PROTECTING OUR MILITARY SPACE SYSTEMS

Steve Fetter

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OVER THE LAST 25 years the United States has become increasingly dependent on space-based systems to support its military forces, and this trend is likely to continue for some time. Satellite systems have become an integral part of nuclear deterrence by providing strategic warning of an attack, tactical warning of missile launches, reliable communications between command authorities and nuclear forces, and nuclear explosion detection. Satellites also aid in conventional war-fighting by providing accurate reconnaissance, intelligence, weather, and navigation information.

Current and future anti-satellite (ASAT) weapon technologies are capable of preventing many of our space systems from carrying out their missions, thereby possibly decreasing the stability of nuclear deterrence and weakening the effectiveness of conventional forces. This paper evaluates a broad range of policy options that could help to protect our space assets. It is found that although unilateral measures could go a long way toward safeguarding satellite systems, bilateral agreements are also necessary if we are to guard against the full range of ASAT threats without generating dangerous instabilities.

WHICH SATELLITES TO PROTECT?

Not all satellites are equally important to our national security. The United States currently performs four basic types of military missions with satellites that are of interest here:[i]

Communications. About a dozen satellites, grouped in four satellite systems, are used for military and diplomatic communications. Except for two satellites that relay messages to the polar regions, all U.S. military communication satellites are in geostationary orbit (GSO) 36,000 km above the surface of the earth.[ii] In addition to the systems already in use, an advanced, inter-service satellite communications system called MILSTAR

(Military Strategic and Tactical Relay) is now under development, with deployment planned for the early 1990s. The MILSTAR system, which will consist of a half-dozen satellites in inclined geosynchronous orbits, is intended to provide command and control communications at all levels of conflict, including general nuclear war.

Navigation. The U.S. has two military navigation satellite systems: Transit and NAVSTAR. Transit, which travels in low earth orbit (LEO) at an altitude of about 1,000 km, was developed to aid in the navigation of Polaris submarines. The much newer NAVSTAR system, when complete, will consist of 18 satellites 20,000 km above the earth. Radio signals emitted from the navigation satellites can be used by special receivers on the earth to obtain very accurate position and velocity information.

Meteorology. Two DMSP (Defense Meteorological Satellite Program) satellites in LEO process visible and infrared images of the earth to provide information on cloud cover, temperature, and precipitation world-wide.

Reconnaissance and surveillance. Under this broad category are grouped several systems that observe electromagnetic signals reflected or emitted from objects on earth. These systems serve different missions: attack warning, nuclear burst detection, photoreconnaissance, and electronic surveillance. Attack warning is provided by three DSP (Defense Support Program) satellites in GSO that detect the infrared emissions of missiles as they are launched. Sensors on two dozen satellites, including those in the NAVSTAR system, can detect and locate nuclear explosions. Photoreconnaissance and electronic surveillance are highly classified programs, but it can be said that a small number of photoreconnaissance satellites travel in LEO, sometimes at altitudes less than 200 km, to obtain high-resolution photographs for use in treaty verification and intelligence.

The Soviet Union uses satellites to perform the same missions, but there are three important differences between U.S. and Soviet satellite systems that should be noted here: (a) Soviet satellites have shorter lifetimes, (b) the U.S.S.R. has more single-purpose satellites, and (c) the Soviets have a large number of satellites in Molniya (highly-elliptical) orbits instead of in GSO. The first two factors combine to give the U.S.S.R. a launch rate five times greater[iii] and a total constellation size nearly twice as great[iv] as the U.S. This does not mean, however, that the U.S.S.R. has an advantage over the U.S. in space capability. Although it may be true that the Soviets can reconstitute satellite systems more quickly in the event of their destruction by ASATs, it is not clear how valuable this would be in an actual conflict (see below).

The third factor may make it more difficult for the Soviets to protect their satellites, because satellites in Molniya orbits pass much closer to the earth than satellites in GSO, and therefore are much more vulnerable to ASATs based on earth.

Which satellite systems need protection most? This question is most easily answered when considering systems that are vital to nuclear deterrence, since increasing the stability of deterrence is clearly in the interests of both sides. To the extent that deterrence depends on both sides having tactical warning of an attack, it is especially important that both sides have confidence in the security of their attack warning satellites. Although attack warning is also provided by ground-based radars, satellites can detect missile launches 15 minutes earlier, doubling the time available for decisions and relaxing the need for a hair-trigger response. More important, without attack warning satellites we would have to rely solely upon radars—there would be no independent confirmation that an attack was underway.

The ability to communicate orders to surviving nuclear forces is also essential to deterrence. At present, the weak link in deterrence is not so much the likelihood that sufficient nuclear forces would survive, but rather the likelihood that the ability to command them would remain after a first strike. To the extent that the ability to maintain continuous communication between the National Command Authority and strategic and tactical forces depends on communication satellites (and the geographically dispersed nature of Western forces virtually requires their use), safeguarding these satellites is essential.

Turning to other military space missions, two appear important, but not essential to deterrence. Navigation satellites successfully targeted during a nuclear war would deny U.S. bombers and submarines accurate guidance information for the destruction of hard, or especially well-defended, targets, but this information would not be required in order to destroy most military, industrial, and population centers. Satellites capable of detecting nuclear bursts may also be tempting targets, since they could be used to assess the success of a U.S. strike or the damage from a Soviet strike. But navigation and nuclear burst detection are clearly less vital missions in the maintenance of deterrence.

Meteorological satellites, while very valuable in peacetime and during conventional wars, are less important to nuclear deterrence. Photoreconnaissance satellites are similarly valuable in peacetime, to monitor compliance with arms control treaties, and during conventional wars and crises. But they may become threatening during nuclear war since they could locate surviving forces for retargeting. If necessary, such missions could be performed adequately by aircraft or fractional-orbit satellites in wartime.

Of the missions performed by satellites now in orbit, attack warning and communications are the most essential for maintaining confidence in nuclear deterrence. We should on that count endeavor to ensure their survival, perhaps even if, to do so, we must accept agreements that help ensure the survival of the same functions for the other side. Safeguarding these systems should be in the interests of both sides, since increasing confidence in their survivability increases the crisis stability of nuclear deterrent forces, thus making preemptive or inadvertent war less likely.

With respect to conventional war, it is much more difficult to determine which satellites should be protected. Attack warning, strategic communications, and nuclear burst detection are irrelevant (unless one is planning to escalate the conflict to the nuclear level). On the other hand, tactical communications, navigation, meteorological, and reconnaissance satellites can aid both sides substantially in targeting enemy forces. The latter systems are force multipliers, and each side will naturally seek to preserve its own capabilities while denying such capabilities to the other side.

The following discussion focuses primarily on protecting U.S. satellites critical to nuclear deterrence, such as attack warning and communications. These are the systems for which bilateral agreements are most likely to succeed. It should be noted, however, that technology developed to attack other systems could threaten these critical satellites, although the high orbits of attack warning and communications satellites serve to make attack on them much more difficult, time consuming, and costly.

THE ASAT THREAT

In the broadest sense, an anti-satellite (ASAT) weapon system is any type of weapon system that can be used to interfere with the mission of a satellite. This includes not only damaging or destroying satellites, but also jamming communications and destroying ground facilities. This paper considers only satellite destruction, however, because the latest communication satellites (e.g., MILSTAR) are virtually jam-proof,[v] and because ground stations can be made much less vulnerable than satellites through proliferation and mobility. This section examines the capabilities of current anti-satellite weapon systems and some others that may be possible in the future.

Earth-based ASATs

All of the current weapon systems that have potential or inherent ASAT capability are based on earth. Earth-based ASATs have the primary advantages of being larger, less vulnerable, and much cheaper to construct and maintain than ASATs based in space. They have the disadvantages of being far from targets in GSO, and of having to cope with the limitations imposed by the earth's atmosphere. The two primary types of ASATs are missiles and directed-energy weapons.

Missiles

Ground, sea, or air-launched missiles can be used to attack satellites provided that their range is sufficient to reach the satellite orbit in question. This includes not only missiles intended for ASAT use, such as the U.S. air-launched ASAT now in development or the Soviet ground-launched ASAT (both of which are only capable of attacking satellites in LEO), but also nuclear-armed intercontinental and submarine-launched ballistic missiles (ICBMs and SLBMs) and the Sprint and Galosh anti-ballistic missiles (ABMs).

With modifications that could be developed and tested in a few years, such as a lighter payload, proper fusing, or an additional rocket stage, ICBMs, SLBMs, ABMs, and current ASATs could destroy satellites in GSO. These weapons could use nuclear warheads of various yields or conventional homing warheads. ASATs using nuclear warheads have a damage radius ranging from tens to thousands of kilometers, depending on the yield of the weapon and the hardness of the target satellite, but they could also damage unhardened friendly satellites. Conventional warheads would have to come much closer to the target—within at least one kilometer—in order to be effective.

The speed of such missiles is on the order of ten kilometers per second, so it would take at least an hour to reach attack warning and communication in GSO. In the case of conventional warheads, mid-course update and terminal homing guidance would be required for adequate accuracy. More sophisticated space tracking systems than those currently in use would probably also be required. Any attack on satellites in GSO with earth-based missiles would be detectable by attack warning satellites, since the rocket boosters required to reach high altitudes are very large. There would be sufficient time to discover the purpose of the missile and alert the nuclear forces, hence fulfilling at least some of the attack warning and communications missions of the satellites. Because they are slow and detectable, earth-based missiles probably do not represent the most dangerous threat to satellites in GSO.

The situation for satellites in LEO is quite different. Earth-based missiles can reach satellites orbiting 200 to 1000 km above the earth in a few minutes, and guidance technologies have already been proven effective enough to use conventional warheads (or no warhead at all, by striking the satellite directly) at these distances.

Directed-energy weapons

Ground-based high-energy lasers (HELs) of certain wavelengths could destroy satellites through heating or shock. HELs have the advantage of delivering energy fast—only a tenth of a second is needed to reach GSO from the ground—and the disadvantages of being large and inefficient in terms of the amount of energy required to destroy a target. Several types of HELs (chemical, free-electron, and excimer lasers) under development are potential earth-based ASAT weapons.

Much has been said about the destructive potential of HELs against space objects, but it is important to note the differing requirements for damaging one unhardened satellite under test conditions, and attacking hardened satellite systems during war. Although a high-quality one megawatt ground-based laser, which may feasible in the next few years, could damage or destroy unhardened satellites in GSO by irradiating them for tens of minutes, this does not mean that effective ASATs could be based on such lasers. An actual attack against a hardened communications satellite system, for example, would require the certain destruction of several satellites in less than a minute. A laser weapon capable of this task would emit at least a hundred megawatts of power. It is likely to take some time to develop such large lasers, and even then it may prove impossible to transmit such large amounts of power through the atmosphere. At least five such lasers located around the world would be needed to provide continuous coverage of all GSO satellite targets.

As noted above, however, satellites in LEO are much less demanding targets. Most could be destroyed by an ASAT system based on the current state-of-the-art chemical laser, although at large cost. Even very hard satellites could be destroyed with lasers that will probably become available in the 1990s.

Space-Based ASATs

Weapons based in space can be much closer to and have a clearer view of their targets than earth-based ASATs; hence, for a given level of technology, they can be more effective against satellites in any orbit. Space-based ASATs are more vulnerable, however, and the costs associated with deploying and maintaining ASATs in space are much greater than the costs of earth-based ASATs. Three types of potential space-based ASAT weapons are explored here: space mines, kinetic-energy weapons, and directed-energy weapons.

Space mines

A space mine would be a satellite that is placed in the same orbit as a target satellite (usually well in advance of an attack), and which attempts to remain within lethal range at all times. Space mines could be salvage-fused, meaning that any attempt to interfere with them would cause them to explode, destroying the target satellite in the process. Although no space mines are known to exist, they could probably be developed in a few years.

If armed with conventional warheads, the space mine would have to stay within a kilometer of the target at all times, a requirement that may be difficult to meet. Nuclear space mines would be destructive at much larger distances (tens or hundreds of kilometers), but they could also destroy or interfere with friendly satellites nearby. The deployment of nuclear weapons in space is banned by the Outer Space Treaty. The deployment of space mines during peacetime could pose the danger of inadvertent war through accidental detonation, and their use during a conventional war to destroy reconnaissance satellites could contribute to the likelihood of escalation.

Kinetic-energy weapons

Kinetic-energy weapons, either homing missiles or projectiles fired from guns, could be used to destroy satellites by direct impact. Rail guns, which use powerful magnetic fields to accelerate projectiles, are theoretically capable of much higher velocities than are achievable with rockets, although current devices are far less capable than rockets. A rail gun would weigh hundreds of tons and would not be cost effective unless it could destroy many satellites.[vi]

Homing missiles could attack satellites in GSO in several minutes if they were "parked" in orbits a few hundred kilometers from the target satellite. (This concept differs from a space mine in that the target normally remains outside lethal range.) The size and technological requirements of such a missile would be comparable to those of the current U.S. air-launched ASAT homing missile, and therefore are feasible in the near-term. Such missiles could carry low-yield nuclear weapons, which would considerably reduce the tracking requirements and be more robust to defensive countermeasures, but would have the liabilities of nuclear use noted above.

Space-based directed-energy weapons

Directed-energy weapons based in space can use uncharged particles (photons or neutral atoms) of any energy. (Charged particle beams cannot be used as ASAT weapons because the earth's magnetic field deflects them.) Candidate technologies, none of which are currently judged feasible in the short-term, are neutral particle beams, the high-energy lasers discussed above, x-ray lasers, and microwave weapons.

Neutral particle beams. Neutral particle beam (NPB) weapons, which are the best-developed directed-energy weapons suitable for space deployment, are similar to the accelerators used by particle physicists. The particle energy is limited by the size of the accelerator; current design concepts generate particles with energies of a few hundred million electron volts (MeV). Protons of this energy have the capacity to penetrate to the center of a target satellite and destroy or damage its electronics. It may be possible to harden electronics, which would lead to a corresponding increase in the amount of time the NPB would have to irradiate the target. Even so, NPBs, if they can be constructed in space, might be very effective against satellites in GSO. Since a space-based NPB weapon is unlikely to cost less than a target satellite, its range would have to be large enough to engage several targets at once. An alternate approach would be to put an NPB in a highly-elliptical orbit that intersects GSO or into counter-rotating GSO, allowing a single low-power weapon to attack all satellites in GSO, though over an extended period of time (at least 12 hours). The power requirements for a NPB could be quite large. Depending on the circumstances, over l0 tons of fuel might be required to destroy a 1-ton satellite. An NPB would have a linear dimension of perhaps 50 meters, making it a very noticeable object.[vii]

Space-based HELs. HELs based in space could be much smaller than earth-based HELs because they could be placed close to target satellites, but as range of the laser decreases so does the number of targets that can be attacked in a given amount of time. For example, less than one-thousandth the power of an earth-based laser would be required to destroy a target in GSO from a distance of 1,000 km, but then the laser could only attack a single satellite at a time. It is very difficult to hide a space-based HEL, because reducing the size of the mirror (which might be several meters in diameter) increases the power requirements. Even a low-power space-based laser would be quite noticeable and identifiable.

X-ray lasers. X-ray lasers have the primary advantage of a very compact and extremely high-power energy source: a nuclear explosion. This allows the possibility that x-ray lasers based in space might not be identifiable, or that they could be put on earth-based missiles and fired as soon as they are above the atmosphere (within a few minutes). They would require the launching and exploding of nuclear weapons in space. In theory, they could be very effective ASATs, capable of destroying instantaneously a number of satellites at very long ranges. They are in the research stage and presently it is not possible to say what can be attained, however.

Microwave weapons. It may be possible to build a device that uses a nuclear explosion to generate a narrow beam of microwaves. Electronic circuits are probably at least three orders of magnitude more vulnerable to microwave energy than to x-ray or particle-beam energy. On the other hand, the destruction of electronics would not usually be noticeable from the outside of a satellite, leading to uncertainty about disablement of the target. Much more work needs to be done on this concept before further judgments can be made about its ultimate usefulness as a weapon.

In the preceding discussion, weapon system size requirements have been posited in terms of their effectiveness relative to U.S. estimates of U.S. satellite vulnerability. Actual ASAT weapons would likely be much more powerful (by perhaps an order of magnitude) for the following reason: for any given destructive mechanism (x-rays, laser irradiation, bullets, etc.), there is a fairly well-defined threshold beyond which a given satellite will fail. The defender, who knows the details of the satellite design, can estimate this threshold with some confidence, although there will always be some uncertainty in the estimate of the system’s vulnerability. Prudence requires that the estimate be lowered, so that one can be confident that the system could survive an attack of that magnitude. The attacker, on the other hand, does not know the details of the design, and will be inclined to substantially overestimate the lethal level required to be confident that the target system will be destroyed. In most cases an attacker will want a “hard kill” of the system (i.e., the damage to target must be easily visible), which also increases the size of the weapon.

POSSIBLE COUNTERMEASURES AGAINST ASATs

Unilateral countermeasures

Unilateral countermeasures are actions that the United States or the Soviet Union could take to safeguard satellites without the cooperation of other countries. Since the ASAT threat to high-altitude satellite systems is as yet undefined, actions taken should be those effective against a wide range of technologies.

Passive countermeasures

Passive unilateral countermeasures are those that enable the satellite to withstand or avoid the attack by ASATs. These may include (a) hardening the satellite against attack mechanisms (heating, shock, irradiation, and jamming), (b) evasion (maneuvering, hiding, and use of decoys), (c) redundancy (spares in orbit or ready to launch, and land-based back-ups to space-based systems), and (d) placing satellites in less vulnerable orbits.

Hardening can be achieved by making the working components of the satellite (e.g., solar cells or microprocessors) less vulnerable to the ASAT threat and/or by surrounding the satellite or vulnerable components with an appropriate shield. Examples of internal hardening are radiation-resistant electronics to protect against the effects of nuclear weapons or NPBs, or heat-resistant components to withstand laser heating. Examples of shields are multi-component x-ray shields against nuclear weapons and reflective or ablative shields and sensor shutters against lasers. The measures taken to address one class of threat must be consistent with and complementary to those taken to guard against other threats.

These hardening measures can go a long way toward reducing satellite vulnerability, and can also have a favorable cost-exchange ratio against the offense. For example, hardening electronics to levels feasible in the near term would force long-range NPB weapons to consume an amount of fuel much more massive than the satellite it is attacking. The attacker might compensate by bringing the NPB closer to its targets, but this would require the construction of additional (expensive) NPB weapons. Another example is hardening against continuous wave (CW) lasers; measures that increase the hardening of satellites by a factor of 10 might cost about 10% of total satellite costs,[viii] but would require a laser 10 times more powerful—and much more costly—to destroy those satellites.

Cost-effectiveness trade-offs are different with regard to hardening against nuclear weapons or kinetic-energy weapons. The cost of a nuclear weapon is not proportional to its yield: for example, a 100 kiloton (kt) weapon may not cost much more than a 10 kt weapon.[ix] Hardening against nuclear weapons can prevent the destruction of more than one satellite by a single weapon, or, in the case of an x-ray laser, decrease the number of satellites a single x-ray laser can destroy. For a given yield, hardening can also force the attacker to come closer to the satellite, thereby increasing warning time and the opportunity for maneuvering.

However, neither a nuclear explosion dedicated to the destruction of a single satellite nor, in the case of kinetic-energy weapons, a direct hit by a projectile, can be countered by any reasonable level of hardening. It is also very difficult to harden against the shock effects caused by very short-duration ("pulsed") chemical or x-ray lasers. For cost-effective unilateral countermeasures against nuclear, kinetic-energy, or pulsed-laser weapons, one must turn to the tactics of evasion and proliferation.

Maneuvering is effective against some threats. High-orbit satellites, for example, need only modest maneuvering capability to evade nuclear-armed earth-based missiles. This is true even if the missiles have terminal homing guidance, because the homing system is not effective until the missile is within a few dozen kilometers from the target, and the satellite can escape from this small volume of space in which the missile expects to find its target before the homing system is turned on. If the ASAT missile is space-based less than a thousand kilometers from the satellite, however, the fuel requirements for effective maneuvering would be excessive, because the satellite would have to accelerate very quickly to escape the homing system. Maneuvering can be defeated by giving missiles mid-course update capability, so they can track the maneuvers of target satellites during the entire missile flight. Maneuvering doesn't help at all if there is no warning, as would be the case with directed-energy weapons or close-by space mines.

Decoys may be deployed before or after attack. If decoys are deployed before an attack, the attacker can examine them. The decoys therefore must be realistic, and therefore expensive. This cost could be reduced by keeping a number of inactive satellites in orbit, and having the decoys mimic these. This is sometimes called "anti-simulation," because one is trying to make the real thing (the inactive satellites) look like the cheap decoys, rather than trying to make expensive decoys that mimic the functions of active satellites. But even inactive satellites must perform a number of sophisticated functions, especially if the military is to trust that these systems would perform properly when called upon. Testing the inactive satellites would, however, let the other side know that they were real and not decoys. If warning of an ASAT attack is available, cheap decoys could be deployed at the moment of attack, but this strategy will only work against non-nuclear homing missiles—ballistic missiles are not smart enough to be fooled by decoys (they have to be targeted on something that is already there), and directed-energy weapons give no warning.

Another form of evasion is hiding, which might be effective against current ground-based radar and optical satellite space tracking systems. But, even though the current optical tracking system can detect nothing smaller than a one meter-sized object at geosynchronous distances,[x] nearly all satellites require exposed components (antennae, solar cells, etc.) that are difficult to conceal. Space-based satellite surveillance systems that use a larger part of the electromagnetic spectrum could make hiding near the earth all but impossible (e.g., reducing the optical signal of a satellite by painting it black inevitably increases its infrared signal by making it hotter).

Redundancy is another possibility. If one could increase the number of hardened satellites by a substantial factor, one would, at the very least, force the ASAT system to become large and obvious. But redundancy alone tends not to be not cost-effective, because if an ASAT system is cost-effective against some number of satellites, it is likely to be cost-effective against twice that number. The advantage might go to the defense, however, if it were possible to replace a few complex, expensive, multi-purpose satellites with many simpler, cheaper, single-purpose satellites, but this is certainly not the current trend in U.S. satellite design. Soviet satellite systems tend to be more redundant than their U.S. counterparts.

A related countermeasure is reconstitution, which is the ability to quickly replace satellites that have been destroyed. This is not a practical option for the satellites and time scales that we are most concerned about. Even if replacement satellites were stockpiled (at a cost of several hundred million dollars each), they would take many hours to launch, and many more hours to maneuver into orbit.

Another potentially effective passive countermeasure would be to move critical satellites into higher, less-crowded orbits. These non-GSO orbits offer several advantages: (a) ground-based ASATs missiles would take longer to reach higher altitudes, increasing the time available for warning, maneuvering, and decoy deployment; (b) the power requirement for a ground-based laser ASAT is proportional to the square of the satellite altitude, so that a target at 10 times GSO would require a laser power 100 times greater to destroy than the same target in GSO; (c) there are many non-synchronous orbits, unlike the single GSO, so such orbits would be less crowded and the identification of potentially hostile satellites or space mines much easier; and (d) satellites in higher orbits are more difficult to track from the ground, which could frustrate ASAT attacks.

There are, however, several disadvantages of basing satellites in high orbits. First, the cost and complexity of satellites and ground stations would increase somewhat, due to tracking requirements (satellites outside GSO orbit more slowly than the earth revolves), and due to the fact that transmitting power and/or receiver sensitivity would have to compensate for the increased distance from the earth. Second, the ability of reconnaissance and surveillance satellites, such as attack warning satellites, to see details on the earth's surface decreases with distance. Third, the cost of launching satellites into orbits above GSO would be somewhat greater, since more energy is required for a given payload mass. Note that the number of satellites necessary to perform a mission need not increase, but that the size, power requirements, and cost of each satellite would be greater.

Passive countermeasures, especially hardening, can go a long way toward decreasing the vulnerability of satellites. They also cause effective ASAT systems to become large, expensive, and detectable. A program of passive countermeasures undertaken now could greatly increase the survivability of future systems, since it would take the Soviet Union at least a decade (and probably much longer) to design, test, and deploy an advanced ASAT capable of threatening critical satellites in GSO. But passive countermeasures are not sufficient by themselves to ensure survivability. There is no known perfect passive countermeasure, nor are there perfect substitutes for space assets. Secure, redundant land systems would not satisfy all strategic requirements and would be very expensive for the U.S. (although less so for the U.S.S.R.). In the case of attack warning, for example, reliance on land-based systems would mean giving up independent confirmation that an attack was on the way, relying on half the current warning time, or giving up reliance on tactical warning altogether, none of which are acceptable.

Active countermeasures

Active unilateral countermeasures are those that threaten an attacking ASAT system. This means deploying one's own ASAT either to deter attack or to destroy the opposing ASAT. Systems with the latter mission are sometimes called DSATs (defensive satellites), but it is not clear what the technical difference might be between systems that are designed to kill satellites generally and those intended to kill ASAT satellites. A basis for a valid distinction might be DSAT systems that are only effective over a very limited range and that are associated with a specific satellite system. In this case, DSATs could legitimately be seen as strictly defensive, since they could not attack an opposing ASAT system unless it advanced within range. Although this might be a reasonable limitation if imposed in relation to ASAT space mines or missiles, such defenses would be worthless against directed-energy weapons unless the range of the DSAT was at least as great as that of the opposing ASAT, which would make it an ASAT in its own right.

Self-defense systems could not be added to current satellites, since the weight and power requirements of such add-on systems would be far greater than those of the satellite they would be protecting. In addition, the operation of some DSAT weapons could destroy any nearby satellite. A separate DSAT satellite, very much resembling the ASAT systems described above, would be needed. Active defense against a nuclear warhead at a range of 1,000 km, for example, would require a very large NPB or laser. DSAT weapons may not be able to defend the satellite at all against nuclear weapons if they were salvage-fused.

The use of space-based DSATs could create an advantage for preemption and therefore could be crisis unstable. If both sides depend on satellites to perform crucial deterrence functions, and both sides also deploy ASATs to threaten the other's satellites (as well as their ASATs), then substantial benefits could accrue to the side going first. This is essentially the same argument that is used when evaluating vulnerable land-based ICBMs: if both sides have valuable but vulnerable weapons, each will fear preemption by the other, and will therefore be tempted to preempt. A crisis or accident (e.g., collision with space debris) could trigger a satellite war and measurably raise the probability of terrestrial war. Active ASAT defense itself is also likely to be arms-race unstable for similar reasons. If ASATs are practical, then so are DSATs, which could also function as ASATs, leading to an almost inevitable measure/countermeasure arms race in space.

These arguments apply especially to space-based systems; if ASATs are earth-based and do not rely on space-based components, then ASATs could not attack other ASATs, and ASAT deterrence may be crisis stable, though it will still add a component to the arms race. An example is the U.S. ASAT under development, which can reach targets anywhere in LEO but cannot easily be preemptively destroyed.

But if ASATs can be made invulnerable to preemption, then DSATs cannot prevent satellite destruction, they can only threaten retaliation in kind. ASAT deterrence may not work, however, if one side valued the destruction of the other side's satellites more than the survival of its own. This appears to be the case with preemptive strategic attack, where attack warning, communications, and navigation satellites would be much less valuable to the attacker after his missiles were launched, or in the case of a conventional war, in which the U.S. would be more dependent on satellites than the U.S.S.R. Thus, even if ASATs can't threaten other ASATs, the situation could still be unstable.

Bilateral agreements

If both sides have a stronger interest—at least with respect to war prevention—in safeguarding their own space assets (or some part of them) than in maintaining a capacity to destroy the other side's, and if unilateral measures taken to safeguard these assets force ASAT systems to be expensive and detectable, then verifiable bilateral or multilateral agreements to limit ASAT technologies or deployments may be possible and may be perceived by both sides to improve the security of both. For this to occur, policy decisions must be reached on both sides to the effect that such factors as enhanced crisis stability and decreased arms expenditures outweigh the potential wartime advantages to be gained by holding satellite systems at risk. On this reasoning, the Scowcroft Commission—formed by President Reagan to evaluate basing schemes for the MX missile—recommended that the U.S. attempt to negotiate agreements to make critical satellites more survivable.[xi]

Measures taken unilaterally to make satellite systems survivable will make bilateral ASAT controls more attractive, because they serve to increase the cost and decrease the effectiveness of ASAT systems, and because they drive ASAT systems to larger dimensions and power requirements so that bans and restrictions are more likely to be verifiable. A variety of restrictions on ASAT development, testing, and deployment might be considered.

Testing and deployment of the current U.S. and Soviet ASAT weapons, as well as the testing of other earth-based missiles in an ASAT mode, might be mutually restricted or banned. If the perceived military utility of being able to destroy low-orbit surveillance and reconnaissance satellites is great, both sides may want to keep this ability while banning tests at higher altitudes. One might also choose to "grandfather" existing ASATs because of the difficulty of verifying a ban on their deployment (the weapons are small and easily concealable), given that they have already been developed and tested (although the U.S. ASAT is not fully tested).

Verifying restrictions on ASAT testing may be problematic, however. If earth-based ASATs can be tested successfully against a point in space, no one might know that a test had occurred, or that the test involved an ASAT weapon. If current low-altitude ASAT weapons are permitted, would low-altitude tests be sufficient to permit development of a high-altitude ASAT? As an example in which this would be the case, adding a third stage to the current U.S. air-launched ASAT might allow it to reach satellites in GSO; one may want to ban the testing of modifications of current ASATs to prevent this from happening. The importance of these issues should be resolved before designing a specific agreement.

Negotiated "keep-out" zones represent a way to increase the separation between satellites of different nations through formal agreements. An important argument for keep-out zones is they are one of what appears to be only two effective defenses against space mines, whether nuclear or conventional, because of the short range and rapid engagement they imply. Any object that *could* be a space mine could be attacked before it could come within lethal range, an arrangement that is fraught with instabilities. Alternatively, we can try to deal with the problem through the type of agreement proposed here.

As an example of a structured agreement, the United Nations could partition certain zones of space. The most crowded and vital orbit, GSO, is already organized to prevent radio interference. GSO might be divided into 36 zones, each 10° wide, 12 of which would be assigned to NATO and other U.S. allies, 12 to the Warsaw pact and other S.U. allies, and 12 to neutral or non-aligned countries.[xii] This type of agreement would have the advantage that only six existing satellites would need to be moved. Satellites stationed in the middle of a zone would be at least 3,700 km from possible ASATs in an adjacent zone. Even a very large nuclear explosion could not destroy minimally hardened satellites at this distance. Homing missile ASATs parked at this distance would require several minutes for an attack, allowing sufficient time for the threat to be assessed and for a warning message to be relayed to earth.

Other orbits might be organized into, say, 72 spherical shells 5,000 km "thick," starting 10,000 km above the earth and going out to the moon's orbit of 380,000 km, allocated in a manner similar to the 36 zones of GSO. This would include the orbits of NAVSTAR and the Soviet's NAVSTAR-like navigation systems. Space inside 10,000 km and outside the moon's orbit would be unregulated.

Structured keep-out zones may not be acceptable to the world community, however. First, equatorial nations will oppose any measure which deeds the use of the space above their nation to some other country or collection of countries. Second, the United Nations current position is that no state can claim a part of space for its own. Keep-out zones may also impose restrictions on satellite missions. It is current practice for satellites to drift several degrees about their mean positions, which would be impermissible at the edges of keep-out zones. Satellites could be kept on tighter orbits, though this would require more fuel.

There are alternative, less rigidly structured possibilities. Spheres of, for example, 1,000 km radius centered on certain satellites could be agreed to be keep-out zones. Foreign satellites would be prohibited from entering these spheres without permission. This would appear to allow only 130 or so protected satellites in GSO, but the actual upper limit would be several times larger, since satellites of allied nations could be stationed within each other's zones by permission, and since slightly tilted orbits could be used. Such agreements would work better in non-synchronous orbits where crowding is less of a problem.

Foreign satellites would have to be allowed the right of friendly passage, subject to certain restrictions, such as a maximum number of transits per day. Satellites from other nations wishing for some reason to share a keep-out zone could be subject to inspection before launch. Counter-rotating GSO satellites and intersecting elliptical orbits pose a problem and might have to be limited or banned.

The fact that many Soviet attack warning and communications satellites are in Molniya orbits rather than GSO may be very important when designing a keep-out zone agreement. These orbits are inclined and highly elliptical, with an apogee (highest altitude) of approximately 40,000 km and a perigee (closest approach) of 500 km. Satellites in this orbit spend over 90% of their time on one side of the earth, where they function like satellites in high circular orbits. But the fact that they come so close to the earth presents a special problem for keep-out zone agreements of all kinds, especially because of the asymmetry between the U.S. and the S.U. in the number of satellites in this orbit. The value of keep-out zones is greatly diminished for satellites in Molniya orbits, because earth-based ASATs would be much more effective against them. Air-launched ASATs, such as the current U.S. ASAT, can be launched from the Southern hemisphere and therefore can attack these satellites at perigee, though to destroy an entire satellite system one would have to wait for all satellites to pass through perigee, which would take up to 12 hours.

Bans on testing large (e.g., greater than 1 MW) ground-based lasers in an ASAT mode and on the testing and deployment of large mirrors in space can mitigate the prompt threat from earth-based systems. Many of the remaining ASAT threats, space-based kinetic-energy and directed-energy weapons, could be ameliorated by a ban on their development, testing, and deployment in space. The testing and deployment of nuclear weapons (and x-ray lasers) in space is already banned. With the exception of nuclear-weapon-driven devices, such a ban should be verifiable since the weapons in question would be large and identifiable, and since they would require testing in space to be reliable, which could be detected.

Finally, if nuclear directed-energy weapons, such as the x-ray laser, are particularly worrisome, a comprehensive test ban treaty or a low-yield threshold test ban treaty could be negotiated to inhibit their development and testing.

Verification

A variety of technologies can be used to aid in verifying the types of agreements proposed here. Improved space tracking and surveillance systems are usually proposed in connection with ASAT arms control, since they would aid greatly in verifying compliance with keep-out zones, restrictions or bans on ASAT testing, and bans on ASAT deployment in space. These systems can cut both ways, however, in the sense that a sophisticated space surveillance system can form the basis for an ASAT system as well as safeguard existing satellites, much as large terrestrial radars can form the basis for an antiballistic missile (ABM) system as well as an early-warning system. The current U.S.-U.S.S.R. ABM treaty prohibits large radars that are not on the perimeter of the nation and looking outward to prevent quick treaty break-out. Just as in the ABM case, the construction of large space surveillance systems may cause concern about compliance with an ASAT treaty.

It may be possible to limit space tracking systems to the mission of verifying compliance with agreements, so that such systems would not be capable of missions that threaten these agreements. For instance, keep-out zones could be monitored by infrared sensors on board the protected satellite, rather than by extensive networks of dedicated satellites which could easily form the basis for an ASAT weapon system. This is a area that should receive more thought.

Space tracking systems can be supplemented by heat, x-ray, and acceleration sensors on board U.S. satellites that verify that the satellite is not being attacked by lasers, NPBs, nuclear weapons, or missiles. Such sensors are a valuable countermeasure to ASAT warfare with or without arms control.

The deployment of nuclear weapons in space (including nuclear space mines, nuclear homing missiles, and x-ray lasers) is banned by the Outer Space Treaty. At present, it is not possible to verify compliance with such a ban. In theory, one could inspect satellites before launch or while in space to detect gamma radiation from the fissile materials, but relations between the U.S. and the U.S.S.R. have not been conducive to such arrangements in the past (although there recently have been hints that the U.S.S.R. may be willing to change its position). The threat from nuclear space mines might be sufficiently defused by keep-out zones, provided that the space surveillance system used for verification can determine if keep-out zones have been violated.

Nuclear explosions in space are banned by the Limited Test Ban Treaty. This ban is verified by nuclear-burst detection systems on board current U.S. satellites, for distances at least out to the moon’s orbit. This verification capability could be extended to much deeper orbits by deploying satellites dedicated to this function.

Verifying a ban on the testing of ground-based lasers in an ASAT mode is, in principle, fairly straightforward. As noted above, lasers powerful enough to pose a threat to high-altitude satellites will be very large. The U.S. has shown the ability to find much smaller lasers. Ground-based lasers are at fixed locations, and can only be tested during cloudless periods, when space surveillance of the lasers is also possible. By posting surveillance satellites over the laser sites, one should be able to detect, by the scattering of light as the beam passes through the atmosphere, whether the laser is being tested in an ASAT mode. In addition, if a comprehensive space surveillance system is available, the optical signals of all large space objects could be monitored, which would make it possible to determine if they were being illuminated by a laser. If necessary, on-site sensors could be placed at large laser installations to ensure treaty compliance.

It is possible to verify a ban on space-based lasers and particle beam weapons, since such weapons would have to be large and distinctive if sized to attack satellites several thousand kilometers away. Testing of such weapons would be easy to detect by observing their thermal signature, or by detecting effluents given off during their operation. The destruction of target satellites by kinetic-energy weapons can also be verified by space tracking and surveillance systems.

Finally, it should be noted that the U.S. must maintain an excellent space intelligence system with or without arms control. In general, it is much easier to detect and monitor certain activities when they are constrained rather than widespread. The surveillance technologies necessary to verify the sorts of agreements outlined here are much less ambitious than those envisioned for the Strategic Defense Initiative (SDI), for example.

IMPACT OF ASAT LIMITATIONS

What impact would bilateral agreements such as those described here (coupled with unilateral actions to make the satellites as survivable as economically practical) have on the military policies of the United States and the Soviet Union? The most obvious effect would be to deny to both countries the ability to destroy high-altitude satellites, both those that are essential for deterrence (attack warning and communications), and those that may not be (navigation and nuclear burst detection). The development of new technologies, such as earth-based HELs, would be allowed, but they could not be tested in an ASAT mode. Space-basing of such technologies would be banned altogether.

SDI

The agreements considered in the previous section would impose restrictions of relevance to many military missions that are not now performed in space, but could be, such as ballistic missile defense. Any ABM system comprised of directed-energy weapons that are powerful enough to destroy thousands of missiles during a few minutes (boost phase) or tens of thousands of reentry vehicles (RVs) over tens of minutes (mid-course phase) would almost certainly be a threat to satellites in GSO. Such systems could be more effective ASATs than ABM weapons, since the

ASAT mission can be performed at the moment of one's choosing, and satellites are in general softer targets which travel on predictable paths.

Critics of this view point out that the distances involved in attacking a satellite in GSO are much greater than in attacking a missile: roughly 36,000 km versus 1,000 km, the commonly-assumed orbit for the space-based laser battle stations that might form the core of an ABM system in space. Since the intensity of a laser decreases as the square of the distance, the intensity at GSO will be over 1,000 times less than that on a booster; since satellites can be made almost as hard as boosters, satellites in GSO should be safe even though the system is potent against missiles. The SDI Organization supports high-orbit ASAT arms control measures, the motivation being that many of the sensors necessary for strategic defense would be placed in high orbits.[xiii]

This analysis is flawed in several ways, however. First, lasers could irradiate satellites for a much longer amount of time than they could irradiate boosters because there are many fewer satellites than boosters. ABM systems will have to successfully shoot at 1,000 (boost-phase) to 10,000 (mid-course) objects per minute, while ASAT systems would only need to attack at most 100 satellites in a few minutes. In addition, many more laser battle stations could participate in an ASAT attack than in an ABM defense, because each laser satellite could target at least half of all high-orbit satellites, while in the ABM case, less than 1/10th of the laser satellites can target missiles launched from a point on the earth. These two considerations nullify the effect of the added distance, and make a space-based laser system at least as effective a high-altitude ASAT as an ABM system. In fact, an ABM system would probably be more potent as an ASAT since satellites are more difficult to harden than boosters or RVs, and since an attack can usually be coordinated better than a defense and can occur at a time of the attacker's choosing. Earth-based laser ABM weapons should be particularly effective against satellites, since in most such schemes the laser energy is reflected from mirrors in GSO to boosters at low altitudes. If the laser beam could destroy boosters after going up to GSO and back again, then it could obviously be even more effective against objects in GSO.

Directed-energy systems capable of boost-phase or mid-course ballistic-missile defense would threaten the high-altitude space assets that the agreements discussed above seek to protect. The development of countermeasures may or may not change this situation. Moving to deep space orbits, for instance, could be effective. But a defense based on technologies with limited range (small homing missiles launched from space platforms, for example) might not have much effect on satellite systems. The interactions between defenses and space systems security will have to be considered very carefully.

How can satellites be protected in an world of space-based ballistic missile defenses? Obviously, hardening and active defense (shooting back) will become even more important. What role bilateral agreements can play depends a lot on whether or not the transition to such defenses is cooperative, as many members of the Reagan administration insist it must be. If defenses are deployed cooperatively, meaning not only that defenses are viewed as desirable and stabilizing by both sides, but even that technologies or systems may be shared, then there is no reason why both sides cannot mutually agree to limit offensive countermeasures to such a defense, including ASAT weapons. Keep-out zones could become, by agreement, self-defense zones. SDI technologies could be designed so they would not threaten the opponent's system with preemptive destruction, and critical satellites could be moved to orbits high enough to avoid the threat posed by these BMD weapons.

If, on the other hand, the transition to defense were not cooperative (which is much more likely), then no controls on ASAT weapons seem possible, for the simple reason that ASAT weapons would be a principle countermeasure to space-based ABM system components. For every ABM system deployed, the opponent would want to deploy an ASAT capable of negating it.

Although one cannot protect present and currently planned satellite systems through restrictions on ASATs and deploy an ABM system at the same time, this does not mean that ASAT arms control is impossible while research continues on SDI. Resolution of this question depends on whether demonstrations and field experiments that may of themselves provide some ASAT capabilities are deemed necessary to the SDI R&D program. If, for some significant period of time, these demonstrations and field tests are not deemed necessary, ASAT limitations could in theory at least be agreed on for that period. In the final analysis, however, developing SDI and ASAT arms control are probably incompatible.

Space as sanctuary

Limiting the threat to high-altitude satellites will create a sanctuary in space to a certain extent. It is possible that this would actually encourage the use of space for military, but non-weapons, systems, since they would be safe from attack. Although it is difficult to foresee examples of this type of behavior, one can imagine that, for instance, a device could be built that could track ballistic-missile submarines from space. Another example might be high-altitude surveillance satellites that could tell if targets were destroyed by an initial nuclear attack, in order to direct additional missiles to the surviving targets. These developments would represent a clear threat to deterrence, and we would certainly want the capability to destroy such satellites. But it seems premature to forego arms control just because of these theoretical possibilities.

Space debris

A side benefit of a ban on ASAT testing would be the reduction of space debris. The debris accumulating in orbit in the absence of ASAT testing—paint chips, pieces of exploded boosters, etc.—are suspected to have damaged several satellites in the past few years. The risk of collision of a shuttle-sized object with a large (greater than one centimeter in diameter) piece of debris is currently about 1% per year.[xiv] It has been estimated that the planned U.S. ASAT tests could double the total amount of debris in LEO.[xv] A more extensive ASAT testing program against real satellites might make whole regions of space unnavigable. The problem would become critical if ASAT tests are conducted at high altitudes, since the debris is removed much more slowly—indeed, at geosynchronous altitude, orbits decay only one kilometer in altitude every one thousand years.[xvi] ASATs could be tested against balloons, which might decrease somewhat the amount of debris generated, but not completely, since such balloons are likely to be heavily instrumented.

CONCLUSIONS

The attack warning and communications satellites based in geosynchronous orbit are essential for the maintenance of deterrence. These satellites are intended to perform vital functions during, or at the outset of, a nuclear war. Although current earth-based weapons do not pose the threat of rapid destruction of high-altitude satellites, a variety of future technologies could be so employed as anti-satellite weapons. These include powerful earth-based lasers, and space-based mines, kinetic-energy weapons (rail guns and homing missiles), and directed-energy weapons (particle beams, optical lasers, x-ray lasers, and microwave weapons).

A variety of passive unilateral countermeasures, including maneuvering, use of decoys, hiding, redundancy, and especially hardening and the use of deeper orbits, can go a long way toward making satellites more survivable and forcing ASATs to become more sophisticated and costly. A vigorous program of passive countermeasures should be begun, and it should not be delayed by progress in space arms control since such measures will make agreements more robust. But passive countermeasures cannot by themselves assure survivability. None can prevent the destruction of satellites from, for example, a space mine placed near the satellite or the lethal fluence of an x-ray laser.

Active defense of satellites may be able to protect satellites and thwart the emplacement of space mines, but this is likely not to be crisis stable. Each side could fear preemption and require a hair-trigger posture to prevent both satellites and ASATs from being destroyed. Active defense would probably also lead to a measure/countermeasure arms race as each side attempted to make its satellites and ASATs invulnerable to the other's ASATs. In any case, ASAT deterrence through retaliation in kind is not likely to work in a number of war-time situations, because the destruction of an opponent's satellite systems is more valuable to an attacker than preservation of systems.

Bilateral or multilateral agreements can play a large role in safeguarding high-altitude satellites. Bans on testing (and in some cases deployment) of new technologies in an ASAT mode can complement negotiated keep-out zones in limiting the threat from earth-based as well as space-based ASATs. Large-scale testing of an advanced ASAT would be observable, so a ban would be verifiable.

Limitations on ASATs are not likely to be compatible with the deployment of a strategic defense with space-based battle stations. Although such battle stations would have to operate over a much larger distance when used in an ASAT mode, the scale of an ASAT attack is so much smaller than that of a missile defense, and so many more battle stations can participate in the ASAT attack than the missile defense, that a successful ABM system (other than terminal or other limited range defenses) would be a potent ASAT. It is unlikely that either country would willingly forego the ASAT option if the other had plans to deploy space-based ABM components, since ASAT weapons may be one of the most effective countermeasures against such a system.

The military uses of space are constantly evolving. The missions described here may become more or less important in the future and entirely new missions may be added that may change the assessment given here.

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[i] For a review of military space systems, see C. Richard Whelan, Guide to Military Space Programs, Pasha Publications, 1984.

[ii] All 24-hour (geosynchronous) circular orbits are about 36,000 km above the earth's surface, and those that are not inclined with respect to the earth's equator (GSO) hover above the same point on the equator. It is this unique property that causes so many satellites to be located in GSO. For a review of satellite orbits, see Ashton Carter, "Satellites and Anti-Satellites: The Limits of the Possible," International Security, Spring 1986.

[iii] Space Analysis and Data Division, "Space Computational Center Satellite Catalog," North American Air Defense, April 1982.

[iv] R. L. Garwin, K. Gottfried, and D. L. Hafner, "Antisatellite Weapons," Scientific American, June 1984.

[v] James B. Schultz, "Space System Designs Promote Survival of the Fittest," Defense Electronics, June 1985.

[vi] U.S. Congress, Office of Technology Assessment, Anti-Satellite Weapons, Countermeasures, and Arms Control, OTA-ISC-281, U.S. Government Printing Office, September 1985.

[vii] Ibid.

[viii] R. Jeffrey Smith, "Space Experts Challenge ASAT Decision," Science, 18 May 1984.

[ix] One kiloton is the amount of energy released by 1,000 tons of high explosive. A 15 kt weapon destroyed Hiroshima, and most weapons in the U.S. stockpile have a yield of a few hundred kilotons.

[x] Donald J. Kessler and Shin-Y Su, Eds., Orbital Debris, NASA Conference Publication 2360, March 1985.

[xi] President's Commission on Strategic Forces, 6 April 1983.

[xii] Albert Wohlstetter and Brian Chow, "Arms Control that Could Work," Wall Street Journal, 17 July 1985.

[xiii] R. Jeffrey Smith, "Limited ASAT Proposal Gains Backers," Science, 18 May 1984.

[xiv] Kessler and Su.

[xv] Eliot Marshall, "Space Junk Grows with Weapons Tests," Science, 25 October 1985.

[xvi] Kessler and Su.