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# Space Weapons: Not Yet

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In this paper I attempt to sketch the utility of space weaponry, primarily from the point of view of the United States.

In this I draw upon the excellent RAND book[1], "Space Weapons, Earth Wars." That study was commissioned by LGen Roger DeKok, DCS Plans and Programs, HQ USAF. I am guided also by the views expressed in presentations and discussions of which I am aware over the past year. But these are my own judgments, which will be refined by the interactions at this Pugwash session.

I come to this study from a background of 40 years as scientist and manager with the IBM Research Division, and more than 50 years of involvement with the US Government's national security programs, beginning with the development and testing of nuclear weapons, and extending to missiles and space.

The US Space Commission Report[2] cited several needs for space-weapon capability:

1. Defensive Counter-space: To reduce US military space vulnerability.

2. Offensive Counter-space: To deny the use of space and space assets to adversaries

3. Rapid and global power projection to earth.

To address these needs, the RAND Report assesses distinct classes of weapons:

1. Directed-energy weapons such as space-based lasers.

2. Kinetic-energy weapons against missile targets.

3. Kinetic-energy weapons against surface targets.

4. Conventional warheads delivered by space-based, or space-traversing, vehicles.

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[1] "Space Weapons, Earth Wars," by Robert Preston, et al, RAND MR1209, June 2002.

[2] Rumsfeld, D.H. et al. "Report of the Commission to Assess United States National Security Space Management and Organization," January 11, 2001.

In addition, any assessment must consider the potential for non-space weapons to perform any of these tasks. This introduces the competing capabilities of:

1. Surface-based anti-satellite (ASAT) weapons such as high-power lasers, or missiles with pellet warheads, or hit-to-kill vehicles.

2. Rapid-response delivery of conventional munitions by forward-deployed cruise or ballistic missiles, or non-nuclear payloads on ICBMs.

And one must consider also countermeasures to space weapons and to these competing systems.

A final element of assessment is the vulnerability of space weapons or of competing systems.

In this preliminary assessment, I take into account the experience of my civilian and military colleagues and their judgments of existing and future threats to US military space, as well as their views of the potential utility of various space and non-space weapons.

We turn to the first application in our list, defensive counter-space. Here we discover that space weapons have little capability for meeting the felt needs identified above.

Satellite vulnerability is and probably will continue to arise in considerable part from jamming or other electronic countermeasures, sensor blinding from high-powered lasers on earth, and pellet payloads on short-range pop-up missiles. Perhaps most proliferated is the threat of Denial and Deception, camouflage that undermines the effectiveness of our reconnaissance satellites, or operations scheduled under cloud or when satellites are not in position to observe. Here is a tabulation of threats, with the most likely ones listed first:

1) denial & deception

2) electronic warfare

3) attack on ground stations

4) sensor blinding

5) microsatellites

6) direct-ascent interceptors

7) nuclear detonation in space

But for most of these threats, space weapons do not help to reduce vulnerability. They are limited to intercepting objects that approach satellites in a noticeably offensive way, such as hit-to-kill kinetic energy weapons; and that capability remains to be assessed.

One of the most effective threats is a microsatellite in the form of a "space mine." Surrey Satellite Technology Ltd., a Surrey University company, is a leader in developing microsatellite technology, and has numerous collaborative programs with other countries and with non-state groups. Although microsatellites have peaceful and military non-weapon uses--observation, communication, and the like--they make particularly good antisatellite weapons. In this role, a microsatellite space mine equipped with maneuver capability exceeding that of the quarry satellite would sit always within lethal range (even a few tens of meters) ready to explode at a moment's notice.

A microsatellite as inspection device might have been useful in conjunction with Columbia's final flight, but a long-endurance microsatellite is a more difficult task. Nevertheless, a cautionary tale is this account of a January 29, 2003, US microsatellite exercise; the XSS-10 repeatedly maneuvered to within 115 ft of its final-stage rocket, taking pictures. A shotgun shell could have destroyed a satellite from such a range.

China carried out similar maneuvers with Surrey technology several years ago.

Since in the vacuum of space (as was known to Galileo) a feather and lead shot fall at the same speed without significant drag, a microsatellite with little payload necessary to devote to other tasks can be equipped to outmaneuver and outlast a major satellite, the primary job of which is surveillance, high-bandwidth communication, and the like.

It is difficult to counter space mines once they are in place. It might be done with defensive microsatellites, but the asymmetric nature of the threat (i.e., tiny expenditures for the microsatellite vs. $200 million-plus for a major US LEO satellite, makes it desirable to prevent the emergence of such threats.

Two general tools for resolving the microsatellite dilemma are rules of conduct in peacetime, and deterrence by holding non-space assets at risk.

In summary, space weapons are generally not good at protecting satellites. In the case of microsatellites, one might plagiarize Jonathan Swift and commit to deploy "smaller still to bite 'em." This is an arms race in which United States resources far outweigh those of any other state, but this advantage is outweighed by the vulnerability inherent in the cost of existing and future high-capability satellites in low Earth orbit.

We turn now to the remaining two uses for space weapons, power projection and offensive counter-space. Different space weapons have varying degrees of utility in these areas, so we will now look at the utility of specific weapons.

We have already seen how useful space mines may be AGAINST those who have valuable satellites and useless against those who have none.

**Another weapon much discussed is long-rod penetrators**. The idea is that these long tungsten or uranium rods would be orbited, and (according to the RAND Report) de-orbited by canceling their orbital velocity, so that they would fall essentially vertically through the atmosphere, striking their target with enormous energy. Two problems that will not be alleviated by the progress of technology: the energy is larger the higher the orbit, but the fall time is greater as well. The energy of high explosive corresponds to a material speed of 3 km/s, and one does not arrive at a similar energy per gram from a projectile dropped from altitude until one reaches 460 km, with a corresponding fall time of 12 minutes; a fall from GEO takes almost 6 hours and provides about ten times the energy density of high explosive.

A rod would need to be guided accurately to strike its target within some meters in order to destroy a surface target by the explosion.

Long rods might be used to penetrate through earth to hard or deeply buried targets. However, the physics of high-velocity impact limits penetration depth as shown by high-speed photography of a bullet impacting steel at just above 1 kilometer per second. A copper-jacketed lead bullet fragments against the hardened steel, but in the process produces a pressure sufficient to leave a small crater. Very strong projectiles impacting earth or rock at similar speed can penetrate to depths several times their length.

Tests done by Sandia laboratory confirm predictions that, even for the hardest rod materials, penetration is maximum around 1 km/s. Above that speed, the rod tip simply liquefies, and penetration depth falls off, becoming effectively independent of impact speed. Therefore, for maximum penetration, such rods would need to be orbited at very low altitudes, and could only deliver one ninth the destructive energy per gram as a conventional bomb. The effort is entirely mismatched to the results.

Dominating the cost is the need to put the rod into orbit in the first place and later cancel its orbital velocity so that it drops back to earth. The propellant required to place the entire weapon in orbit must suffice to lift both the rod and its attendant deorbiting propellant. For low earth orbit, the total velocity change of about 15 km/s typically requires several thousand times the orbiting mass in propellant. Taking the typical $10,000 per kg launch cost to LEO, and assuming a 0.1 ton rod with the 3 tons of propellant to stop its orbital motion, the launch cost to orbit would be some $30 million. And for timely delivery against a single target at temperate latitude, several rods in each orbit would be required and a good many orbits—say 10. Clearly, the more conventional deorbit maneuver would be preferable, with a small energy change and the use of atmospheric drag (combined with wings or a lifting-body approach) to preserve much of the orbital velocity as the rod approaches the vertical.

Whatever the effect actually achieved against a target, it is far better to propel the rod directly from launch to target and avoid orbits altogether -- by placing the rods on ballistic missiles. Specifically, a one-km/s penetrator could be provided flexibly by a nominal solid rocket motor giving an acceleration 30 times that of gravity—so 300 m/sec$^2$. The desired 1 km/s would be obtained in 3.3 s, over a distance of 1.65 km. A speed of 3 km/s would take 10 s and a distance of 15 km. The cost would be some $100,000 or less, plus whatever cost for the terminal guidance system--which is surely no greater for the ballistic missile than for the orbiting projectile.

Looking now at the common aero vehicle (CAV) carrying conventional ordnance or intelligence payloads, one finds again that this capability is dominated by CAV delivery by ballistic or cruise missiles-- perhaps guided by observation from space. Indeed, the role of the CAV itself is largely supplanted by the familiar "bus" technology for delivering multiple payloads from a ballistic missile launch.

We turn now to space weapons (and their competition) for missile defense. For boost-phase intercept—BPI-- space-based kinetic-energy (hit-to-kill) interceptors are in competition with surface-based interceptors (on land or sea, or even on aircraft). The non-space options excel against a small state such as North Korea, largely surrounded by water. For BPI, space-based interceptors must be given acceleration and divert capabilities very similar to those required for surface-based interceptors, if they are not to pass harmlessly by the quarry missiles. For missile launches from a small area, space-based interceptors have their required number multiplied by the number of simultaneous launches, and also by the "absentee ratio" because most of the SBI will be on the other side of the Earth and unable to join the fray for a clustered launch.

However capable the surface-based interceptors would be against North Korea, Iraq, or even against launches from Iran, unless based within the target country they are ineffective against ICBMs launched from China or Russia, because the interior of those countries is so far from the borders.

Yet China and Russia are highly capable powers, and it would be much easier for them to destroy space-based interceptors as the constellation is gradually built than it would be for the US to use the SBIs to counter ballistic missile launch. Some observers are skeptical that Russia or China (or France, for that matter) would destroy SBIs in peacetime, but when the question is posed what the US would do if another state deployed a vast number of SBIs, the response of many of my colleagues is that we would destroy them—"shoot them down".

The airborne laser (ABL) under development and in early flight test (in contrast to the SBL for which no US program currently exists) might serve as a BPI capability against ICBMs launched from North Korea. In the spirit of a "capabilities based" system, it would to some extent complicate NK's ICBM program: North Korea would need to deploy from the beginning countermeasures to mid-course and would have to consider countermeasures to an ABL BPI defense. Unlike the mid-course interceptors which once deployed would always be ready for use, the ABL would incur large operating costs to maintain a constant presence.

Another weapon of considerable interest is the Space Based Laser. These weapons could attack over long distances at the speed of light, although space mines and the ABL could be equally prompt. A SBL could also attack terrestrial targets, but only with suitable laser wavelengths to penetrate the atmosphere. The current candidate SBL lasers cannot attack ground or airborne targets.

A single SBL, costing billions of dollars, could typically have a range of at most 3000 km, unless the SBL constellation were conceived to have a large number of redirecting ("fighting") mirrors[3]. Under those circumstances, a competitive system could use a ground-based laser, redirected by such mirrors[3]. Cloud at the GBL site would cancel the capability of a GBL, so several would be needed to have high probability that the system would be operable at any time. In any case, the fighting mirrors might be classed by the potential victims as weapons in space as well.

An SBL would be a very expensive means of attacking a satellite, but might be more useful for missile defense purposes. With relatively few SBL in orbit, one might need to be used at 3000 km range. At that distance, with no loss through the atmosphere, a perfect mirror of 3 m diameter, and laser power output of 3 MW in the 3.8-micron DF band, a target protected with 3 cm of cork could withstand about 200 $MJm^{-2}$ before exposing the target surface to laser heat. (Some Minuteman ICBMs have had a 0.6-centimeter layer of cork to protect the booster from skin friction heating during launch. Such a layer would be vaporized with about 50 $MJm^{-2}$ (5 $kJcm^{-2}$) from a SBL.) The laser consumes fuel at a rate of some 3kg/MWs, or 9 kg/s, and it would need to fire for 1700 s at the assumed 3000-km range, thus using 15 tons of fuel, at a launch cost for fuel of $150 million per target attacked. At a range of 1000 km, the launch cost would be some $16 M per target.

Other countermeasures are feasible and could be multiplicative—such as the slow rotation of the booster during launch.

A substantial constellation of SBLs covering the strategically important region of the Earth could consist of 20-50 such satellites, which could provide rapid illumination of most important points, providing that the target can be destroyed by the laser, and that it is not covered by cloud. Cloud coverage is typically 30-40%, but can range to 70% or more in parts of Germany or North Korea.

But, as analyzed in detail in the RAND publication, many targets are not vulnerable to destruction by SBL, and many that are can be protected by smoke, by water shields, or in other ways. Aircraft yes, and combustible targets or thin-skinned storage tanks. But not bunkers, armored vehicles, or many buildings.

We have already seen that the use of an SBL can easily cost in the range of $100 million per target and is contingent on the target being thin-skinned and not obscured by a cloud. For comparison, a Tomahawk missile costs some $600,000 and will attack heavily armored and non-flammable targets, and is not affected by cloud.

Even enthusiasts consider SBLs a weapon to attack very special targets, while most military capability against similar targets is to be provided by more conventional means. In contrast almost all portions of the earth are reachable by existing cruise missiles (Tomahawk Block 3) launched from outside the 12 nmi limit. The flight time can be several hours.

For the space-based laser, "rapid response" is a sometime thing, since it is necessary to have clear air to allow the laser beam to strike the target—no cloud in the way.

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[3] Bethe, H.A., and Garwin, R.L., "Space-based Ballistic-Missile Defense," Scientific American, Volume 252, No. 4, October 1984. (Figure on p. 44).

With these competitive means of striking the target, observation could still be provided by non-weapon space assets, so that in addition to attack by navigation (using GPS) one could use a laser-target designator from space with observation and designation provided at the time when a destructive payload arrives in the vicinity of the target—an example of non-weapon military space capabilities contributing to US military capability.

In summary, the one target which can surely be held at risk at modest cost is important and costly satellites, of which the US possesses by far the greatest number and value.

The US Space Commission Report is generally considered as support for the proposition that the US should proceed to develop and deploy space weapons in order to counter the evolution of space weapons by others, and to effect the needed reduction in vulnerability of US satellites. In fact the commission does not specifically advocate the development of offensive weaponry for deployment in space. In particular, it reads,

> "The government…should:
> • Invest in technologies to permit the US Government to field systems one generation ahead of what is available commercially to meet unique national security requirements.
> • Encourage the US commercial space industry to field systems one generation ahead of international competitors."

Also,

> "Fourth, we know from history that every medium—air, land and sea—has seen conflict. Reality indicates that space will be no different. Given this virtual certainty, the US must develop the means both to deter and to defend against hostile acts in and from space."

And

> "The US must participate actively in shaping the space legal and regulatory environment."

My own analysis indicates that US deployment of space weapons will encourage and demand the development and deployment of space weapons by others. Others can and will respond to space weapons in asymmetric ways--including the deployment of space mines in their vicinity and the use of short range missiles to lift ton-class pellet payloads against LEO weapons. Furthermore, such responses would inevitably threaten and legitimize counters to US non-weapon LEO satellites essential to our entire military capability.

It is therefore essential to judge the utility and necessity of space weapons. Of course, any proposed augmentation of US military capability must compete with other means for accomplishing the task. Capabilities unique to space weapons use resources, which must be taken into account.

Net judgments on space weapons utility:

- For offensive counterspace—deny military space to others
  - Jam uplinks or downlinks (from ground or space)
  - Attack ground stations essential to satellite capability
  - Obscure line of sight by screens in space
- For defensive counterspace—preserve US military space capability
  - Attack ground systems which might be disabling satellites
  - Interdict ASAT in powered flight
  - Deter by promise of retaliation—not against satellites but against military and political assets

- For destructive antisatellite (ASAT)
    - The most prompt means is probably microsatellite as space mine, orbiting Earth within 10-100m of its quarry
    - Short-range missiles lobbing ton payloads of coarse sand to orbital altitude at the right time
    - Homing kill vehicles as direct-ascent ASAT

The United States can do it best, but others will soon do it well enough.

- Global and prompt force projection
    - Kinetic-energy (KE) weapons on ICBMs or shorter-range missiles
    - Advanced conventional weapons on ICBMs (CAV?) with observation or designation from space, ground, or UAV
- Non-space *weapons* will provide more capability *and* sooner than space weapons
- Destructive ASAT and space-ASAT weapons are a serious threat to overall US military capability and its dependence on space.

Countering satellite vulnerability: A general approach to reducing satellite vulnerability is to reduce our dependence on satellites while maintaining the benefits of satellites at reasonable cost. This can be achieved by supplementing satellite capabilities in wartime by theater resources:

- High-power pseudolites (on the ground and on UAVs) in the theater of operations so that the adversary would obtain no benefit in theater conflict by destroying GPS satellites.
- UAV and rocket capabilities for imagery. At altitudes of 20-30 km, a 20-cm aperture would have the same resolution as a 2-m diameter mirror at a range of 300 km. Such platforms can provide near-constant presence, as well.

A primary means of reducing vulnerability is to reduce the threat—by agreements not to damage or destroy non-weapon satellites. This should be backed up by US developments to intercept or counter such weapons or ASAT used in violation of such an agreement.

We have found general acceptance of this (conditional) conclusion:

> **If space weapons and destructive ASAT could be avoided by the United States giving up such capability, it would be in our national security interest to do so.**

Asserting a "might makes right" rule in space and elsewhere leads, again, to the asymmetric use of force, and this might be the destruction of valuable satellites in peacetime rather than holding them at risk for future destruction.

Nothing is forever--perhaps not even the regime we favor--so an aggressive campaign to prevent the deployment of weapons by others might best be implemented as a US commitment:

> **not to be the first to deploy space weapons or to further test destructive antisatellite weapons.**

This should be supported by a US initiative to codify such a rule—first by parallel unilateral declarations and then by a treaty. Such a campaign would legitimize the use of force against actions which would imperil satellites of any state.