Satellites and Anti-Satellites
The Limits of the Possible

Ashton B. Carter

Analysis of the complex anti-satellite (ASAT) issue is still in its infancy. There are signs, however, that the subject will have to grow up fast in the coming year. The Geneva arms control negotiations seem likely to depart the familiar terrain of strategic and theater nuclear weapons and launch into the lesser-known reaches of space. As the ASAT issue gains prominence, members of the national security community will need to acquaint themselves with its specialized jargon and technologies. Just as a rudimentary understanding of throwweight, flight times, and post boost vehicles is indispensable to discussion of strategic forces and arms control, so a modest knowledge of orbits and satellites is necessary for informed discussion of ASAT. One purpose of this article is to provide that background to non-technical readers.¹

Military and technical analysis, of course, will play only a modest part in the ASAT policy process, getting submerged quickly in the swirl of domestic politics, posturing at the negotiating table, legalisms, and bureaucratic interests. In addition, the political agenda of conciliation or competition with the Soviet Union is a paramount, and within limits legitimate, basis for supporting or rejecting an arms control approach. Yet behind these political

This article is based upon a paper prepared for the Aspen Strategy Group Summer Workshop on “Anti-Satellite Weapons and the Evolving Space Regime,” Aspen, Colorado, August 12–14, 1985. The author wishes to thank the Aspen Strategy Group for its hospitality. Material in this paper was presented previously by the author at: the Congressional Office of Technology Assessment’s “Workshop on Arms Control in Space” (January 30–31, 1984; proceedings published as OTA-BP-ISC-28); the Annual Meeting of the American Association for the Advancement of Science (May 28, 1984); the MITRE Corporation National Security Issues Symposium (October 25–26, 1984); the United States Space Foundation Annual Symposium (November 26–28, 1984); and in the author’s testimony before the Senate Armed Services Committee (March 18, 1985).

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agendas and other diversions are concrete and specific threats to U.S. military security and to peace. These are the bedrock and ultimate rationale of all U.S. military programs and arms control efforts in space.

Discussion of arms control for nuclear forces has come over the years to revolve around a canon of “problems” and a body of lore about which developments are destabilizing or disadvantageous to U.S. security. It is no secret that many of these problems have in fact little technical or military basis; they are salient only because the political process has invested so heavily in them. Military space operations are a newer focus for arms control, and a comparable canon of problems has not yet been framed, either within the U.S. or in negotiations between the U.S. and the U.S.S.R. It is important that ASAT issues be formulated at this early stage with adequate regard for technical and military factors, before they gain political momentum. Phony “windows of vulnerability” become hard to dispel later. A second purpose of this article is to identify the technical and military factors that should inform a mature policy debate.

For many, military activities in outer space have a certain mystique—reflected equally in urgings that we “must seize the high ground” and that we “must avoid militarizing space”—that is not very helpful in perceiving or obtaining the military space programs we need. This article starts from the premise that however special or dramatic space might appear, it should be regarded merely as another medium for national security activities. We should apply to military missions conducted from space the same standards of cost effectiveness, survivability, and trade-offs with alternatives that we apply to our other military decisions. The drama can be taken into account after we have gotten our bearings in a more hard-headed military sense. Nor does this article seek arms control “solutions” for ASAT problems to the neglect of unilateral military initiatives and acts of self-restraint. In fact, it is not clear that ASATs are a fruitful, or even an appropriate, focus for arms control. For one thing, some satellite functions are easily disrupted—too easily to be verifiably prohibited. For another, some satellite functions are threatening and do not deserve sanctuary. Furthermore, unilateral satellite survivability measures might suffice to give adequate protection to stabilizing space missions like missile warning without the help of negotiated restraints. Elaborating these statements, which together compel some skepticism about the value of ASAT arms control, is the third purpose of this article.

2. The U.S.–Soviet anti-satellite negotiations conducted in the late 1970s framed the ASAT issues of the time, but without the conspicuous political and public attention that space is receiving today.
A healthy skepticism, however, is not the last word on ASAT arms control. To be sure, the objections to comprehensive ASAT arms control are sound and persuasive. Can one conclude that the logical contradictions of ASAT arms control are so pervasive that there is simply no scope for negotiated measures that would provide genuine stabilizing benefits without disserving U.S. military interests? Something like this conclusion seems to have been arrived at by the Reagan Administration. Yet upon close analysis, it appears that there might be ASAT proposals, albeit limited and rather complex ones, that satisfy even the most stringent precautions against U.S. military disadvantage. Sketching these proposals is the fourth purpose of this article.

Plainly, a great deal more analysis needs to be done on the ASAT question. Given the current state of research, further analysis is almost certain to yield new insights. This is particularly true of, first, the competition between ASAT technologies and satellite defense measures—a matter for technicians—and, second, the plausible circumstances and purposes of attacks on satellites—a matter for strategists and political scientists. This article therefore suggests many more avenues of inquiry than it can pursue adequately. Providing a rubric for further detailed research is the fifth and final purpose of this article.

Current Military Uses of Space

For the thirty years of the space age, military space activities have been divided into five traditional missions: communications, reconnaissance and surveillance, navigation, meteorology, and geodesy. This section surveys these current space missions. No other missions have yet proved attractive enough to the superpowers to result in deployment. A remarkable amount of authoritative information is available from U.S. sources on the entire Soviet military space program. Several specific U.S. space systems cannot be discussed at all in an unclassified setting. But general characteristics of military satellites and their orbits follow from basic technical considerations.

ORBIT TYPES
A small vocabulary of satellite orbits is an indispensable background for following the ASAT discussion (Figures 1–4). Learning this vocabulary is

4. A useful and well-informed compendium of Soviet space activities is published every year by Nicholas L. Johnson, Principal Technologist at Teledyne Brown Engineering, Colorado Springs, Colorado 80910.
Figure 1  THE FOUR MAJOR ORBIT TYPES, drawn here to scale, contain almost all military satellites. The LEO region, represented here by a 1500 km (930 mi.) circular orbit, is subject to attack by both the US and Soviet ASATs. The US ASAT also has the propulsive capability to attack Molniya orbit, though it will not in fact have that capability in its proposed operational deployment; the Soviet ASAT cannot attack Molniya orbit. Neither ASAT can climb to semi-synchronous orbit or GEO. The nature and orbits of US reconnaissance satellites are classified. The supersynchronous region above GEO is little populated today, but its vast reaches offer opportunities for satellite survivability that are likely to be exploited in the future.
made easy by the fact that orbital motion is independent of spacecraft size and weight, so all satellites travel around a given orbit in exactly the same way regardless of their natures.  

All orbits are circles or ellipses. Rather than quoting the dimensions of the orbit itself, it is customary to quote its altitude above the earth for circular orbits and the altitude of its highest point (apogee) and lowest point (perigee) for elliptical orbits. A satellite’s speed is greater in low orbit than in high orbit and greater at perigee than at apogee. The lowest possible orbit—a circular orbit just above the atmosphere at an altitude of 200 kilometers (km) or so—has the shortest possible period, about 90 minutes. Satellites in high-altitude orbits have most of a hemisphere in view at one time, but only a smaller patch of the earth’s surface is visible from low orbit (Figures 5 and 6).

As the satellite moves through its orbit, the earth turns below it. The satellite’s ground track, tracing the point on the earth’s surface directly below the satellite, is the composite of these two independent motions (Figure 7). Orbits are termed “equatorial,” “polar,” or “inclined” depending on the orientation of the orbital plane with respect to the plane of the earth’s equator. If the inclination angle is small, only a small band above and below the equator can be surveyed, the highest latitude reached by the ground track being equal to the inclination angle. Only polar orbits overfly the entire earth surface.

Just five orbit types contain all military satellites.

LOW EARTH ORBIT (LEO). “LEO” is the term applied to the region below about 5000 km altitude. Orbits there have periods ranging from 90 minutes to a few hours.

GEOSTATIONARY ORBIT (GEO). A circular orbit with altitude 35,700 km (6 earth radii)—extending about a tenth of the way to the moon—has a period of 24 hours. A satellite in eastward equatorial orbit at this altitude therefore remains over the same point on the equator as both it and the earth go around. The satellite has line-of-sight contact with more than 80 percent of the hemisphere beneath it. To all observers who can see the satellite, it remains in the same position in the sky at all times. Several satellites spaced evenly around the equator give coverage of the whole world except the polar

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5. This seemingly insignificant fact is actually a deep physical principle and is the basis of Einstein’s general theory of relativity.
Figure 2  SPECIFICATIONS OF ORBIT TYPE include inclination angle as well as altitude. The inclination angle is the angle made by the orbital plane and the plane of the earth’s equator. The orbits of most LEO military satellites are polar; Molniya orbits are always inclined; currently-populated semi-synchronous orbits are inclined; and the GEO belt is equatorial.
regions (Figure 8). Most U.S. and an increasing number of Soviet communications satellites are in geosynchronous orbit.

MOLNIYA ORBITS. The appealing property of geosynchronous orbit—uninterrupted visibility between an earth station and a single satellite—can be partially realized with the Molniya orbit, named after the family of Soviet communications satellites that makes use of it. The orbit is highly elliptical—40,000 km apogee and 500 km perigee—and has a 12-hour period. Because a satellite in Molniya orbit travels very slowly near its apogee and very rapidly at perigee, it spends more than 11 of every 12 hours on one side of the earth. The orbit is inclined, so the satellite dwells high over the northern hemisphere—convenient for communications within the U.S.S.R. The particular inclination angle of 63 degrees is chosen because at this angle the orbit is stable and does not drift under the influence of the earth’s equatorial bulge.

SEMI-SYNCHRONOUS ORBIT. A circular orbit at an altitude of 20,000 km has a 12-hour period. This general altitude band is referred to as semi-synchronous orbit and is sometimes defined to range all the way from LEO to GEO.

SUPER-SYNCHRONOUS ORBIT. Orbits between GEO and the moon are thinly populated today but offer vast reaches for stationing future military satellites. The U.S. deployed a constellation of nuclear burst detection satellites in 11-day orbits halfway to the moon in the 1960s.

COMMUNICATIONS
There are only two ways to communicate information over long distances within seconds—by landline (including transoceanic cable) and by radio. Because the earth is round, line-of-sight radio contact between widely separated points on the earth’s surface is impossible. One way to propagate radio waves over the horizon is to bounce them off the ionosphere; shortwave (HF, high frequency) radio propagation in this manner was until recently the U.S. Navy’s chief means of communicating with its far-flung ships. But ionospheric reflection is unreliable and cannot support large rates of message traffic. Long-distance communication companies have long placed microwave radio relays on towers and mountaintops for over-the-horizon relay. The communications satellite is just an extension of the relay principle to higher altitudes and consequently longer relay distances.

Most operational communications satellites (COMSATS) today use ultra-high frequencies (UHF) and super-high frequencies (SHF), but extremely high frequency (EHF) systems are under development. The move to higher frequencies for military satellite communication (SATCOM) is motivated by
Figure 3  MILITARY SATELLITE CONSTELLATIONS illustrate the four orbit categories.
   (a) Five US TRANSIT navigation satellites in polar LEO, arranged in five separate orbital planes.
   (b) Four US DSCS communications satellites in GEO equatorial orbit.
   (c) Four Soviet Molniya communications satellites in inclined Molniya (hence the orbit name) orbits, arranged in four planes.
   (d) Eighteen US Navstar GPS navigation and nuclear burst detection satellites in inclined semi-synchronous orbits, arranged in six planes.
Figure 4  TYPICAL DISTRIBUTION of military satellites deployed by the US and the USSR at any given time is broken down in the bar chart according to two factors: orbit type and mission. (From R.L. Garwin, K. Gottfried, and D.L. Hafner, "Anti-satellite Weapons," *Scientific American*, June 1984.)
five factors. First, higher-frequency radio waves have a higher limit to their data-carrying capacity than lower-frequency waves. Second, transmitting antennas for higher frequencies can be made smaller without sacrificing performance, since the effectiveness of a transmitter dish is determined by the ratio of its size to the wavelength of the radio waves it is transmitting. Three additional reasons favor high frequencies (accompanied by wide bandwidths) for the peculiar needs of military SATCOM: 1) it is easier to protect higher-frequency links against hostile jamming; 2) covert (“low-probability-of-intercept” or LPI) communication, which does not betray the location of the transmitting ground terminal, is easier with wide bandwidths; and 3) higher frequencies suffer less distortion in passing through an ionosphere disturbed by nuclear detonations. Laser communication is also coming into use for satellite-to-satellite links and for satellite-to-aircraft links. Ground-to-space laser communication links could obviously be frustrated by clouds.

Military COMSATS are deployed in a variety of orbits. GEO is high enough to allow widely separated ground stations to communicate through a single satellite, and a stationary satellite makes it easy for users to point their antennas. But the polar regions are invisible from geosynchronous equatorial orbit. The Soviets, with many military installations at high latitudes, deploy COMSATS in Molniya orbits. A communications satellite in LEO is only visible at any given time from a relatively small patch of earth below. Two terminals within the patch can communicate directly, but widely separated users must store messages on board the satellite when it is overhead, ordering the satellite to “dump” the message when it passes over the recipient. The Soviets deploy large numbers of such store-and-dump satellites in LEO.

Users of military SATCOM fall into three categories: high-data-rate peacetime users, including intelligence and diplomatic terminals; tactical forces needing moderate data rates but worldwide coverage, small mobile terminals, and resilience to disruption; and nuclear forces and their commanders, needing low data rates but performance under severe stress. Today’s U.S. Defense Satellite Communications System (DSCS, pronounced “discus”), Fleet Satellite Communications (FleetSatCom), and Air Force Satellite Communications (AFSATCOM) systems correspond roughly to this tripartite division.

The DSCS is the U.S. government’s version of INTELSAT, providing worldwide (except the polar regions) high-data-rate voice and data communications. The main peacetime DSCS users are the Diplomatic Telecommunications Service (DTS) linking embassies worldwide with Washington, intelligence users moving large amounts of data, the major military com-
mands, and the White House Communications Agency (WHCA) on Presidential trips. DSCS provides U.S. embassies and other overseas installations with a link to Washington that cannot be severed at will by the host government. The DSCS would also serve U.S. task forces deployed to a crisis area. In the event of nuclear war, the DSCS satellites could connect warning sensors to ground and air-borne command posts and the command posts to B-52 and B-1 bombers, cruise missile carriers, and Minuteman launch control centers. During the Mayaguez incident in 1975, the President communicated with the Marine commander of the landing party through the DSCS system. The DSCS constellation consists of four spacecraft plus two on-orbit spares in case of failure, positioned in synchronous equatorial orbit over the Atlantic, the Indian Ocean, and the eastern and western Pacific.

The FleetSatCom (FLTSAT) constellation consists of four synchronous satellites distributed about the equator in almost the same positions as the four DSCS spacecraft. The FLTSATs relay a fleetwide broadcast, transmitted to the satellites from ground stations, for which almost all Navy ships have a receiver. Many surface ships and submarines can transmit messages back to shore stations as well. All channels in the FLTSAT system operate in the military UHF band except for an SHF uplink that carries the fleet broadcast up to the satellites.

The AFSATCOM program does not consist of a particular satellite constellation, but rather of communications packages on spacecraft designed sometimes for entirely other purposes. In addition to channels on the FLTSATs, the AFSATCOM system includes communications packages on the DSCS spacecraft, covering the non-polar regions; on the Satellite Data System (SDS) spacecraft in Molniya orbits; and, in the future, on the eighteen satellites of the Navstar Global Positioning System (GPS) constellation, providing worldwide coverage. Obviously, almost any military spacecraft would make a convenient “host” for a small AFSATCOM transponder, and it would be possible in principle for the Department of Defense (DoD) to put simple transponders on civilian satellites as well.

The array of COMSATs available to the U.S. military is completed by a few Allied systems, various experimental communications spacecraft, and out-of-service but still partially usable satellites. Services of COMSATs owned by civilian companies and other nations might in some circumstances be made available to the military.

Transmitting a message from one hemisphere to another requires an intermediate ground station in view of two satellites, the satellites in turn being
Figure 5  VIEW OF EARTH FROM 36,000 KM GEOSYNCHRONOUS HEIGHT over 0 degrees latitude and longitude. (Adapted from W.G. Collins and J.L. van Genderen, Fundamentals of Remote Sensing, London, 1974.)

Dashed circle indicates visible Earth surface from 1000 KM height.
Figure 6  VIEW OF EARTH FROM 1000 KM HEIGHT with satellite nadir at 0 degrees latitude and longitude. (Adapted from W.G. Collins and J.L. van Genderen, Fundamentals of Remote Sensing, London, 1974.)
in view of the originator and recipient. Likewise, a low-earth orbiting satellite that collects its data out of sight of its processing station must have either a local earth station connected by landline or satellite relay to the processing station, or tape recorders to store the data until the satellite passes over the processing station and can "dump" it. And control of complex spacecraft requiring frequent ground commands depends on a worldwide network of earth stations. Suitably located earth stations stable to political change, not to mention military conflict, are hard to provide. Direct satellite-to-satellite relay links avoid all these problems. NASA’s Tracking and Data Relay Satellite System (TDRSS), consisting of a pair of spacecraft in synchronous orbit, will provide essentially uninterrupted relay between satellites at all altitudes and a ground station at White Sands, New Mexico. Satellite crosslinks and relay COMSATS are crucial for freeing satellites of their dependence on overseas ground stations.

**RECONNAISSANCE AND SURVEILLANCE**

Electromagnetic radiation emitted or reflected from terrestrial objects can be detected from space in any of the three wavelength bands to which the

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**Table 1. Communications Satellites**

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<tr>
<th>System</th>
<th>Orbit</th>
<th>Approximate Number*</th>
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<tbody>
<tr>
<td><strong>U.S.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSCS</td>
<td>GEO</td>
<td>4–6</td>
</tr>
<tr>
<td>FLTSATCOM</td>
<td>GEO</td>
<td>4–6</td>
</tr>
<tr>
<td>AFSATCOM</td>
<td>Transponders attached to military satellites in a wide variety of orbits.</td>
<td>&gt;25</td>
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<tr>
<td>MILSTAR (planned)</td>
<td>GEO, equatorial and polar</td>
<td>6–8</td>
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<tr>
<td>SDS</td>
<td>Molniya</td>
<td>3</td>
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<tr>
<td>TDRSS</td>
<td>GEO</td>
<td>2</td>
</tr>
<tr>
<td><strong>U.S.S.R.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Various</td>
<td>GEO</td>
<td>10</td>
</tr>
<tr>
<td>Molniya</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Tactical, “Store and Dump”</td>
<td>LEO</td>
<td>25</td>
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* Denotes nominal constellation size (actual or planned) or average on-orbit active population.
intervening atmosphere is transparent, viz., the visible band, certain infrared bands, and the microwave radio band. It follows that these are the bands used for military surveillance.

In peacetime, these remote sensing techniques are used to characterize foreign weapons for U.S. force planning and treaty monitoring and to contribute to strategic warning. Collection of peacetime intelligence is characterized by a leisurely time scale and a benign environment. Naturally one would like to use these remote sensing techniques for wartime purposes as well—tracking fleet movements, locating rear area targets, sorting out enemy lines of supply and command, monitoring activities at airbases, intercepting field communications, warning of enemy advances, and so on. Though many of the same remote sensing technologies apply to both tactical and strategic intelligence, there are three crucial differences between these two missions. First, battlefield intelligence must be processed and disseminated rapidly if it is to be useful. Second, tactical sensors of genuine military value must expect to come under attack, whereas peacetime intelligence collection is not directly impeded. Third, space-based sensors—a necessarily global capability—must compete in cost-effectiveness and survivability with other collectors, such as aircraft and remotely piloted vehicles, which can be brought rapidly to bear in a theater of conflict. These factors make the notion of an "electronic battlefield" orchestrated from space somewhat less compelling than a first thought might suggest. Since tactical intelligence is probably the most important potential contribution to direct military strength that space can make, trade-off against non-space collectors is a crucial issue.

In the realm of nuclear operations, space is used to detect missile launches and nuclear detonations. Missile warning data permits the safe escape of bombers, tankers, cruise missile carriers, airborne command posts, and, for launch-under-attack (LUA), ICBMs. Confirmation of detonations on U.S. soil might also serve as a last check on an LUA decision. But the most important use of missile launch and nuclear detonation data would probably be to give decision-makers a clear assessment of what happened—information crucial to responsible action and, under the chaotic circumstances, hard to come by otherwise.

IMAGERY. The resolution of a given spaceborne optical camera is proportional to its altitude.⁶ Thus a photoreconnaissance satellite orbiting at 200 km

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⁶. In practice many factors determine image quality, including contrast, brightness, air quality, and others.
Figure 7  GROUND TRACK of a two-hour circular orbit inclined 60 degrees. The altitude of this orbit is about 1600 kilometers (1000 miles), or a fourth of the earth's radius. The satellite makes 12 revolutions in a day, while the earth turns just once beneath it. The ground track therefore crosses the equator on 12 descending passes and 12 ascending passes, retracing itself every day. The highest latitude surveyed by the satellite is equal to the chosen inclination angle of 60 degrees, meaning that the satellite never passes directly over points more northerly than Leningrad, Oslo, and Anchorage. Since the period is exactly 2 hours, the satellite retraces the same ground track every day, getting the same view. Changing the period to slightly more or slightly less than 2 hours (or allowing the uneven shape of the earth and other factors to cause natural precession) would cause the entire ground track pattern to shift slightly sideways every day rather than to reproduce itself exactly. Eventually the shifting pattern would pass over the entire earth between 60 degrees north and 60 degrees south latitude, allowing this entire region to be surveyed in detail. Since the orbit altitude is quite high, the satellite actually has line-of-sight visibility to higher latitudes, and the satellite's sensors can survey a swath on either side of the ground track.
altitude and yielding imagery with one-foot resolution (about the view the human eye gets from the top of a skyscraper) would at 5000 km yield Landsat-like imagery useful for forestry and for National Geographic, but useless for most intelligence purposes. Photoreconnaissance satellites are therefore confined to low-earth orbit. Coverage at all latitudes requires polar orbits for these satellites. If the satellite furthermore has an on-orbit lifetime of longer than a month, it should make use of the sun-synchronous property of certain near-polar orbits, which maintain the same orientation with respect to the sun as the seasons change, always taking pictures at the same local time on the earth below regardless of season (Figure 9). Low altitude, polar, sun-synchronous orbit is therefore the home of long-lived photoreconnaissance satellites.

Infrared cameras would collect information about the surface temperature of objects on the earth, potentially revealing features obscured at visible wavelengths. Radar images can be formed by illuminating the earth with microwaves and collecting the reflected signals. Radar satellites would provide nighttime and all-weather imagery, since they would supply their own illumination, and microwaves penetrate easily through clouds.

**SIGNAL DETECTION.** Satellites can also detect discrete signals in the three atmospheric bands, including microwave pulses from the air defense radar on a ship, telemetry from a cruise missile test vehicle, the visible flash of a nuclear detonation, or the infrared plume of an ICBM launch. If the signal is sharply structured in time—like the flash of a nuclear burst or the pulses of a radar—the emitter’s location can be deduced from the differences among the signal’s arrival times at several well-separated satellites.

Orbits for signal detection should be chosen to provide continuous coverage of target areas, preventing the opponent from performing tests, sending messages, moving mobile radars, or launching missiles during coverage gaps. Geosynchronous orbits offer continuous dwell over mid-latitudes; the U.S. acknowledges stationing warning satellites there. Long dwell times (and

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7. Orbiting synthetic aperture radar (SAR) imaging systems provide their own (microwave) illumination, which penetrates cloud cover. The SAR satellite emits a pulse and processes the reflected signal. The returns from different patches of earth are separated as follows: the delay between generation of the pulse and receipt of the return gives the patch’s distance from the satellite; the frequency of the return gives the patch’s angle with respect to the satellite’s ground track, since returns from patches in front of the satellite are Doppler shifted to higher frequencies (like the siren of an approaching ambulance), returns from patches behind the satellite to lower frequencies (like a receding ambulance), and patches to the side at the same frequency as the emitted pulse. Sorted in this way, the returns from all the patches can be combined to form an image of the scene below. The data rate and processing load from an SAR are very great.
Figure 9 THE PRINCIPLE OF SUN-SYNCHRONOUS ORBIT. The plane of this near-polar orbit precesses by 90 degrees every three months, retaining the same relation with respect to the sun in all seasons. Photoreconnaissance satellites in sun-synchronous orbit take photographs of the earth below at the same local time in all seasons. If the orbital plane established in spring for noon viewing of the earth were not arranged to precess in synchrony with the sun, by autumn the satellite could only take dawn and dusk photos (dashed orbit).
coverage of northern latitudes) are also possible from Molniya orbits; the Soviet Union deploys warning satellites in this way. Continuous coverage by several widely separated satellites, permitting emitter location by the time-difference-of-arrival technique, requires a “birdcage” constellation; the U.S. Nuclear Detection System (NDS) aboard the Navstar GPS satellite is in this kind of orbit.

Apart from geosynchronous missile warning and birdcage NDS deployment, the U.S. has not revealed the locations of its other signal detection satellites. They could make use of all three possibilities: geosynchronous, Molniya, and low- and mid-altitude “birdcage” constellations.

**NAVIGATION**

Navigation is not a glamorous mission, but it is essential for supporting reconnaissance, weapon delivery (including SLBMs), precision emplacement of sensors and mines, and rendezvous. Terrestrial navigation systems have either restricted coverage (LORAN) or poor accuracy (OMEGA). In one satellite navigation method, used by the U.S. Navy’s TRANSIT system and its Soviet equivalent, the user listens to how the received frequency of a radio signal changes as the transmitting satellite passes from horizon to horizon, like the wail of an ambulance siren as it first approaches and then recedes.

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<thead>
<tr>
<th>System</th>
<th>Orbit</th>
<th>Approximate Number</th>
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<tr>
<td><strong>U.S.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missile Warning</td>
<td>GEO</td>
<td>3</td>
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<tr>
<td>Nuclear Burst Detection</td>
<td>Semi-synchronous, inclined (“birdcage”)</td>
<td>18</td>
</tr>
<tr>
<td>Photoreconnaissance</td>
<td>LEO, polar, sun-synchronous</td>
<td>few</td>
</tr>
<tr>
<td>Other</td>
<td>Classified</td>
<td>Classified</td>
</tr>
<tr>
<td><strong>U.S.S.R.</strong></td>
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<td></td>
</tr>
<tr>
<td>Missile Warning</td>
<td>Molniya</td>
<td>9</td>
</tr>
<tr>
<td>Photoreconnaissance</td>
<td>LEO</td>
<td>2–3</td>
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<td>ELINT</td>
<td>LEO</td>
<td>6</td>
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<td>Radar Ocean</td>
<td>LEO</td>
<td>0–2</td>
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<tr>
<td>Reconnaissance Satellite</td>
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<td>(RORSAT)</td>
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<td>Elint Ocean</td>
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<td>(EORSAT)</td>
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Knowing the satellite’s orbit and the pattern of frequency change allows the receiver to deduce its location on the earth’s surface. Global coverage points to polar orbits for these satellites, and frequent revisits of all locations to a number of orbital planes.

In a second navigation method, the user measures the arrival times of signals from several well-separated satellites and then uses the inverse of the time-difference-of-arrival emitter location technique to deduce its position. This points to a birdcage constellation like Navstar GPS.

**METEOROLOGY**

Military operations, special operations, and reconnaissance planning all require knowledge of the weather patterns in distant parts of the globe. The U.S. Defense Meteorological Support Program (DMSP) satellites are in 850-km near-polar sun-synchronous orbits. With a 100-minute period, they orbit the earth 14 times per day. From 850-km altitude, the width of the swath of earth visible below is almost 3000 km—one 14th of the earth’s circumference. Thus on its 28 passes over the equator each day, a DMSP satellite views nearly every point on the equator twice, once on an ascending pass and once on a descending pass. At other latitudes the swaths overlap. The U.S. also deploys the GOES civil weather satellites in geosynchronous orbit, whose data is available for military use, and civil weather satellites in LEO similar to DMSP.

**GEODESY**

This peacetime mapping function has little importance for the ASAT problem, since it would be accomplished by the time hostilities began.

### Table 3. Navigation Satellites

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<tr>
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<tr>
<td>TRANSIT</td>
<td>LEO</td>
<td>5</td>
</tr>
<tr>
<td>Navstar GPS</td>
<td>Semi-synchronous</td>
<td>18</td>
</tr>
<tr>
<td><strong>U.S.S.R.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRANSIT-like</td>
<td>LEO</td>
<td>10</td>
</tr>
<tr>
<td>Navstar-like (GLONASS)</td>
<td>Semi-synchronous</td>
<td>~12</td>
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Table 4. Meteorological Satellites

<table>
<thead>
<tr>
<th>System</th>
<th>Orbit</th>
<th>Approximate Number</th>
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<tbody>
<tr>
<td>U.S. Defense Meteorological</td>
<td>LEO</td>
<td>2</td>
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<tr>
<td>Support Program (DMSP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GOES</td>
<td>GEO</td>
<td>4</td>
</tr>
<tr>
<td>U.S.S.R.</td>
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<td></td>
</tr>
<tr>
<td>Meteor</td>
<td>LEO</td>
<td>&gt;3</td>
</tr>
<tr>
<td>GOMS (planned)</td>
<td>GEO</td>
<td>4</td>
</tr>
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</table>

Future Military Uses of Space

"BENIGN" AND "THREATENING" SATELLITE FUNCTIONS

Through the first three decades of the Space Age, the superpowers have found it technically and economically attractive to use space only for the five traditional military support missions of communications, reconnaissance and surveillance, navigation, meteorology, and geodesy described above. Though located in space, satellites perform the functions of a host of other military equipment (reconnaissance aircraft and ships, microwave communications towers, terrestrial navigation beacons like LORAN) about which much less fuss and certainly no arms control proposals are made. Though these satellites do not carry weapons and do not shoot anything, some of them can directly support military operations. It therefore seems oddly inconsistent to seek to create a sanctuary in space for this threatening military equipment. Why shouldn’t satellites be subject to attack like all the other instruments of warfare?

The impetus for negotiated limits on ASATs is the observation that next to these threatening satellites is a class of relatively benign satellites that should not be subject to attack. Missile warning satellites exemplify this benign class most clearly. There could in principle arrive a day when the U.S. saw no alternative to large-scale nuclear attack on the Soviet Union. On that fateful day it would be meaningfully (decisively would be putting it much too strongly—the Soviets have many SLBMs and other nuclear weapons) better for the U.S. to be sure of taking Soviet ICBMs by surprise in their silos. To the extent (again, incomplete—the Soviets have warning radars, too) that the capability to attack Soviet warning satellites instantly would
contribute to successful surprise, the U.S. would on that day wish for that capability. Soviet warning satellites would in that circumstance be threatening to U.S. military interests. The problem with acquiring the capability to attack warning satellites, and the reason why missile warning comes closest to being a clearly “benign” space mission, is that it causes Soviet reactions in peacetime and Soviet anxieties in crisis that are harmful to U.S. interests. In most people’s minds, the harm done by this capability on every other day outweighs its hypothetical value on the hypothetical day of attack.

In the case of other space missions, the balance is harder to strike. The Soviet radar ocean reconnaissance satellite (RORSAT), or rather an improved version thereof, capable of tracking U.S. carrier battle groups and directing air attacks on them would probably exemplify the “threatening” category most clearly. Other missions fall somewhere between benign and threatening. It is vital to realize that the designations “benign” and “threatening” inhere not in the spacecraft’s mission only, but in the circumstances of its use as well. A benign U.S. photoreconnaissance satellite monitoring a crisis abruptly turns threatening to the Soviet Union when war begins and its daily imagery becomes the basis for air strikes on Soviet supply lines entering the theater. At that point the Soviets will wish to have an ASAT.

If today’s military uses of space include a substantial fraction of benign missions, in the future this fraction seems destined to decrease. Many of the potential future military uses of space—for directing tactical battlefield operations, for ballistic missile defense, and so on—are clearly threatening. It is natural to want to be able to threaten these satellites in return. Thus arises the basic paradox of ASAT arms control: to the extent that ASAT development is suppressed and the vulnerability of spacecraft masked, the superpowers will be more and more tempted to deploy threatening spacecraft. And to the extent they do so, pressures will in turn build to set aside the treaty and deploy ASATs.

POSSIBLE FUTURE MILITARY USES OF SPACE
A host of hypothetical future space missions vie for attention and funding. Which of these concepts will actually arrive at deployment depends not only on technical feasibility (not demonstrated in many cases) and the value of the mission they serve, but most importantly on their prospects for surviving ASAT attack. Missions that would never be taken seriously if they had to face an unconstrained ASAT threat will be much more tempting if the threat is constrained. Since some of these missions fall decidedly in the “threaten-
ing” category, giving them sanctuary in space could well prove intolerable over time.

**Adjuncts to Current Missions.** The advance of technology will permit support functions performed from space today to be performed better. For instance, introduction of SATCOM at EHF frequencies in the U.S. MILSTAR system will allow improved resistance to jamming, low-probability-of-intercept transmission that does not betray the communicator’s location or even existence, and better emergency communication through ionospheric regions disturbed by nuclear bursts. Missions performed by terrestrial equipment today might be augmented or backed up by spacecraft. For instance, blue-green laser communications are proposed as a backup to terrestrial and airborne VLF radio for communicating with missile submarines. Space-based infrared sensors could perform the vital job of continuously surveying all orbiting objects, replacing the current network of ground-based radars. Relay satellites like the shuttle-launched Tracking and Data Relay Satellite System (TDRSS) continue the process of freeing U.S. satellites from dependence on overseas ground stations.

**Elaborations to the Nuclear Offense** can be envisioned along four lines. First, space-based sensors might be used to seek out and direct attack on relocatable or mobile targets: air defense radars, mobile missiles, mobile (even airborne) command posts, etc. A second elaboration would be a means by which to assess the damage to an opponent from an initial nuclear strike and to re-strike whatever targets survived. One such scheme would use data from the Nuclear Detection System aboard Navstar GPS to observe detonations of U.S. weapons over the Soviet Union and to “fill in the blanks” where expected detonations did not occur due to the imperfect reliability of U.S. missiles. Two-on-one targeting of silos and other hardened targets would then be unnecessary. A more sophisticated idea would involve placing small radio transmitters aboard U.S. reentry vehicles (RVs). The transmitters

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8. Seawater is opaque to all but VLF and ELF radio frequencies, used for communications to submarines today, and to blue-green visible light. In the blue-green laser scheme, a laser beam originating on a satellite or reflected from a space-based mirror would be directed at a spot on the ocean and modulated in accordance with the message to be transmitted. After transmission of the full message, the beam would move and dwell on a neighboring spot and transmit again, and so on, eventually covering all submarine patrol areas. Optical sensors on the submarine hull would detect the message. The need to retransmit the message at each spot obviously limits the effective data rate possible with this scheme.

9. Richard L. Garwin, “Bombs That Squeak,” unpublished paper. Future ICBMs and SLBMs will be so accurate that imperfect reliability, not imperfect accuracy, will be the impetus for two-
would emit a radio signal just before detonation, allowing space-based receivers to locate the detonation point precisely by time-difference-of-arrival. The precision would be so great that RVs landing farther than a lethal radius from their target silo could be identified and a second wave of RVs launched against those silos. Damage assessment would also support a “shoot-look-shoot” tactic designed to penetrate a preferential ballistic missile defense.  

A third offensive elaboration would use satellite navigation to reduce missile guidance errors to 10s rather than 100s of feet, ushering in “useable” low-yield strategic nuclear weapons and even nonnuclear strategic weapons. Satellite navigation could also reduce the cost of Midgetman missiles which must otherwise each carry an expensive guidance system to have silo-killing accuracy. The fourth category of hypothetical elaborations to the nuclear offense comprises the space-based components of all the countermeasures the offense will need to compete with “Star Wars” defenses. Though these elaborations cannot be specified without specifying the type of defense system deployed, they would be akin to the short-range attack missiles (SRAMs), cruise missiles, stealth and other electronic countermeasures (ECM), and ICBMs that were the elaborations made to U.S. offense of the 1950s, based upon the high-flying bomber, when the Soviet Union improved its air defenses. In the “Star Wars” case the space-based components of penetration systems might include orbiting jammers, shields, decoy dispensers, and ASATs.

Nuclear defense includes all the beam and kinetic energy weapons, together with their sensors, discussed in the Strategic Defense Initiative. Orbiting radars or infrared sensors for tracking aircraft, and laser battle stations to attack them, might be components of a future air defense against intercontinental bombers. Last, this category includes still-hypothetical sensors for locating and tracking strategic missile submarines through their hydrodynamic, thermal, or other signatures.

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on-one targeting. The value of locating detonations extremely precisely can therefore be questioned.  


11. The reentry vehicle could take a navigation “fix” shortly before reentry and then adjust its course enroute to the target. Terminal guidance akin to that used on U.S. cruise missiles, on the other hand, would probably not require satellite support.  

12. Radio beacon guidance also obviates the need to stabilize and initialize the inertial guidance system after it has been jostled in moving about its deployment area.  

SUPPORT TO CONVENTIONAL FORCES is a vast category that ranges from the monitoring of rear areas (akin to peacetime strategic intelligence) to detailed participation in battlefield operations—locating targets, guiding “smart” weapons to them, and relaying voice and data traffic.

ANTI-SATELLITE (ASAT) AND SATELLITE DEFENSE (DSAT) comprise all the paraphernalia of a military competition in space: 1) mines, directed-energy weapons, kinetic energy weapons, jammers, and ECM pods to destroy or fool enemy satellites; 2) defensive escorts for friendly satellites, carrying jammers, decoys, shields, or weapons to fight off ASATs; and 3) space-tracking and identification sensors for ASAT, DSAT, and treaty monitoring.

SPACE-TO-EARTH WEAPONS discussed from time to time include beam weapons, orbiting nuclear- and conventionally armed reentry vehicles (RVs), and electromagnetic pulse (EMP) generators. Space-to-earth beam weapons have to contend with atmospheric attenuation, which rules out most types, and with the abundant shielding available to terrestrial targets. Nuclear-armed RVs stored in space have never competed in terms of cost, accuracy, or command and control with RVs stored in the noses of ICBMs.

HUMAN PRESENCE IN SPACE. The perennial question of the military utility of staffed spacecraft really should be divided into two questions. First, are there military space missions that can only be done or done much better by human beings? Second, do such missions require a continually staffed space station or just a space shuttle capable of periodic visits? A third question is whether the military will find uses for a space station if it is justified, built, and paid for by the civilian space program. This third question is easily answered in the affirmative and is sometimes confused with the first two questions, even though it does not address itself to the true military requirements for staffed spacecraft.

Human beings can perform varied, innovative, and subtle functions that cannot yet be mechanized. It also appears that humans can operate efficiently in space for at least six months without physical harm. But humans require life support, safety, and reentry systems that are expensive and heavy, and they need a habitat spacious enough to keep them physically and mentally healthy. Motions caused by humans moving about in the cabin can impair certain kinds of surveillance. Radiation is also a serious limitation: humans are about 100 times more susceptible to harm than ordinary space equipment and about 10,000 times more susceptible than hardened electronics. Operation in the radiation belts for more than a short period is impossible, and in the polar orbits most useful for earth surveillance, protons from solar flares.
would expose even shielded humans to radiation doses far in excess of those permitted for terrestrial workers. Needless to say, staffed military spacecraft would be very vulnerable to radiation from nearby nuclear bursts and also to radiation from distant detonations that got trapped in space by earth's magnetic field.

Continuous coverage and redundancy are usually more important than complexity for military spacecraft anyway, so many unstaffed satellites can be the obvious preference to a few staffed spacecraft. Satellite repair, replenishment, and assembly, identified by NASA as available from a space station, can also be accomplished from the shuttle. If necessary, the shuttle can be equipped with supplies to allow it to remain on orbit for longer periods than it now can. Since the space station would be in inclined LEO and most military satellites are in GEO or polar LEO, fetching the satellites to be repaired requires orbit transfer vehicles that need themselves to be refurbished on orbit. Repair will not pay for itself unless the number of candidate space systems to be repaired is large. GEO satellites have lifetimes of 7–10 years after which users usually wish to launch improved models rather than repair old ones. Photoreconnaissance satellites could profit from periodic refueling, since they use propellant to compensate for atmospheric drag experienced in their low orbits and to adjust their ground tracks for timely viewing of important reconnaissance targets. Assembly of large space structures from many small units transported separately to space has some theoretical attractiveness, but there is as yet no identified military need for it. And assembly, like repair, might be better accomplished from a shuttle than from a space station. For all these reasons, the Department of Defense and the intelligence community greeted the NASA space station rather coolly.14 Once NASA has made the investment, however, military users are certain to find the station convenient for some purposes.

Some of the future military uses of space described above are technically fanciful, and some address military problems of peripheral concern, but an important reason that some of them have not gained popularity or been deployed already is that they have been judged too vulnerable to destruction by ASATs. ASAT limitations might encourage rather than discourage some of these deployments.

ASAT Today: Separating Means from Ends

Analyses of ASAT frequently situate themselves in a hypothetical future world of advanced and exotic ASAT and DSAT technologies. Though looking ahead is necessary where policy decisions will have long-lived effects, there are dangers in this method of analysis. First, it focuses on the destruction of satellites rather than the disruption of space missions. Some satellites can accomplish vital missions even though they are vulnerable: peacetime intelligence satellites and nuclear warning satellites are in this category. Furthermore, some space missions can be disrupted most easily without touching the satellite, e.g., by deceiving sensors or by attacking ground stations. Second, a review of future technology suggests what ASATs might be able to do, but not whether, why, or when they might actually be used. Unlikely, purposeless, or out-of-context attack scenarios based solely on technical capability distract attention from the genuinely dangerous ASAT issues. Third, focus on the technological future risks the analytical error of posing tomorrow’s threats to today’s satellite, which stands no chance of survival because it was not designed to face them. Fourth, vu-graph analyses gloss over the many operational complexities and minor technical annoyances that end up looming large in actual fielded systems. To avoid these four pitfalls, it is worthwhile grounding the discussion of the ASAT issue firmly in the present before setting out into the future.

CURRENT MEANS TO DISRUPT SATELLITES

THE SOVIET ASAT. An undisclosed number of Soviet ASAT vehicles, presumably a handful or less, stand hours away from launch at Tyuratam, with more no doubt able to be prepared in the weeks or months of tension preceding the circumstances in which they would actually be used. Going on the basis of propulsion alone and the apparent requirement that the intercept be co-orbital (i.e., unlike the nascent U.S. ASAT, which needs only be in the same place at the same time as its quarry, the Soviet ASAT must furthermore be going in the same direction and at the same speed), the Soviet ASAT can destroy all U.S. satellites—photoreconnaissance, TRANSIT navigation, DMSP weather, and anything else—below about 2000 km altitude in polar orbits, with a greater altitude capability at lesser inclinations (see Table 5). Propulsion alone does not give a very vivid picture of this weapon’s limitations, however. These will be touched on below.
Table 5. Characteristics of Current ASAT Intercept Systems

<table>
<thead>
<tr>
<th></th>
<th>Soviet ASAT</th>
<th>U.S. ASAT</th>
</tr>
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<tbody>
<tr>
<td>Spacetrack Support</td>
<td>Ground-based radars</td>
<td>Ground-based radars</td>
</tr>
<tr>
<td>Launch Site</td>
<td>Ground</td>
<td>Air</td>
</tr>
<tr>
<td>Propulsive Velocity</td>
<td>8–9 km/sec</td>
<td>4–5 km/sec</td>
</tr>
<tr>
<td>Increment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ascent Guidance</td>
<td>Ground command</td>
<td>Inertial</td>
</tr>
<tr>
<td>Homing Guidance</td>
<td>Radar (or Optical)</td>
<td>Long-Wave Infrared</td>
</tr>
<tr>
<td>Warhead</td>
<td>Fragment</td>
<td>Impact</td>
</tr>
</tbody>
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Since the present was chosen for definiteness, the developmental U.S. ASAT should be left out of the picture, though with the months of growing tension that would probably precede its use it might quickly be made operational. It will have roughly the same capability against circular orbits that the Soviet ASAT has. But the fact that it is not co-orbital has two consequences: first, it need not maneuver into its target’s orbit but only cross that orbit, so it completes its attack more quickly; second, it can in principle attack Soviet missile warning and communications satellites in Molniya orbits as they swoop down low over the southern hemisphere, if moved from its bases in the northern hemisphere. The Soviet ASAT can reach the perigee altitude of Molniya satellites but cannot match their speed when it gets there; yet, to home on its target, the Soviet ASAT must close on its target at low speed—this is the meaning of “co-orbital.”

These observations, based purely on propulsive characteristics, obscure some operational complexities, namely the timing constraints imposed by orbit phasing, the placement of space tracking radars crucial for programming the ASAT with its target’s orbital parameters, and the possibility that the target will maneuver out of harm’s way. These operational constraints are too complex to go into at length here, but they mean that an engagement is considerably more complex than suggested by propulsion characteristics alone. Operational constraints will be touched on briefly below.

The Soviet Union possesses boosters capable of lifting the heavy Soviet ASAT to geosynchronous orbit, but the duration of the ascent alone makes attack on geosynchronous satellites by this method a dubious proposition. By normal transfer ellipse, the ascent from a LEO parking orbit would take
five hours, and even with an enormous propulsive effort—essentially a second booster launch from LEO (11 km per second velocity change)—the journey would take an hour. Once at geosynchronous altitude, the Soviet ASAT would have to have yet further propulsion to give it the speed it requires to home on its quarry. Such a conspicuous and protracted attack on a warning satellite would, of course, constitute a kind of warning in its own right.15

ABM SYSTEMS. The Galosh exoatmospheric anti-ballistic missile (ABM) interceptor deployed outside Moscow can climb to several hundred kilometers altitude, where its multi-megaton nuclear warhead could harm normal satellites hundreds of kilometers away.16 The U.S. has tested its nonnuclear Homing Overlay Experiment exoatmospheric BMD interceptor against ICBM RVs in intercepts at orbital altitudes. The U.S. also possesses old Spartan interceptors left over from the Safeguard ABM system. If the Soviet Union had tested but never deployed such ABM systems, the U.S. would need to be concerned about their appearance in an ASAT role. But the Soviets are able to monitor U.S. programs better, and they probably have a clearer idea of the present status of HOE and Spartan.

ICBMS AND SLBMS loft warheads to apogee altitudes of over 1400 km, where if suitably fuzed they could detonate in the vicinity of satellites. The use of nuclear ABMs as ASATs is sometimes dismissed on the grounds that detonation of a nuclear warhead above one’s own territory would generate an electromagnetic pulse harmful to one’s own military on the ground below. Whatever the merit of this argument, it does not apply to ICBMs and SLBMs, since they can be detonated on the descending rather than ascending portion of their trajectories, when they are over enemy rather than friendly territory. Nuclear weapons used to attack enemy satellites might still harm friendly satellites, however.

OTHER SPACE ACTIVITIES. U.S. commentators sometimes express concern over the oft-demonstrated docking ability of Soviet spacecraft, and the Soviet Union has professed concern over the U.S. space shuttle. It goes without saying that spacecraft under attack could make life unpleasant for their manned pursuers.

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15. An ASAT vehicle designed for short journeys in LEO would also need to be outfitted with longer-lived batteries, increased command link power, and other modifications to be used at GEO.
16. It is conceivable that, with proper radar support, Galosh could be used for ASAT with a non-nuclear warhead.
SPACE MINES. Are there space mines in orbit today? If so, their existence has not been revealed. It is unlikely that it could be long concealed, since the mine would need to match its maneuvers to those of its assigned quarry to stay within striking range. Multi-satellite constellations would require a mine next to each member. Only in GEO could a mine plausibly be stationed within a few hundred kilometers of a foreign satellite without causing alarm. There are some 200 military and civilian satellites in GEO today, spaced an average of about 1000 km apart. Somewhat less than half of these are still active, and all have plausible missions.

GROUND-BASED DIRECTED-ENERGY WEAPONS. The Department of Defense has revealed the existence of a large deuterium fluoride laser at White Sands Proving Ground\(^\text{17}\) and the existence of ground-based lasers “that could be used in an antisatellite role today” at Sary Shagan in the Soviet Union.\(^\text{18}\) With proper pointing mechanisms, the U.S. laser is probably capable of damaging Soviet photoreconnaissance satellites that focus on its vicinity and of applying warming, and thus potentially disruptive, fluxes to other low-orbiting satellites. The U.S. has taken the important step of designing missile warning sensors that observe infrared light at wavelengths to which the earth’s atmosphere is opaque. This would mean that missile plumes would not be detected until they rose to the upper atmosphere, but it would also mean that ground-based lasers could not blind the sensors. Other mechanisms to protect sensors include wavelength-selective filters, and low-sensitivity sensors that survey a region before the main sensor and activate a shutter over the main sensor’s aperture. Satellites carrying sensitive radio receivers might be susceptible to damage from high-power radio frequency transmissions, though this cannot be stated with certainty without knowing the precise characteristics of the receivers.

JAMMING. U.S. and Soviet satellites using UHF frequencies, and to a far lesser extent SHF and EHF frequencies, are susceptible to uplink jamming to a degree that depends on the details of the satellite and its signal structure. Normally, the “friendly” signal is enhanced relative to the jamming signal by pointing the satellite’s receiving antenna at the friendly transmitter. Anti-jamming techniques involving the signals themselves are varied, but almost all amount to reducing the data rate, essentially repeating the message

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enough times to make it intelligible despite the jammer’s noisy interference. The new U.S. DSCS III satellites are capable of detecting a jammer and configuring their receiving antennas to block it out. Crucial command links that keep spacecraft functioning properly must be jam-resistant and also encrypted to prevent an opponent from giving disruptive false commands.

DECEPTION. The Soviet Union is known to encrypt telemetry from missile test vehicles, one of many non-destructive methods for frustrating peacetime intelligence collection from space. Electronic countermeasures could be quite effective against targeting satellites such as the Soviet RORSAT. In general, demonstrating the feasibility of a remote sensing technique is just the beginning of establishing its military usefulness. For example, the many hypothetical schemes for locating submerged strategic submarines from space must, if realized technologically in realistic situations, be proof against deception—an area where the battle is yet to begin. “Making the oceans transparent” would likely not be the end of the submarine any more than the air’s transparency to radar pulses spelled the end of military aircraft.

GROUND STATION ATTACK. Ground receiving and processing sites on U.S. territory are easy to destroy but, of course, require homeland attack. Fragile above-ground facilities, especially those overseas, could conceivably be vulnerable to jamming by agents and to attack by special forces. Mobile ground stations are coming into operation for some U.S. satellites vital to nuclear operations, and satellites are being made more and more independent of constant “care and feeding” by ground controllers. Political change and Soviet military pressure could close overseas ground stations. Crosslinks such as those on Navstar GPS and relay satellites such as TDRSS are making U.S. data links independent of ground stations on foreign shores.

NUCLEAR EFFECTS. Quite apart from deliberate attack, detonation of nuclear weapons above and at the top of the atmosphere induces a number of disruptive effects: EMP effects on ground stations; damage to spacecraft from enhancement of the radiation belts in space; blackout and scintillation of radio uplinks and downlinks; and “redout” of infrared sensors. Current U.S. space systems have foreseen and adapted to these problems in varying degrees.

MATCHING MEANS WITH PLAUSIBLE ENDS
To illustrate the difficulty of identifying ASAT “scenarios” that are both worrisome and plausible, consider the case of photoreconnaissance satellites. In peacetime, the vulnerability of photoreconnaissance satellites is of no more
consequence than the vulnerability of many other national security assets, and whatever stops the Soviets from destroying these other assets presumably stops them from attacking satellites, too. At the other extreme, in a large nuclear war, the uses to which the U.S. could put surviving photo satellites are somewhat ill-defined and exotic: damage assessment and re-strike, monitoring a stand-down, and so on. Even if the Soviet ASAT were dismantled, the U.S. ground stations supporting these satellites would still be vulnerable to nuclear attack, and the satellites themselves could be attacked by Soviet nuclear-armed ABMs and ICBMs. So the existence of an ASAT threat to photo satellites adds little to the dangers of nuclear war.

In a large conventional war or small nuclear war, the U.S. can use photo satellites to survey rear areas, monitor Soviet supply lines and airfield status, and so on. The Soviets would not welcome this surveillance, and in circumstances where they were killing Americans anyway they would have no reason to spare unmanned satellites. So U.S. leaders must plan to lose their photo satellites at this point and do their best with airborne reconnaissance (armed if necessary). The Soviets would lose their ability to observe U.S. rear areas, too, since the U.S. would attack their satellites. In peacetime, loss by both sides of photo satellites would be a net loss for the U.S., an open society facing a closed Soviet society. But in wartime, the U.S. would also be a much more closed society. In wartime, too, there is no risk to the Soviets in “trying out” untested “baling wire” ASATs (including ground-based lasers) not credited by U.S. intelligence in peacetime. Such systems might not work, but there is no premium on “high confidence” since there is no penalty for trying and failing.

That leaves a crisis or proxy war somewhere in the world. The U.S. would have intelligence collectors of various sorts in the conflict area, as would the U.S.S.R. Which side would be “more dependent” on space-derived imagery would depend on the particulars of place and circumstance. Attack upon any of these intelligence collectors in the conflict area would be a provocation, and interrupting the flow of information to the adversary would itself present the indirect risk of dealing thenceforth with an adversary whose view of the situation was incomplete and unreliable. ASAT attack might have a somewhat lower “threshold” than attack on intelligence ships and planes that risk loss of American lives and so might be somewhat more likely. But does this added danger make an already-dangerous situation that much worse? It is questions such as these that must be answered— for each space mission
individually—before it is possible to say whether anti-satellite activities would materially worsen the dangers of superpower confrontation, or whether the "ASAT problem" is a relatively minor addition to the wide variety of opportunities for conflict that already exist.

Missile warning is another space mission feared to come under ASAT threat, but here again it is not easy to match ends and means. The U.S. uses its warning satellites to alert bombers, tankers, and airborne command posts to escape from their airstrips; to support a decision to launch vulnerable ICBMs under attack; and to assess the Soviet attack so the U.S. leaders could base subsequent decisions on accurate information. Soviet leaders feeling themselves driven to a nuclear strike presumably would have little interest in disrupting the assessment function, but the warning function affects the number of warheads that would land on Soviet territory. The Soviet leaders would also be aware that the U.S. had SLBMs with which to retaliate and radars with which to detect attack even if its satellites did not, and that something unexpected could go wrong with their own missile attack. It would therefore be an exaggeration to suppose that loss of warning satellites would loom large among the many factors affecting Soviet behavior at such a time. Still, warning system vulnerability's contribution to stability has a negative sign whatever its magnitude.

To take advantage of a warning sensor's vulnerability, however, the means of attack must be neither time-consuming nor obvious. If the attack takes time, surprise is lost. If the source of the attack is obvious, the attack itself constitutes warning. Measured against these criteria, some ASAT methods fail immediately. For instance, the oft-discussed possibility of the Soviets launching their existing ASAT into GEO on a larger booster is not really threatening to the U.S. satellite warning function because the ascent would take several hours. Directed-energy blinding attack satisfies the criterion of rapidity, but U.S. satellites can and should be made able to detect, identify, and report such attack promptly to earth. It is also likely that early warning satellites in high orbits can be shielded quite effectively against attack from directed energy weapons on the ground or in LEO. Even a space mine lurking one degree away in the geosynchronous orbital arc (740 km) and possessing substantial propellant would still take several minutes to arrive at its quarry. During this time on-board sensors or a distant spacetack system could give warning of the attack. With adequate attention to the survivability features of its own warning satellites and some ability to keep space mines at a
distance, therefore, the U.S. might have little to fear from ASAT attack in relation to the other means the Soviets could use to try to achieve nuclear surprise.

In the future the technologies of ASAT attack will change, but the problem of identifying plausible scenarios for their use will remain. To maintain perspective on the ASAT problem, one must not be alarmed by the mere capability to attack a satellite if a plausible reason for doing so cannot be identified. A sensible winnowing of real security problems from phony “windows of vulnerability” is a major research problem.

OPERATIONAL COMPLEXITIES
To illustrate the operational complexities that make simple statements of the capabilities of current-day ASATs potentially misleading, suppose the Soviet ASAT sets out to attack the TRANSIT navigation satellites used by U.S. submarines to initialize the guidance systems on SLBMs. The TRANSIT satellites are in polar orbits at 1100 km altitude. The Soviet ASAT has been tested at this altitude but never in polar orbit; we will assume, however, that polar intercept entails no extra difficulties. The five TRANSIT satellites are arranged in five orbital planes about 36 degrees apart. The Soviet ASAT must wait until the earth’s rotation brings the Tyuratam launch site underneath the orbit of one of the target satellites. This happens about every two and a half hours. Even if Soviet ASATs could be launched at this rate, it would take twelve hours for Tyuratam to pass beneath all five TRANSIT planes. During this twelve-hour attack on its navigation satellites, the U.S. would surely become aware that attack was in progress. How useful is such a capability to the Soviets?

Operational analysis of the existing ASATs gets more complicated when one considers the possibility that the putative victim might maneuver during the engagement. The U.S. ASAT is provided with a tape detailing its target’s orbit before the F-15 carrying the ASAT takes off from its base. The tape in turn programs the inertial guidance system on the ASAT booster to guide the vehicle to a predicted intercept region. There, the miniature homing vehicle uncaps its infrared sensor, acquires its quarry, and homes in for impact. If the victim is not within the relatively small “basket” predicted by the tape, the homing vehicle cannot find or attack it. This means that even a small maneuver executed by the Soviet satellite between the time the U.S. spacetrack system determines its orbital parameters and the time of intercept—a space of several hours—will cause the intercept to fail. Of course, an
orbiting Soviet satellite cannot afford to be maneuvering this often for weeks on end, and the Soviets should not be allowed to know when the U.S. is preparing its ASAT to attack. Frequent maneuvering would also disrupt a satellite’s data collection. But for short periods Soviet satellites could almost surely evade the U.S. ASAT. A freshly launched Soviet satellite would have a grace period to collect intelligence or perform other missions before it had passed over enough U.S. spacetrack radars for its precise orbit to be measured. Maneuvering is probably an even more attractive defensive counter-measure for U.S. satellites, since launch of the Soviet ASAT would be detected immediately, and two to three hours would pass before the ASAT drew near to its target.

Future ASAT systems will have different operational constraints. At the conceptual or vu-graph stage, it is easy to forget the constraints of real fielded systems. But these constraints loom large when one comes to consider the political and military utility of ASATs.

**ASAT vs. DSAT: The Technological Future**

A previous section surveyed the host of hypothetical military satellites that might appear on orbit in the future if accorded a sanctuary there free from ASAT attack. It is equally important, though hazardous, to try to project the outcome of a future competition between ASAT and DSAT constrained only by the limits of technology and not by any bilateral agreements.

Satellites are in effect fixed targets, since their orbits are predictable and frequent orbit changes are impractical. A powerful array of destructive technologies can be hypothesized for ASAT. If all or many of these hypothesized threats actually come to pass, the general outlook for the survivability of spacecraft, like for fixed targets on land, is not good.\(^{19}\) Though the result of unrestrained ASAT/DSAT competition might not be a true “ASAT dominance” akin to the current nuclear “offense dominance,” many military missions will simply be driven from space because they cannot survive there. They will have to be abandoned or fulfilled by terrestrial alternatives. Boost-phase ballistic missile defense might well be in this category, the terrestrial alternatives being midcourse and terminal defenses. Large, complex, and expensive satellites in low orbits appear worst off. But a combination of small

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\(^{19}\) Fixed targets on land actually have the advantage of being located on sovereign territory where the enemy cannot come near.
size, low observables, hardening, proliferation, and high (even supersynchronous) orbit might allow simpler missions to be accomplished even in the face of an unconstrained threat. Communications with nuclear forces and missile warning, two relatively “benign” functions, are happily in this latter category.

Besides the traditional threats of jamming, deception, attack on ground stations, and collateral nuclear effects, the future holds three categories of more explicit and determined threats.

DIRECT INTERCEPT

The current Soviet and U.S. ASATs are just the first generation of direct intercept ASAT. Future models will be characterized by six features: 1) space tracking network to determine the target’s orbit and choose an intercept point; 2) launch site (ground, air, space); 3) propulsion capability (measured by the velocity increment or “delta vee” imparted by the ASAT’s rocket motors); 4) ascent guidance, which guides the vehicle from launch to a predicted intercept region; 5) homing guidance (unnecessary for nuclear warheads); and 6) warhead (impact, fragment, or nuclear).

The homing system determines whether the interceptor needs to close upon its quarry at low speed and from a restricted direction or whether it can approach at high speed from any direction. If the latter, the ASAT’s trajectory must only intersect the target’s orbit at the proper moment. If the former, the ASAT must actually enter the target’s orbit. Co-orbital intercept takes more propellant, since the ASAT must not only arrive at the target’s altitude but must match its speed and direction as well. As these extra maneuvers are costly of propellant, they limit the orbits that can be attacked. An intercept system’s capabilities are not adequately expressed by the altitude it can reach; the proper measures are derived from its propulsive “delta-vee” and the limitations of its homing sensor. Orbital mechanics also dictate the amount of time it takes to intercept all the members of a constellation of target satellites. The “counter-rotator,” “looper,” and “node crosser” of Figure 10 illustrate the orbital mechanics shortcuts available to the ASAT planner.

The spacetrack network is the other crucial ingredient of an intercept system. Space-based tracking systems would avoid many of the limitations of ground-based radars. A ground-based radar must wait until a target satellite passes overhead to measure its orbital parameters; this happens only twice a day for a target in LEO. Furthermore, the pooled data from several sightings are necessary before a satellite’s orbit is characterized well enough
Figure 10  ASAT INTERCEPT SCHEMES seek to avoid having to attack each of the satellites in a constellation by a separate set of orbital maneuvers. The “counter-rotator” traverses the GEO belt in the “wrong” direction, attacking all the satellites there within 12 hours (a). The “looper” climbs up to semi-synchronous orbit every 4 hours to pick off one of the Navstar GPS satellites, which are phased every 4 hours in 12-hour orbit (b). A battery of direct-ascent ASAT interceptors based at the north pole could attack all the satellites in polar LEO within the space of less than 2 hours (c).
to plan an attack; this process can take several hours. The U.S. and U.S.S.R. have a limited number of radars, and they are not optimally positioned for rapid measurement of target orbits. If the satellite maneuvers to change its orbit, the spacetrack process must begin again. Newly launched satellites make several revolutions before their orbits are known precisely. Ideal positions for spacetrack radars supporting LEO intercept would be at the points on the globe opposite the enemy launch site and opposite the ASAT launch site. Satellites launched from a ground launch site must pass over the site’s antipodal point no matter what their orbit inclination, so a radar there will be sure to view a newly launched satellite on its first revolution. A radar at the antipodal point to the ASAT launch site is certain of seeing the target satellite a half a revolution (about 45 minutes) before it passes over the ASAT and can adjust its attack plan or abort the attempt if the target has maneuvered.

High altitude deployment of military satellites, arrangement in many widely separated orbital planes, irregular phasing, and satellite proliferation are all countermeasures designed to force the ASAT interceptor to consume propellant and time. Low observables (“stealth”) techniques might conceal certain types of satellites in high orbits from space tracking. Decoys dispensed at the time of attack might fool simple homing sensors, as might electronic countermeasures such as radar jamming. But a decoy designed to mimic an ordinary satellite over long periods of spacetracking observation would need to stationkeep and emit signals just like the real satellites; it would be much easier for decoys to match satellites that are themselves “stealthy.” The satellite defender can always attack the ASAT vehicle itself, its launch facilities, and the spacetrack system that supports it. Reconstitution of destroyed satellite constellations is only worthwhile if the enemy ASAT system has been incapacitated in some way; otherwise, the reconstituted satellites will be destroyed as well. Perhaps the most effective countermeasure to direct attack is to maneuver the target satellite slightly sometime after the enemy spacetrack network has committed the ASAT to a particular intercept “basket.” Target maneuvers during ASAT homing are also possible. These countermeasures require the defender to have a good alerting system to warn of attack in time.

**SPACE MINES**
The simplest version of a space mine is a radio-activated bomb placed in orbit next to its target, but this simple model is just one in a wide family of
possibilities. The mine can contain a fragmentation warhead or a nuclear warhead, or it can home in on its quarry and ram it. The mine can be a laser or other directed energy weapon which need not necessarily be positioned very near to its victim if it is bright enough to attack from a distance. In fact, a space-based directed energy weapon can be thought of as a long-range space mine.

A space mine need not even destroy its target. If its victim is a communications, electronic intercept, or radar satellite, the “mine” positioned nearby might be a jamming transmitter. Or it could be a dispenser of chaff, aerosols, corner reflectors, decoys, or other devices to frustrate rather than destroy its victim. Or the minefield could consist of a constellation of nuclear weapons in LEO which, when detonated on command, would disrupt propagation of space-to-ground radio links and create unwanted background for infrared sensors. The only requirement of a space mine design is that the minefield be cheaper, or at least not much more costly, to build and orbit than the satellite capability it is meant to deny.

Against space mine concepts that require proximity to their target satellite to be effective, the only clear countermeasures are keep-out zones. These can be set forth in international agreements or declared unilaterally. Unilateral declarations, in effect laying claim to regions of the international medium of space, need not be as obnoxious in practice as they seem in principle. The U.S. placed its Vela nuclear burst detection satellites in extremely high supersynchronous orbits—five times geosynchronous altitude, or halfway to the moon—in the 1960s, and no Soviet spacecraft have since come near. While the Soviets might wish to orbit supersynchronous satellites as well, they could easily choose, say, four times geosynchronous instead of five times geosynchronous yet stay a full 36,000 km from U.S. satellites. Concentric orbital shells of alternating “sovereignty” are a practical scheme for semi- and supersynchronous orbits. Such orbits are “non-unique”: there is nothing that makes one more desirable than the other, and there are plenty to go around. Informal parcelling-out of these orbits could be an important vehicle of tacit restraint for military users of space.

Unilateral declarations will obviously not work for unique orbits like GEO: nowhere else but in GEO will satellites maintain a fixed position in the sky to terrestrial observers. Claims to this unique band would stand little chance of being honored. Likewise LEO is the only place for satellites that need to be near the earth. Molniya orbit is in certain respects unique because it is “stable”: once placed in Molniya orbit, a satellite will not drift out of the orbit
under the influence of irregularities in the earth's shape. More importantly, Molniya orbits pass through crowded LEO. Semi-synchronous orbit is not really very special, as evidenced by the fact that the Soviet Union positioned its Navstar-like constellation (called GLONASS) some 1000 km below Navstar.

Keep-out zones for unique orbits will likely need to be the object of specific agreement. One scheme for keep-out zones in GEO would divide the synchronous arc into 36 sectors 10 degrees (7400 km) wide. Each sector would extend from 30,000 to 40,000 km in altitude. Twelve of the 36 sectors would be assigned to the Western allies, 12 to the Warsaw Pact, and 12 to neutral nations. Each bloc would have the right to destroy intruders into its zones. Occasional transit by foreign satellites through a zone would be permitted by prearrangement. A nation would be allowed to position a satellite in a foreign zone if it submitted to ground inspection of the satellite before launch. LEO and Molniya orbits present much more difficult problems of definition. LEO is unique and crowded, and Molniya orbit passes through LEO with every revolution. A 50 km-radius keep-out sphere around each LEO satellite and moving with it would give some protection but requires extensive coordination among nations owning spacecraft.

The function of a keep-out zone is to give a satellite under attack time to react, either by defending itself, maneuvering, deploying decoys and other self-defense aids, or, very importantly, informing its owners that it is undergoing deliberate attack. If the mine was in fact a directed-energy weapon, the size of the keep-out zone would be chosen to keep it far enough from potential targets that a relatively long illumination time would be needed to deposit a lethal fluence. During this time the victim could deploy shields, shoot back, try to fool the attacker's pointing mechanism, or radio home that it was under hostile attack. The beam weapon might even be forced by the long range to consume a prohibitively costly amount of energy on attacking a single satellite. The size and effectiveness of keep-out zones obviously depend on the brightness of the directed energy weapon. Keep-out zones might be policed by a spacetracking network augmented with small radars aboard each satellite.

21. Ibid.
Without agreed or tacitly accepted keep-out zones, space mines could easily develop into the single most pernicious threat to a stable military regime in space. The mine layer might be expected to show restraint by excluding some of its opponent’s satellites from mining, but when it comes to threatening satellites like missile defense battle stations or targeting sensors, the overt, trailing mine must be anticipated. Simply attacking and destroying overt space mines positioned near one’s satellites is a policy option without legal warrant, at least as provocative as the deployment of the minefield, and possibly impractical if the mine layer persists in launching new and better mines. The space mine problem points up most starkly the difficulty for either side of relying solely on unilateral measures to protect its satellites.

**DIRECTED ENERGY WEAPONS**

Whatever one’s views of the potential of directed energy weapons for boost-phase BMD, they should be taken much more seriously for ASAT. ASAT attack can be mounted from friendly soil, whereas boost-phase intercept must take place from outer space and over enemy territory. BMDs must handle many targets in a short time, whereas ASATs need engage relatively few targets at a leisurely pace. The ASAT operator picks the timing of attack; BMD must react to the initiative of the offense. BMD must operate in the most hostile circumstances imaginable, whereas ASATs are just as likely to be used during crises and conventional conflicts. One factor in the BMD satellite’s favor is its ability to accumulate over time more shielding and self-defense equipment on orbit than a booster can carry with it at launch; yet this shielding must protect it at all times from all angles and be maintained on orbit.²²

Among candidates for space-based directed-energy ASAT are chemical lasers, nuclear-bomb-pumped x-ray lasers, and neutral particle beams. Ground-based concepts include excimer, free-electron, and chemical lasers (perhaps with mirrors in space and adaptive optics), and pop-up x-ray lasers. The atmosphere is opaque to x-rays and neutral particle beams.²³

In assessing the ASAT potential of directed-energy weapons of the “Star Wars” type, one must be careful about transforming the generalization that an effective BMD system is *a fortiori* an effective ASAT into a blanket state-

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ment applicable across the board. High-orbiting satellites facing directed-energy attack have the great advantage of the vastness of space on their side. Consider, for example, the ASAT potential of a 20 megawatt hydrogen fluoride laser “battle station” with 10-meter perfect optics based in LEO. This is about the laser brightness that the Strategic Defense Initiative Organization would consider a good start for the BMD role. This laser could dispose of hundreds of ICBM boosters at a range of hundreds or a few thousand kilometers within the space of a minute, unless successfully countermeasured. If this laser’s beam were directed at a satellite in GEO (36,000 km distant), the received energy flux would be about 100 times what that satellite would be receiving from the sun. The effect of such illumination on the thermal balance, power system, sensors, and antennas of a present-day satellite would be serious. But properly designed spacecraft for many missions could be made to withstand such illumination for hundreds of seconds, if not indefinitely. A determined satellite hardening effort could make spacecraft resilient to much stronger illumination. Hundreds of seconds of lasing time might consume the entire store of fuel aboard the laser, making this attack a costly one-on-one affair. Alternatively, the target satellite could use this long illumination time to deploy shielding, to deceive the laser’s pointing sensor, to counter-attack, or to alert others to the attack. This is an example of a case where full deployment of a nominally effective “Star Wars” BMD would not be inconsistent with rather good protection of GEO satellites.

Principles for U.S. Military Exploitation of Space

ASAT arms control faces two basic problems. First, ASAT attack on some space missions is both tempting and relatively easy. Complex satellites in LEO will probably remain fairly cheap to attack in relation to their cost, and if they are engaged in threatening military activities they will present an irresistible temptation for ASATs. Other arms control regimes have sought to limit activities that were less easy and less tempting. The ABM Treaty and the SALT limitations conformed to the prevailing technical facts that effective missile defenses could not be built and that offensive superiority was unobtainable without large and conspicuous departures from the status quo (if at all). Militarizing the Antarctic and stationing nuclear weapons in space were not tempting enough to stimulate concerns over “breakout” of the treaties that forbade them. Limiting ASAT might mean swimming against the tide of technological advance and military opportunity in a way that limiting
these other activities by treaty did not. Covert ASATs and the possibility of breakout might be much less far-fetched in an ASAT treaty regime than in the ABM treaty regime. And, as always, the possibility of covert threats would work to the advantage of the closed U.S.S.R. over the open U.S. An ASAT treaty regime could therefore be technically and politically unstable unless properly designed.

The second problem with ASAT arms control is that not all uses of space are benign and deserving of protection. An improved version of the Soviet RORSAT less susceptible to non-destructive countermeasures could pose a threat to multi-billion dollar carrier battle groups. If ASAT attack can dispose of this threat cheaply (the rising cost of the U.S. ASAT together with other sources of carrier vulnerability makes this unclear) and before it can be used effectively to guide Soviet air strikes (also unclear), the temptation to do so will be all but irresistible.24 Paradoxically, any possibility of sanctuary from attack will probably encourage the superpowers to place more and more threatening satellites in space.

Skirting these two problems will be a challenge for negotiators, and the resulting treaty—if one ever emerges—will surely be quite complex. It is therefore worthwhile plotting a clear course of actions the U.S. should take with or without ASAT arms control. The next section hazards a guess at how a complex ASAT treaty that faced up to the two problems might eventually look.

1) TAKE ADVANTAGE OF THE MANY MEANS AVAILABLE TO IMPROVE SATELLITE SURVIVABILITY. The survivability features of satellites on orbit today are not a good indication of what is possible at relatively modest cost. No arms

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24. Of course, certain U.S. military users of space might be willing on purely military grounds to trade wartime survival of Soviet satellites for the protection of U.S. satellites. Indeed, some analysts argue in favor of a U.S. interest in ASAT arms control by alleging a military advantage to the U.S. in a treaty regime. Their argument holds that the U.S. profits more from or "depends" more on space than the U.S.S.R. This argument seems to the author to be an unsteady foundation for U.S. policy. It is true that the U.S. and Soviet military space programs differ somewhat in style, technology, and missions emphasized. But it is difficult to gauge the military importance of these asymmetries. They have different significance in different scenarios. In certain respects, the asymmetries are becoming less pronounced with the passage of time; in any event, they cannot be confidently predicted to persist into the future. Furthermore, arms control offers uncertain protection for precisely those satellite functions—e.g., photoreconnaissance—on which the U.S. is supposedly more dependent. If the arms control provisions are not clearly defined and verifiable, one must also consider the possibility of asymmetric compliance and its contribution to the calculus of relative "advantage." It is true, however, that U.S. military users of space support are rarely heard from in the ASAT debate, in part because of security restrictions.
control provisions can protect a satellite whose designers have left it open to “cheap shots.” Adequate satellite survivability programs are not an alternative to, but a necessary precondition for, effective arms control. To the extent that satellites can be made immune to all but elaborate, verifiable threats, ASAT limitations will be meaningful. The ability to detect attack can be a deterrent even if the attack cannot be prevented.

The unclassified Navstar Global Positioning System displays the kind of features, available at reasonable cost, that can make attack much more difficult, time-consuming, and conspicuous (see Table 6). Though a complete description of these spacecraft is not possible in unclassified form (and the design has evolved somewhat over time), a 1980 description by the builder serves the present purpose of illustration.25 Each GPS satellite, according to this description, carries three payloads: a navigation beacon, a nuclear burst sensor, and a simple communications transponder (part of the AFSATCOM system geared to emergency communications in nuclear war). Navstar’s constellation consists of 18 satellites plus several spares. Its ability to supply useful navigation and nuclear burst data degrades gradually as the number of satellites is reduced, so that even with as few as 6 satellites left, the system would continue to provide users with useful, if intermittent, service.

The fact that Navstar is arranged in six widely separated orbital planes makes the interception of a large number of satellites time-consuming. The constellation has slight phasing irregularities to frustrate orbital mechanics shortcuts like the “looper” of Figure 10. The satellites are widely enough separated that two of them cannot be destroyed by a single nuclear detonation, so even nuclear intercept requires one-on-one attack. A modest on-board propulsion system might allow the satellites to maneuver out of harm’s way. The nearest satellites to the Navstar constellation are the members of the similar Soviet GLONASS system, some 1000 km lower in a similar constellation. A constellation of 18 space mines emplaced next to each Navstar satellite would be easily interpreted as a hostile deployment (though U.S. options for response to such mining are less clear). Finally, Navstar satellites are designed to resist the warming effects of distant lasers.

Navstar’s ground stations track the satellites and transmit their positions to the satellites. The satellites in turn broadcast this data to users on the ground, who need to know the satellite’s exact position in order to calculate their own. Certain ground station equipment will be deployed in mobile vans

<table>
<thead>
<tr>
<th>Attack Method</th>
<th>Protective Measures</th>
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<tbody>
<tr>
<td>Intercept</td>
<td>Graceful degradation&lt;br&gt;Many planes&lt;br&gt;Irregular phasing&lt;br&gt;On-orbit spares&lt;br&gt;Nuclear hardening&lt;br&gt;Propulsion module (?)</td>
</tr>
<tr>
<td>Laser</td>
<td>Resistant to warming&lt;br&gt;Nuclear hardening&lt;br&gt;Propulsion module (?)</td>
</tr>
<tr>
<td>Mines</td>
<td>Unique orbit&lt;br&gt;Crosslinks&lt;br&gt;Mobile ground stations&lt;br&gt;Satellite autonomy</td>
</tr>
<tr>
<td>Ground segment destruction</td>
<td>NDS receiver on airborne command posts</td>
</tr>
<tr>
<td>Electronic attack</td>
<td>Encryption via pseudorandom noise sequence&lt;br&gt;Uplink anti-jam via AFSATCOM SCT and crosslinks&lt;br&gt;Downlink anti-jam via PRN, nulling antennas, and spatial diversity&lt;br&gt;Crosslink anti-jam via frequency hopping and antenna nulls</td>
</tr>
<tr>
<td>Nuclear effects</td>
<td>Radiation hardened satellites&lt;br&gt;Automatic re-start after transient upset&lt;br&gt;EMP hardening of receivers for nuclear users&lt;br&gt;Compression and coding for NDS downlink data&lt;br&gt;Spatial diversity</td>
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The satellites also have radio cross-links, meaning that a single surviving ground station can communicate with all of the satellites even though most of them are over the radio horizon. Similarly, data about nuclear bursts can be transmitted from hemisphere to hemisphere over the crosslinks without reliance on vulnerable ground stations. This data is partially processed aboard the satellites, and the remaining processing is simple enough to be accomplished aboard the Presidential airborne command posts: no surviving ground stations are necessary. Even if all the ground stations that track and control the satellites are destroyed, they can operate as a navigation system autonomously for quite some time, in part by helping to keep track of one another’s positions through the crosslinks.

Electronic attack on Navstar is also well guarded against. All data and command links are encrypted so that the Soviet military cannot easily profit from the precise navigation beacons or tamper with the satellites. The “pseu-
dorandom noise” encryption technique also helps users protect against jamming of their receivers. Some receivers furthermore have antennas that can “null” or block out downlink jammers. The uplinks are also well protected against jamming by the way their signals are structured. The crosslinks provide further protection against uplink jamming, since even if a satellite’s uplink is being jammed, it can receive over its crosslink a message uplinked to an unjammed satellite. The crosslinks are in turn protected from ground-based jamming by frequency hopping and by directional antennas that will accept signals from other satellites but not from the direction of the earth.

The Navstar constellation is located in the Van Allen natural radiation belts, so its spacecraft are designed to withstand a large accumulated radiation dose. The on-board computers are also programmed to re-set themselves if a burst of radiation from a distant nuclear detonation upsets their electronics. Critical nuclear burst detector data is processed on board the satellite and transmitted in such a way as to pass ungarbled through regions of the ionosphere “blacked out” by nuclear bursts. Since several satellites would be visible to a receiver at a time anyway, a receiver that could not “see” through a blacked-out patch of sky could look for another satellite in another direction where the ionosphere was clearer.

All of these survivability features are incorporated into a satellite system that will be fully established in the very near future. Negotiating verifiable agreements to protect this satellite constellation is clearly much easier than protecting a lone photoreconnaissance satellite in LEO designed for peacetime operations only. In the future, small and sturdy missile warning and narrowband communications constellations in high orbits can be made very difficult to disrupt. New materials used in spacecraft design will increase substantially their resistance to lasers.

2) IMPROVE SPACETRACKING AND SURVEILLANCE. To alert U.S. satellites to attack, to support attack upon Soviet satellites, and to monitor ASAT limitations will all require much better space surveillance than the U.S. has today. Time to react to threatening events can be crucial, and opponents should know that disruption of spacecraft will not go unrecognized by the U.S. The system of ground-based radars and television-telescopes used for spacetrack today can require several hours to characterize precisely the orbits of newly launched satellites, and the system does not follow minute-by-minute the hundreds of active on-orbit satellites. Supersynchronous orbits are all but invisible. A particularly useful system would seem to be the constellation of
long-wave-infrared spacetrack satellites (recently absorbed into the SDI with changes and renamed the space surveillance and tracking system—SSTS) that has been under study by the Air Force for quite some time. These satellites would track satellites as warm bodies—warmed by the sun and by their electronics—against the cold background of space. By pooling their data, these sensors could keep track of many satellites out to considerable altitudes. Decoys and stealth measures to reduce infrared emissions might nonetheless frustrate observation of small satellites at very high altitudes.

Besides space tracking systems, the U.S. will need improved reconnaissance systems to examine and characterize foreign spacecraft and to detect Soviet tests of interceptors and directed energy weapons. Last, individual satellites can be supplied with small on-board radars to determine whether any foreign spacemines are sneaking up on them.

3) AVOID DEPENDENCE ON VULNERABLE SPACECRAFT. Space systems assigned wartime roles should have to prove themselves in terms of cost-effectiveness and survivability or not be assigned such roles. Threatening satellites deployed in a way that makes them inherently vulnerable to attack (e.g., in low orbits) cannot be protected by any treaty, and no treaty can easily survive if such temptations to break out of it are ever-present.

4) EMPLOY SURVIVABLE BACK-UPS TO SATELLITES. Almost all of the missions performed by satellites can be performed—not as well, perhaps, but sometimes adequately—by terrestrial systems. Thus data relay, reconnaissance, and navigation in the NATO theater can be performed from aircraft (in the manner of some existing U.S. programs), remotely piloted vehicles, and aerostats (balloons). Sounding rockets can also be used for meteorology and photoreconnaissance. And, of course, radars located on U.S. shores and requiring strategic attack to destroy are an effective backup to warning satellites. Even if the backups are not quite as capable as the satellite systems they replace, their existence might have the effect of reducing Soviet incentives to attack satellites in the first place.

5) TO THE EXTENT POSSIBLE, SEGREGATE “BENIGN” FROM “THREATENING” MISSIONS AND NUCLEAR-WAR-RELATED MISSIONS FROM CONVENTIONAL WAR-FIGHTING MISSIONS, ON DIFFERENT SATELLITES. This will give the Soviet Union the opportunity to respect these distinctions and to exercise restraint in the kinds of threats it poses to “benign” missions like missile warning.

6) PLAN TO ATTACK SOVIET SATELLITES TO THE EXTENT DICTATED BY U.S. SECURITY INTERESTS. No ASAT treaty will ban all methods of disrupting all
types of satellites. The U.S. therefore cannot avoid the responsibility of
developing a serious and reasonable policy towards attack on Soviet satellites.
The U.S. should not forbear to possess ASATs if they are of a type not clearly
forbidden by treaty, if using them would have an effect on Soviet military
capability worth its cost (and not just fulfil someone’s idea of symbolic
strength), and if they are tailored to avoid threatening “benign” Soviet sat-
ettes to the extent possible. In the author’s mind, these criteria do not justify
development of a high-altitude ASAT for the U.S. at this time. On the other
hand, the U.S. should demonstrate the ability to give threatening Soviet
satellites such as next-generation RORSATs and “Star Wars” battle stations
a rough time in low earth orbit.

The Analyst’s Tentative ASAT Agreement

The unilateral measures prescribed in the last section are by themselves a
good start toward protecting “benign” space missions like missile warning
and narrowband emergency communications. Between self-protection and a
modicum of restraint on the Soviet side, the most obvious dangers to stability
posed by ASATs might be skirted without any formal bilateral agreements.
It is nonetheless worthwhile to search for limited negotiated agreements that
would bring about this result more cheaply and more predictably. Some sort
of ASAT agreement might end up being a piece of a broader political jigsaw
puzzle regardless of its narrower merits, and it is therefore worthwhile
surveying what is technically and militarily sound and hoping that the po-
itical process can approximate it.

There are two common objections to ASAT arms control, as explained in
the last section. The first, stated crudely, is that “attack on satellites is too
easy,” meaning that many imaginable ASAT limitations are not verifiable.
The second objection is that some satellite functions are threatening and do
not deserve sanctuary—functions symbolized, if not realized in fact, by ROR-
SAT. The question before us is whether arms control provisions can be
devised that answer these objections and yet that provide meaningful pro-
tection to “benign” space missions. It appears that there are indeed provi-
sions that answer the two objections, even when these objections are stated
in their strongest, and therefore undoubtedly somewhat exaggerated, form.
This section describes such provisions in a tentative way. A much more
careful and lengthy analysis will be necessary to confirm the value of these
provisions and to quantify the details.
Before addressing the two objections to ASAT arms control, we should acknowledge a third. The third objection, raised by proponents of space-based boost-phase ballistic missile defense, is that an ASAT ban that suppressed development of systems to destroy objects in space would also suppress development of systems for destroying ballistic missiles passing through space. That is, ASAT bans would add to the constraints already imposed on the SDI by the ABM Treaty. It turns out that this third objection is related technically to the first two and can be answered in the same partial way.

The key to devising ASAT arms control provisions that answer the two objections, and also the third, is to observe that the objections apply much more strongly to attack on near earth orbit (NEO) than to attack on higher earth orbits (HEO). Here NEO is defined to include Molniya as well as circular LEO orbits, and HEO ranges from about 10,000 km upward. GEO is a separate case.

The “easy” ASAT methods that would be hardest to verify are most effective against NEO. The tested U.S. and Soviet ASATs are confined to NEO intercept. ABMs and ICBMs could be easily configured for NEO attack but not for HEO attack. Keep-out zones are most problematic in crowded NEO (and in GEO, a point to which we will return below). Ground-based lasers disguised as innocent facilities must be more conspicuous if they are to destroy hardened satellites in HEO. HEO’s vast size and range from earth make hardening, stealth, maneuvering, keep-out zones, and other survivability measures more practical there.

At the same time, many of the threatening space missions that would invite or even compel development of ASATs by the opponent would have to be accomplished in NEO, whereas the benign missions of missile warning and emergency communications can be accomplished from HEO. The radar signal returned to a RORSAT-like radar satellite is inversely proportional to the fourth power of its altitude: raising its orbit from 400 km to 4000 km would reduce the strength of its radar returns 10,000 times, making it even more susceptible to jamming and other countermeasures. The resolution of ordinary cameras is proportional to their altitude, confining photoreconnaissance satellites to NEO. The effectiveness of Star Wars laser battle stations decreases in proportion to the square of their distance from their targets. Space-based kinetic energy missile defenses must be near earth if their projectiles are to arrive at a target booster before the end of boost phase. In short, many satellites that would participate in warfighting on earth do their
job best if they are near the earth. There are unfortunately some exceptions to this proposition. For instance, the Navstar GPS satellites that would provide precision guidance to U.S. forces in wartime are in high orbit. Signal detection satellites that locate hostile emitters by time-difference-of-arrival also need not be in NEO. The success of the proposed agreement will depend on whether these exceptions loom large enough to upset the logic and offset the advantages of the agreement.

An effective boost-phase BMD would also be a potent NEO ASAT, and it makes no sense to imagine stringent bans on NEO ASAT coexisting with unbridled testing of Star Wars defense systems. A successful SDI weapon must be lethal even to shielded objects at ranges of hundreds of kilometers. But such battle stations would not pose nearly as serious a threat (in cost effectiveness terms) to shielded HEO satellites at ranges of tens of thousands of kilometers. It is therefore possible to imagine substantial protection of benign HEO satellites coexisting with development and conceivably even deployment of Star Wars battle stations in LEO. Perhaps enthusiasm for SDI need not preclude an interest in ASAT arms control after all.

The effect of taking a minimal approach to ASAT arms control—banning only those ASAT methods that are clearly verifiable—is therefore to offer some protection to hardened satellites in HEO but to abandon NEO satellites to their own devices. Note that this is not a “high-altitude ban” per se. The logic is not to ban “high-altitude ASATs” but to ban what can be verifiably banned and then to observe that the result is substantial—but by no means perfect—protection for HEO satellites. In effect, NEO would be associated with the air, sea, and land as fair game for military activity, and satellites there would have to fend for themselves like all of the other instruments of terrestrial warfare. ASAT threats to HEO would be constrained firmly enough to give protective countermeasures a fighting chance at protecting simple missile warning and narrowband communications constellations.

In outline, the agreement that follows from this general approach would only seek to ban direct intercept above about 3000 km and stationing of directed energy weapons (including mirrored laser relays) above about 1000 km. Keep-out zones in semi-synchronous and super-synchronous orbits would soften the space mine threat. (Establishing keep-out zones in GEO would be much more difficult since this is a “unique” orbit.) The agreement would not seek to ban all ground-based lasers on the supposition—perhaps much too pessimistic—that the absence of modest-sized lasers could not be
verified with confidence. It would not place limitations on SDI “battle stations” in LEO. It would not seek the dismantling of the current U.S. and Soviet ASATs or their LEO offspring. It would not deny the potential of existing ABMs and ICBMs to ascend to LEO and destroy satellites. Benign warning and communications satellites in HEO would have to take self-protective measures against distant lasers and against distant space mines, but this is a challenge the U.S. must strive to meet with its own satellite survivability programs. Meanwhile, RORSATs, Star Wars battle stations, and other threatening satellites in LEO would face the complete menu of ASAT threats that they deserve.

To this basic scheme one can add any number of elaborations. Keep-out zones can be devised for GEO. Ground-based lasers of modest brightness might be judged conspicuous enough to be verified and thus banned. If SDI is judged unpromising, space-based directed-energy generators or relays of brightness greater than that needed for laser radar or other non-lethal purposes can be banned. Another way to get at ASATs is to constrain the threatening satellites they are designed to attack. Since many “Star Wars” weapons, space-based radars, and other threatening satellites require nuclear power supplies, an easily verified ban on nuclear reactors in space might have the indirect effect of restraining ASATs. Wide bans on ASAT use can be added to narrower bans on possession and testing, as is common in international treaty regimes. In short, the minimum ASAT agreement constructed to conform to a strict interpretation of the three objections can be expanded to accommodate weaker interpretations. The interesting point is that there is a coherent arms control regime that seems able to accommodate the objections in their strongest form.

The proposed regime protects U.S. military interests by allowing the U.S. to develop and deploy ASAT systems to destroy threatening Soviet satellites in NEO and by taking a harsh approach to verification that bans only the most conspicuous ASATs. The treaty regime does not prevent all types of provocative activities in space—attack on a photo satellite for example—recognizing that many of these ASAT “windows of vulnerability” are either

26. The author is grateful to Harold Agnew for emphasizing the potential importance of limitations on high-power nuclear space power supplies. A problem with a comprehensive ban on nuclear power supplies is that low-power generators can be an aid to satellite survivability by eliminating the need for large, conspicuous, and vulnerable solar arrays. The ban should attempt to distinguish the two types of power supply.
overstated or unavoidable. It does, however, protect the key stabilizing functions of missile warning and emergency communications. Last, it precludes the political abrasions and financial waste of an unbridled, technologically exotic, and likely inconclusive ASAT/DSAT race in HEO.

To define these provisions precisely will require a major analytical effort. It is even possible that a detailed look will reveal so many exceptions to the distinction between NEO and HEO sketched above that the distinction cannot be maintained as the grounding principle of a treaty. But if analysis confirms the technical and military soundness of this approach, even those who emphasize the defects of ASAT arms control will be able to propose a limited but meaningful agreement.