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ENSURING THE FUTURE OF U.S. SPACE SECURITY AND STABILITY THROUGH ADVANCEMENTS IN DIRECTED ENERGY TECHNOLOGY

by

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Disclaimer

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Preface

Throughout my military career, I have had the opportunity to work with cutting edge technologies and not only employ these technologies at the tactical level but also experience how they integrate into the larger operational and strategic battlespace. As a former F/A-18 aviator in the U.S. Marine Corps, my experience with the space domain has been somewhat limited but given the future of technology trends presenting themselves, these topics have evolved into a large interest of mine. I previously had the experience of working on a think tank strategy paper concerning the future of space security and this opportunity greatly expanded my interest on the matter. I feel strongly that moving into the twenty first century, the space domain will become the new contested high ground not only militarily but also economically and it is in the United States best interest to establish and maintain dominance in this arena while working side by side with its allies.

I would like to thank Dr. Michael P. Ryan of Georgetown University for the opportunity to work on my previous program's strategy paper, Dr. Leslie Curda for assisting with this initial research proposal, as well as all of the professors at the United States Air Force Air Command and Staff College. I very much look forward to expanding my interests and knowledge base around this topic moving into the future.

Abstract

During the Cold War and following the fall of the Soviet Union, the space domain was frequently contested and sought after by world powers seeking the ultimate high ground. This competition has reemerged in the twenty-first century with rapidly expanding economic powers such as China, seeking influence in the new multipolar environment. The U.S. no longer has the sole advantage in this domain and must decide on the best approach moving into the future in order to protect its interests and those of its allies.

The research paper uses the problem-solution framework to examine historical behavior within the space domain, both from a technology and policy standpoint to determine what path the U.S. must take moving forward. Quantifiable examples of activities and policy assessments are examined to answer the research question: Given previous global behavior in the space domain moving into the twenty first century multipolar landscape, how should the U.S. leverage directed energy technology advancements to ensure superiority against current and future threats?

The study concludes that the multipolar environment must be acknowledged and given the rapid decrease in cost and limitations for applicable space technology, the U.S. must counter these potential threats in the most effective manner through directed energy technology investments. While the study also concludes that the militarization of space has already begun, the U.S. must remain cognoscente of the perception of weaponizing space, in order to avoid further escalation.

INTRODUCTION

Overview of the Study

The bipolar global stage during the Cold War was relatively predictable, with both the U.S. and the Soviet Union racing to expand into all forms of warfighting domains, including space.[1] After the fall of the Soviet Union, the U.S. was fairly comfortable in its technological advantage over all other nations concerning space technology. Over the past two decades, this advantage has begun to erode. This reduction in the technology gap results from both natural cost efficiency as technology advances and foreign nations' increased interest in gaining a foothold in space.[2] While kinetic technologies and large-scale space exploration remain relatively expensive and out of reach for most nations or global entities, advancements in other areas such as directed energy have decreased costs dramatically, creating previously unavailable opportunities.

The research presented will pose the hypothesis that the U.S. must maintain the strategic advantage within the space defense technology realm by increasing its investment and fielding in both ground and orbital-based directed energy weapons in order to ensure the security, stability and freedom of movement for this vast frontier, against potential aggressors and threat nations with less than friendly intentions. Compared to traditional kinetic technologies, these types of technologies provide a cost-effective defensive solution, combined with flexibility and economy of scale protection through proliferation.[3] The Space Domain is rapidly becoming the high ground for military superiority moving into the twenty first century, with multiple global players attempting to gain the advantage through the increased proliferation of both kinetic and non-kinetic weapons systems that pose a direct threat to the U.S.[4] Activity from competitor nations such as China and Russia, not only in space exploration and research, but also military technology has rapidly increased over the past several decades.[5] Opponents of the U.S. taking such a dominant stance in the space domain would argue that aggression only invites counter aggression from potential hostile actors and that a more peaceful solution should be pursued. Unfortunately, humankind has been unable to avoid conflict over resources and territory anywhere on Earth to date, and to assume this would not continue beyond terrestrial boundaries moving into the future would be naïve at best.[6,7] Strategic decisions must be made to ensure the U.S. remains a dominant space power for the global good.

The Nature of the Problem

Many nations and global companies have already begun gambling on the financial implications of space exploration and advancements, as well as maintaining military advantage and freedom of navigation, communications and commerce.[8] Many countries such as China, have exponentially increased their efforts outside the Earth's atmosphere.[9] Some of these threats presented by adversaries gaining the advantage in space, are not necessarily tied to direct military threats. However, rather various forms of soft power centered around the economic advantage. At times, these global interests with space exploration and advancements are purely economical, such as rare earth minerals or satellite communications, imagery and global positioning technology. However, the line between purely civilian and military technology usefulness has become increasingly muddied. These advancements are arguably for pure military use, such as kinetic technologies adapting Anti-Satellite Weapons systems (ASAT).

Despite increased defense spending across the globe by numerous advanced nations, the U.S. still maintains a large advantage in the Air, Land and Sea domains, usually from a sheer numbers standpoint but mostly through technology means. While this gap has been dwindling compared to rival nations, the main concern in the space domain is whether the U.S. seeks to gain and maintain this same advantage for the foreseeable future. This advantage will be required to maintain the status quo as the world's economic leader, shaping both policy and security environments. Similar to the previous increases in human occupation around the globe during various points in history, one can and should assume that the space domain will be no different. Humans have been unable to avoid contested areas within the terrestrial domain, with even the Arctic being militarized.[10] It would be unreasonable to assume that space will be any different once the technological playing field is leveled.

Space should be considered the ultimate “high ground” from a global economic standpoint, military offensive or defensive posturing and infrastructure. The problem is that the space warfare domain moving into the future represents abundant opportunities for nations to gain tremendous leverage on the world stage. The U.S. must decide strategically what position it wants to maintain within this adapting global order.

Purpose of the Study

The purpose of this study is to analyze past and present global behavior in space exploration and technology advancements in order for the U.S. to properly evaluate and shape future policy decisions concerning technology investments in the space warfighting domain. While a large portion of this research paper will show the historical data of quantifiable activities in space launches and associated technology advancements by foreign countries, a qualitative component remains that will be addressed. This qualitative aspect is primarily concerned with past and current behavior of various state actors, and will seek to persuade future or predictive behavior of these same actors given their trajectories in the space domain. Assessments will then be made given the state of current directed energy technology advancements not only in the U.S. but also for potential adversary countries, as well as comparisons between the deltas that might be present. The totality of this information from both historical and current standpoints as well as cost comparisons, will be used to paint a figurative picture for the reader and educate policy makers and technology influencers alike of the necessity for the U.S. to take the lead in further developing directed energy capabilities in the space domain.

Research Question

The research question posed by this paper is, "Given previous global behavior in the space domain moving into the twenty first century multipolar landscape, how should the U.S. leverage directed energy technology advancements to ensure superiority against current and future threats?" While there is a multitude of ways the U.S. can advance in military strength, the amount of information and scenarios would be overwhelming to apply to the scope of this paper. The primary areas that also balance the sensitivities around the militarization of space perceptions within the global community, are that of directed energy technology, hence the focus presented here.

Definition of Terms

Anti-Satellite (ASAT). Most commonly referred to in the context of directed energy or kinetic weapons used to destroy, degrade or disable satellite activity.

Co-Orbital. The concept in satellite terminology and physics where physical bodies interact within associated or similar orbital planes in space and sometimes used in conjunction with weapon technology to describes an ASAT capability launched, guided or fired from space to its intended target also in space.

Directed Energy (DE). An umbrella term covering technologies that relate to the production of a beam of concentrated electromagnetic energy or atomic or subatomic particles.

Directed Energy Weapon (DEW). Weapons using concentrated electromagnetic energy, rather than kinetic energy, to incapacitate, damage, disable, or destroy enemy equipment, facilities, and/or personnel.

Figure 1: Visual depiction of the three primary satellite orbits by comparison to give the reader a better interpretation of the research discussion (Graphic from EOS Data Analytics website)

Geostationary equatorial orbit (GEO). Generally defined at distances of 36,000 km above the Earth where satellites placed in this orbit remain above the same point on the Earth's surface and this orbit is most commonly used for communications, weather and missile warning satellites given the fixed-point coverage ability.

High-Energy Laser (HEL). A class of DEW consisting of pulsed lasers which emit light pulses with relatively high pulse energy in order to deliver heat to the surface of a target.

High-Powered Microwave (HPM). A class of DEW that delivers either a continuous or pulsed stream of microwave energy toward a target in order to destroy or degrade the targets electrical components.

Low Earth Orbit (LEO). Generally defined between 500 and 1,200 km above the Earth's surface and is the most common orbit for imaging satellites but they must constantly remain in an orbital path circling the Earth.

Medium Earth Orbit (MEO). Generally defined as the orbital area in between LEO and GEO, it is usually designated between 5,000 and 20,000 km above the Earth's surface primarily used for GPS and other Navigation applications where satellites must constantly orbit the Earth.

Space Transportation System (STS). Commonly referred to in the U.S. as the "space shuttle", STS is the formal definition for a reusable transportation vehicle for personnel and material to space with the intent of returning to the Earth's surface.

Unmanned Aircraft System (UAS). An aircraft that is operated without the possibility of direct human intervention from within or on the aircraft.

The Anticipated Significance of the Study

This study's significance is multifold and may vary depending on the reader's background, experience and perceptions of U.S. global policy and security stances. The primary takeaway is that the data presented will show quantifiable increases in potential adversary nations interests in the space domain and technology that also crosses into military use. While there are certainly speculative assumptions made about future behavior from global actors and governments that can certainly change course and ambitions, the ultimate question will be how the U.S. properly prepares for these scenarios. Like many global policy paths, every decision will inevitably have some level of reaction or repercussion.

Research Methodology

The problem-solution method will be utilized in this paper.[11,12] Historical data of quantifiable activities in space launches and associated technology advancements by foreign countries will be analyzed. These activities will be quantified in several areas, including a number of space launches, satellites in orbit and space-oriented kinetic activities, such as ASAT weapons tests by various countries around the globe. Technology assessments in the directed energy realm will also be included to quantify the various capabilities of the same leading countries in space advancements as best as possible.

A qualitative component will also be addressed that evaluates the historical policy behavior of state actors to the research question. This qualitative aspect will seek to demonstrate the future or predictive behavior of these same actors, given their trajectories in the space domain. As space technology decreases in cost and increases in capability, this opens up potentially massive opportunities for countries that previously had little influence in this domain. This expanded influence could be from a multitude of areas, such as military or even economic and communications. This paper will provide the relevant and recommended solution for U.S. strategy in the space domain by emphasizing directed energy technology advancements.

The most challenging aspect of this approach will be avoiding confusion with the scenario planning framework. The research argument in this paper will maintain the primary assumption that militarization of the space domain has already begun, and the solution now sought is how the U.S. appropriately adapts to this new reality. Much of the argument will be based on assumptions for future behavior from other global actors. Causality assumptions will need to be made concerning historical data and behavior from other potential global threats and allies, with the arguments based on these same assumptions.[13] Objectivity will need to be assessed given that this paper reflects U.S. national security interests. However, the primary goal will be to focus on the quantifiable data as much as possible to avoid any perceived bias toward one state actor or another.

LITERATURE REVIEW

The Cold War and Space

Following the end of World War II, the U.S. and the Soviet Union soon became the two dominant superpowers competing for influence in the newly established bipolar world order.

Under President Eisenhower's administration, this foreign policy approach was primarily concerned with the rise of communism and its influence on the developing world previously dominated by colonial powers.[14] Initially concerned with the rise of Soviet nuclear weapons capabilities following the end of the Korean War in 1953, competition between the two nations soon expanded into the space domain in 1957 once the Soviet Union launched Sputnik, a rudimentary piece of satellite technology.[15] Many historians consider this singular event to have marked the beginning of the space race between the two nations and was quickly followed up by the U.S. Congressional signing of the National Aeronautics and Space Act of 1958.[16] This piece of legislation created the National Aeronautics and Space Administration (NASA), as well as the National Aeronautics and Space Council, composed of various political leaders and private citizens to help coordinate NASA's mission priorities.[17] The following year, the NASA Long Range Plan was released, primarily focused on scientific research and vehicle space flight. However, overt expectations for potential military use were evident in the document and administration direction to support the Department of Defense in research opportunities.[18]

The U.S. and Soviet Union had previously launched various examples of animals and organic life into space, but the focus soon turned to human-occupied space flight toward the late 1950s. Various endeavors began with Project Mercury, consisting of six manned flights to space from 1961 to 1963, soon followed by Gemini and culminating with the first humans on the Moon during Apollo 11 in 1969.[19] While the primary emphasis for these activities remained scientific research and space travel, military advances continued to run in parallel.

As terrestrial technology advanced, the gap battle between aircraft technology and counter-air defense systems continued to close. The U.S. and the Soviet Union began looking to satellite options for surveillance and reconnaissance, as these global regulatory norms were much less defined than airborne overflight of territories. The U.S. initiated various satellite surveillance programs such as Argon, Lanyard and Corona in the 1960s, with successor programs such as Gambit and Hexagon running into the 1970s.[20] These previously classified programs, at the time, greatly expanded the U.S. ability to gain valuable imagery intelligence on Soviet activities with negligible risk and plausible deniability advantages compared to manned overflight operations. Inevitably, however, the defense against these same technology advancements soon became a concern for both countries.

While there was a surveillance concern on both sides, a perceived threat of nuclear weapons employment from space-based satellites or launch vehicles remained. During the 1950s and 1960s, guidance technology was limited, necessitating using nuclear-tipped interceptor missiles for Anti-Ballistic Missile (ABM) or ASAT operations.[21] The basic assumption of this approach was that a nuclear explosion would be large enough to offset the accuracy of hitting a fast-moving target at long range, despite the undesired effects of damaging surrounding objects within a relatively large radius. By the 1970s, this ASAT approach had also expanded into the co-orbital regime, essentially seeking to target an opposing satellite from the same orbital plane, significantly reducing the distance and trajectory accuracy required by launching from the Earth's surface. With the signing of the U.S. and Soviet Union Treaty on Limitations of Anti-Ballistic Missile Systems in 1972, this co-orbital ASAT threat was greatly reduced, given the multitude of surveillance satellites being used to enforce the Treaty.[22]

Beginning in the 1980s, the U.S. began to explore technology advancements with kinetic aircraft-launched ASATs and it was reported that the Soviets were exploring these opportunities as well. However, evidence of the seriousness of Soviet advances is limited. In 1985 restraint was realized between the U.S. and Soviet Union that carried on for several years, effectively banning the testing of ASAT weapons and signed into law by the U.S. Congress.[23,24,25]

During the 1980s, defense spending had begun to change direction concerning ASAT testing, and the U.S. began to explore other non-kinetic avenues using directed energy technology. Despite the U.S. Congress failing to extend the ASAT testing ban, the landscape for both countries had shifted.[26] The U.S. had a definitive interest in high energy laser systems for offensive and defensive purposes. The primary goals were driven by perceived Soviet threats along similar technology lines and the remaining mutual agreements concerning kinetic testing. In 1981 the Reagan administration published the National Security Decision Directive Number 12, which laid out goals for the strategic force modernization and what is commonly referred to as the nuclear triad comprised of bombers, submarines and land-based missiles.[27] This initial strategy document, released shortly after Reagan's reelection, was soon followed up with an official policy announcement providing further clarity on the administration's interest in directed energy technology. On March 23rd, 1983, President Reagan announced the Strategic Defense Initiative (SDI) program on national television, sometimes called the "Star Wars" program.[28] The general concept behind SDI was a ground-based system of lasers and directed energy weapons that would be capable of defeating Soviet ballistic missiles in space before they could either reenter the atmosphere and threaten U.S. Soil. To this day it remains debatable whether the U.S. actually had the means to develop the technology that Reagan was proposing at that time, given the limitations not only on directed energy weapons themselves but also the complex guidance required to impact an extremely fast-moving target at great distances with a fixed energy beam. It is however generally theorized that the administration was actually pursuing these goals, however far-fetched at the time.

Regardless of the realities presented with these technology goals, both the U.S. and the Soviet Union continued to make assumptions about the opposing side's capabilities as a reason for furthering developments in the directed energy-based ASAT arena. Global reactions to the administration's announcement of SDI were somewhat mixed, with many in the U.S. applauding the effort despite feasibility arguments in the background. However, European nations reacted with concern, fearing that the U.S. might be signaling a more isolationist stance given a potential technology defense of nuclear weapons, negating a legitimate need to defend large portions of Europe from Soviet aggression[29]. Regardless of the program's realities, the events led to further arms negotiations that "resulted in the Intermediate-Range Nuclear Forces Treaty (INF) going into effect in 1988 and ultimately laying the groundwork for the follow-on Strategic Arms Reduction Treaty (START) in the 1990s."[30,31]

In 1989 a U.S. delegation was allowed to visit the Soviet ballistic missile defense test facility at Sary Shagan which was long rumored to be a site for ASAT research and Development. The observations from this visit reinforced the notion that the Soviet Union was not as advanced in directed energy technology as previously thought by U.S. Intelligence.[32,33] Shortly after, the U.S. Congress once again placed another ban on ASAT testing specifically tied to laser technology given the understanding of true Soviet threat capabilities.[34,35] While the precise timelines and causal factors for the collapse of the Soviet Union will not be examined in this paper, the widening balance concerning defense advancements between the two countries toward the end of the Cold War should be noted as potential causal factors for shifts in policy toward the Soviet Union.

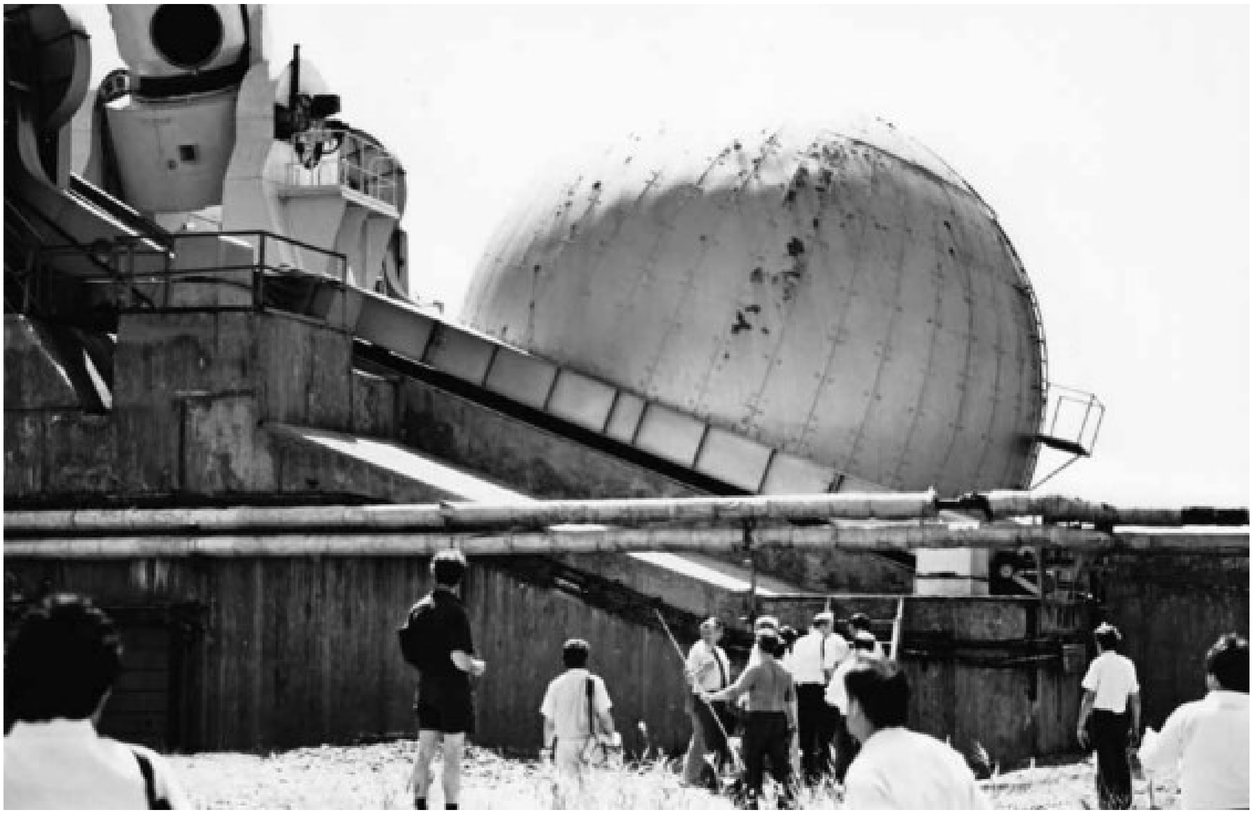

Figure 2: U.S. delegation visit to Soviet Union Sary Shagan facility as photographed in 1989 which gives the reader a size comparison of the technology during the time period (Grego, *A History of Anti-Satellite Programs*; photo courtesy of Thomas Cochran, Natural Resources Defense Council)

Collapse of the Soviet Union

The culmination of the shift of global power came in the last few years of Soviet existence and following the ultimate demise and its transition to the modern-day Russian state. During this period the U.S. realized a large shift in political and strategic goals as it adapted to what is commonly referred to as the unipolar global order.[36] The combination of dwindling defense budgets and the greatly reduced necessity for advanced weapons programs with no sizable adversary remaining to counter U.S. influence, resulted in many space-based weapons systems being largely cut from funding priorities or relegated to back-room programs. No longer under constant threat of Soviet aggression, the U.S. turned its focus to the reunification of Europe, the spread of democracy and countering the rise of new threats such as Weapons of

Mass Destruction (WMD) and Terrorism.[37] While the basic assumptions of nuclear deterrence remained, the space domain became primarily focused on the tenants of cooperation and scientific research.

While previously beginning in 1981 during the height of the Cold War, NASA launched its first Space Transportation System (STS) otherwise referred to as the space shuttle, with forty-four launches prior to the collapse of the Soviet Union.[38] Post-Cold War, this pace was increased with another fifty-two mission launches before the end of the twentieth century.[39] Further cooperation efforts were expanded in 1993 when "Russia was invited to join the International Space Station (ISS) program alongside the U.S. Japan, Canada and nine European countries acting through the European Space Agency."[40] During this period, the U.S. foreign policy approach was working to foster technological advancements in scientific research and space exploration along peaceful lines. The transition timeframes between the Bush and Clinton administrations moving into the last few years of the twentieth century, further broadened the political rationales for cooperation with the former adversary. In U.S. government circles there was a real concern over Russian reform-based policy as well as the risk of power vacuum and corruption with high potential for former Soviet technology and knowledge to fall into the hands of rising threat organizations and third-world autocracies.[41]

The Multipolar Landscape

However, the U.S. dominance in the unipolar landscape was short-lived, and the dawn of the new century saw rise to other nations competing for economic and defense influence in the new multipolar environment. China's Gross Domestic Product (GDP) saw moderate to steady increases in the late twentieth century but increased nearly fifteen-fold in the past two decades.[42]

While still trailing the U.S. in total economic clout, both Russia and India have continued moderate gains with China rapidly closing the gap with the U.S.[43]

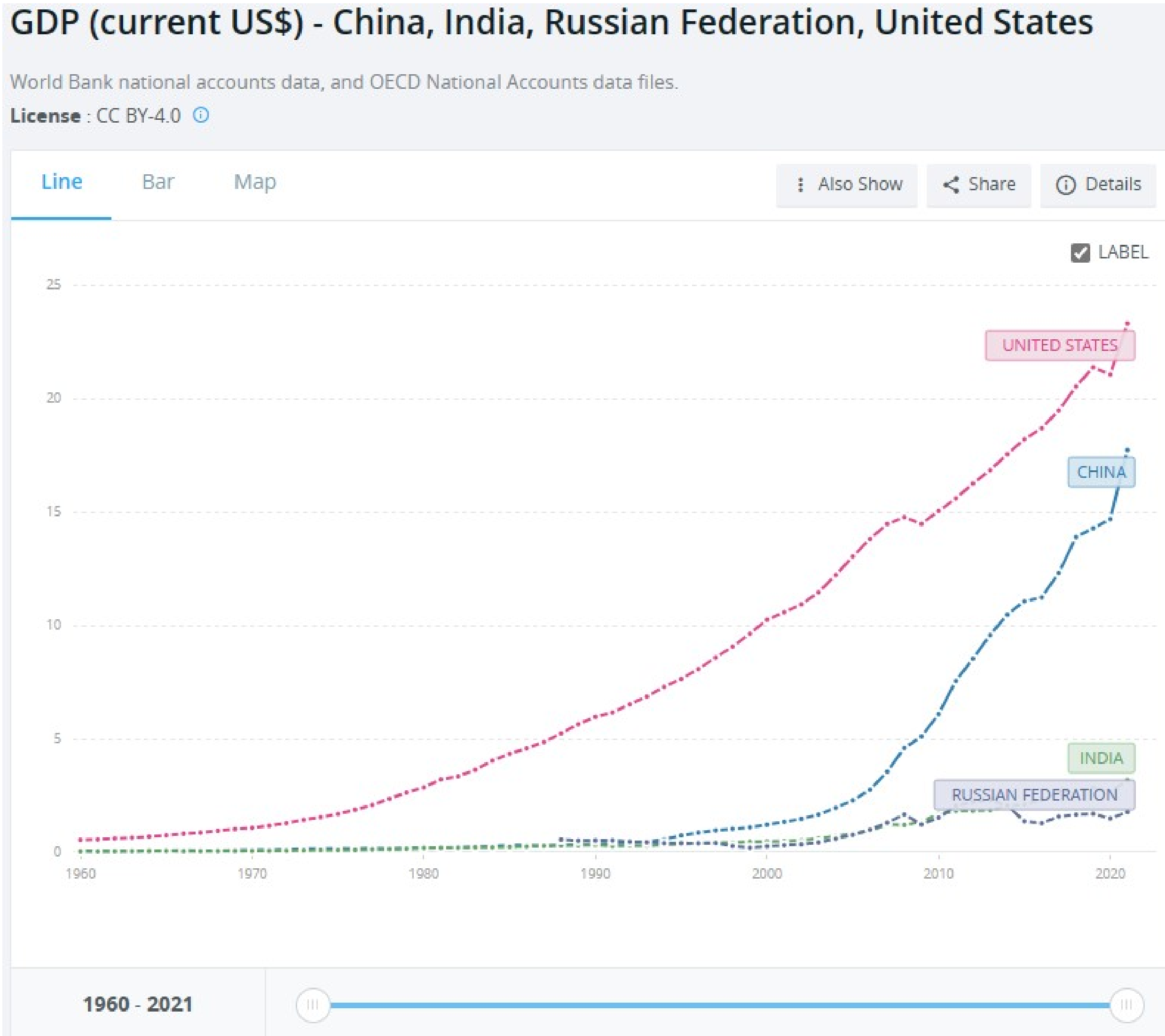

Figure 3: GDP comparison from 1960-2021 (World Bank website data)

Relative defense spending during this same period has steadily increased for both India and Russia and risen more than thirteen-fold for China during the same period.[44] While there are too many indicators to list within the scope of this paper for assessing a nation's true intentions, defense spending will usually indicate some level of power projection aspirations, whether offensive or defensive. Chinese aspirations in recent years have been heavily centered around

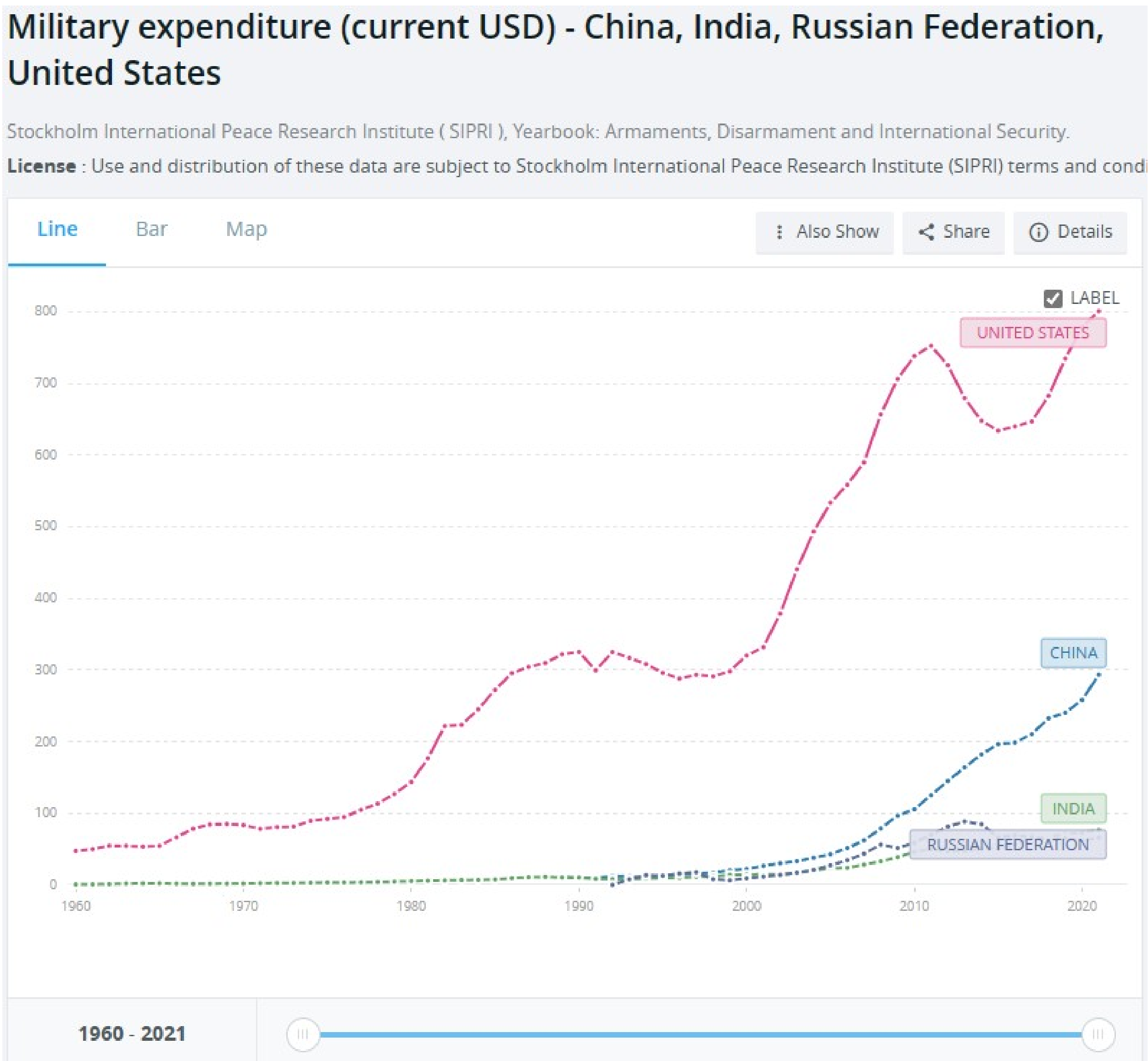

Figure 4: Defense spending comparison from 1960-2021 (World Bank website data)

While China remains the most glaring example of policy influence and shift in the multipolar landscape, several nations, including China, have rapidly expanded their influence and capabilities in the space domain. This technological expansion represents threats to not only U.S. government and defense abilities, but also that of global commercial space entities. As of 2021 the "value of the global space economy was estimated at $469 billion with some analyses projecting this to increase to over $1.25 trillion in annual revenue by 2030."[47] Currently, there are also "5,400 satellites in orbit today with more than 24,500 anticipated to be launched in the next 10 years."[48] China currently "operates four spaceports and a family of space launch vehicles and doubled its number of satellites in orbit between 2019 and 2021, with a record 150 satellites put into orbit in 2022."[49] While a vast majority of this technology supports China's economic interests around the globe, some experts are concerned about the overlap of civilian and defense transfer through state owned agencies in the country. In 2007 "China made history with its first successful test of a kinetic ASAT weapon, firing a direct-ascent SC-19 missile which targeted and destroyed an aging Chinese meteorological satellite."[50] In 2013 a subsequent ASAT test using a Chinese DN-2, while ultimately not successful, was "determined by the U.S. Department of Defense to be evidence of Chinese ability to reach satellite targets in Geostationary Equatorial Orbit (GEO)."[51] Aside from the inherent risks that these missile launches present with post-impact debris, the primary concern from defense experts is that China has demonstrated the ability to solve complex guidance and targeting problems previously out of reach. China's rapid advance in technology and knowledge continues to close the gap on respective U.S. capabilities by comparison.

While Russia's space activity has drastically reduced since the end of the Cold War, its aspirations have slowly tracked upward moving into this century. 2021 Russia successfully tested a direct-ascent ASAT, destroying a defunct Soviet-era satellite using a PL-19 missile interceptor.[52] In 2018, "a modified Russian MiG-31 fighter jet was photographed carrying an unidentified missile reported to be a mock-up of an air-launched ASAT weapon."[53] While there is little evidence on any further developments with this technology, the approach isn't new and most likely continues previous efforts during the Cold War. Russian defense activities in space have additionally been tied to questionable satellite behavior, most notably from a surveillance standpoint. Both in 2020 and 2022 it was reported that Russian satellites performed close approach and maneuvers to U.S. National Reconnaissance Office (NRO) satellites. While the U.S. does not acknowledge any degradation or interference with satellite abilities in these instances, the commanders of U.S. Space Command at the time have commented on the irresponsible and intentional behavior of Russian space operations.[54] Many experts believe these instances represent a potential shift in approach for Russian space agencies now experimenting with various co-orbital abilities that could include signals intelligence gathering as well as kinetic testing. The concept of sacrificial satellites being used to physically impact an opposing target in orbit has been brought up in the past and these instances may represent Russian interests in this area.

India has steadily been increasing its space activity over the past decade and while previously focused on scientific missions, the past few years have seen increased military-based activity. In 2019 India successfully launched a PDV MK-II missile defense interceptor destroying one of its own aging satellites.[55] While the impact trajectory of this test resulted in far less debris which minimized international concern, the event did manage to place India in a select group of only four nations alongside the U.S., China and Russia, to successfully conduct such a test.

Figure 5: Illustration example of India's ASAT missile test (The Daily Guardian, *ASAT Operationalism: A Simplistic View*)

In 2022 the U.S. announced a commitment to end destructive ASAT missile testing to increase sustainability and stability in space, followed shortly by a United Nations (UN) resolution to the same degree.[56] It should be noted that China, Russia, Iran, North Korea and India did not vote in favor of the resolution.

Directed Energy Futures

Historically nations have experimented and expanded in the realm of kinetic technology such as aircraft, missiles and satellites. The Cold War fueled this competition in the air and space dominance race. Inevitably, however, all technology advances and generally becomes more cost-effective or efficient. While previous examples such as the Reagan administration's lofty goals with SDI were arguably unattainable at the time for anyone, the interest in these potentials has never ceased. In previous decades the limitations for directed energy weapons were mainly tied to computing power and the sheer magnitude of energy requirements to power such devices.

Given the relative cost and feasibility of such devices versus existing kinetic technology for missile guidance, the majority of this research was exploratory in nature. It failed to produce any significant gains for even the leading countries.

Two of the primary technology areas that have been greatly expanded upon in the twenty-first century are High-Energy Lasers (HEL) and High-Powered Microwave (HPM). While laser technology has existed for some time, the power and distance limitations generally precluded military or space applications. While this paper does not intend to delve into the detailed physics of laser or microwave technology and its function, the reader needs to understand the basic uses for defense purposes. When used as a point-target-style weapon, HEL delivers focused pulse energy to the surface of a physical target, creating intense heat. This act intends to degrade or destroy a physical object. This can be used in either a defensive or offensive capacity but the primary limitation is still that of a point target weapon given the basic concept of laser energy.[57] It is also important to note the atmospheric limitations of HEL devices, simply the limitations from clouds, rain and vapor in the atmosphere that might inhibit or block laser energy's travel.

Devices in the HPM arena allow for both the engagement on point targets and wider areas but are generally considered more of an area target weapon. With HPM there is undoubtedly a result of higher heat generated. However, the intent is less focused as compared to lasers, with the ultimate goal of degrading or destroying electrical components within a complex device. In military and space applications, this minimizes physical damage from an outside viewpoint, but instead renders the object or device potentially unusable. Compared to conventional or kinetic type weapons, these classes of DEW also have the advantage of near unlimited firing capability. As long as the devices continue to receive power and relative cooling is maintained, the concept of ammunition in historic terms, is relatively unlimited.

Employment for these types of devices can vary with early and historical examples being relatively fixed surface-based locations or facilities, given the technology's size, weight and power (SWAP) limitations. The primary downside of this approach from a military standpoint is the ease of enemy fixing and targeting. More modern examples with advanced power usage and component shrinkage have seen mobile-based systems developed on vehicles or ships, making them naturally harder to locate by potential enemies. With either example this still presents challenges for targeting space-based satellites or installations, given the distance and relative trajectories. Placing these technologies on space-based platforms still reversibly presents the same terrestrial targeting problems but allows for co-orbital advantages when targeting other enemy satellites.

In 2015 China underwent a major military reorganization within the People’s Liberation Army (PLA). This created the Strategic Support Force (SSF), which is responsible for developing and employing most of the PLA’s space capabilities. This was the first known instance that China designated space as a military domain.[58] Chinese white papers associated with this event highlight the nation's interests in space strategically. DEW is a key component of counter space strategy, following the basic premise that militarization of this domain is already underway.[59] China is pursuing several notable avenues to challenge the dominance and control over the space domain. However, many experts are confident that DEW technologies are within this scope. Indications as early as 2006 suggest Chinese interference on U.S. satellites using lasers, and in 2019, the Defense Intelligence Agency (DIA) reported on concerns that the Chinese government was most likely continuing its advancements in laser technologies to target opposing countries’ satellites in orbit.[60] Information concerning Chinese DEW programs can be elusive given the highly secretive nature of their programs, but many experts in the field have been able to discern from open sources the definite interest in these areas by the Chinese government.

Russian interest in the space domain and associated technology never truly stopped after the fall of the Soviet Union, instead experiencing a massive drawdown due to economic reasons. While these efforts have not completely rebounded to Cold War levels or comparable expenditures, they have markedly increased in the last few years. Evidence not only suggests that a Soviet-era laser weapon program had been revived to potentially target LEO satellites, but there have additionally been photographs and reports of vehicle and aircraft-based HEL systems in development.[61] While HPM technology is most likely a continued interest for the Russian military, recent evidence for these systems suggests they are primarily for ground-based warfare. In addition to laser technology, Russia has shown an increased interest and usage of electronic systems such as Radio Frequency (RF) jamming and spoofing devices used against satellites.[62] While less destructive in nature than comparable HEL or HPM attacks, these behaviors arguably indicate intent of the Russian government's desire to control or disrupt the space domain, either for military or economic purposes.

Other adversary militaries might be severely inhibited by spending when compared to China and Russia, but that has not slowed their intent to research and develop efficient technologies for military use. While there is no known evidence that Iran or North Korea have been able to substantially field anything related to DEW, the constant pressure from their missile and nuclear test programs continues to make national news. There are reports that in 2019 the Turkish military used a laser weapon to destroy a UAS during the Libyan conflict, but what is most notable in reporting by the USAF Research Laboratory is that as of 2021, at least 31 countries were expected to have some level of DEW technology.[63] Most of these observations were related to defensive base or force security, centered on counter-UAS operations primarily, but the reader should note that these same defensive systems are almost always capable of offensive target engagement. Some level of skepticism toward the true level of proliferation with these technologies should certainly remain, but the reality is the implications for transitioning existing systems to space or counter-space applications is possible as technology continues to advance.

The U.S. has also continued advancements in these same technology areas, but has tended to stay more aligned to defensive employment. HPM systems such as the "Tactical High-Power Microwave Operational Responder (THOR) technology demonstrator, the Phaser High-Powered Microwave system and the Counter-Electronic High-Power Microwave Extended-Range Air Base Defense (CHIMERA) system", have all been funded and fielded in recent years.[64] However, it is notable that these are all ground-based systems used for base defense in counter-UAS or anti-aircraft scenarios, and not primarily intended as offensive weapons. The U.S. has fielded additional HEL technology in line with the same defensive approach. The "High-Energy Laser Weapon System (HELWS), the Directed Energy Maneuver-Short-Range Air Defense (DE M-SHORAD) system, the Indirect Fire Protection Capability-High Energy Laser (IFPC-HEL) and the Self-Protect High-Energy Laser Demonstrator (SHiELD)", have been tested and fielded in low-rate production with mixed results.[65] All of these systems are again designed to be defensive in nature-centered around ground-based force protection, except for SHiELD, an airborne platform. The U.S Navy has implemented similar systems such as "Optical Dazzling Interceptor, Navy (ODIN), the Laser Weapons System Demonstrator (LWSD), the High-Energy Laser with Integrated Optical-dazzler and Surveillance (HELIOS) and the High Energy Laser Counter ASCM Project (HELCAP)."[66] While ship-based versus ground or vehicle based, these systems still serve the same general purpose of friendly force protection, or in the Navy's example, protection from enemy cruise missiles or ships.

Figure 6: USN Laser Weapons Demonstrator System, USAF High Energy Laser Weapons System and Turkish Army ground based ROKETSAN Laser Weapon. These images convey the noticeable decrease in size for comparable technology over the past few decades (U.S. Air Force Research Laboratory, *2060 Directed Energy Futures*)

Funding in the U.S. for DEW technology has fluctuated at times but generally increased over the past few years. From 2017 to 2023, authorized and appropriated congressional funding for research and development remained between $400M and $1B, with actual procurement increasing to a rough steady-state annual of $300M.[67] The debate over the cost of these U.S. systems will continue and should be considered nothing new from a defense procurement standpoint. With every early-stage defense technology investment, elected officials will weigh the return on investment for the taxpayers and balance the needs against national defense priorities.

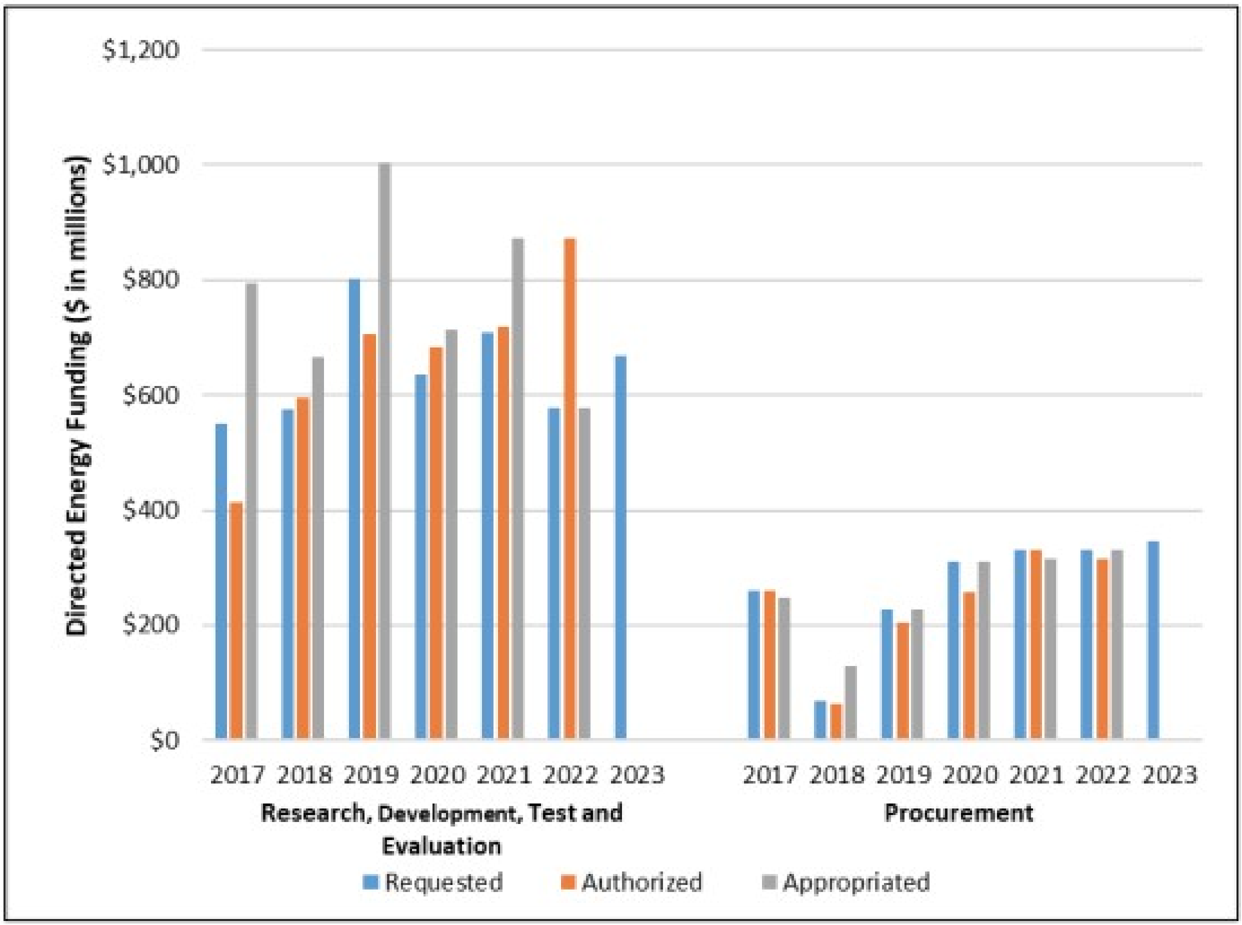

Figure 7: Requested, Authorized, and Appropriated funding levels for selected DE programs (Congressional Research Service, *Department of Defense Directed Energy Weapons: Background and Issues for Congress*)

Every evolution of technology has encountered the same concerns, whether it be the needed usefulness versus the cost or return on investment. As these technologies' SWAP advantages improve and field use increases, the financial debate will most likely quell. While there is no shortage of sources speculating on global interest in employing DE technology in space rather than land or sea-based, there is little evidence to show that any country has been able to do so. The nature and implications of these programs would also most likely be highly classified, inhibiting the current evaluation of such abilities, especially by countries with weaker defense spending.

ANALYSIS, CONCLUSIONS AND RECOMMENDATIONS

Analysis

Throughout history, there are examples of global state behavior and the competition for territory and control, whether economic or military in nature. Although relatively new to the human experience, the space domain has proved to be no different than any other terrestrial domain. During the Cold War the bipolar environment and competition between the Soviet Union and the U.S. was obvious. Competition between the two nations was fierce, not limited to air, land or sea power. Early on both realized the possibilities of space and what that might bring, either from a military high ground standpoint or simply through propaganda campaigns to assert technological dominance. Following the success of Sputnik, the U.S. quickly followed up with the Gemini and Apollo missions in the quest to be the first humans on the surface of the moon. These rapid advances by both countries were not only a battle between capitalism and communism and the ultimate ideological victory, but also driven by paranoia around military threats. Referencing the sources from NASA historical archives, one can see the direct correlation between Soviet and U.S. activities in the space and the inherent competition between the two nations. Focus soon turned to satellite intelligences, surveillance opportunities, and early warning for nuclear weapons. While the skies and seas were already heavily regulated, space was lacking and allowed for a multitude of opportunities to the first nation that could master the unknown. The NRO reference pertaining to previously classified background on U.S. satellite activity presents a compelling example of the level of interest that the U.S. had at the time when countering the Soviet threat. A multitude of programs were pursued in attempts to stay ahead of the competition and retain the advantage on the potential battlefield. Technology at this time was sometimes rudimentary and programs were unsuccessful, but these historical examples reinforce the notion that the U.S. was serious in the space race against the Soviets. The Reagan administrations SDI or Star Wars program was a bold initiative aimed at deterring Soviet aggression. When referencing the Atomic Heritage Foundation's archives on SDI, one can determine that the feasibility of such technology at the time was naturally suspect, but the posturing example is absolute given two superpowers competing for effective control of the globe. It is also important to assess in parallel similar examples with Reagan's NSDD 12 references from the National Archives, which demonstrates the resolve that the administration had at the time when countering Cold War threats and competition.

While many of these examples present pure escalation and competition, it should also be noted that some measure of restraint was also realized during this time period. The ABM treaty in 1972 as referenced in the U.S. State Department archives, shows a measure of mutual understanding between the two nations. Once again in 1987 the INF treaty as referenced from the National Archives, additionally represents some level of control over the competition during this period. There is naturally speculation from the 1987 example as to what financial state the Soviet Union was in and how this played into signing additional treaties however. While most of the examples during this time period represent clear escalation between the two powers competing for dominance in space, various treaties would suggest that diplomacy was able to achieve some measure of success. It is important for the reader to realize however that this was the classic bipolar example where actions and reactions were focused on one adversary respectively. No other country possessed any reasonable space capability at the time by comparison to the two superpowers.

After the fall of the Soviet Union, the U.S. remained the dominant super power in a unipolar world, but this power vacuum environment did not last long. Hal Brands book about the shift to the unipolar order presents not only historical context for the end of the Cold War but also the transition that the U.S. experienced and how it adapted to this new period. When combined with the context in Logsdon's Space Policy Institute writing, one can clearly see the retrenchment of sorts for the U.S. concerning space policy. The emphasis at this time was clearly more focused on scientific exploration and cooperation with former adversaries, with less of an emphasis on the militarization of space. Shortly after the turn of the century, China began to experience rapid economic growth surpassing even the growth rate of U.S. GDP, as referenced by the World Bank financial data charts. This same world bank data shows similar reinforcing facts with Chinese defense spending trends. While less of a threat by comparison, this same economic data shows countries like India and Russia also beginning to rebound and increase economic and military dominance in regional parts of the globe. The most well-known examples referenced are Chinese behavior in the South China Sea concerning locations like the disputed Spradley Islands and the ongoing potential for conflict over Taiwan. Chinese national interests that were always simmering under the surface have been allowed a certain measure of reality given the increased means to pursue them. While the U.S. determined after the Cold War that draw down and retrenchment was necessary given the collapse of the primary threat, other countries discovered there were opportunities for the taking. These opportunities have quickly evolved into the multipolar landscape competition shown today, where space is simply the next open frontier in the fight for superiority.

Kinetic space weapon technology has proven to be slightly more elusive with the exception for a handful of nations. The simple reality is the physics and guidance solutions needed to fire and intercept targets at such vast distances and incredible speeds has proven to be a decades long problem to solve. Grego presents early examples of Cold War ASAT technology which tended to be ABM defense oriented and relied on the concept of a nuclear area detonation to achieve the desired effect. In the early twenty-first century, the 2020 and 2023 CSIS space threat assessments by Harrison and Bingen respectively, have shown that a handful of nations can shoot down satellites in orbit. Some of these capabilities with high confidence even at GEO orbit altitudes. The ability to shoot down satellites in orbit with kinetic vehicles presents little argument for scientific research, but instead more toward a nation's desire to develop military technology for either offensive or defensive purposes. Russian Federation examples referenced in this paper concerning satellite behavior also present a serious concern. Countries have already begun to experiment with co-orbital maneuvers for surveillance and possible impact tactics. Johnsen's article and Harrison's space assessment in the literature review, show this aggressive behavior by the Russian Federation, in what has been noted by experts in the field to be intentional and potentially reckless. These cases simply reinforce the idea that the U.S. is not the only country worried about military threats in orbit.

Although not a new concept as DE technology was being explored even during the Cold War by both the U.S. and the Soviets, the limitations in the early years proved to be prevalent. The Soviet ballistic missile defense test facility at Sary Shagan example in 1989 showed the sheer size and power limitations of technology at the time. Ultimately determined to be benign and wholly less capable than originally thought by U.S. intelligence services, this still showed the challenges that both countries faced in tackling such technology for use in space. The current known examples of DEW in use by the U.S. either in fielded form or experimental, highlights the rapid reduction in size limitations and power efficiency that the technology has experienced in only a few decades. Many of these HEL and HPM systems are fielded on ships or even smaller military vehicles capable of self-sustained operations. Limitations on research for modern DE exploits are certainly apparent given the classified nature of such endeavors by foreign governments, but the interest is certainly not lacking. Pollpeter's report for the RAND Corporation presents notable examples of Chinese interests in the space domain. While much of this report is centered around Chinese military structure and doctrine, it is very important to note that the Chinese government has acknowledged space as a warfighting domain and DE technology is a primary emphasis for the country's future aspirations. The references from the U.S. Air Force Research Laboratory and the Congressional Research Service for Directed Energy Weapons, do however present evidence of U.S. involvement in DE technology and what these implications for the future might be. The various systems that are discussed in these readings show the noticeable reduction in scale for such technologies, especially when compared to the Sary Shagan example. Assumptions can be made that these technologies will and probably already have been reduced further with regard to SWAP limitations and restrictions and could soon expand opportunities for the space domain.

Conclusions

Global competition has proven absolute, and it is concluded that moving into the twenty-first century, this will remain the dominant status quo in the space domain. The bipolar competition of the Cold War proved that superpowers will contest the very domains of warfighting that allow for global influence. To some degree this stage in history proved to be slightly more manageable with only two realistic competitors in the mix. The U.S. experienced a relative lull in competition at the end of the twentieth century, where strategic interests were centered around scientific advancements in space rather than militarization. It should be concluded however that this period was short lived with countries like China, India and the reborn Russian Federation beginning to compete in the space domain after the turn of the century. China has certainly shown an upward trajectory with their defense spending and increased interest in space. It can be concluded that the current multipolar environment the U.S. finds itself in presents more difficult diplomacy challenges given multiple competing interests. This competition will also increase, not only from a military standpoint but also that of commercial interests around the globe. The current world's technological and connectivity needs are intertwined with space and when combined with the hypotheticals on minerals and resources in this untapped domain, everyone with the means will be fighting for a seat at the high table. Even the Artic has been militarized to some degree and it should also be assumed that not all countries in this equation have the most benevolent interests at heart. The most recent ASAT testing ban example shows that some countries do not agree along the same peace and stability lines as the U.S. and have already proven to be a threat that will carry over into the space domain. Some have argued that the militarization of space should be avoided, but this research paper has concluded that this has already begun and started with the first spy satellite launch during the Cold War.

The research has concluded that technology will continue to decrease in size and cost, allowing more countries to participate in this new domain. Moore's Law essentially states that "the number of transistors on a microchip doubles every two years and we can expect the speed and capability of our computers to increase every two years because of this, yet we will pay less for them."[68] While this concept was originally coined in 1965 discussing the commercial computing industry, some adherence to this concept should apply to modern military technology. As this technology reduces in size and gains efficiency, potential hostile countries will continue to invest in these avenues. These pursuits will not simply be based on cost and efficiency, but also covert aspirations in nature as well. The political landscape continues to become fraught with international pressure on some of the same repeat offenders, and they will continue to seek opportunities that leverage military strength while avoiding the overt military approaches that invite outcry from the international community.

Recommendations

First, the U.S. must acknowledge the realistic assumption that the world is now a multipolar competitive environment, not only on Earth but also moving into the space domain. Given regional power vacuums, other countries and entities with expanding financial means will continue to compete for both military influence and economic clout. As more global players in this environment find these opportunities moving into the space domain, they will challenge the U.S. no differently than they have in terrestrial regimes. The U.S. must deem this a territorial threat to some degree and continue to treat the space domain as a warfighting domain applying the same doctrine and strategy approach as anywhere else.

Second, the U.S. must avoid the perception of increased or overt weaponization of space. The militarization has been underway for some time, but creating the perception that there are offensive weapons placed in space constantly orbiting friendly or potential adversary nations will only invite paranoia. The direct definition of this weaponization concept is difficult to pin down, but certainly anything kinetic in nature that is based in space has the potential to be perceived as such. This should be avoided as much as possible in an effort to prevent a future arms race or escalating what has already begun. These pursuits should concentrate on defensive weapons or technologies that message potential adversaries that aggression will not be tolerated and the useful retaliation with such technologies is always on the table.

Finally, the U.S. should continue to invest in DEW and associated technology such as HEL and HPM options. Elected officials need to understand that these new technologies differ no more than any other investment. At times there might be questions about the usefulness or need as well as research and development failures, but the funding must continue and even increase to achieve results. These technologies will continue to decrease in size and cost while increasing in efficiency. This trajectory will soon allow for a multitude of opportunities in the space domain that can be primarily defensive. With rapid investments and program support, these DEW opportunities will be feasible for space-based operations and support, protecting U.S. interests and assets in space and on the Earth's surface. This defensive investment in DEW technologies approach will help the U.S. avoid potential weaponization perceptions or outcry from the international community, while also ensuring the global stability of the warfighting domain and protecting friendly economic interests across the globe.

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