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Full Spectrum Space Deterrence: From Laws to Technology

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Full Spectrum Space Deterrence: From Laws to Technology

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1. Abstract

Conflict in space is becoming an ever-real possibility, with the potential of rendering the space completely useless for future generations. Current talks are centered around limiting or preventing any weapons deployed to space, but this is not the most effective way of dealing with the issue. The focus should shift to agreeing on how nations should act responsibly in space together instead of preventing nations from acting at all. The best way of accomplishing this goal is by improving satellite design, creating agreed upon and understood rules of engagement, fostering widespread cooperation between nations, and choosing not to be the aggressor in any given situation.

2. Introduction

Satellites have fully integrated themselves into the daily operations of the United States of America and many other nations around the world. They are relied upon for everything from communications, to navigation, and even accurate timing, but this criticality and utility is what makes them a tempting target to adversaries. At the same time, decreased launch costs and increased experience has made the idea of launching new systems into space, including weapon systems, more tempting. This increasingly crowded space has created significant concerns over space debris (random scraps and pieces that have been deposited in the atmosphere over the years), which, if left unchecked, could create a cascading cycle of destroyed satellites creating debris that destroys more satellites. Space debris management becomes all the more pressing with the fear that more would be created if space weapons were fielded and conflict erupted in space. These problems are not a sudden development, but instead a trend that has continued from the very beginning of space exploration in the 20th century, which has been accompanied by an equally long running discussion about what stance the U.S. should take in this environment.

One of the long running focal points of this debate is whether or not we should "weaponize space." The biggest question with the discussion then becomes what constitutes "weaponizing space," with the core issue being the question of what exactly qualifies as a "space weapon." By some of these definitions put forward, space has already been weaponized (Center for Strategic and International Studies [CSIS], 2020). While weapons that are based in space have been fielded, there are no known constellations or even single satellites currently being fielded by nations with the ability to strike other targets in space. This underscores that there is still a lacking factor of persistence. Conversely, Earth-based missiles are some of the most developed space weapons and are currently being fielded by multiple nations, but for the purposes of this paper, these are considered trans-domain weapons, which while they affect space and are space weapons, they do not weaponize the domain of space. Therefore, while space can be weaponized, space itself is not currently weaponized, which leads to the necessary discussion that states will be tempted to weaponize space in times of war (Mineiro, 2008).

This topic is constantly debated, partially because of the way the original question is framed. There are never really discussions about other domains being weaponized, such as the air or sea. Instead, discussions focus on managing the extent to which conflict occurs in these domains. With space, the focus on defining exactly what a weapon is has stymied discussions and treaties related to space. Even if a definition was decided upon by all countries, and restrictions were put in place to prevent deployment of weapons under this definition, it would either limit pursuit of useful technology, or there would be technology existing that could be easily weaponized during war. Instead, the focus should shift to the management of conflict in space and the deployment of weapons thereto. Furthermore, this should all be done while understanding the true limiting factor of weapons in space: the economic and technological practicality of weaponizing space. (Mineiro, 2008; Sankaran 2014) While development has gone on for a long time, it is only recently that the embers of real, practical space weapons have been seen.

Much of the debate around space weapons circles around whether or not we should put weapons in space, this paper aims to take a step back and evaluate the practicality of placing and the deterring of placement of weapons in space in hopes to anchor the debate around weapons in space. Instead of trying to absolutely prevent conflict in space, it would be best to focus efforts into managing and deterring conflict in space so as to mitigate and control damaging effects. This will be accomplished by first framing the discussion of weapons in space with its key considerations: firstly addressing current laws surrounding space, then the practicality of space weapons, and finally the position and potential of the U.S. in this discussion. Realistic options for policies and measures will be discussed with a recommendation drawn for the U.S. with regards to how to deal with weapons in space.

3. Key Considerations

3.1 International Law and Norms

At the present time, the most relevant discussion pertains to weapons orbiting Earth and to a lesser extent in outer space. There are discussions to be had surrounding weapons, the military, or conflicts on other celestial bodies, but the current lack of practicality, desirability, and controversy in doing so reduces their relevance to the current discussion. Therefore, most documents and proposals focus on the orbital space surrounding Earth, and several seminal texts generally frame the current conversation around weapons in space (Mineiro, 2008).

The terminology and discussion surrounding the idea of warfare in space has been guided by treaties and measures such as the Outer Space Treaty of 1967 (OST) and the Moon Agreement of 1979. These treaties were mostly concerned with banning the deployment of nuclear weapons into outer space and thus did not do much for the discussion of conventional weapons in outer space. However, between Russia and the U.S., the Anti-Ballistic Missile Treaty did effectively curtail the placement of conventional weapons in orbit as well, but with the lapse of the treaty in 2002, there are currently no restrictions on the placement of weapons in orbit. This means that the United States currently faces no legal obstacles to deploying conventional space-based interceptors, of which it is currently pursuing development (Harper, 2019a, 2019c). Therefore, the discussion of the question of conventional weapons in space is fairly open-ended.

This current situation is not an accepted norm, however, and there are many proposed treaties that seek to curtail such a system and to cover the idea of space weapons more fully in general. Currently, two of the most prominent proposals is the Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects (PPWT), which has been pushed by Russia and China, and the International Code of Conduct for Outer Space Activities (ICoC) put forward by the European Union. The PPWT defines a space weapon as, "... any outer space object or its component produced or converted to eliminate, damage or disrupt normal functioning of objects in outer space, on the Earth's surface or in the air, as well as to eliminate population, components of biosphere important to human existence, or to inflict damage to them by using any principles of physics" (Ministry of Foreign Affairs of the People's Republic of China [MOFA], 2014). On the other hand, the ICoC does not define space weapons *per se* but instead calls states to, "refrain from any action which brings about, directly or indirectly, damage, or destruction, of space objects unless such action is justified: by imperative safety considerations, in particular if human life or health is at risk; or in order to reduce the creation of space debris; or by the Charter of the United Nations, including the inherent right of individual or collective self-defence" (European External Action Service [EEAS], 2014). Both proposals have garnered some support, but there are concerns with both that prevent wider adoption.

Through the various discourses surrounding defining and restricting weapons in space, several noteworthy points have emerged. According to the Center for Strategic and International Studies (CSIS), there are four distinctions with space weapons (2020); additionally, Mosteshar points out other considerations related to weapons in space (2019). Combining the two creates a set of key distinctions for space weapons that have risen out of international treaties, laws, and discussions: the distinction between nuclear and conventional, the location of the weapon, the amount of space debris created by the weapon, whether the weapons are used for self-defense rather than for offensive purposes, and the distinction of peaceful use.

3.1.1 Nuclear Weapons vs Conventional Weapons

The first distinction to be considered is whether a system is a nuclear or conventional weapon. The OST was one of the very first treaties related to outer space, and clearly and deliberately banned the placement of nuclear weapons in outer space, and to this day deployment of nuclear weapons in space is effectively banned by existing treaties and thoroughly reinforced with accepted international norms. However, as stated before, there exists no such consensus for conventional space weapons. There are some minor restrictions on the placement of any weapons on or orbiting celestial bodies, but there are no blanket restrictions on the placement of conventional weapons in orbit around the Earth (CSIS, 2020).

3.1.2 Location of Space Weapons

A second distinction made with respect to space weapons is whether the weapon is stationed on Earth or in space. The definition for weapons in the PPWT is thoroughly defined, but it is framed to exclude any weapons originating from Earth's surface by definition; thus, the anti-satellite (ASAT) missiles of any country are unaffected by the terms of this treaty. Conversely, even defensive measures put in place would violate the treaty since they are intended to affect other objects in space. The main point is to leave satellites vulnerable to a first strike during a conflict with ground-based ASAT weapons. This is the main reason the terms are so vehemently opposed by the U.S. which, by virtue of having the largest satellite constellation and the greatest reliance on it, would be most affected (CSIS, 2020). If adopted as it was, the PPWT would encourage strikes against basically undefended satellites. It is worth noting that the International Code of Conduct for Outer Space Activities penned by the European Union has garnered less support than the PPWT, but the European Union's Code of Conduct is distinct from the PPWT in that its provisions restrict the effect on the target in space, but is enigmatic as to the delivery method, thus it also restricts Earth-based weapon systems that strike targets in space (CSIS, 2020).

Furthermore, if a space weapon is placed in space, there is the question at what height does space begin so as to not infringe on another state's airspace. Mineiro notes "If a space weapon is deployed at an altitude within the unresolved boundary of air and outer space above the territory of a sovereign State, that State may perceive the deployment of the space weapon as a legal violation of their national sovereignty" (2008). Since there has never been a clear demarcation, the acceptable height of space weapons has developed as more of a norm. If satellites were orbiting at that height for some time with no protest from other nations, then the height does not infringe on any nation's airspace. With this norm set in place, any country suddenly coming forward to challenge a satellite as crossing into its airspace will find little support in the international community. Today, basically any satellite in operation is accepted as not infringing on another nation's airspace, but this is likely to be challenged if space weapons are deployed in orbit as countries will likely protest any of them being positioned overhead. To counteract this, it might be worth establishing a clear demarcation for airspace like that which exists for a country's exclusive economic zone (EEZ) at sea in the future.

3.1.3 Space Debris Creation

A third distinction is whether the weapon produces orbital debris, as a facet of the discussion around the use of space is space debris mitigation and cleanup. Space debris is a primary concern of otherwise disinterested nations, with many non-aligned states having stated their main motivation is the prevention of orbital debris and the preservation of the space environment for peaceful uses (CSIS, 2020). Launches throughout the space age have steadily built up debris in orbit. There are proposals, like one from the Space Safety Coalition (SSC), that seek to create rules for participants that mitigate space debris creation (Space Safety Coalition [SSC], 2019), and even space fairing enterprises outside of those agreements are eminently aware of the problems produced by space debris and often seek to mitigate its creation in their own way. It should be understood with all these measures that they only "mitigate" they do not "eliminate" the creation of space debris. Accidents happen such as the famous incident in 2009 where the Russian satellite Kosmos-2251 collided with the American satellite Iridium 33 and in turn created a massive debris cloud that persists today (Wall, 2019).

Undoubtedly, whether through design error, human error, or malice, more space debris will invariably be created. Therefore, it is desirable that systems be created that can clean up space debris. Fortunately, there are multiple proposed methods for this. The main design requirement for all of those is to create a device that seeks out an object in space, with which the space debris cleaning system itself does not necessarily have any communication, to then apply some method of deorbiting the object of interest. On the other hand, the main design requirement for a space-based weapon is to create a device that seeks out an object in space, with which the weapon system itself does not necessarily have any communication, and to then apply some method of destroying, deorbiting, or interfering with the object of interest. The crux of the issue is that the core of a space-based ASAT weapon and a space debris cleaning system is nigh indistinguishable.

It is clear however that space debris cleanup measures should be in place since more debris will inevitably be created, so any measure that limits the creation of space debris cleanup systems in order to prevent space-based weapons is counterproductive. In addition, other systems which use the same principles such as satellite refueling or satellite repair missions are being developed and have significant purpose for existing in space. These systems mean that tracking and targeting other space objects will be developed; all that needs to change is delivering something destructive instead of something constructive.

3.1.4 Peaceful Use

A fourth distinction is understanding and defining what falls under peaceful use of space, use which has been clearly stated on multiple occasions that states are free to engage. This is somewhat related to defining what is a space weapon, but many countries contend that it extends beyond that, while others do not. The U.S., for example, considers the definition of peaceful use to be more along the lines of "nonaggressive" rather than "nonmilitary" (Mosteshar, 2019). Imaging satellites are a prime example of this nonaggressive but most definitely military use, which has led to the consideration of the term militarization, since it is hard to define these satellites as weaponized. As the CSIS notes, "These passive uses of space to support military forces are often referred to as the militarization of space, and there is little disagreement that space systems have and will continue to be used for military purposes" (CSIS, 2020). The difference between the two is that space weaponization is always a form of militarization, but the placement of military spacecraft in space does not necessarily involve space weaponization (Mosteshar 2019). It would be best to look at imaging satellites as tools of war, not weapons of war. However, it does pay to note that they are military targets just like any other in times of war, so while they do not weaponize space, they have the chance of bringing conflict into space.

The use of dual-use satellites has complicated the discussion as to what is peaceful use and whether they make for relevant targets in times of war (Mosteshar, 2019). Dual-use satellites are satellites that are used by two or more parties, which includes both civilian satellites used for military purposes and satellites utilized by more than one state. The necessary assumption is that the satellite becomes a target during times of war under the same provisions of proportionality outlined in traditional war theory. Mosteshar clarifies, "Given the growing dependence on satellite communication and information in modern civilian life, these factors need to be included in proportionality analysis. Consequently, attacks against satellites invoke the requirements of international humanitarian law. It may therefore be that the balance of proportionality will generally be against attacks on satellites" (2019).

A further fear about weaponizing space is that any satellite can technically be weaponized. All that needs to be done is to put it on a collision course with another satellite, and assuming the targeted satellite makes no maneuvers, and assuming the trajectory is predicted accurately enough, the satellite used will ram into the target. While satellite to satellite attack is possible, it is highly limited and very inefficient. This should limit contempt for civilian and military satellites without specific weapon systems, and for the purposes of laws, it must also be recognized that while all satellites can be weaponized and many can be militarized, they are not inherently threatening and must not be treated as weapons. It also may be desirable to cover such concerns with rules of engagement that may equate attacking civilian targets in space to much the same as targeting non-combatants down on Earth (Manual on international law applicable to military uses of outer Space [MILAMOS], 2019; Woomera manual [Woomera], 2020).

3.1.5 Self-Defense vs. Offensive Use

A final distinction nations have begun considering as technology has developed and the probability of fielding space weapons increases is the distinction of whether space weapons are used for self-defense rather than for offensive purposes. While the PPWT does state, “States Parties to this Treaty shall… not resort to the threat or use of force against outer space objects of States Parties,” it also adds, “This Treaty shall by no means affect the States Parties' inherent right to individual or collective self-defense” (MOFA, 2014). These provisions clearly leave room to strike objects in space during times of war or for claimed self-defense. The CSIS has commented that, “The latest version of both the PPWT and Code of Conduct include exceptions for self-defense, and the Code of Conduct is more specific in delineating when the use of space weapons in self-defense is legitimate” (CSIS, 2020). Additionally, it still opens up the opportunity to deploy weapons in space once war breaks out. As a result, many analysts posit China or Russia would directly attack U.S. satellites at the outbreak of a war in hopes that it would cripple U.S. military capabilities for years (Sankaran, 2014).

Furthermore, it should be noted that it is difficult to ascertain the extent of the meaning of self-defense in times of war, as actions can be justified as self-defense for the purposes of winning. Even civilian targets could be attacked under the guise of defending one's country once war breaks out. The position of the United States Space Force (USSF) on the matter states, “Just like all forms of warfare, the prosecution of space warfare and the potential generation of collateral damage is judged against the principles of military necessity, distinction, and proportionality” (Headquarters of the United States Space Force [USSF], 2020). This would seem to leave it under the provision of normal military theory except for the existence of the OST and the Liability Convention that followed it. However, as Mosteshar details about any combative action that creates space debris, “Any such action, therefore, will affect not only the target satellite but also potentially all satellites. It is arguable that direct attacks on satellites in Earth’s orbit are contrary to the requirement that states ‘shall conduct their activities in outer space, including the Moon and other celestial bodies, with due regards to the corresponding interest of all other States’ and thus would be in breach of international law” (2019). Whether states will suffer consequences under such provisions is yet to be seen, and it would likely depend on who is the victor in a hypothetical conflict in space.

3.2 Effectiveness of Space Weapons

To begin discussion on the effectiveness of space weapons, it would be worthwhile to functionally decompose space weapons and consider the fundamentals of what the weapon system actually needs to accomplish. Functional decomposition is a basic design principle that allows a designer to break a design down into basic functions and then to come up with concepts to fulfill each basic function, which are intrinsically intended to be independent of each other and, therefore, can be combined in many combinations to create a functional design. Space weapons can be functionally decomposed into 4 basic functions that need to be accomplished for it to fulfill its role.

The first aspect to a space weapon's design is to discern what target(s) it will be attempting to strike. If the intended targets are on Earth, then it is a fairly simple discussion of how large of an effect is needed on the target and how accurate the strike needs to be, but if the intended target is in orbit, then it is more complicated. As a general rule, the higher the orbit of the satellite, the harder it is to target. However, an additional complicating factor is that satellites with lower orbits have faster orbital speeds, which makes them harder targets as small errors in targeting result in big errors in distance. Additionally, more satellites are then required at lower altitude to provide persistent coverage of an area; on the other hand, due to that same reasoning, fewer satellites are required at higher altitude to provide coverage. What this translates to is that while satellites at lower orbits are more easily reached with weapons, they are not necessarily easily targeted and destroyed. More significantly, there are more of them, so to create a significant dent in coverage for a particular area, multiple strikes have to take place, and even then this would only produce periodic windows in time with no satellite coverage. An example of this is imagery satellites, which typically orbit at about 1,000 km and are thus some of the easiest to target, but in order to create an actual effect by targeting them, multiple satellites need to be knocked out through multiple successful strikes. GPS satellites orbiting at about 20,000 km and communications and signals intelligence (SIGINT) satellites orbiting at 36,000 km are some of the hardest to target, yet GPS satellites are also some of the most critical satellite infrastructure to target. Additionally, fewer satellites need to be destroyed to create a noticeable effect (Sankaran, 2014). It should be noted that actions that occur on Earth that affect satellites in space must also be considered. However, conventional strikes, electronic warfare attacks, or any other offensive action that originates from Earth and strikes another target on Earth in order to affect targets in space is hard to regulate. The systems used exist for other purposes and it is only when they are turned on terrestrial satellite support systems that they affect satellites in orbit.

Secondly, the target needs to be located and tracked, which can be done by either a ground-based system, other space-based systems, or some combination of the two. Between space and terrestrial targets, terrestrial targets are easier to locate and track for the simple fact that there is less area of interest through which to scan. On the other hand, tracking satellites requires global coverage and precise instruments to accurately locate and continually track targets in space. This has been identified as a key capability that is lacking for many nations that have otherwise successfully used weapons such as ASAT missiles (Sankaran, 2014).

Thirdly, there needs to be a method or vehicle by which the strike is delivered. The weapon system can be ground-based, mounted in aircraft, mounted on spacecraft that travel into space and then return to Earth, or based in space on another satellite. Ground and aircraft-based systems have been demonstrated, and do not carry the same controversy that surrounds placing weapons on spacecraft or satellites. Their major downside is their positioning has additional difficulty in striking the highest satellite orbits. Spacecraft have not quite reached a mature design state, but there are already perceived benefits of such a system. The weapons they would carry have the benefit of not being permanently stationed in orbit, and they can operate above any country due to being outside of any country's airspace. Plus, their higher travel velocities mean they could have a global response time of just a few hours. Satellites gain the benefit of semi-permanence relative to spacecraft, but their periodic orbit leaves them vulnerable to being attacked (Rose, 2008).

The final design function that needs to be fulfilled is the strike method, and it is worth breaking down the different types of space weapons in more detail. Various methods have been used to accomplish this, but one framework used by the CSIS simply divides weapon types into kinetic and non-kinetic categories (2020). While this framework serves to simplify the discussion, it lacks some much needed granularity between the types of weapons, which helps in more accurately identifying their effectiveness. An alternative, more distinct breakdown is used for this discussion, as detailed in Figure . Kinetic weapons should distinguish between non-nuclear and nuclear weapons, and even non-nuclear kinetic weapons should be divided along the lines of projectile or ramming, Ramming specifically is separated due to the implication that it would sacrifice a system or satellite that was intended to be used for different purposes; in contrast, a projectile was built and intended for strike purposes from the beginning. Additionally, cyber attacks and electronic warfare (EW) have been separated from other Non-Kinetic weapons, such as lasers and particle beams, as they are not inherently intended to destroy the satellite.

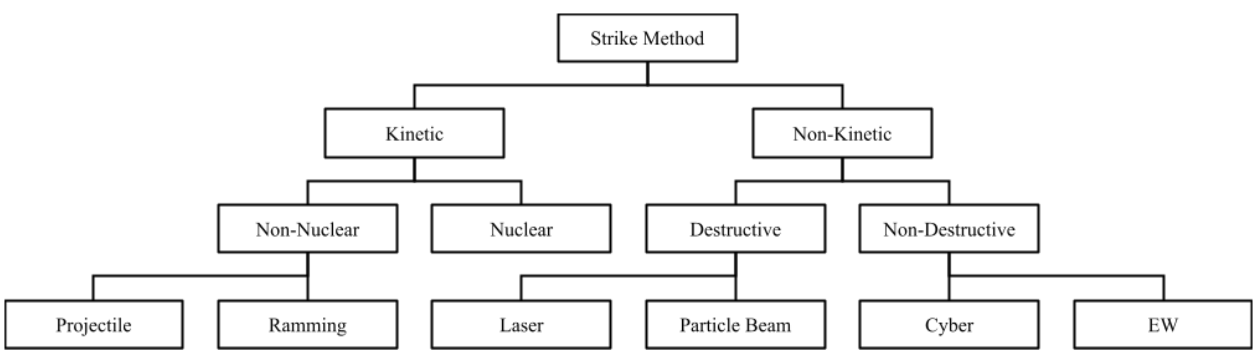

Figure 1: Decomposition of different weapon strike methods

3.2.1 Kinetic Projectile

Some of the most controversial and discussed ASAT operations have been ASAT missiles, which are some of the most inefficient methods of conducting ASAT warfare. While it is technically possible to conduct missile or projectile ASAT operations from the Earth to space, the economic practicality of doing so does not exist. If using missiles for example, larger and heavier rockets are needed to reach a satellite commensurate with its orbital height. Smaller, more mobile, and widespread missiles do not have the ability to even strike above low earth orbit, and even China's most powerful solid fuel missiles cannot reach the orbit of GPS satellites. In order to target the highest orbiting satellites, it requires using liquid propellant instead of solid fuel rocket motors, which further lengthens and complicates the launch process in addition to effectively requiring fixed infrastructure. In effect, the cost of launching a missile to strike a satellite quickly approaches that same launch cost of putting the satellite there. This cost is further exacerbated with the fact that even purpose designed missiles and projectiles are not certain to hit fast-moving, low-orbit satellites, as demonstrated with the Indian ASAT missile tests. Multiple kinetic projectiles are likely needed to guarantee a kill (Sankaran, 2014).

For space-to-space engagements, missiles and inert projectiles are less than ideal. The main benefit they carry is that they can be placed in space at relatively low cost as the basic technology is fairly advanced already and each of the projectiles would likely not be particularly massive or heavy. However, this is where the benefits of such a system would end. For propellant-based projectiles intended to be stationed in space, the extreme environment of vacuum and radiation will likely mean that new propellants will need to be developed that are more stable in space, and even if they are developed, it is likely they will still degrade but over a longer period of time. If one wanted to deploy non-propellent-based projectiles, more technological development would be required to field a system such as a rail gun, but it would avoid the problems surrounding the chemical stability of the propellants (Rose, 2008).

Furthermore, fielding conventional space-to-Earth orbital strike systems is one of the most destabilizing courses of action. From a logical perspective, their strike capability is rather limited, and they are not invulnerable to being attacked. Additionally, lots of other ground-based systems have the same practical capability. However, the psychological effect of a strike system constantly poised right over your head is quite significant. The most commonly discussed version of space-to-Earth kinetic weapons is the concept commonly known as “Rods from God,” which involves placing tungsten carbide-uranium cermet rods in orbit with the intent to simply drop them to strike the globe at high velocities, and thus relying on their kinetic energy for terminal effect. However, this is one of the most impractical versions of delivering kinetic ordinance back to Earth as the inert unguided projectile would be imprecise, have a long response time, have uncertain terminal effect, and be financially prohibitive to actually place in space in sufficient quantities (Rose, 2008).

3.2.2 Kinetic Ramming

One of the worries about weapons in space is the idea that all satellites in space could be weaponized by changing their orbit to collide with another satellite. While satellite-to-satellite attack via ramming with any satellite is possible, it is highly limited and very inefficient. There are a few problems with the practicality of ramming with satellites not originally designed to ram. One is the requirement that the satellite needs to be close in orbit to its intended target, as it is unlikely the satellite possesses enough thrust capability to travel very far. Second is that the implication is that the satellite being used is not inherently designed to ram and is instead using its maneuvering systems to create the collision. While the orbit of satellites is periodic, it is not precise enough that a satellite can simply be put on the same orbit at the same place as another satellite and expect to collide with it. For a satellite to effectively perform this action, it would require sensors that are not normally equipped to provide terminal guidance to the target. Finally, this entire discussion also ignores the fact that it takes a satellite that would normally serve a functional purpose and just throws it away. The whole concept is fraught with complications reducing its practicality.

3.2.3 Nuclear

Nuclear weapons are some of the most practical weapons that can be used or stationed in space. One of the main benefits they have when being deployed to space is that their effect is disproportionate to their size, which makes them economical to deploy. The area of effect of not only the blast of nuclear weapons, but also the electromagnetic pulse reduces the need for accurate targeting when used against satellites, yet this also means nuclear weapons could create a large amount of collateral damage in striking their intended target, to the point of being undesirable. Additionally, nuclear weapons effectiveness against terrestrial targets is self-explanatory, and stationing them in space allows for an effective second strike-capability. Still, the main reason it is unlikely nuclear weapons will be employed in space in future is due to well respected norms in space.

3.2.4 Laser

The term lasers under this context refers to lasers that are of sufficient strength to cause physical damage to a target, thus excluding any lasers used for targeting sensory equipment which would be categorized under EW. A fundamental aspect of directed energy weapons is that as they travel at or near the speed of light; thus, they are easier to aim and require little or no lead for the target. However, they do not have unlimited range as the beam does diverge over distance, and they distort and diffract if traveling through a medium such as air, thus losing energy over distance (Rose, 2008). Therefore, when it comes to deploying lasers to or from space, there is a balance between using more energy and effort for transportation in order to position energy weapons closer to their target and utilizing larger and more energy intensive weapons in order to position them further away.

Ground-based lasers and particle beams do not easily pierce the atmosphere and are impractical for striking satellites, as even if an installation could be large enough to strike satellites, it would make for a very enticing target. Also, a laser's effect occurs over a period of time, and if the craft being targeted is capable of any maneuvers, it could potentially blunt the ground-based instrument's effort to attack it through maneuvers. One further aspect is that any ground-based instrument can only cover a narrow area of space. The area it can cover is even narrower than a theoretical horizon-to-horizon range of sight. The laser would require a designed angle of operation where the full strength of the beam would reach, since the beam is naturally passing through more atmosphere and is traveling further before it strikes its target as the angle of elevation for the beam decreases.

Energy beams meant to strike from space to Earth have all of the same downsides as the terrestrial versions without any of the benefits. The beam still has to pass through the atmosphere of the Earth with all the detriments that doing so brings while at the same time not possessing the ground-based infrastructure to support a powerful enough beam. With current technology, such a satellite launched into space would be massive and extraordinarily expensive (Rose, 2008).

Space-to-space energy weapons avoid the issue of travelling through the atmosphere. The lack of an atmosphere eases some of the burdens required to generate an intense enough beam, which in turn makes it more practical to power such systems in space, and their likely closer proximity to their target reduces the concerns with beam divergence. Space deployed space lasers used as defense systems for satellites will likely be the first place these systems see deployment with the French defense minister stating that France is pursuing installing these as defensive systems (CSIS, 2020). Therefore, it is possible to install point laser defense systems in the current U.S. military satellite constellation and doing so reduces the practicality of direct action against U.S. satellites, but it can be seen as a controversial and provocative move at the moment.

3.2.5 Particle Beam

Particle beams have a lot of the same characteristics and pitfalls as laser systems, such as beam focus and distortion; however, particle beams are being favored in some areas of development as they have one primary technical advantage in that they can be far less energy intensive for the same desired terminal effect and are thus more suited to being deployed to space. The U.S. is currently strongly pushing the development of particle beam weapons. One of the primary perceived benefits of a space-based directed energy weapon is in missile defense systems where they are more practical than kinetic interceptor due to the negligible flight time. This allows more time in the decision-making process about whether to intercept the missile or not, and it would allow deployment of fewer satellites for a missile defense constellation; however, the cost per satellite would likely be higher. Furthermore, they could be reused and fire as many shots as their energy storage and production will allow (Harper, 2019d). Due to these advantages and the long-held desire of the U.S. to field a space-based missile defense system, the military is investing research money into directed energy weapons and may field a system as early as 2023 (Weisgerber, 2020; Tucker, 2019).

3.2.6 Cyber

Cyber and EW are the most practical ground-based countermeasures to satellites as they require minimal investment compared to their ability to deny an ostensibly expensive space-based system. While cyber warfare capability is undoubtedly possessed by states such as Russia and China, it is more unnerving that it has been demonstrated and used by non-state actors on multiple occasions. Oftentimes, these actors have done so with little effort as the systems themselves had under-implemented security methods. These actions have led to urges from those interested that satellite designers consider building encryption into their command and control systems to prevent hijacking, but because the attacks have not been of paramount concern, satellite cybersecurity has remained limited in scope and function. Better security will probably only occur with increased threats and validated exploitation. Still, the ability to inexpensively co-opt and disrupt satellites makes cyber warfare an extremely valuable terrestrial tool for space warfare which avoids directly destroying satellites (Vacca, 2017; Wall, 2019).

3.2.7 Electronic Warfare

Electronic warfare has just as much potential as cyber attacks for a ground-based system and substantial potential as even a space-based system. Uplink or downlink jamming effectively takes satellites completely out of the fight. For people on the ground using the satellite, it is no different than if the satellite was destroyed. Satellites positioned in space can provide wide area jamming capabilities. Uplink jamming is the more commonly available means of attacking space systems, which interferes with the signal received by the satellite. Multiple countries are suspected of possessing the capability, and countries like the U.S. have even conducted tabletop exercises under the assumption of satellite jamming, in some minor effort to prepare for the event (Hitchens, 2008; CSIS, 2020).

Beyond basic jamming, it is possible to use a lower-power laser deployed on Earth or even in space to dazzle or blind a satellite's sensors non-destructively (CSIS, 2020). This is using the laser in more of an electronic warfare capacity as opposed to a directed energy weapon, which is more commonly implied as being destructive, but the line between the two is a bit blurry. The primary use of this ability would be to locally blind imaging satellites passing overhead of a battlespace, and with sufficiently focused and powerful beams, it may be possible to affect satellites in higher orbits. With the disruption being localized, it avoids permanently disabling satellites that may otherwise be critical for functions in other areas. This ability to cheaply negate satellites' advantage without the need to destroy the satellite itself makes EW, in addition to cyber, the preferred method of attacking space capabilities (Secure, 2016).

3.3 U.S. Interests and Proposals

3.3.1 Resilience of Satellite Constellations

The U.S. relies on space assets for both its civilian's daily life and its military's daily operations, and their importance will only increase in future, with the USSF defining, "Like any source of national power, the United States must cultivate, develop, and protect these benefits in order to secure continued prosperity" (USSF 2020). This reliance creates a drive for the U.S. to protect them as well as incentive for them to be attacked by adversaries. The U.S. military's heavy use of satellites core to its net-centric warfare doctrine is what has driven China to develop, test, and deploy ASAT missiles and technology as one component of its access denial strategy intended to counter U.S. military presence in the Asia-Pacific area (Rose, 2008;

Hitchens, 2008). In reality U.S. armed forces are not as critically dependent on satellites as is often said, and, therefore, they are not as vulnerable to disruption from ASAT attacks as is often assumed. It is not even clear whether many nations would find attacking U.S. military satellites operationally feasible and desirable even in a conflict (Sankaran, 2014). However, this perceived vulnerability has led to the U.S. pursuing technologies to counter ASAT operations. There are multiple methods of accomplishing this outside of the deployment of space weapons as defense systems, these methods involve increasing the capabilities of individual satellites, diversifying and deploying more satellites, and enhancing ground-based installations.

There are a few proposed measures for increasing the survivability of individual satellites, which sacrifice the normal minimalist design of satellites and will increase the size and weight of satellites (and thus their launch costs). An aspect is that satellites are currently blind in the environment in which they operate. They are designed under the assumption that they are operating in a void, on a defined path, with minimal chance of striking another satellite. While technically true, this ignores any unintentional or intentional collisions or strikes that might occur. There should be more systems, both terrestrial and satellite based, that enable detection and tracking of space objects which will both help to deter attacks and to identify sources of anomalies and malfunctions. When combined with improved avoidance systems to enhance the maneuverability of satellites, it is possible for satellites to take evasive maneuvers when coming under attack or under threat of collision. Anti-jamming and cyber security need to become a more important aspect of satellite design. A change in the current mindset is required to effectively understand protecting satellites: satellites and space capabilities should be understood as basically computers in space, with the assumption that they will have all the challenges the terrestrial computers would (Secure, 2016).

Due to their size and expense, most satellites face the drawback of having zero redundancy (Rose, 2008). The development of microsatellites offers an alternative with the advantage of creating a network of lightweight, easily deployed satellites that share functions within the system, thus making them more resilient than a single satellite. This type of satellite constellation would work to replace some systems that currently rely on lower numbers of larger, more expensive satellites. This advantage is further compounded with the demonstrated capability to launch multiple satellites into orbit at once, which vastly reduces launch costs (Rose, 2008). Additionally, deployment of satellites spread out over multiple orbital heights creates further difficulty in successfully disrupting the whole array (CSIS, 2020).

The resilience of satellite arrays can be further enhanced by improving ground-based infrastructure, firstly by reducing how critical satellites are to operations. This can be accomplished by having redundant ground-based systems and plans put in place in case part of the satellite array goes down. This does not mean to obfuscate the advantages of satellites, but instead to just have existing, less-capable ground-based infrastructure in reserve in case the worst was to happen. The U.S. Strategic Command has made calls to prepare U.S. forces for disruptions or degradation of U.S. space capabilities (Sankaran, 2014). By reducing their criticality further, it enhances deterrence against ASAT operation by reducing the benefit an enemy would receive, thus reducing support to fund efforts to challenge the capabilities in the first place (Sankaran, 2014). Additionally, cultivation of the civilian space industry is necessary to continued and sustainable military and civilian use of space. The USSF has voiced its support for civilian industries stating, “Military space research, development, and materiel acquisition must be closely coordinated with civil, commercial, and national intelligence space programs” (USSF, 2020). Continued support of these programs with military funding will make spaceflight cheaper for both the military and civilian sector and will further support for peaceful use of space while also preparing the military for conflict in space. This improved launch infrastructure and cheaper launch cost will make it easier to replace any losses suffered in the satellite array. Combining all of these methods would greatly enhance the resilience of U.S. satellite arrays.

3.3.2 Free Use of Environments

One of the core tenets the U.S. supports is to have environments outside of direct control of any particular nation be free and useful to all. Even from a military perspective, it does not necessarily pay to completely dominate the domain as would normally be the case in the air or at sea. The current guiding documents of the USSF explicitly state (USSF 2020):

> "Space supremacy is not always desirable, or attainable against a peer adversary, and should not be the unconditional goal of military spacepower. A rival may wish for their adversary to maintain some space capabilities to reduce the probability of a strategic miscalculation or larger escalation in the conflict and to allow certain elements of national infrastructure to continue without disruption, such as medical services and communication between friendly and adversary decision-makers to broker a de-escalation."

The U.S. has clearly understood the need to not achieve "space supremacy" as fully denying the environment to the opponent stating instead, "Ultimately, Space Security seeks to encourage partners, not compel an adversary" (USSF 2020), which is an idea probably known to other nations but has thus far not been clearly articulated. The U.S. has identified that building a partner's spacepower capacity provides non-violent opportunities for strategic effect by promoting U.S. interests through encouraging our partners to act in support of U.S. objectives (USSF, 2020). This mindset of bringing more people into a space to stabilize it contrasts with most nuclear nonproliferation philosophy which seeks to keep as many actors out of the field as possible. With more actors participating in the field, it dissuades any actions that would compromise use of the space for all as it would anger any of the other participants. Additionally, investing in joint satellite operations with allies and partners is a good way to dissuade attacks against satellites for fear of also inciting multiple countries against the offending nation. The concept of encouraging and supporting other nation's exploration of space does not need to stop with just allies and partners; it can be further extended to expand the number of countries with access and interest in space and to even engage with adversaries and bring them into the global community instead of isolating them. As greater and greater utility is derived from access to space, this can provide the opportunity to create internationally run satellite arrays (Sankaran, 2014).

Beyond just engaging more nations in the use of space, or as a way to involve them in the use of space, Countries should push the development and deployment of space debris cleaning and mitigation methods. The European Space Agency (ESA) is already developing what will likely be the first space debris cleaning satellite; although, the craft is very rudimentary and only intended to retrieve one piece of large space debris before burning up in the atmosphere making it very inefficient (ESA, 2019). SpaceX has proposed using its starship reusable rocket to go around collecting space junk (Wall, 2020). In addition to the efforts to clean up space debris, steps need to be taken to mitigate debris created in normal spacefaring endeavors. There are widespread proposals for more efficient space operations that produce less space debris. The most complete of these is the SSC's Best Practices for Space Operations, which amounts to anti-littering guidelines and regulations depending on the orbit of the satellite (SSC, 2019; Wall, 2019). Additionally, deployment of robotic refueling can extend the life of systems and reduce the need to leave dead satellites in orbit. Whatever methods end up being used to clean up space debris, they will likely be quite expensive, but this cost can be shared among participating nations. Debris clean up could eventually be likened to mine clearing operations: expensive but doable, and a way to engage the international community.

As a final note, the U.S. military and the country it serves constantly desire freedom of action, that is to say, the freedom to act and respond to situations as needed. Currently the unknowns, the lack of deployed capabilities, and the vulnerability of assets in space paralyzes decision making. It is obvious that the U.S. wishes to continue utilizing and fighting for the right to utilize satellites in warfare. Jammers are already widely available and will likely be deployed in wartime against the US to counter its asymmetric advantage from space. To counter this, the US can fold suppression of adversary counterspace capabilities (SACC) into suppression of enemy air defense (SEAD) operations already being conducted by geolocating the source of the jamming and destroying, avoiding, and/or negating the device (Lincoln, 2015).

3.3.3 Stability of the Liberal International Order

The UN and all facets of the liberal international order that the U.S. set up after WWII has been shown to be a stabilizing force in the world, which in turn benefits the U.S. directly. Therefore, the U.S. should seek to maintain that stability in every field including space. The U.S. wholeheartedly wants space to be used for peaceful purposes and fully intends to defend its ability to conduct activities in space (USSF, 2020; Carlson, 2000). Despite the U.S. assertion and belief that any action it takes is in an effort to keep the peace, it is hardly surprising that many nations do not view it as such given the power of the U.S. (Mineiro, 2008). The increase in spending on space technology is one of the reasons Russia characterizes the U.S. as the main aggressor in a space arms race (Rose, 2008). Mineiro notes that, “if the United States maintains the position that its actions in outer space, including any programs of weaponization, are purely for non-aggressive purposes, it may be to its advantage to provide a greater degree of transparency in its activities than is currently required under international law" (2008). Going beyond just its own transparency, it is probably best for the U.S. to push for transparency in what all nations are deploying while fostering greater cooperation and understanding. The current international legal and structural situation around space is sorely lacking as nations are afraid to move forward with treaties because there is not enough experience in space. The U.S. can be at the forefront by cooperating with allies, pushing for international organization monitoring space traffic, enforcing rules of engagement for space, and creating arms control treaties.

A jointly run space traffic control is not without controversy, but it is at least agreed that some level of oversight of all the satellites in space is needed. Setting up such a system would be intended to prevent any future collisions between satellites, especially as more and more satellites are being deployed to the same orbit. Furthermore, the U.S. and Russia already have launch warning systems. These could be expanded and other nations brought into the fold to monitor space launches. This reduces the chance that a nation could covertly launch a satellite into space and would increase transparency. The goal would be to have open reporting of satellite orbits as well as direct monitoring of those orbits. Besides the cost, the most ardent reason for objection would be that such systems could be used for targeting of a state's satellites. This is mostly unfounded as the tracking data does not have to be accurate enough nor directly available to states in a way that would allow them to piggy-back off of it for a strike. At most it allows the locating of satellites. The biggest real reason is that such a system would make it difficult to deploy unreported "secret" satellites (Mineiro, 2008).

Any coherent plan to deter ASAT attacks must also include negotiations and arms control agreements. One of the main benefits of an arms treaty isn't necessarily that it limits arms but instead that it provides transparency as to what a nation possesses and reduces their confidence in any capability they currently possess (Sankaran, 2014). The downside of an arms treaty is that it effectively acknowledges a state's right to possess any outlined weapons system, and this is probably unacceptable to those still hoping to prevent deployment of weapons to space.

A consensus on what are responsible and proportional military actions to take in space can reduce conflict and unproportional responses to conflict in space. A couple of manuals are in the works that hope to address the lack of rules of engagement in space, which emulate similar recognized and authoritative documents such as the San Remo Manual on International Law Applicable to Armed Conflict at Sea, the Harvard Manual on International Law Applicable to Air and Missile Warfare, and the Tallinn Manual on International Law Applicable to Cyber Warfare (MILAMOS, 2019; Woomera, 2020). Clarifying at what point an attack on a satellite becomes an armed attack and the proportional response to such attacks is pivotal in having proper conduction in space (Secure, 2016). As Sankaran notes, "the international community should be convinced of the justice to punish a space aggressor and to support the United States in its use of lethal force to do so. Engaging in discussions to establish ground rules during times of peace will help to provide such support." (2014)

4. Recommendation & Conclusion

We should not focus on deterring weapons in space as that is a losing battle; instead, we should focus on making attacks on satellites eminently undesirable. Additionally, it is also not even remotely clear that restricting weapons is desirable. By confronting the actual deployment of space weapons, steps can be taken to address a potential arms race that would bring states into direct competition which in turn would raise tensions and increase the chances of sparking a war.

While there are competent weapons systems and ways of attacking satellites that exist, the balance of attack versus defense is currently in favor of satellites, and it is unlikely any state could achieve complete dominance in space at the moment, and it is probably not the best course of action to pursue anyway. There are many options for addressing the issues of weapons in space, and fortunately many of them are independent of one another. This allows multiple options to be pursued at the same time. There are steps the U.S. itself can unilaterally take with one main option being to change how we design satellites and expect to maintain our satellite constellation in order to make it more resilient and sustainable. These measures are distinct due to being mostly internal, and they do not have large ramifications on relations with other nations or impact on international laws. The only barrier to implementing these is the will and financial cost invested in improving the nation's satellite architecture. Additionally, while more controversial, the pursuit of defensive weapon systems allows the development of technologies and capabilities that dissuade attacks from other nations on satellites. The systems' architecture is very similar to those for some space debris cleaning systems, and both can be developed simultaneously. However, for the moment, it is probably best to avoid deployment of offensive weapons in space with the extensive ramifications that currently come with them, and it would be worth remembering that any militarization of space will be emulated by other international space powers.

But the U.S. should not stop with measures taken by itself, and it should pursue cooperations with both allies and adversaries. The core of engaging with other nations is finding common ground, such as both sides wanting to allow their civil and scientific sectors to explore and exploit space. This can be leveraged as a starting point for engaging with other countries in regards to space. Creating a less hostile space for countries to launch spacecraft will open the door for smaller nations to begin participating in space, and an international organization that regulates civilian and military spacecraft launches would foster more cooperation among participating nations. This could be further compounded with joint space debris cleanup. However, the primary concern with engaging with others in space is that there are no clearly defined rules on operating in space and the U.S. should push for them so that they reflect its own goals and desires. This can possibly be expanded upon in future with arms control measures when the opportunity presents itself, but it should not be forced and risk curtailing technological developments that would help our efforts in space.

Ultimately, ensuring a space environment that can be used by future generations to come is the primary goal. Improving satellites, setting up competent rules of engagement, cooperating with other nations, and avoiding provocative acts is the best way of accomplishing this goal.

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Appendix

U.S. Space Operations SWOT Analysis

SWOT Stage 1

Strengths	**Weaknesses**
● Strong space industry ● Military ● Allies/Relations ● International norms	● Large dependence on space ● Large number of satellites ● Launch Cost ● Vulnerability of satellites
Opportunities	**Threats**
● Undecided norms and regulations surrounding space ● Space debris cleanup system ● Space-based missile defense system ● Orbital strike system	● Destruction of U.S. satellites ● Disruption of U.S. satellites ● Creation of space debris ● Space arms race

SWOT Stage 2

Use Strengths	**Improve Weaknesses**
● Open up space industry to be used by other countries ● Exploit military cooperations in space ● Support allied and peaceful uses of space ● Expand international norms into space	● Create redundant terrestrial systems ● Share satellite constellation with allies ● Advance launch technology ● Improve basic satellite design and requirements
Exploit Opportunities	**Mitigate Threats**
● Lead building of new relationships ● Lead creation of new international space related treaties and norms ● Develop key technologies	● Create a resilient satellite constellation ● Increase local sensing and movement capabilities for satellites ● Develop technologies and institutions to clean up and manage space debris ● Develop technologies that do not create a threatening technological gap ● Employ electronic warfare countermeasures ● Increase satellite cybersecurity

Options SWOT Analysis

Increase satellite resilience

Strengths	**Weaknesses**
• Decreases chance of a military wanting to target U.S. satellites • Reduces individual launch costs • Serial production reduces satellite costs • Spreads knowledge and involvement in space endeavors	• Increases total cost of operating the U.S. satellite constellation • Additional features add to satellite costs • Could be off putting as a military build up
Opportunities	**Threats**
• Can be used to invest in private space industry • Can partner with allied nations •	• Chance of sparking increased investment of other nations in their satellite constellations • Increased satellite density increases chances of creating space debris

Field laser point defense systems

Strengths	**Weaknesses**
• Increases survivability of satellites • Decreases desire to strike satellites	• Requires additional systems on already existing satellites, or new satellites with lasers mounted • Increases cost
Opportunities	**Threats**
• Gain experience with operating laser systems in space • Share technology with some space debris cleaning systems • Can be developed into space-to-space weapons	• Potentially sparks an arms race • Can be perceived as threatening

Field conventional orbital strike systems

Strengths	Weaknesses
• Strong military advantage ○ Persistent precision threat	• Requires additional satellites • Expensive to operate • Limited terminal effect
Opportunities	**Threats**
• Can lead to pushes for arms control talks	• Very destabilizing • Probably sparks an arms race • Increases chance of ASAT due to threatening target

Develop space debris cleaning systems

Strengths	Weaknesses
• Enables more freedom to act in space • Supports global use of space • Costs can be shared with other nations •	• Minimal initial returns • Long term support required
Opportunities	**Threats**
• Gather international support • Avenue to experiment with space weapons	• Could be challenged by space weapon limitation treaties • Could be construed as threatening

Create international space organizations

Strengths	Weaknesses
• Engages all countries participating in space • Eases tensions created in space • Reduce risk of accidental collisions	• Potentially constrains actions the U.S. can take • Limits deployment of “secret” satellites
Opportunities	**Threats**
• Good starting place for building norms • Can start small and be built up over time	• Transparency can leave space assets open to easier targeting

Invest in satellite operations with allies

Strengths	**Weaknesses**
• Spreads cost of constellation operation • Disincentivizes attacking the satellites in question • Strengthens space assets of allies	• Competing for use of the same asset • Reduces U.S. freedom of action
Opportunities	**Threats**
• Builds relations with other nations • Spreads knowledge of operation space systems	• Drawn into conflict due to allied nation • Soured relations with allied nation could limit use