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Safeguarding Our Military Space Systems

MICHAEL M. MAY

The vulnerability of military space systems depends on their orbits, functions, and other characteristics. The high-altitude satellites needed for warning and communications in particular could be vulnerable to prompt destruction by certain space-based systems and, in the future, possibly by ground-based high power lasers. A combination of passive countermeasures and arms control agreements could give these satellites some protection against such attack. Deployment of strategic defensive systems with the capability to reach far into space would invalidate this approach.

THE MEASURES THAT CAN BE TAKEN TO SAFEGUARD OUR military space systems or the functions carried out by these assets, the potential effectiveness of the measures, and the utility of arms control agreements vary according to the function to be safeguarded. Broad statements, arguing that space assets are few and fragile or that the deployment of antisatellite systems (ASAT's) is unverifiable, do not usefully summarize what can or cannot be done.

Military space systems consist of satellites, earth stations, and links between them (Fig. 1). The characteristics that mainly affect the vulnerability of these systems, such as altitudes of orbits, nature of components, and the like are discussed in the first part of this article. Then various ways of attacking the systems along with steps that can be taken to counter the attack or make it less effective are described. Next, the adequacy of these steps in safeguarding some space system functions are evaluated, mainly to illustrate the kind of analysis that must be done in each case. Finally, the potential value of some arms control agreements in further safeguarding these functions is discussed.

Vulnerability of Military Space Systems

Space systems can be used for surveillance of either strategic assets or tactical situations, for warning, for communication, for weather information, for navigation, and for targeting. Figure 2 displays typical orbits for these various kinds of missions. The orbit is the main determinant of vulnerability. It determines the time and cost for an earth-launched ASAT to get to the satellite, as well as the power needed for a laser or particle beam to destroy a satellite. Warning and communication satellites are typically in very high orbits. Surveillance, weather, and targeting satellites, which need to see details on the surface of the earth, will typically be in lower orbits—how low depends on the scale of the details needed and on the resolving power of the optics. Radar surveillance and navigation satellites can be in intermediate orbits.

Several kinds of componentry might go into the various kinds of satellites (Fig. 3): transponders used for communication, radar antennas, solar power panels, and internal electronics. Not all componentry would be on any one satellite, and there are other kinds. The ones shown in Fig. 3 are all necessary for some satellites. They illustrate the range of vulnerabilities that can be expected from most componentry.

Vulnerability can be due to material damage, blinding or jamming of sensors, or damage or false signals induced in the electronics. Let me take up material damage first. Some of the materials used on satellites that were designed without special attention to hardening can be quite fragile. Normal solar panels, for instance, will fail at relatively low levels of laser or nuclear irradiation. With special attention to the materials and design, however, the material problem can be solved to the point that a satellite can only be destroyed by either (i) a direct hit, (ii) a nuclear explosion sufficiently close that it can destroy only that satellite and no other (*1*), or (iii) laser irradiation at levels than can be delivered only by sizable, costly facilities designed and tested for the purpose.

The blinding or jamming of sensors must be done by radar, infrared, or visible light sources according to the frequency band the sensor operates in. Such "in-band" jamming can be countered by rapidly changing the frequency at which the radar operates, by rapidly shuttering the optical elements of a camera, or by other measures. One particular countermeasure applies to infrared sensors. For launch warning purposes these sensors need only pick up

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the infrared signal from the missile plume above the atmosphere. The plume emits over a whole range of frequencies. The frequency chosen for the sensor to react to, therefore, can be one that does not penetrate the atmosphere. Jamming such a signal would require mounting the source on a rocket, greatly increasing the cost and difficulty.

Damage to electronics componentry can be induced by nuclear explosions above the atmosphere, by penetrating neutral particle beams from space platforms, or possibly by extremely powerful radar transmitters. There are effective countermeasures against damage by radar transmitters. Nuclear explosions can destroy a satellite, but, with proper system design, one nuclear explosion per satellite would be required. Space-based particle beams that can disable satellite electronics have not been designed. Counters to them are possible in principle at some cost in weight, and the particle beam satellite can itself be attacked.

Ground stations and links between the satellites and the ground are also needed for space systems (Fig. 4). Ground stations usually are large buildings. The major options for lessening the vulnerability of ground stations are the same as the major options for lessening the vulnerability of strategic weapons systems: to defend them actively, to harden them by putting them underground, to hide them, or to make them mobile and proliferate them. The latter is probably the preferred approach for ground stations. Underground siting is difficult for facilities that must keep communications open most of the time with space, hiding is unreliable in the United States, and active defense would run afoul of the Anti-Ballistic Missile Treaty requirements and may also be unreliable unless combined with some form of mobility and proliferation. Mobility can be, and is being, undertaken for several key systems with the use of airplanes, ships, and ground-mobile terminals.

The third element of space systems are the (electromagnetic) links between satellites and ground stations or among satellites. These links can be vulnerable to interference (including covert, deniable interference) unless measures are taken to protect them. The measures and countermeasures in this area are complex and classified and do not decisively favor either the offense or the defense. In general, it is difficult or impossible to deny with any confidence simple information, such as warning, even over a short period of time. Given a longer period of time, it is difficult to deny even complex information. If the information needed is both complex and time-urgent, however, as would be the case for a ballistic missile defense system, various means of interference, including nuclear means, could be very disruptive. Laser communication links are very robust against jamming and could offer a solution.

Attacking and Protecting Military Space Systems

With this general survey of key componentry and vulnerabilities in mind, let me turn to the various methods of attacking and safeguarding space systems, concentrating on satellites since that is where the main technical questions are currently. Safeguarding ground stations and electronic links from attack is equally important, but the technological problems and potential solutions are probably more familiar.

Let me begin with nuclear explosives, which were the earliest ASAT's historically. Since there is no way to harden against a nuclear explosion that comes close enough to the satellite, the key improvement from the standpoint of survivability is to make sure that one nuclear explosion is needed to destroy each satellite. That is possible to do, except possibly against nuclear-driven x-ray lasers. Satellites are typically thousands of kilometers apart, whereas the lethal range of even a 1-megaton explosion against a satellite hardened to a feasible level of hardness is less than 100 km. (An unhardened civilian communication satellite could be damaged at distances of thousands of kilometers by a high-yield nuclear explosion in space.) Making satellites nuclear-hard thus serves to make the task of attacking space systems more complex and time consuming. Nuclear weapons, however, probably remain the cheapest way to attack a properly designed and hardened space system.

Conventional explosives and kinetic energy weapons, the latter of

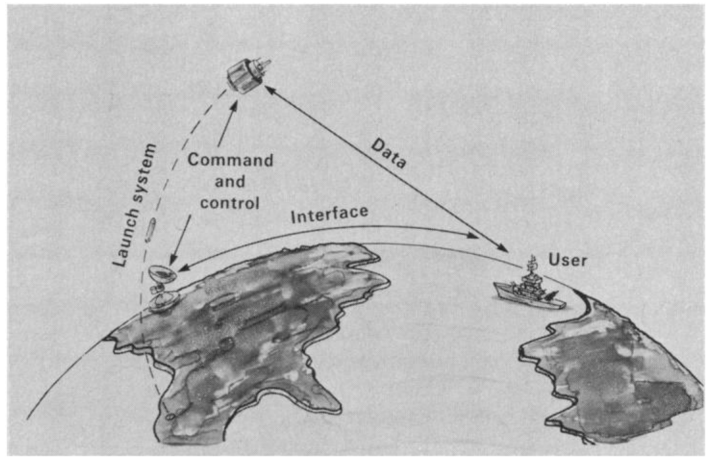

Fig. 1. Components of a satellite system.

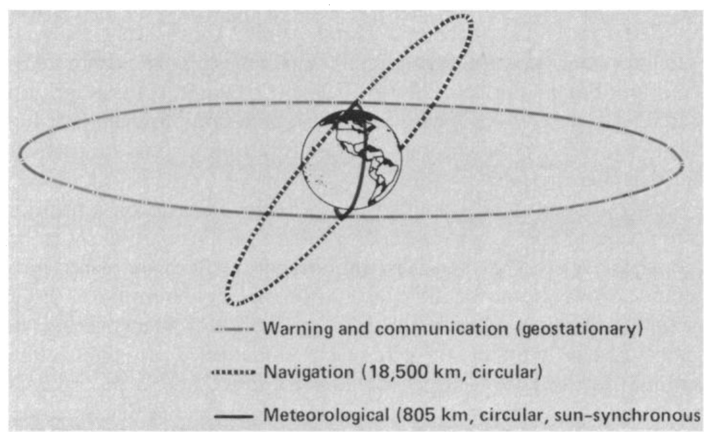

Fig. 2. Typical orbits for various types of satellites.

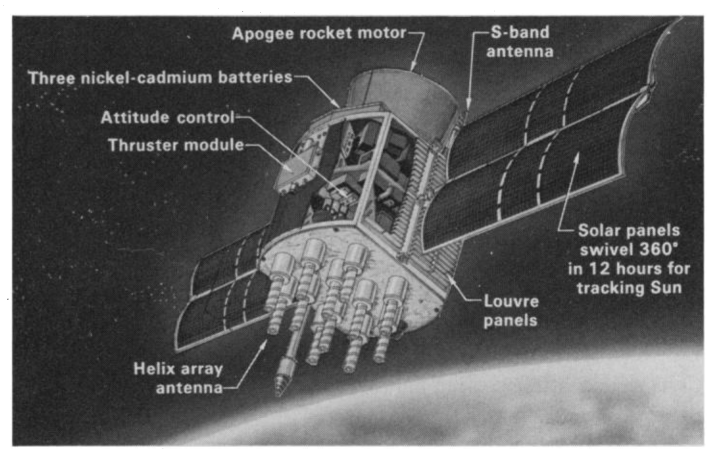

Fig. 3. The Navstar global positioning system showing typical satellite componentry.

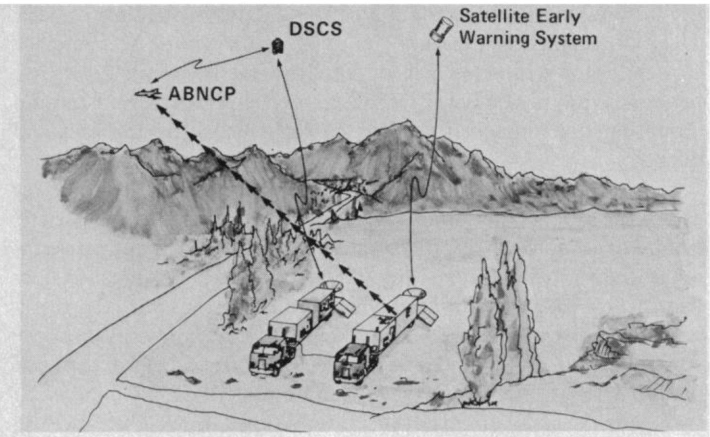

Fig. 4. (Left) A fixed satellite test center in Sunnyvale, CA. (Right) An illustration of a deployment of a mobile ground terminal in communication with an early warning satellite, an airborne national command post (ABNCP), and a satellite of the Defense Satellite Communication System (DSCS).

which are sophisticated guided bullets, can also be used against satellites. The guidance requirements are much more severe for high-explosive weapons than for nuclear weapons and even more severe for kinetic energy weapons that must hit the target.

Nuclear weapons, conventional weapons, and kinetic energy weapons could all be stationed in space. (Nuclear weapons in space are prohibited by the Outer Space Treaty.) Space-basing would greatly increase the cost of any ASAT system. On the other hand, space-basing an adequate number of weapons can decrease the time needed for ASAT's to put a target system composed of several satellites out of commission (Fig. 5). This time element is particularly important in the case of warning and strategic communication satellite systems. ASAT systems which can accomplish the destruction of these systems without giving any warning could be particularly dangerous.

Space-based ASAT systems that are to be effective on a prompt time scale against a hardened set of target satellites are likely to be noticeable, however, especially if the target satellites are placed into unique orbits. It may be difficult or impossible to determine without actual inspection what is inside a satellite. But maneuvering or emplacing a number of otherwise unidentified satellites close enough to the several target satellites to destroy them promptly is likely to give warning of hostile intent. Agreements that satellites will be kept a certain distance apart when in the particular orbits, or that they will submit to some sort of identification procedure if they come closer than a certain distance, would greatly increase the likelihood of warning. Such agreements, conventionally termed "rules of the road," will be discussed below.

Laser ASAT's, both ground-based and space-based (Fig. 6), have the advantage that they deliver their lethal punch at the speed of light and the disadvantage that it is much more difficult and costly to package enough energy to do damage in laser beams than in explosives or bullets. For this discussion, assume that the sensors have been designed so that lasers cannot do permanent damage by in-band illumination at any greater range than they can damage other materials in the satellite. Materials can be damaged either by continuous irradiation above a certain level or by a large single pulse of energy. We will assume a damage threshold against both mechanisms within the present state of the art—that is, above that of unhardened satellites but below what advanced material research promises to do.

Under these conditions, powerful but presently or soon to be available laser systems (lasers with the necessary optics, pointing, tracking, and computer capability) could damage a satellite from 100 to 1000 km away. Satellites in relatively low orbits could be damaged by such systems based on the ground. The main problem is not the laser power but adaptive optics to compensate for the natural fluctuations in the atmosphere's optical properties. The lasers and optics could probably be hidden, but the pointing and tracking and other experiments needed to develop the full ASAT system would probably be detected.

A high-orbit satellite of the stated level of hardness, on the other hand, could not be damaged from the ground except by lasers with power and optics far beyond what is now available or what will be available operationally in the next 10 years. Not only are these lasers not available now or expected soon, but they would be extremely difficult to hide. They would probably be the size of a football field, with optical components and stable bases for them larger than most astronomical installations, with power supplies in the hundreds of megawatts at least, the whole installed in a region that should be free from cloud cover most of the time if the ASAT system is to be effective.

Research on advanced material and other techniques could give us satellites orders of magnitude harder than the present state of the art. To damage such future satellites even in comparatively low orbits would take very complex, noticeable laser facilities.

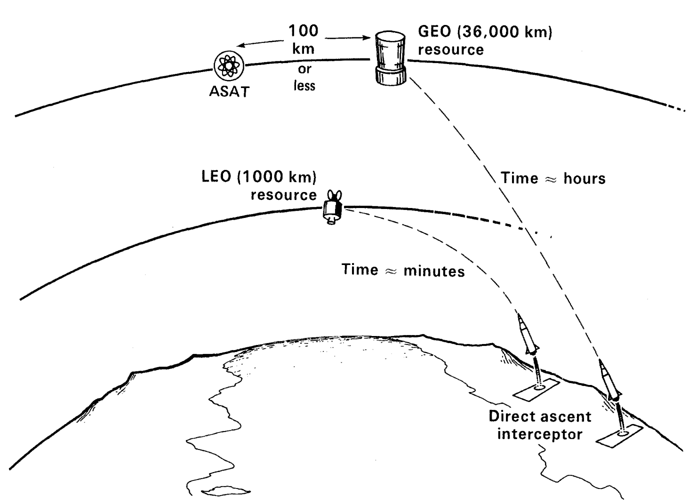

Fig. 5. Antisatellite systems in space and on the ground. Attacks from the ground to geosynchronous earth orbit (GEO) take hours. Attacks of low earth orbit (LEO) satellites can be accomplished in a few minutes. ASAT's pre-positioned in space near satellites could attack in minutes.

High-orbit satellites with state-of-the-art level of survivability could be damaged by space-based lasers deployed within 100 to 1000 km of the targeted satellites, but such space-based laser ASAT's could not sweep the sky clear of satellites in a short time unless they were deployed one-on-one. This would make the space-based laser ASAT system not only difficult or impossible to deploy covertly, but also probably much more expensive than the targeted system.

In addition to lasers that operate in the visible and infrared frequency range and can be based on the ground, x-ray lasers and particle beams, which cannot penetrate the whole atmosphere, could be based in space or launched into space at the time of the attack. The x-ray lasers would involve the use of nuclear explosions. Particle-beam accelerators would be high-cost items, for the same reason that optical and infrared lasers are, namely that expensive and heavy facilities would have to be orbited. Both x-ray lasers and particle beams are in the research stage.

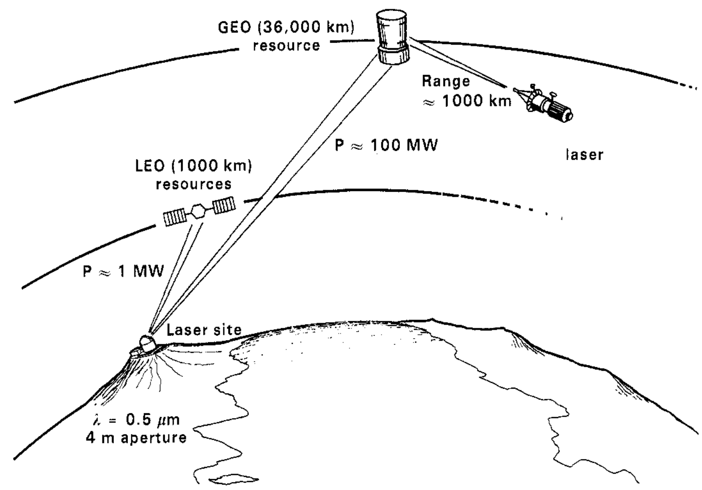

Fig. 6. A laser antisatellite system. Ground-based lasers of about 1-megawatt power may be able to attack low earth orbit (LEO) satellites in the near future. More advanced systems of about 100-megawatt power and with improved beam compensation (to reduce spreading by the atmosphere) may be able to reach geosynchronous earth orbits (GEO) with lethal fluences.

Survivability of Military Space Systems

How do these various threats to the space systems interact with the timely functioning of the systems and what can be done about it? The question of space survivability must be dealt with separately for each of the main types of space systems.

As a first example, let me consider warning and communication systems. They are stationed in high orbits, usually geosynchronous. They must function in minutes. Because of their central role in nuclear operations, interference with these systems in situations that do not threaten to become nuclear in any participant's judgment is perhaps unlikely. In situations involving nuclear threat or alert, on the other hand, these systems become salient potential targets.

Ground-launched, direct-ascent ASAT's would take hours to reach geosynchronous altitudes. During that time, there is a chance (how much of a chance depends on our detection capability and alertness) that they could be recognized and action could be taken. Such action could include evasive motion on the part of the targeted satellites (the reaction of ASAT's in turn could confirm whether or not there was an attack on the system), higher states of alert, and attaching more credibility to the other means of strategic warning. The plausibility of any particular action would depend on the circumstances.

Although direct-ascent ASAT's against warning and communication systems might well be used in connection with a nuclear attack, space-based ASAT's and future, very powerful ground-based lasers that might be able to destroy the systems rapidly or without notice are of greater concern. As noted above, however, if we carry out the various measures now planned or in progress to make the warning and communication systems less vulnerable, to give them unique orbits, and to improve our ability to monitor what is going on in space in real time, we will probably be able to detect any ASAT system likely to be effective rapidly and will probably also know if an attack is in progress.

Low-altitude systems offer a more difficult safeguarding problem. The lower orbits make it easier for ground-based lasers and faster for direct-ascent ASAT's to destroy the satellites. We would probably know, from testing and other necessary activities, whether a threat existed and, with proper system design for survivability, the required ASAT system would have to be large and expensive. Thus, although sudden denial in a crisis of the information these satellites bring could not be ruled out, an attack could probably not be carried out in a covert or deniable way if we design the systems appropriately.

Different space systems have their own time lines, cost elements, and vulnerabilities. In most cases, perhaps all, easy or deniable interference with the systems can be prevented through the use of sophisticated techniques to protect communication links and by hardening satellites so that low to moderate power, ground-based lasers cannot damage them.

Discussion

To reach some conclusion regarding the usefulness of various possible arms control arrangements in space (*2*), we must have some notion of what eventualities we want to prepare against and at what level of priority. On the whole, there has been agreement that the essential warning and communication capabilities should be preserved at a very high priority even in the face of a nuclear attack. Much can be done to preserve these capabilities by unilateral measures. Stabilizing this situation seems a reasonable objective for arms control agreements in space, assuming there is no overriding rationale for deploying ASAT's in connection with or to deter conventional wars or crises, an assumption which seems warranted by history to date. Such an objective would lead us to focus first on space-based weapons and on ground-based laser systems sufficiently capable to damage hardened satellite systems, especially at high altitudes.

Verification is a major concern. There is no hope of arms control agreements being adequately verifiable unless we take the steps outlined above, as well as others, to enhance the survivability of the space functions as much as possible unilaterally, consistent with reasonable increases in systems cost. If we do not take these steps, small, not readily identifiable ground-based lasers, for instance, could have an ASAT capability. If we do take those steps, however, several agreements might enhance the security of at least the high-altitude space assets most relevant to nuclear stability in an adequately verifiable way. The following is a tentative and partial list.

1) Develop rules of the road, that is, international agreements governing the use of space. These agreements might, for example, make it legal for any signatory nation to take some action regarding other nations' satellites coming closer than certain stated distances to specified satellites of its own. The stated distances and specified satellites would have to be worked out according to the orbits of the satellites to be protected and according to the requirements of civilian space users. Rules of the road that provide effective protec-

tion or warning may only be feasible in orbits that are not heavily used by civilian space users. The action to be permitted would also depend on the circumstances. It could range from requiring that entering legal satellites carry beacons to providing opportunities for inspection to actual destruction of a trespassing satellite (*3*). These rules of the road would not provide foolproof safety against space mines and other space-based ASAT's. They would make the task of effective attack against certain space functions, which should already be a difficult matter if the systems carrying out these functions are suitably designed, more difficult yet and more uncertain.

2) Ban the test and deployment of ground-based lasers in an ASAT mode. Bans on lasers in the appropriate power range coupled to sophisticated compensating optics to send the light through the atmosphere are probably very likely to be verifiable.

3) Ban the test and deployment of projectile launchers, lasers, particle beams, and any other ASAT's in space. These would be in the main distinctive space installations that would require testing in space. The associated test program and deployment in numbers adequate to constitute a threat to a properly designed space system should both be verifiable.

Such arms control measures would not make our satellites safe against nuclear attack by specially configured intercontinental ballistic missiles, for example. They could, however, augment unilateral measures in ensuring that warning and communication systems, especially, could survive for some crucial period of time in the event of a nuclear war or crisis. They could also help avoid deployments that seem to add little or nothing to our security and that might make the handling of lower level conflicts more difficult and more risky.

If extensive strategic defenses are deployed, the ASAT and counter-ASAT picture changes completely. This is particularly true if space-based weapons are developed and deployed. Under such circumstances, all space assets, whether needed for defense or offense, for warning or other purpose, would have to operate in a very hostile environment. They would have to be hardened beyond anything now contemplated, at commensurate cost, or alternatively be mobile, defended, or proliferated. Space hardware would replicate the characteristics of earth-bound military hardware. We would have the space analog of tank corps and carrier battle groups. The recommendations herein do not apply to such an era. Arms control in such an era, if it were possible, would be closer to the Strategic Arms Limitation Treaty–type of agreements, in which limits in the thousands or perhaps hundreds are agreed to.

The question of whether and when to proceed toward strategic defenses thus subsumes the question of safeguarding present space functions. Space assets much more complex and expensive than the present ones must be safeguarded if there are to be effective space defenses, and they must be safeguarded against very severe threats. It is not clear to me when we will know whether this can be done. The sort of partial ASAT ban suggested above would not in the long term be compatible with an active R&D program aimed at testing the survivability of strategic defenses in space. We are therefore thrown back on whether and at what pace to proceed toward strategic defenses as the first question to settle.

My view is that the right kind of strategic defenses could be helpful both to deterrence and to survival but that we are a long way from being able to tell whether that potential will be realized. Defenses could be helpful to deterrence, if coordinated with survivable offensive forces, by reducing both the real and the perceived differences between first and second strikes and by offering the possibility of defending against accidents and of stalemating limited attacks. They could also limit damage from a nuclear attack, if they are sufficiently survivable and sufficiently cost-effective so as not to lead to offsetting buildups.

However, we are not close to knowing whether an effective defense system can be built or what it would look like. We do not know for instance whether it should be based in space and to what extent, nor do we know what the components of the system should be. If space deployments are needed, a whole new regime of launch capabilities will have to come into being first. It thus seems unlikely that a strategic defense deployment of any value can begin within at least 10 years.

Thus the United States and the Soviet Union could agree to maintain the Anti-Ballistic Missile Treaty for some period of time, perhaps 10 years, possibly with exceptions to be negotiated for certain tests, without substantially harming the prospects for an effective defense. We could also complement the Anti-Ballistic Missile Treaty with ASAT agreements and rules of the road, those again to be good for the same period of time. Such measures could give us a chance to see what if anything new technologies might lead to in the way of a more satisfactory basis for peace.

Conclusion

Space systems are not all the same from the point of view of survivability. High-altitude systems, such as warning and communication systems, have the best prospects.

Similarly, ASAT systems are not all the same from either the standpoint of effectiveness or verification. In general, the more survivable the space system, the more costly and extensive the ASAT system needed to attack it effectively and the more verifiable a ban on such effective ASAT systems is likely to be. The exception is in-orbit weapons, which might be handled with rules of the road.

Thus, from the point of view of safeguarding our space assets, especially our warning and communication assets which are most crucial for nuclear stability, there is a definite advantage to at least partial ASAT bans, if verifiable, and to appropriate rules of the road.

The deployment of strategic defense systems might change these conclusions. It might for one thing enormously increase the amount of resources that we would launch into space. However, that technology does not appear to warrant an early deployment decision for strategic defenses. As a result, it seems that proceeding with space arms control measures, in conjunction with unilateral survivability measures, is well warranted.

REFERENCES AND NOTES

1. What is said here and elsewhere in this article regarding nuclear explosions or lasers in space may not apply to nuclear-driven x-ray lasers.
2. For a history of ASAT negotiations and a survey of current positions, see *Nuclear Arms Control, Background and Issues* (National Academy Press, Washington, DC, 1985), chap. 6.
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4. Supported by DOE contract W-7405-ENG-48 to Lawrence Livermore National Laboratory.