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Notes on Space, Satellites, and Survivability

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NOTES ON SPACE, SATELLITES, AND SURVIVABILITY

by

Gregory H. Canavan

ABSTRACT

The satellites most at risk in the near term are sensors and the brilliant pebbles for boost-phase defense. The availability of countermeasures for kinetic energy anti-satellites (ASATs) tends to downgrade them. Space-based interceptors and lasers are even less effective. Space mines appear to be the dominant space-based threat. Their main advantages are simplicity and low mass. If they can be forced to use decoys or cannot discriminate, that advantage is lost. For fundamental reasons discrimination should become more robust in time and combined defenses should become more effective.

I. INTRODUCTION

This note gives a few comments on the evolving role of satellites in military space, the reason for and means of placing them at risk, and the techniques and technologies for restoring their survivability to near and midterm threats. It does not attempt to condense 15 years of survivability discussions into a few pages that only the initiated could follow. It presents instead a brief roadmap to the discussion and informal survey of the recent literature. The intent is more to inform than to convince.

II. WHY SATELLITES?

Over the last 25 years both the U.S. and the Soviet Union have found satellites to be the most effective way of performing warning, surveillance, and reconnaissance functions. For the U.S. they are essentially the only way of gaining that information. Given the growing importance of those functions under START and follow-on constraints, it is likely that we will want to use more, rather than less of them. This statement is true exclusive of strategic defenses, which only make the case stronger.[1]

III. WHY ANTI-SATELLITES

There are certain conditions under which either side might want to block or delay the dissemination of information on developments. For example, if the Russians lost control of one or more of their national republics and sought to recover it by force, they could see the value of screening it from overhead reconnaissance, lest their preoccupation there be exploited elsewhere. That is but one example of a class of developments that could give them an incentive to suppress overhead observation.

For an essentially closed society that might not seem so big a step, particularly since it would only involve destroying robots--and doing so over one's own territory at that. It would be preferable for such impulses could be restrained by agreements, but history suggests that under such provocation, treaties become mere paper. Denied information, we assume the worst. Thus, it is useful to provide some measure of survivability for at least critical satellites as a means of enhancing crisis stability.

IV. SATELLITE SURVIVABILITY

Satellite survivability concerns the physical means of making satellites survivable against these threats and the cost effectiveness ratios (CERs), or ratios of attack to defense costs, for the resulting platforms and constellations. The problems have been discussed in some detail for SBIs, i.e, ≈ 100-kg space-based interceptors (SBIs) deployed 1-10 per carrier vehicle (CV). Analyses generally indicate that current SBIs could, with proper, moderate mixes of hardening, maneuver, and decoys, achieve CERS of 2-10:1, which are acceptable in light of the Nitze effectiveness criteria.[2]

An important technical question is whether the cost of the SBIs should be included in the defense costs in calculating the CER.[3] The answer varies. In configurations in which the SBIs should survive, the CER should not include the SBIs' mass, because it is not expensed. In suppression attacks in which the attacker commits enough weapons to assure the CVs and SBIs' destruction, the CV's mass must be included, and is a dominant component of the defensive penalty. The distinction tends to get missed in both pro and con arguments, which is one reason for keeping the math simple so readers can verify that point for themselves.[4]

The shift from conventional SBI designs to single-interceptor "brilliant pebbles," largely on the basis of these survivability arguments, has been rapid. But analyses based on conventional SBIs rather than brilliant pebbles do show that the latter would still have significant margin even if their design parameters slipped significantly. They also avoid the accusation that one is invoking "brilliant pebbles" to salvage current SBIs.[5] In the last few years brilliant pebbles have become the standard, but "current" SBI trades are still useful for showing how these techniques degrade for higher satellite masses. They apply for surveillance and reconnaissance satellites as well. The CERs for brilliant pebbles are factors of 3-10 higher than those for current SBIs.[6]

At this point the distinction between SBIs and pebbles is dropped. The former have been displaced; there is nothing left but pebbles. Note, however, that some would like to put several pebbles on a CV to share their "lifeboat" costs. That sounds economical, but runs counter to the point raised above. Putting

10 pebbles together synthesizes a satellite that is 10 times as valuable as 1 pebble--and hence 10 times more attractive to attack--which therefore has about 1/10th the survivability and CER of a singlet. Maybe that is acceptable. Pebbles have a lot of margin, but this would certainly erode it.

V. MEDIUM AND HIGH ALTITUDE SATELLITES

Earlier notes on survivability[7] did not add much on low-altitude satellite survivability to what was said above, but they did sketch out how the arguments change for medium- and high-altitude satellites. The variations are discussed in some detail in recent reports.[8] The general subject is called long-term survivability, but the reports actually survey the issues from the present to the long term.

A. Ground-based interceptors (GBIs)

GBIs can be treated as extensions of the arguments about nuclear direct-ascent anti-satellites (ASATs). The basic observation is that if hardening, maneuver, and decoys can evade a nuclear interceptor that can kill from 10-100 km, it is quite plausible that those techniques, plus a few humble things like jamming and flares, could beat the sensors on a nonnuclear interceptor that has to come within a meter or so. A more earthy example is the large number of fighter pilots who came back from southeast Asia alive because they could jam, drop flares, and pull more g's than a SAM, once they were alerted. The trick is being alert.

Current GBI-derived kinetic-energy ASATs are designed to go against dumb, ballistic, lightly hardened satellites. If one put a few-hundred-million-dollar satellite into low earth orbit, one might at least put a "fuzz buster" and a package of highway flares on it. There is no reason that retrofit could not be accomplished much faster than GBI-ASATs could be developed and deployed. That tends to downgrade the GBI-ASAT problem relative to others, which tend to ignore obvious countermeasures.

B. Ground-based lasers (GBLs)

GBLs are in one way easier and in another way harder to survive than GBIs. Because of their serial kill, long irradiation, limited footprints, and vulnerability, GBLs are not a suppression threat. They are, however, an attrition problem. Although is not possible with the fluxes transmitted to space by the current generations of lasers, the next generation of lasers could burn holes in satellites during a single pass overhead. Current satellites are light; perhaps 1 kilojoule per square centimeter could burn through critical components. Since the satellites are accessible for ≈ 100 s, that means an average incident flux of only ≈ 10 W per square centimeter. Current infrared lasers have enough power to provide that fluence over a spot ≈ 3 m across.

Unfortunately, their spots currently are about that big. Simple optics indicates that an infrared laser with a 3-m mirror should be able to concentrate its energy in a spot 30 cm across, but atmospheric turbulence and heating spreads the beam out to about 10 times that size. Techniques have been demonstrated to correct both. If implemented, GBL lethality would increase ≈ 100-fold to levels that could kill satellites promptly, rather than simply heat them up. Thus, optics is more important than brute power. Once these techniques are available, much smaller lasers that could be hard to detect could kill satellites.

A satellite could shield itself heavily to avoid having a hole bored through it on a single pass. However, if unopposed, the laser could eventually burn off the shielding and kill the structure below it. The main problem is that it is much cheaper to generate laser power on the ground and beam it up to attack a satellite than it is for the satellite to bring up more shielding. For that reason, lasers appear to be the climax ground-based ASAT, as is discussed in more detail in the references.[9]

C. Space-Based Interceptors and Lasers

Space-based interceptors and lasers are much less effective as ASATs. The interceptors are generally in the wrong place and at the wrong time, which they must compensate for with enormous velocity changes if they are to have any impact. That increases their mass and cost exponentially. Lasers in space that carry their fuel with them lose the inexhaustibility which is the primary advantage of GBLs. When both the laser and its prey are in space, it takes the laser more mass for fuel to attack than it takes its prey in shielding to negate the attack.

VI. SPACE MINES

Thus, one comes down to the humble space mine--not because it is so powerful, but because anything that tries to approach a satellite or shoot it from far away is quite ineffective. The first of the two sensitivities of space mines was covered above. They need decoys to be effective against brilliant pebble-derived satellite self-defense missiles. Thus, if the satellite moves slightly and the mine has to leave its decoys behind and then redeploy more, that could cost the mine more mass than the satellite, since each maneuver could be quite small, which would negate the mine's principal advantage, its smaller mass. Without decoys, nonnuclear mines could be killed before they get close to the satellite. Nuclear mines are, of course, prohibited by the outer space treaty, our oldest arms control agreement.

The second sensitivity is related. Even if the mine approaches without decoys the satellite can still use them--to rather good effect. The satellite could do a small maneuver, throwing out a few decoys in the process. Then the mine would have to decide which object to follow--on the basis of its own on-board instruments. It would be too far away for help from the ground. Thus, to use in attempting to detect the real satellite, the space mine would probably have sensors that were considerably smaller and whose ability to discriminate was considerably worse than those that critics of the SDI give little ability to discriminate decoyed missile threats.

Thus, the space mine would either have to be given much better sensors than the primary defensive ones or each mine would have to contain many smaller mines so that one could continue to follow each undiscriminated object. In the latter case the mine would obviously lose any mass advantage after a few maneuvers. The use of satellite maneuver and decoys reduces the space mine problem to one that is claimed to be solved for SBIs.

VII. SURVIVABILITY IN THE LONG TERM

The issues governing survivability and effectiveness in the long term have been studied less than those above. The subject is a bit of a jumble, because no one seems to have even thought to categorize or organize the threats. After a certain point, current reports degenerate into inventing plausible threats and striking them down, alternatively.

The survivability of particle beams, relay mirrors, and free-electron lasers are of particular concern because of their large sizes. The first has been discussed adequately, if not prominently. Because neutral particle beams can rapidly discriminate decoyed threats and efficiently kill the weapons found, they are among the most survivable of space platforms, despite their size.

Other directed energy platforms are harder to discuss. There are a few general observations. If the platforms can not discriminate, decoys will bleed it to death. It is hard for lasers to discriminate, but discrimination could be provided for them either by an idle weapon-level particle beam or by a low-current platform deployed for just the purpose of providing discrimination for other platforms.[10] Either could discriminate quickly from considerable range. Given discrimination, lasers could either kill light ASATs themselves or dispatch kinetic energy self-defense interceptors against the weapons. The argument is as sound as that for particle beams, but less elegant because the laser platforms cannot stand alone.

VIII. DISCRIMINATION AND COST EFFECTIVENESS

Calculations of cost effectiveness depend on those of survivability, because to be effective, defenses must survive long enough to engage. A comparison of kinetic and directed-energy defenses is particularly illuminating in that light.[11] Overall, they indicate that directed energy has much less sensitivity than kinetic to threat modernization, and that it produces CERs of 3-6 against rapidly modernized threats. Kinetic energy holds up there, too. Directed-energy platform costs obviously scale inversely with their survivability. Calculations of kinetic-energy interceptors are also sensitive, indirectly. Brilliant pebbles are relatively insensitive to the details of survivabilities anything like the CERs discussed above, but their leakage is likely to be such that a significant number of weapons will have to be intercepted in midcourse.

Calculations for GBI and laser effectiveness assume excellent discrimination. If they do not have it, decoys will require the deployment of large numbers of GBIs, whose costs significantly degrade the CERs of both. There only seems to be one way to get robust discrimination: neutral particle beams. The strongest defense of other approaches is the statement that "passive discriminants had not yet been disproved," but that constitutes faint praise indeed.[12] While popup particle beams could be preferred for minimizing absenteeism, mass in orbit, and overflight issues, neutral particle beams in space appear to be no less survivable for the reasons discussed above, and could be useful for coverage against accidental or limited attacks.

IX. CONCLUSION

The discussion above attempts to clarify the relationships between survivability, discrimination, and brilliant pebbles, particularly in the context of phase 1. Over the last 25 years satellites have proved themselves to be the most effective way of performing warning, surveillance, reconnaissance, and defensive functions. It is likely that those functions will grow. There are, however, conditions under which either side might want to block or delay information, which could give them an incentive to suppress overhead observation. That could be attempted with lasers or interceptors based on the ground or in space.

The satellites most at risk in the near term are the brilliant pebbles for boost-phase defense. Against nuclear or nonnuclear interceptors, however, they appear to be capable of achieving large cost effectiveness ratios. Singlet pebbles should exceed the requirements of the Nitze criteria by a significant margin.

The availability of countermeasures for GBI-derived kinetic energy ASATs tends to downgrade them relative to other threats. GBLs are not a suppression threat, but do present a formidable attrition threat in the long term because of their economic advantage over satellite shielding. When compensation for the atmosphere is implemented, modest lasers could be a significant threat. Space-based interceptors and lasers are less effective as ASATs. Interceptors are generally in the wrong place, need enormous velocity changes, and suffer unacceptable delays. Space lasers that carry their fuel are no longer inexhaustible, so they require more mass to attack than their prey requires to shield.

Space mines are thus the dominant space-based threat, not because they are so powerful, but because other ASATs that try to approach a satellite fast or shoot it from far away are quite ineffective. A space mine's main advantage is its low mass. If it can be forced to shed its decoys or cannot discriminate decoys used by the satellite, that advantage is lost.

Thus, survivability should not degrade in the long term if the threats remain variants of those discussed above. Large platforms can be quite survivable. Particle beams can survive on their own resources; lasers and large sensors should survive on the basis of discrimination provided by other platforms. With survivability, discrimination should become more robust and combined defenses should become more effective in time.

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