that tend to spread a laser's energy over a larger area, compromising its effectiveness. In other words, developing a high-powered, ground-based laser ASAT weapon would require a serious investment of both money and expertise.

45 For more information on the power needed to dazzle, blind, or damage satellites, see (for example) Section 11 and Appendix A in Wright, Grego, and Gronlund 2005.

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- *Securing the Skies: Ten Steps the United States Should Take to Improve the Security and Sustainability of Space*
- UCS Satellite Database: a free database of all operational satellites currently in orbit around Earth, revised quarterly

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