The Alternate Futures Delivered by Starship

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ABSTRACT

This paper is an exploration of alternate futures for the US Space Force assuming that SpaceX's Starship launch vehicle meets all of its reported targets. Starship achieving its objectives will likely be a watershed moment for the Space Force. How then, will the newest branch of the US military respond? The paper explores different variables within the control of the new branch including acquisitions, control, and weaponization. Then, it extrapolates trends to create four possible futures: "Resilient Mega-Constellations," "Peacekeeper Guardians," "Fortresses in the Stars," and "Commander's Dream." Each of these explores the limitless potential brought by the limitless mass-to-orbit capability of SpaceX's Starship. Space Force leaders, acquirers, and operators should all take notice of the new capability and push to change the future in their favor.

Mass Effect: The Alternate Futures Delivered by Starship

INTRODUCTION

The newest branch of the US Armed Forces, the US Space Force (USSF), comes at an extraordinary time in the space age. SpaceX, Elon Musk's rocket company, has just attempted a launch of what stands to be the first fully reusable space launch vehicle in history. Simultaneously, more than ever, adversaries of the US are not only copying SpaceX but have been developing space weapons to deny the US the ability to use its space capabilities. While the space domain has always been a contest of great powers, it has been almost 30 years since a significant challenge presented itself. Even then, the threats are changing rapidly.

Space is not the first domain to face this challenge; the air domain was once new and struggled to find its purpose. The US Army Air Corps post World War I "lacked a prudent vision to net significant war-winning power" from assigned resources.[1] "Only through conceptual work and technological achievement did airmen craft an air arm that proved so decisive in WWII." This paper aims to help Space Force Guardians envision the realm of the possible.

The Starship launch vehicle may be the most revolutionary thing to happen to a domain since the jet engine with air or the steam engine for the Navy. Each brought about a massive change in weapon systems and the design of the force. From the size of the vehicles to the armament, everything changed. Manning, organization, and tactics may all change due to rapid technological change. So, what's the best way to explore the possibilities?

Futures analysis has been used historically to study those possibilities. Traditionally, a futures analysis will extrapolate trends into the future to create possible scenarios to explore options. Those possibilities can inform leaders to guide planning and decision-making.

For the Space Force, futures typically involve the bigger picture, geopolitical and scientific. For example, before the stand-up of the Space Force, Air Force Space Command published its Space Futures Report that looked at geopolitical scenarios for 2060.[2] While beneficial, there is room to explore a more focused arena.

This paper will look instead at the future of force design with a near-term focus within the next fifteen years. Instead of comparing space futures on a global scale, the future will be explored through a lens of a completed and fully functional Starship and its consequences. The future will be analyzed using variables entirely within the control of the Space Force.

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[1] Deptula, David, Lt Gen, "Space Force: Go Slow, Learn from the Army Air Corps," breakingdefense.com 29 March 2023

[2] United States, Air Force Space Command, Office of the Chief Scientist, "The Future of Space 2060," September 2019.

The remainder of this section will discuss the paper's significance, limitations, and remaining structure. This aims to contribute to the body of knowledge driving future possibilities and outcomes. Instead of focusing on the past, Guardians, senior leaders, and industry partners must look to the future to take advantage of a massive increase in capability. This will help future force designers guide planners, requirements, procurement, and budgeting for the future.

While comprehensive, this analysis is notably missing a focus on the adversary and fiscal constraints. The adversary most definitely gets a vote in determining the potential and *raison d'être* of a military; however, designing toward an adversary may limit the potential, which would be antithetical to the aim of this paper. Additionally, the Department of Defense (DoD) budget process is long and grueling. For this paper, that process is assumed to be solved and functioning according to today's standards. Guardians can fully work within the system to achieve the ends presented here.

The structure of this paper first introduces the history of the launch industry, current trends, and assumptions on the capabilities of Starship. Then the report will detail the methodology for selecting the different future scenarios. After the method, the article will take a deep dive into each spectrum used in creating the future. Then, four possible future designs will be showcased as a result. Finally, recommendations and implications will be discussed before concluding the paper.

While the technology may seem straightforward, its applicability to change is profound. This is an iPhone moment for the space industry. When the iPhone was launched, all the services it provided could be done better by other devices. It was the combination of applications on the machine that made it revolutionary. Starship is the iPhone, and satellites are the application layer on top of the hardware that will launch a new generation of platforms. A profound change is underway with reusable launch vehicles. Without exploring the potential for the future, opportunities will be missed, and the adversary may gain an advantage. Let's dive in.

METHODOLOGY

The alternate futures methodology followed in this paper follows the generic guidelines for similar analysis. This analysis aims to extrapolate the trend of low-cost launches to derive potential outcomes. Extrapolation is based on the compounding technological trends within the assumptions chapter and is further expanded in the following chapters.

First, a timeline was chosen to scope the alternate futures. The timeline considered for this analysis is 10 to 20 years in the future. Previous timelines typically have reached farther into the future, usually some 20-50 years.[3] Alternately, too close to now, and the analysis becomes more of a planning exercise. This timeline was chosen because of the Starship vehicle's current status and fiscal and schedule constraints for new satellite development. Given that the first Starship vehicle just launched, the story is nearing completion and becoming more of a reality than vaporware. Additionally, ten years leaves plenty of time to generate action within the governmental and bureaucratic processes of the US.

Matrix Scenario Development

An approach similar to a 2x2 scenario planning process was used to determine future scenarios. In a traditional 2x2 matrix, two variables are chosen and compared across a spectrum of extremes.[4] The variables are placed on a matrix, and each corner represents a different possibility. An additional variable was selected for this paper to allow for more future options while keeping it within reasonable limits of effort. Unfortunately, this method does not capture all everything possible, but it can cover a range of extremes.

Next, key variables were chosen to drive the alternate possibilities. To scope the research project, variables were few but varied. However, a central goal of this paper is to drive change within the Space Force toward one or more of the futures presented. Therefore, the research primarily focused on variables under the control of the Space Force and potentially ripe for change.

Critical variables for consideration in this future analysis include the ability of the space acquisition and procurement community to keep pace, the organizational and command and control approach, and the level of weaponization within the domain. Each variable was assessed on a spectrum from starting little to no change to complete and opposing change. Each variable is represented in the figure below. In this case, the type of change was dependent on the variable.

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[3] Nichiporuk, Brian, "Alternative Futures and Army Force Planning: Implications for the Future Force Era," RAND Corporation, March 15, 2005. https://www.rand.org/pubs/monographs/MG219.html.
[4] Alun Rhydderch, "Scenario Building: The 2x2 Matrix Technique," June 1, 2017. Dana Mietzner and Guido Reger, "Advantages and Disadvantages of Scenario Approaches for Strategic Foresight," SSRN Scholarly Paper (Rochester, NY, 2005), 231 https://papers.ssrn.com/abstract=1736110.

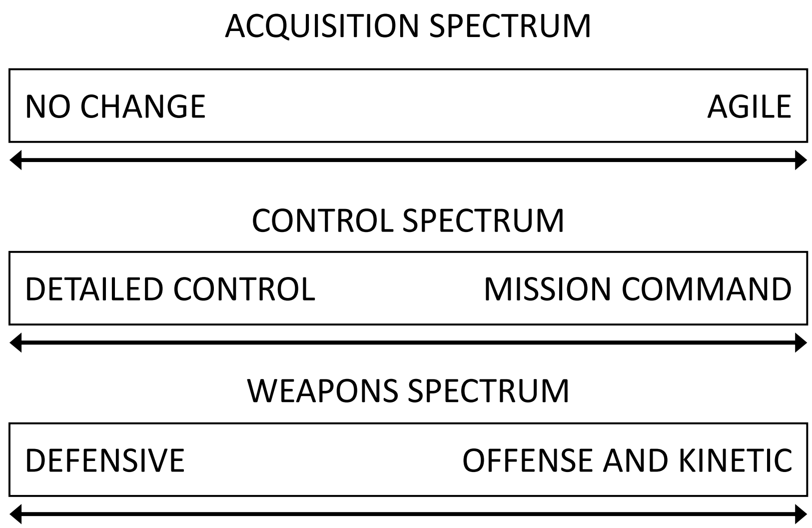

Figure 1: All Spectrums

The assessment was based mainly on iterative design and development capability for space acquisition and procurement. The current state of affairs includes no significant increase in iteration and development capability. Judging by major acquisition programs in the US, the current iteration cycle is over ten years. The opposing end of the spectrum is the ability to fully iterate on capability within a given fiscal year leading to rapid improvements within two to five years and more as the year progresses. In the middle is a partial iterative capacity that makes more significant changes only on a five to ten-year cycle.

For command and control, the spectrum of the variable is governed by the level of control of a commander. Varying from a current structure of detailed and centralized control, to mission command at the middle of the spectrum, toward finally, autonomous operations at the far end. Understanding where the control lies may determine the outcome of force design in the future.

The final variable assessed was the level of weaponization within the domain. The current end of the spectrum assumes space weapons do not exist but that defensive capabilities will increase. The middle option includes non-kinetic reversible weapons, and the far end includes kinetic weapons.

More variables were considered but ultimately decided against. For example, budgetary constraints were considered but eventually dismissed due to the general lack of control and influence from the Space Force. Furthermore, additional global variables were not considered due to the size and scope, such as the state of the economy, geopolitics, and demographics. The overall intention of the paper was to focus on variables of influence by Space Force leaders and servicemembers.

The three primary variables remained due to their ability to provide different study outcomes and the potential for control. Previous futures analysis looked at timelines farther out into the future using significant and global variables. For example, an alternate futures study from AFSPC focused on the 2060 time frame.[5] While helpful in setting the stage for the future, the potential from Starship is so great a longer timeframe would have required a more in-depth analysis which would have been too significant for this effort. Starship is almost ready, and action can be taken now to drive towards one of the futures presented here.

Selection of Futures

After determining the variables and their likely outcomes, the next stage focused on the future. If all possibilities were selected for the development of futures, the study could see 27 different futures. Additionally, the scenarios may see few enough differences between them to the same effect.

Three main futures were selected because of their differences. Unsurprisingly, a future using different ends of the spectrums was preferred. Each end produced a vastly different future to draw from. Finally, a scenario using the middle of the spectrum was generated to show a potential future between the two extremes.

The first future, entitled “Resilient Megaconstellations,” showcases a most likely path for the near future. This future highlights changes in the acquisition variable, leading toward smaller satellites in vastly greater numbers. It also describes satellites with a higher degree of autonomy, decision-making software, and with the least amount of commander control. This future also assumes little to no change in the weaponization of the domain.

The second future, “Peacekeeper Guardians,” explores a middle-spectrum future. Some changes are made along each variable. Mission command becomes the default control. The acquisition accelerates but stalls. This future moves the service to a capability that allows for offensive action via non-kinetics but refrains from exploring destructive potential.

The third future, “Fortresses in the Stars,” expands the spectrums to the opposing end of the first. Tight control of weapons systems remains, similar to today’s Space Force, but weaponization is fully kinetic. The acquisition arm of the service has changed little and continues on its path of acquiring larger systems at a slower pace.

The final future discussed, “Commander’s Dream,” reaches across some of the most exciting aspects of each spectrum. This future explores a full kinetic weaponization of the domain, a mission command level of control, and a future that accelerated into industry speed.

[5] United States, Air Force Space Command, Office of the Chief Scientist, *The Future of Space 2060*, September 2019.

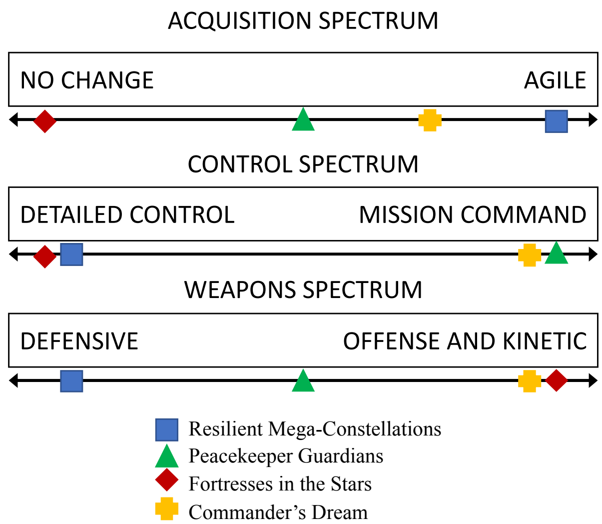

Figure 2: All Spectrums with Scenarios

Now that the explanation of the methodology is complete, the paper will go deeper into the process of getting to the future and then explore the scenarios themselves.

Each future shares one commonality: all futures assume Starship reaches full operational capability. This also assumes cost and production targets are passed to the DoD customer. This paper explores the possibility once launch costs have declined dramatically.

Additionally, each future relies heavily on continuing technology trends over the past two decades. Starship success and technological advancement are considered 'constants' for this paper. These constants are discussed in the next chapter. Then each variable and the spectrum will be explored in its chapter, followed by a shorter chapter on each future scenario.

TARGETS AND TRENDS

For the analysis in this paper, some assumptions had to be made. First, SpaceX will achieve its cost, price, performance, and production targets. Second, current technological trends will continue and be fully captured by the space industry. If SpaceX achieves its targets, Starship will radically reduce the cost to orbit while increasing the amount of mass delivered to orbit. This chapter will explore that cost reduction and what it looks like, then will explore the four major technological trends that will impact satellites as a result. Understanding Starship and related technological trends will be critical to developing scenarios later in the paper.

Starship Compared

Starship stands to radically bring down the cost to orbit and simultaneously increase the mass to orbit. The goal for SpaceX is around $2 million in cost per flight.[6] Starship will also seriously increase the mass to orbit capability. The goal for SpaceX is for the Starship vehicle to carry 100 metric tons to orbit, with greater mass to more accessible orbits.[7]

Compared to other options, the cost difference to mass is enormous. Compared to the previously discussed NASA Space Launch System, the difference in cost is $4.1 billion. The price difference is staggering in comparison. The difference between $2 million vs. $4 billion is 2,000 times different. If one were to compare a Honda Civic to a Ferrari, one would only get a price difference of 20 times.[8] The range in cost is not just vast but extreme.

One might imagine that the difference can be explained through the exquisite capability provided by NASA, similar to other governmental programs. The cost of a Nimitz-class aircraft carrier is approximately $10 billion.[9] For the world's largest cargo ships, it may cost you around $100 million.[10] The difference between the two is around 100 times. The United States premier warfighting naval ship and a similarly sized commercial ship still have a price delta 20 times lower than the two programs mentioned above.

A more relatable example may lie in the air domain for cargo aircraft. A C-17 Globemaster costs the U.S. Military around $218 million per unit.[11] In comparison, a

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[6] Debra Werner, "Elon Musk Discusses Starship at Air Force Space Pitch Day," *SpaceNews* (blog), November 5, 2019, https://spacenews.com/elon-musk-space-pitch-day/. Conversation between Elon Musk and Lt Gen John Thompson SMC/CC.

[7] "SpaceX Starship," SpaceX, accessed 12 December, 2022, http://www.spacex.com.

[8] Cost of a 2023 Honda Civic is approximately $25,000. Cost of a Ferrari Spider is $400,000. kbb.com and ferrarilakeforest.com

[9] "Aircraft Carriers - CVN," accessed February 6, 2023, https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/article/2169795/aircraft-carriers-cvn/.

[10] "Cargo Ships Cost Less Than You Think! – Casual Navigation," accessed February 6, 2023, https://casualnavigation.com/cargo-ships-cost-less-than-you-think/.

[11] "Boeing C-17 Globemaster III - Price, Specs, Photo Gallery, History - Aero Corner," accessed February 6, 2023, https://aerocorner.com/aircraft/c-17-globemaster/.

similarly sized Boeing 777 aircraft cost around $300 million per unit.[12] In this case, not only were both the aircraft similar in cost, the government equivalent cost less on a per unit basis. This, finally, brings up the most exciting aspect of the Starship Vehicle.

Starship is radically cheaper than every previously developed launch vehicle because it employs reusability. All launch vehicles have previously been expended upon launching. That means that every time the launch vehicle lifted off the launch pad, it was disposed of. To launch another payload, another rocket would have to be built and launched again, only to be thrown away. The logic is straightforward yet profound.

However, the difference is even more staggering when mass and cost are combined, as was done in the history of launch vehicles. For NASAs Space Launch System (SLS), the cost per kilogram is $50,000.[13] And Starship's target is $20 making the difference in cost per kilogram a 2,500 times difference. The price difference primarily comes from the reusability. Given that the cost of development of Starship is relatively unknown, it may be that the initial cost for one Starship and one SLS rocket is roughly similar to the aircraft example above. The simple difference would be that SpaceX can amortize the cost of their rocket over many thousands of flights, similar to an aircraft, instead of throwing the vehicle away.

Additionally, given the reusability capability of the vehicle, SpaceX intends to be flying Starship as often as possible. Launch rate, or the tempo, pace, and cadence of launches, is targeted at many hundreds per year. The SLS, in comparison, may only launch once per year. Even at the high flight rate of Starship, given the cost difference, the annual cost will again be much lower with Starship.

To summarize, SpaceX's Starship vehicle will be in a class of its own for launch vehicles. With a drastically lower cost, significantly higher payload capability, and high flight rate, Starship may revolutionize the space industry unlike anything before.

With such vast differences, the capability provided by Starship will be a game changer, so when will it be fully operational? As of this writing, SpaceX launched its first fully stacked Starship on the 14th of April. While unsuccessful in reaching orbit, it succeeded on many different parameters. Additionally, traditional aerospace companies may only have one vehicle built, and a loss would be enormous. SpaceX already has multiple iterations of the design ready to go. The following targets include routine flights in 2024, targeting a launch to Mars in early 2025. While this timeline seems ambitious, the program has been delayed from its initial timeline. Initially announced in 2017, the initial target flight was in 2020. If routine operations are delayed by a few years, the US government will have plenty of time to purchase payloads for Starship before 2030. With

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[12] "Boeing Aircraft Prices 2022," Statista, accessed May 6, 2023, https://www.statista.com/statistics/273941/prices-of-boeing-aircraft-by-type/.

[13] Michelle Codiva, "Side-by-Side Comparison of NASA's SLS and Saturn V: Cost, Height, Weight, Speed, Thrust, and Payload," Science Times, August 12, 2022, https://www.sciencetimes.com/articles/39330/20220812/side-comparison-nasa-s-sls-saturn-v-cost-height-weight.htm.

a budget cycle of five years, the time for designing and budgeting for those payloads is now.

Technological Trends

While the delivery and routine operation of Starship will radically change the launch industry. However, a few other technological trends will compound upon the leverage provided by radically decreased cost by mass to orbit. Four key trends impacting the space industry are the miniaturization of electronics, solar panel improvements, autonomous operations, and mega-constellation deployment. Launch cost itself is not the only trend at play, and the combined intersection of these trends makes for an exciting outlook for the next few decades.

Electronics Miniaturization

First, the ongoing trend in the miniaturization of electronics has not impacted the space industry in the same way as other industries. While Moore’s law has steadily continued its march on Earth, the same is generally not true in the Space Domain. Satellites may have individually taken advantage of the miniaturization of electronics. However, one would expect to see a translation of the silicon and electronics improvements into lower-cost satellites.

A good approximation of this trend can be seen in data bandwidth. For example, the trend can be seen within military satellite communications (MILSATCOM) but not at the rate of earth-based communications technology. The Defense Satellite Communications System (DSCS), launched in the ’80s and 90’s, had a bandwidth of around 200Mbps.[14] Its follow-on, Wideband Global SATCOM (WGS), has a bandwidth of 2.4Gbps, about 10 times the capacity of the previous generation.[15] The advancement is there, but compared to the Starlink constellation, it leaves something to be desired. Each Starlink Satellite is reportedly at 20Gbps, about 10 times that of WGS, with significantly more satellites in orbit due to the reduction in launch costs.[16]

Solar Panel Advancement

The advancement of solar panels in the past twenty years is another technology trend that will be enhanced with lower launch costs. Solar panel price has dropped by ten times in the last decade and is forecasted for a similar price reduction by 2030.[17] Virtually

[14] “Defense Satellite Communications System > U.S. Air Force > Fact Sheet Display,” accessed February 6, 2023, http://www.af.mil/About-Us/Fact-Sheets/Display/Article/104555/defense-satellite-communications-system/.
[15] “Wideband Global SATCOM (WGS) / Wideband Gapfiller System,” accessed February 6, 2023, https://www.globalsecurity.org/space/systems/wgs.htm.
[16] “SatMagazine,” accessed February 6, 2023, http://www.satmagazine.com/story.php?number=1026762698.
[17] Adam Dorr and Tony Seba, “Rethinking Energy 2020-2030 100% Solar, Wind, and Batteries Is Just the Beginning,” n.d.

all satellites use solar panels for power and will continue until other feasible forms of space-based power generation are found.

Within a space mission design and development, different solar panels would be evaluated not based on cost but on performance for the mission. That would likely include some trade between solar panel efficiency, weight, power, and length of life.[18] Typically, the cost was not the governing factor. This led to manufacturers choosing solar panel designs that may not be the most cost-efficient but had suitable other characteristics. But because weight is losing importance, and performance in terms of efficiency and power is improving rapidly, cost now becomes a factor in design. It could be speculated that with the improvements of this technological trend, powering satellites will no longer be a significant consideration within the design, allowing for more rapidly and cheaply produced satellites to come to bear.

Software and Autonomy

Another trend affecting the industry is the continued improvement of software technologies, including autonomy, machine learning, and artificial intelligence. Software development is undergoing a renaissance of sorts. ChatGPT and Microsoft's Copilot are making coding more accessible than ever before. These large language models can translate natural language into coding solutions almost as fast as they are created. One example saw an iPhone application that would have taken a week to develop shrink to under an hour.[19] Software development is improving with the advent of these artificial intelligence solutions.

The Space Force has yet to capture these improvements fully. Take, for example, the next generation of the GPS ground station. It has been plagued with cost and schedule overruns for years. Some attribute this to the legacy software design in big aerospace companies. In an interview conducted by the author, new space company True Anomaly has created ground control software that allows their newest satellite to fly completely autonomously, only seeking decision input from an operator.[20] This software was created in a matter of months. Anduril, a tech start-up focused on defense, recently developed hardware-agnostic autonomy software.[21] Any future satellite could run on this software platform fully autonomously. The pace of innovation will only continue to improve and, as a by-product, improve spacecraft performance.

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[18] James R. Wertz and Wiley J. Larson, eds., Space Mission Analysis and Design, 3rd edition (El Segundo, Calif. : Dordrecht ; Boston: Microcosm, 1999).
[19] "Developer Asks ChatGPT to Code a Flappy Bird Clone, This Game Ensued," TechEBlog, April 2, 2023, https://www.techeblog.com/chatgpt-flappy-bird-clone-game/.
[20] Nichols, Thomas, Interview with True Anomaly Cofounder, March 27, 2023.
[21] Jaspreet Gill, "Anduril's New Tech Could Allow Single Operator to Control 'hundreds' of Autonomous Systems," Breaking Defense (blog), May 3, 2023, https://breakingdefense.sites.breakingmedia.com/2023/05/andurils-new-tech-could-allow-single-operator-to-control-hundreds-of-autonomous-systems/.

Mega-Constellations

Combining all these technologies has driven the design and beginnings of mega-constellations. Constellations of satellites are multiple satellites that work together to perform a task or objective. Depending on the orbit, a single satellite can only serve a small part of the globe. The closer the orbit to Earth, the less ground area it can provide service, and the more satellites you need in a constellation.

Constellation sizes have typically been in the single digit to tens of satellites, but mega-constellations are in the thousands. For example, the GPS constellation is 31 satellites large.[22] Starlink, the most well-known mega constellation, has ambitions of 42,000 satellites.[23] Given the high launch cost, delivering larger satellites in orbit made more sense. Lower cost launch reverses this trend, and the cost equation now favors smaller payloads in a greater quantity with iterative development that can capture the trends.

The targets and trends here are considered part of the baseline for creating the futures. All futures assume Starship works. All futures assume the four trends continue and that the space industry fully captures the trends. Combining all these trends will drive some of the critical technologies discussed in future scenarios. Next, each of the variables will be explored as spectrums of possibility.

[22] "GPS.Gov: Space Segment," accessed February 6, 2023, https://www.gps.gov/systems/gps/space/.
[23] AFP-Agence France Presse, "SpaceX Says Likely Won't Need 42,000 Satellites For Starlink Internet," accessed February 6, 2023, https://www.barrons.com/news/spacex-says-likely-won-t-need-42-000-satellites-for-starlink-internet-01663009507.

ACQUISITION SPECTRUM

The first variable in discussion is the pace of the acquisition of US Space Force weapon systems. For this paper, the terms acquisition and procurement will be used interchangeably. A program manager can manage and measure a specific program through cost, schedule, and performance. Current programs are high in cost and slow in schedule but high in performance. On the other end of the spectrum, what will be called the Agile end of the spectrum, acquisition programs will be faster, cheaper, and iterate on performance; the middle attempts to achieve benefits in all three aspects of acquisition with hints of greatness. Rapidly improved launch vehicle performance does not necessarily drive the service to the agile end of the spectrum but will undoubtedly influence the industry toward that baseline. This chapter will cover an overview of cost, schedule, and performance. Then each end of the spectrum from the same perspective and the implications of each.

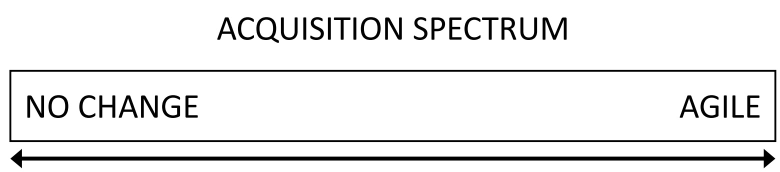

Figure 3: Acquisition Spectrum

Cost, Schedule, and Performance

Total lifetime cost is a crucial metric for government programs. The F-35 program is the most expensive program the Department of Defense has ever purchased.[24] Total lifetime cost is the single metric used to determine that moniker and where the public ultimately judges the program. What aspects are included in the total cost? Research and Development, design, test, operations and maintenance, and end-of-life cost.[25] Plotting each of these items on a chart, with time from left to right and dollars spent vertically, creates the cost curve. Aircraft cost curves end up with the highest total cost during the operations and maintenance phase of the program. When you fuel and maintain an aircraft for thirty years, the cost eclipse research and development primarily due to the amount of time of the phase. The cost could also be considered the unit cost of each aircraft or satellite. Cost is only one of the big three of acquisition.

Schedule for acquisition programs is more complex than it sounds as any different measures for schedule can be used. A program's life cycle could encompass the initiation of a requirement until full operational capability and would be considered one measurement of schedule. Another could be the schedule from one acquisition milestone to another, for example, from design to test or from test to operations.[26] This paper will discuss the term schedule more globally regarding an average overall speed. Any method that improves or reduces pace would be addressed as an improvement or reduction in

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[24] F-35 Cost
[25] Items that go into total and lifetime cost
[26] Scheduling from DAU

schedule, respectively. Likewise, an improvement in schedule is generally seen as an improvement in speed. Though speed may not always be good, as an independent variable, faster is better.

Performance is another tricky variable that has multiple definitions. Doctrinally speaking, performance is simply whether or not the program in question meets the key requirements and objectives set forth at the program's initiation. The requirements can come from many sources. Fundamentally they may be driven by some combination of joint force commanders and then negotiated by program managers with defense contractors concerning what is possible within cost and schedule parameters.

With simplified definitions out of the way, the paper will now turn to the acquisition spectrum. Anecdotally, program managers joke that you can choose two of the three main variables. If you optimize for cost and schedule, you lose out on performance. The same could be said about the others. Considerations were made to divide the spectrum between cost and performance or some arrangement of the three main acquisition variables but were dismissed. The limitation is dividing three variables across a two-dimensional range. Instead, it will be shown that focusing on the whole, will improve all aspects instead of focusing on individual variables. Additionally, rapid reduction in launch costs and performance will drastically improve all programs across all measures. Therefore, the spectrum is distributed between a current end with little to no change and a hypothetical end where improvements are seen across all three metrics.

Spectrum Current

Performance has been a mainstay of satellite acquisition programs for over thirty years. Many public and high-cost failures in the '80s and 90's led to the rise of mission assurance in a large percentage of DoD satellite programs. Mission assurance is the management of an individual program's technical risk. It focuses mainly on the system and maximizes performance objectives to the potential detriment of cost and schedule.[27] Currently, traditional Space Force acquisitions of satellites follow a model that ultimately places them in a position that necessitates a high degree of mission assurance. The more complex the satellite, the higher the launch costs, the fewer the alternatives, and even the more significant the "national significance" dictate the level of effort. Each of these is assigned a significance for a given program or satellite, then given a "class" rating. Table 1 shows the categories a breakdown of the categories.

[27] Cynthia R. Cook et al., "Ensuring Mission Assurance While Conducting Rapid Space Acquisition" RAND Corporation, December 15, 2022, https://www.rand.org/pubs/research_reports/RRA998-1.html.

Table 1: Risk Profile Characteristics[28]

Characteristic	Class A	Class B	Class C	Class D
Risk Acceptance	Minimum practical	Low risk	Moderate risk	Higher risk
National Significance	Extremely critical	Critical	Less critical	Not critical
Payload Type	Operational	Operational or Demo Op	Exploratory or Experimental	Experimental
Acquisition Costs	Highest life cycle Cost (LCC)	High LCC	Medium LCC	Lowest LCC
Complexity	Very high–high	High–medium	Medium–low	Low–medium
Mission Life	>7 years	≤7 years	≤4 years	<1 year
Cost	High	High–medium	Medium–low	Low
Launch Constraints	Critical	Medium	Few	Few–none
Alternatives	None	Few	Some	Significant
Mission Success	All practical Measures	Stringent/minor Compromises	Reduced mission Assurance standards	Few mission Assurance standards
Typical Contract Type	Cost Plus Award Fee (CPAF)*	CPAF–Firm Fixed Price (FFP)	Cost Plus (CP)–FFP	FFP

The logical conclusion, similar to that described above, is that the greater the performance, the more likely the other categories are to be raised in tandem. For example, if the national significance is high, that would imply that you need a minimized risk posture. Less risk likely means more government involvement and more precise or additional testing requirements. Once you add these requirements, you likely gain in cost, further elevating the class of a satellite system beyond what may seem comprehensible to the average taxpayer. The first "Advanced Extremely High Frequency" (AEHF) satellite cost the Air Force $2 billion.[29] In contrast, on the other end of the spectrum, the first Iridium satellite, designed in the same decade, was likely on the order of $5 million per satellite.[30] This represents a 400 times cost differential. The capability differential is vast, AEHF being a highly complex system that operates the United States Nuclear Communications suite and is highly secure.

Getting this level of performance comes at both a high cost and typically long schedules. Before transitioning to the Space Force, the AEHF program was cited as one of the most expensive acquisition programs on record.[31] Additionally, the technical challenges have led to schedule overruns on many occasions. A recent notable example can be seen in the ground software for the newest GPS satellites.[32] Schedule delays are also seen in life cycle duration. Infrared sensing satellites like the Space Based Infrared

[28] Ibid, 77.

[29] Mark A. Lorell, Robert S. Leonard, and Abby Doll, "Extreme Cost Growth: Themes from Six U.S. Air Force Major Defense Acquisition Programs" RAND Corporation, October 6, 2015, 12 https://www.rand.org/pubs/research_reports/RR630.html.

[30] Finkelstein, S. and Sanford, S. H. 2000. "Learning from Corporate Mistakes: The Rise and Fall of Iridium." Organizational Dynamics, 29 (2):138-148

[31] Cynthia R. Cook et al., "Ensuring Mission Assurance While Conducting Rapid Space Acquisition" RAND Corporation, December 15, 2022, https://www.rand.org/pubs/research_reports/RRA998-1.html.

[32] "Raytheon's GPS System Was Delayed Six Years. Now It's Held Up Again," Bloomberg.Com, February 17, 2023, https://www.bloomberg.com/news/articles/2023-02-17/pentagon-s-raytheon-gps-satellite-system-delayed-further.

System (SBIRS) have life cycles stretching 40 years from idea to end of life.[33] A Space Force program manager would never see the entire program duration during a twenty-year career.

The current end of the acquisition spectrum is challenging. But it has provided the best Space Force in the world. Let's now look at what could change if adopting a more agile acquisition approach.

Spectrum Agile

For satellites that must operate in the physical challenges of space, development and design take a significant priority. The previously mentioned high launch costs are also factored into the first phases. Finally, fuel and replacement part costs are not issues for present-day satellites. Re-fueling satellites is effectively non-existent. The cost of building, developing, and launching a refueling satellite is similar to just launching another satellite you are trying to refuel. Aircraft fall from the sky without fuel. Satellites do not suffer the same fate once the fuel is depleted and may continue to offer valuable services with an empty tank. Additionally, today's satellites were developed during a period of no competition. Maneuverability, and therefore fuel, was not a significant design priority for a completely permissive environment. The ISS is the only satellite refueled, is done so only due to its political pressures, and is frequently a topic of conversation for abandonment. Parts replacement has similar cost savings to the above for similar reasons. It is simply easier and more cost-effective to build another satellite than to replace parts for an old one, the exception again being the ISS.

Therefore, once the satellite is on-orbit, the only continuing costs are operating via software and maintenance via software updates. When extrapolated over a cost curve, a satellite's cost differs from an aircraft's. Most of the total cost of a satellite is to the left in time at the beginning of the program.

Applying agile development principles to space hardware could rapidly transform the industry. Agile is the term used to describe a development and project management process that focuses on rapid iteration with minor incremental improvements over time.[34] Traditional DoD program development focuses on the waterfall approach to development. Waterfall methodology proceeds linearly, beginning with the end in mind and proceeding sequentially from start to finish, each development phase waiting on the previous one to complete. The lifecycle process described above is a representation of the waterfall method applied. Typically, agile development is focused on software because of the challenges of rapidly iterating hardware. While code changes can take minutes to hours and have a marginal cost, retooling a manufacturing line could take days to weeks. Meanwhile, the line is down and no longer producing. However, the strengths agile development brings to the table are also winning over in manufacturing.[35] Agile has shown that rapid improvement can be made when focusing on delivering capability,

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[33] "Space Based Infrared System," United States Space Force, accessed December 6, 2023, https://www.spaceforce.mil/About-Us/Fact-Sheets/Article/2197746/space-based-infrared-system/
[34] "Agile," accessed January 23, 2023, https://www.atlassian.com/agile.
[35] United States, Government Accountability Office, "Agile Assessment Guide" September 2020, 2.

focusing on the end user, and focusing on outcomes. Indeed, the DoD has been attempting to become more agile over time. Though most significant programs have not successfully employed agile methodology across the board, smaller arms of the DoD have seen more success. Kessell Run is a software and acquisition team separate from the core of Air Force acquisition and is focused on agile software development and deploying helpful code to the warfighter.[36]

Agile uniquely impacts cost and can significantly improve costs to DoD space operations if employed with traditional satellite hardware. Key aspects driven by agile development include simplicity, waste elimination, quality, accountability, rapid delivery, and transparency.[6] All of these can help reduce the cost of space acquisition programs if done correctly over time.

An agile approach could be made in the space domain with a rapid decline in launch costs. For example, imagine a weekly space launch that carried satellite hardware iterations, tests, and experiments. In today's landscape, a weekly launch is impossible due to the lack of manufacturing of single-use rockets. If the launches were carried out with today's cost structure, a weekly launch would cost north of $5 billion, nearly five times today's cost. In a world where Starship is launching weekly at the forecasted price of $5 million, a weekly launch becomes only $250, the cost of some single launches today.[37] When comparing the capability of 50 launches against one single launch for the same price, it becomes difficult to understand the positive impact on capability. Each launch is treated like a software deployment, with iterations of hardware each week, various tests of capabilities like thrusters or antennae, and "spaceworthiness" testing for various commercial-off-the-shelf products or current earth-bound DoD hardware. Spaceworthiness testing is simply the method used to determine if an item can withstand the extreme conditions of outer space. Starship enables a low-cost option to test the spaceworthiness of already-developed technology that could benefit capability within the domain or back on Earth. For example, an airborne radar could be repurposed into a space-based radar without the need for the stand-up of a new radar acquisition program. A weekly launch looks feasible, an agile approach becomes the favored development method, and a new era of satellite development is achieved.

The agile approach is not new to the space industry, though it may seem radical. An agile approach to hardware is the exact approach SpaceX has taken with the Starship vehicle and their Starlink satellites. Many more commercial companies are approaching satellite development in the same way. The Space Force can lean into these developments and take advantage of the approaches for better warfighting capabilities sooner rather than later.

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[36] "Kessel Run | Code. Deploy. Win.," accessed January 23, 2023, https://kesselrun.af.mil/about/.
[37] This math comes from the figures in the previous chapter.

Conclusion

This paper is not a judgment on current acquisition practices but instead a paper on possibilities. Though it is widely said across USSF leadership that improvements need to be made, it is also said by other experts that the Space Force is the best in the world at what it does. What does a future in the Space Force look like with a rapidly different launch industry with no change to current acquisitions? Likewise, what if the launch industry changes military acquisition and procurement in tandem?

WEAPONS SPECTRUM

Over the next few years, the United States will decide the extent of weaponization in the space domain. How does an increase in the capability of mass-to-orbit change this decision? While space has been militarized since the beginning, the United States has refrained from creating and using weapons in space. As adversaries increase their capabilities in space and terrestrial domains, the US will explore options to counter these capabilities, and space may hold the key. This chapter will discuss the decision space concerning weaponization, generating a spectrum of possibilities. The spectrum ranges from being defensive to driving towards offensive capabilities that start with non-kinetic effects and progress towards kinetic effects. This chapter will focus on satellites, tactical-level capabilities, and what a potential increase in mass-to-orbit may bring along the spectrum. The discussion will primarily be on what are physically and technically feasible and not necessarily specific systems. This will include intelligence, surveillance, and reconnaissance (ISR) capabilities and other options. Like the other spectrum chapters, this spectrum will drive the alternate futures later in the research. The discussion will begin with a brief overview of how to create effects with weapons. Then, it will move toward where current capabilities lie on the spectrum and how they will change. Finally, the discussion will move across the spectrum towards total kinetic activity before concluding.

Creating Effects Through Weapons Systems

First, a brief overview of creating effects and the military context. Weapons effects can attempt to achieve one or more of the "Five Ds": Deceive, Deny, Degrade, Disrupt, and Destroy.[38] Each has a distinct and different purpose, but all focus on preventing the adversary from accomplishing a task or objective. The five D's are helpful because they can showcase a range of effects. For example, deception and disruption effects could be non-kinetic and reversible. If the US or its adversaries attempted to prevent total kinetic warfare in space, it might still use non-kinetics to create effects. Typically, degradation and destruction techniques are considered kinetic warfare. Kinetic attacks are the most traditional in warfare: bombs, bullets, mortars, and explosives. A typical non-kinetic effect could be a cyber attack, jamming, or even the signal provided by GPS. When applied toward that end, the five D's are primarily offensive but may provide defensive options for a new weapon system.

From an ISR perspective, the weapon system generates information that can be turned into ISR. The intelligence collection process is vast and complex and will not be the focus of this discussion. However, within weaponization, the targeting cycle helps focus a subset of the larger world of ISR. For this paper, the targeting process of Find, Fix, Track, Target, Exploit, and Assess (F2T2EA) will drive the discussion for space ISR. F2T2EA is a targeting process that can enlighten the broad array of intelligence activities needed to create effects on a target.[39] A single weapon system or many different weapon

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[38] "The Five Deadly Ds of the Air Force's Cyber Arsenal – Foreign Policy," accessed March 2, 2023, https://foreignpolicy.com/2013/04/12/the-five-deadly-ds-of-the-air-forces-cyber-arsenal/.
[39] US Air Force 3-60 Targeting

systems can complete the process. For example, a fighter jet or a foot soldier may be able to complete the F2T2EA process independently. Another example would be a remotely piloted aircraft generating the Find, Fix, and Track pieces to pass the data to a Special Forces unit to Target, Exploit, and Assess. For this paper, the F2T2EA process will be used as a discussion tool to aid the discussion of ISR capabilities along the weaponization spectrum.

The following sections discuss the current level of weaponization, then create the spectrum and divide it into three distinct parts. The sections include maintaining the current low to no weaponization level, moving then to non-kinetic and reversible effects, then finally to kinetic and non-reversible effects.

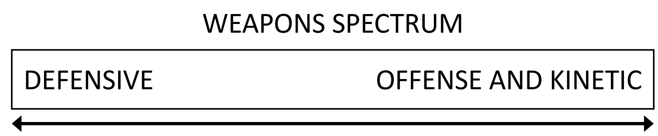

Figure 4: Weapons Spectrum

Current Weaponization (or lack of)

Currently, USSF satellite systems have little to no defensive or offensive capability.[40] Many satellites in operation today were designed, developed, and launched in the post-Cold War era. At the time, Russian space capability was either stagnant or non-existent, and China had yet to rise to its current prominence. No distinct adversarial threat existed that could challenge the services provided from the space domain. When competing with other priorities in design, warfighting capability fell off the table.

At the time of design, choosing services over defense made sense. With the launch capability of the past 30 years, distinct choices had to be made to keep satellites within the size, weight, and power requirements. In a careful design balance, where the developer must choose between capabilities and design objectives, adding additional defense capability does not make sense when the threat does not exist. Today's satellites in orbit are built and operating as designed with little to no defensive capability.

USSF satellites today are almost exclusively "force enablers" or intelligence sensors. The Global Positioning System (GPS), the Space Force's most publicly known service, provides precision position, navigation, and timing services to the joint force. This enables the force with data previously unavailable. Programs developed in the 1990s still provide valuable services to the joint force. One of those systems, Overhead Persistent Infrared (OPIR), creates infrared intelligence products like missile detection and warning.

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[40] Copp, Tara, "Pentagon Scrambles to Defend 'Juicy Targets' After Rivals' Space Tests," Defense One, November 18, 2021, https://www.defenseone.com/threats/2021/11/pentagon-scrambles-defend-juicy-targets-after-rivals-space-tests/186925/.

Additionally, terrestrial services built and paid for satellites to win the terrestrial conflict. The Air Force developed most space services, but the Navy and Army also had distinct contributions. Furthermore, the latest guidance from the newest USSF service chief reiterates the objective of the USSF is to enhance the capabilities of the sister services.[41] The deputy of USSPACECOM has called Earth the prime directive of the Space Force.[42] However, the adversary has recognized the US reliance on space and sees it as a weakness ripe for exploitation.

The focus on the terrestrial fight has created a vulnerability that will only grow as the US and its Allies generate more and more space capabilities with greater launch capacity. The critical upcoming decision surrounds weaponization. Will the US focus on defensive capabilities or seek to weaponize the domain? The decision space lies on a spectrum of choice and has been reproduced visually below for reference.

Defensive Weaponization

The first end of the weaponization spectrum is defensive capabilities. Defensive capabilities may be the most logical next step in design. The capabilities and services provided by the Space Force have proven immensely valuable over the years. The combined increased reliance on space by the joint force and a lack of defensive capabilities create "big juicy targets" for the adversary.[43] When considering the factors of weaponization initially outlined in this chapter, defensive capability may seem easier than moving toward offensive capability.

Additionally, a defensive capability is likely not as politically charged as an offensive space capability, given the consistent call to use space for peaceful purposes.[44] Calls for defensive capabilities are on the rise. Congressmen, DoD senior leaders, and others have all made calls that the successive iterations of satellites must have defensive capabilities.[45] But what does defense in space look like?

A simple way of determining defensive capabilities is using the logic of the 5 D's and the F2T2EA process. Defensive capabilities deny the adversary the ability to generate one of the 5 D's against a friendly capability. Likewise, disrupting the F2T2EA process for the adversary will have a similar effect.

In that vein, defensive capabilities include maneuver capability and deception. Greater maneuverability allows evasive action and repositioning to avoid a threat. Deception may disrupt a targeting cycle. Increased launch capability increases the capacity of both defensive options. Previously, fuel budgets were primarily based on

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[41] USSF CSO Theory of Success

[42] John E Shaw, Jean Purgason, and Amy Soileau, "SAILING THE NEW WINE-DARK SEA," *Aether* 1 (Spring 2022).

[43] Sandra Erwin, "Space Force Not Buying Large Satellites for the Foreseeable Future," *SpaceNews* (blog), January 24, 2023, https://spacenews.com/space-force-not-buying-large-satellites-for-the-foreseeable-future/.

[44] Jinyuan Su, "Use of Outer Space for Peaceful Purposes: Non-Militarization, Non-Aggression and Prevention of Weaponization," Journal of Space Law 36, no. 1 (2010): 253–72.

[45] Space Force Quotes

mission profiles that did not include defensive maneuverability but just enough to complete the mission over the designed life. Adding fuel adds weight and complexity to the system, but lower launch costs make the decision easier. Likewise, deception becomes more accessible with lower launch costs. Deception could be accomplished through stealth which may add weight to material selection. Deception with decoys could also be enabled with a lower-cost launch due to the affordability of additional mass.

However, improvements to weapon systems are not the only defensive option enabled by lower-cost launches. Additional architecture and force design choices may inherently be defensive as well. For example, two topics broadly discussed are resiliency and reconstitution. Resiliency is the ability of a weapon system to survive an attack, and reconstitution is the ability to reorganize or refill a constellation that has suffered losses due to an attack.[46] Both architectural components help the survival of the delivered service or effect.

For example, resilient satellite constellations can provide a form of defense without needing specific capabilities. A resilient satellite constellation defined would be one that can withstand losses without degradation in services provided. In general, the more a capability is distributed across multiple satellites, the more resilient that capability is.

The GPS constellation provides a simple case study. A user only requires a signal from four GPS satellites to generate position, navigation, and timing. To provide the GPS service globally, the constellation requires 24 satellites, given the orbit selected for the constellation.[47] Additional satellites serve to provide resiliency for the constellation. As of this writing, the GPS constellation has 31 satellites in orbit. The other satellites offer redundancy. From a service perspective, the user may routinely be provided signals from 6-11 satellites just based on the timing and orbital positions of the satellites. In that scenario, the user could suffer a ‘loss’ of up to seven satellites and still receive accurate position, navigation, and timing.

Lower-cost launch, coupled with other compounding technologies, can provide resiliency to an extreme in the form of mega-constellations. Starlink has popularized the concept of the mega-constellation, and the military has called for similar capability in defense.[48] Instead of one satellite with many jobs, the system becomes many satellites with one job.

Resiliency can be gained in other ways as well. The Proliferated Warfighter Space Architecture seeks to use different layers of orbits with multiple satellites performing separate united functions across the constellation.[49] In this example, distributing the many

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[46] “Leveraging Responsive Space and Rapid Reconstitution - Joint Air Power Competence Centre,” May 14, 2021, https://www.japcc.org/essays/leveraging-responsive-space-and-rapid-reconstitution/.
[47] “GPS.Gov: GPS Accuracy,” accessed March 22, 2023, https://www.gps.gov/systems/gps/performance/accuracy/.
[48] CSO SASC Comments March 2023
[49] Rachael Zisk, “The Proliferated Warfighter Space Architecture (PWSA): An Explainer,” Payload, December 5, 2022, https://payloadspace.com/ndsa-explainer/.

desired service tasks across the system decreases the risk of any single point of failure. Resiliency is discussed again during the alternate futures.

Finally, defensive ISR is used for attribution and defensive readiness preparations. Increased quantities of these satellites coupled with artificial intelligence algorithms can vastly increase information gathering while decreasing the workload on intelligence analysts.[50] Before it causes a service disruption, knowledge of threat activities may be all that is needed to prevent the interruption. Space Force Guardians will undoubtedly welcome more actionable intelligence produced by the effects of cheaper launches.

This end of the weaponization spectrum will likely still provide the warfighter with a massive leap in capability. But newer, more attack-focused capabilities are on the cusp of usefulness. The following two sections move along the spectrum heading towards full kinetic action but stopping first to explore the potential gains within non-kinetic weaponization.

Non-Kinetic Weaponization

As we move along the spectrum, offensive power grows to include non-kinetic warfare capabilities that seek to deny, disrupt, or degrade adversary capability. Typically, the non-kinetic activity includes Electronic Attack (EA), lasers, and cyber activity. To narrow the scope of this research paper, cyber activity has not been included in the discussion.

Non-kinetic activity within the electromagnetic spectrum can benefit significantly from decreased launch costs. Power consumption is a critical component for both satellites and EA systems.[51] The upcoming decrease in mass-to-orbit cost makes launching solar panel power generators significantly easier. More power means more capability. That power could drive an increased engagement range or less precise targeting for an EA system. Both of which expand the possibilities of the space domain.

Increasing power capacity can open opportunities for both space-to-space and space-to-ground EA. Pointing accuracy and targeting could be challenging in space-to-space engagements due to extreme orbital velocities and distances. More power lessens the challenge. More power may make the difference in a battle for electromagnetic spectrum control. This is even more true for space-to-ground targets. More power onboard a satellite may open the opportunity for EA from space via downlink communication jamming like how a C-130J Compass Call jams or using satellites to target terrestrial radars. Satellites' persistence, reach, and overflight capabilities make them excellent providers of these services in anti-access area-denied environments.

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[50] Forrest E. Morgan et al., "Military Applications of Artificial Intelligence: Ethical Concerns in an Uncertain World" (RAND Corporation, April 28, 2020), https://www.rand.org/pubs/research_reports/RR3139-1.html.
[51] US Air Force Weapon School, "Basics of Jamming," 2018.

This same power generation may allow for satellite-based lasers. Laser activity is already occurring in space, used for communications and ranging.[52] However, more powerful lasers may provide more options to commanders to create effects. Lasers can be used to dazzle sensors or damage solar panels.[53] Like Electronic Attack capability, more powerful lasers may provide more range and greater effect generation possibility. Depending on the desired effect, a laser may provide a more permanent and non-reversible effect that simultaneously avoids potential questions on space debris. The optionality provided by lasers makes them an excellent target for the improvements created by greater mass-to-orbit.

Yet power is not the only capability increase in non-kinetics provided by launch. The increase in ISR capability seen above in the defensive section also applies here. Better ISR through more space domain awareness can grow, help create knowledge of the environment and assist in developing non-kinetic targeting profiles for use in a future conflict. Targeting profiles will be useful in this section of the weaponization spectrum and enhance the fight's kinetic end.

Non-kinetic weapons can play a critical role in providing optionality to a commander. Unlike defensive options, non-kinetics allow commanders to go on the offensive to generate effects. Simultaneously, some non-kinetic options prevent permanent damage and allow reversible effects. The non-kinetic option provides a middle ground of opportunity that may escalate from defense but prevents full kinetic activity. However, commanders and national decision-makers may face a decision point where they must choose to escalate into destructive territory.

Kinetic Weaponization

The end of the weaponization spectrum contains kinetic activities. Though partially colloquial, kinetic weaponization is simply using force to create effects. Few kinetic activities are reversible, and most take advantage of the as-yet discussed "fifth D," Destroy. The USSF equips Guardians with tools to win the nation's wars. Kinetic options are on the table for Guardians to fight with.

Kinetic options typically involve the use of physical force to destroy an object. Military options typically involve explosives or ballistics. What does kinetic look like in the space domain? Ballistic weapons on Earth could include artillery, bullets, and bombs. Orbital physics and trajectories prevent simple ballistics from taking pre-eminence as they do in other domains. Space is too big, the distances are too vast, with too many variables at play to make ballistics as simple as point and shoot.

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[52] Petr Boháček, "Peaceful Use of Lasers in Space? Potential, Risks, and Norms for Using Lasers in Space," Space Policy 61 (August 1, 2022): 101489, https://doi.org/10.1016/j.spacepol.2022.101489.
[53] Kari A. Bingen et al., "Space Threat Assessment 2023," April 14, 2023, https://www.csis.org/analysis/space-threat-assessment-2023.

Explosives face a different problem: space debris. Explore a target in orbit; the debris from both the explosive and the target may remain in their orbits for centuries.[54] In low earth orbit, the debris will propagate over time to encompass the entire globe.[55] In other key orbital terrains, the debris will remain an issue at those decisive points for millennia.

Kinetics in space takes a different form. Missile-type objects would likely be guided until impact to overcome the physics complications. Rational state powers would likely minimize debris to keep Earth's orbit and valuable for their purposes. In essence, kinetic weapons would attempt to be guided, low debris systems. Additionally, space kinetics may not be limited to destruction. Denial, disruption, and degradation may gain pre-eminence: space tugs, mass clamps, and cutting tools could all be used to create an effect.

Another exciting technology made possible by increased mass to orbit is kinetic bombing from orbit. Given the high speed of orbital velocities, simply dropping a heavy payload will create a destructive effect.[56] The estimated required mass for such a system may now be within reach to fully explore this potential weapon. Though not a solved issue, the fact that it's possible warrants special attention for this paper.

Rapid cost declines in the launch industry will see a rapid increase in capability in the next few years. Debates will likely ensue. The development of both the air domains

Conclusion

Among the three main variables, weaponization holds the most wide-ranging and new possibility space. Moving from the realm of the current to the realm of the possible opens up warfighting possibilities previously unseen in the domain. While a future exists that weaponization as defensive only, fully weaponization cannot be ignored as a possibility. Politics of the day change. States seek advantages over one another. With advancements in launch technology, the possibility in the weaponization spectrum is vast. Next, the variable of 'control' will be discussed before diving into the alternate futures.

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[54] Chia-Chun Chao and Felix Hoots, *Applied Orbit Perturbation and Maintenance, Second Edition*, 2nd Revised edition (El Segundo, California : Reston, Virginia: AIAA American Institute of Aeronautics & Ast., 2018).

[55] Ibid.

[56] "Rods From God," New York Times (Online) (New York, United States: New York Times Company, December 10, 2006).

CONTROL SPECTRUM

Command and control is part of warfighting that governs who is in charge of who as well as who is giving the orders and making decisions. Modifying this variable can change how the US Space Force fights its wars, organizes its people and weapon systems, and builds and designs its systems. Marine Corps Doctrine Publication 6 outlines two parts of the spectrum: detailed control and mission command. "The two approaches… mark the theoretical extremes of a spectrum of command and control."[57] Figure XX is a simplified version of the control spectrum written initially in Marine Doctrine in 1996.

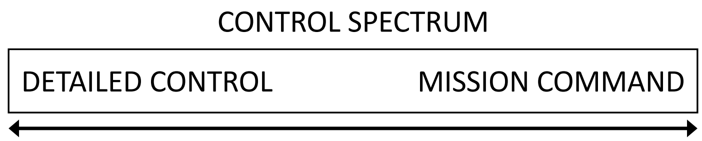

Figure 5: Control Spectrum

The spectrum provided here will form the basis for the discussion below and will follow similarly with translations to the space domain. A brief overview of common challenges and misconceptions is provided below, followed by a more expanded look at each end of the spectrum within the domain.

Overview of Control

Command and control of space forces require some nuance organizationally. While the US Space Force equips Guardians with the tools to conduct warfare, US Space Command (USSPACECOM) is the entity responsible for the command and control of space forces assigned to it.[58] In practice, the US Space Force builds a weapon system and delivers it to USSPACECOM for Operation. US Space Force acquires a weapon system based on the requirements developed by the joint service, which is informed by all the combatant commands like US Space Command. Given that US Space Command is the entity with the preponderance of space assets, the requirements set forth by the command considerably influence the US Space Force. How US Space Command chooses to command and control its forces will influence how the US Space Force chooses to build its weapon systems.

Additionally, the nuance of control and its impact on technological development may spark debate. Does the spectrum of control influence the weapon system and its design? Or does the weapon system and its design influence control? In other words, what came first, the technology or the governance of the technology? Either side of the argument can be made. But, for this paper, the assumption becomes that the embedded culture and bureaucracy ultimately drive the requirements of the technology developers.

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57 United States Marine Corps, Command and Control, Marine Corps Doctrinal Publication. 6 1996, 80-88.

58 "United States Space Command Fact Sheet," United States Space Command, accessed April 10, 2023, https://www.spacecom.mil/Newsroom/Fact-Sheets/Fact-Sheets-Editor/Article/2181548/united-states-space-command-fact-sheet/.

With this assumption, choice becomes a factor within the requirements design, and requirements language may be crafted to dictate a design toward a specific control bias.

What about technology? Does it improve control capabilities? The research suggests that more data and clearer understanding do not produce better decision-making. Because C2 technology improves simultaneously with battlefield technology, the decision timing worsens. For example, comparing battles at sea through time, while naval commanders graduated from flags to radios, contact with the enemy dropped from 6 hours to 90 seconds.[59] The same will be true as technology advances.

Surprisingly, joint doctrine is relatively silent on who can have explicit control. The commander is specified as the owner, but it can be delegated. Doctrinally defined, who has control varies on several factors: number of subordinates, number of activities, range of weapon systems, force capabilities, the size and complexity of the operational area, and the method used to control operations (centralized vs. decentralized).[60] In other words, according to joint doctrine, who has control is up to the commander.

Cultural inertia can play an essential role in the outcome of this spectrum. Cultural change is hard, and the more entrenched the Space Force becomes in any culture, the harder it will be to change.[61] The Space Force and its commanders are in the driver's seat for this spectrum. Whether or not it changes is as crucial to its commanders as to the weapon systems and autonomy presented.

Detailed Control

The first end of the spectrum of control is detailed control, where significant decisions for action and maneuver need approval at high levels of the combatant command. Though detailed control may sound rigid at first glance, it provides advantages to a commander. First, detailed control at a high command level makes sense, given the relatively low activity in space coupled with the strategic implications of space assets. The security picture is not incredibly complex, and the impact of a single space asset is high. Detailed control provides higher synchronization between forces and more precise lines of responsibility, integration between weapon systems due to the broader picture.[62] USSPACECOM commanders use detailed control today. Large satellites with substantial strategic implications are typical.

Rapidly reducing the cost of space launch while maintaining a culture of detailed control may lead to similar detail-control-oriented satellites. It may also lead to weapon systems that follow the same level of control dynamically. Given that the control

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[59] Michael A. Palmer, *Command at Sea: Naval Command and Control since the Sixteenth Century* (Cambridge, UNITED STATES: Harvard University Press, 2005), 321. http://ebookcentral.proquest.com/lib/cfvlibrary-ebooks/detail.action?docID=3300371.

[60] United States. Joint Chiefs of Staff. Doctrine for the Armed Forces of the United States. JP 4-3. Vol. 1. Washington, D.C.: Joint Chiefs of Staff, 2020.

[61] Juan D. Carrillo and Denis Gromb, "Cultural Inertia and Uniformity in Organizations," Journal of Law, Economics, and Organization 23, no. 3 (October 2007): 743–71.

[62] United States Marine Corps, Command and Control, Marine Corps Doctrinal Publication. 6 1996, 80-88.

environment that exists today, the logical extension of detailed control leads to weapon systems similar in form and function today.

If mass-to-orbit increases significantly, size and mass may increase; however, quantity and independence may not. Detailed control seeks centralization, discipline, and optimization.[63] Larger weapon systems and fewer forces are easier to centralize and optimize. Smaller quantities of forces, in either number of troops, or the number of weapon systems, maybe an easier sell to Congress. Detailed control communicates explicitly and vertically through the telling of orders. Fewer weapon systems may allow tighter communications within the limited space Force.

Weapon systems developed within these parameters could be large situational awareness systems, more extensive systems with bigger and better sensors, higher-level commanders controlling more and more satellites, command and operations centers to centralize data and decision-making, and less control at the unit and spacecraft level.

Mission Command

Mission command is characterized by decentralization. It assumes that lower-level commanders understand the guidance and intent of senior leaders and are given the authority to execute what they think is best within that context. Relative to detailed control, mission command is more informal, favoring implicit communication and ad hoc organization required to get the mission accomplished. It also relies upon the initiative of lower-level commanders and the self-discipline needed to complete execution. Mission command accepts a higher level of disorder and uncertainty in a trade for the benefits.[64] Disorder and uncertainty in circles like the space community are words typically associated with risk.

Given the strategic nature of orbits, the Space Force actively struggles to engage mission command. Though recently promoted by the Chief of Space Operations as a desired characteristic in Guardians, it is much harder to achieve in practice.[65] As previously mentioned, current satellite systems cost the US government hundreds of millions and sometimes billions of dollars. Any additional risk created by mission command is hard to swallow without elements of detailed command baked into the process.

Radically cheaper launch costs may change the young service due to the changing nature of satellites. More satellites may drive more opportunities for risk-taking. According to the mission assurance tables previously discussed, less expensive satellites could directly translate to less risk. More capability that is more evenly distributed across orbital regimes may require ad hoc organizations. Deliberately planning for and training

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[63] Ibid.
[64] Ibid.
[65] United States Space Force. Office of the Chief of Space Operations, “CSO’s Planning Guidance,” November 2020, 5.

these principles can create mission command principles useful for combined arms warfare in orbit.

Autonomous Operations

Autonomous control finds itself in a unique position on the spectrum of control. Autonomous operations require a critical look due to the rise of software and machine learning algorithms. Autonomy can mean many things. Autonomy can encompass low-level systems or higher-order procedures depending on how the software is designed and implemented.

For example, some current Space Force satellites require the active download of health data. In practice, this looks like a Guardian requesting time on an antenna, connecting to the satellite, running the proper download, and assessing the data. This series of steps could be considered a low-level task.[66] Some of these low-level tasks are actively in progress toward autonomy. The software would perform each step instead of the Guardian to automate the low-level task. In the case of the example above, autonomy would save a Guardian a significant amount of time or free the Guardian to work on higher-order tasks. Lower-level autonomy is a virtual requirement the larger the constellation.

A similar software mechanism would work for higher-order tasks. Planning and executing a maneuver would involve fuel analysis, creating the maneuver software, assessing the maneuver, uploading the maneuver software, and performing the task. Even higher order could be deciding a maneuver is needed in the first place and dynamically maneuvering based on that decision. This could happen in a safety or collision avoidance maneuver or whatever the software rules dictate.

The above may have been considered science fiction, but software has closed the gap between fiction and reality. The next step is determining approximately how much control a commander will give to a satellite system and a set of controls. Painfully obvious would be to prevent programming anything that would erroneously trigger an act of war. Rules of engagement could then be programmed into software to prevent any action that could be considered hostile.

Developers building from scratch have created some impressive orbital mechanics software. During interviews with the author, some of the newest satellite companies developed training agents that develop proximity operations software and trained satellites on satellite maneuver operations over a billion times to master the maneuvers.[67] In the Air domain, an AI agent successfully flew an F-16 against a human pilot and won.[68] The industry is progressing rapidly compared to historical maneuver software,

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[66] Author's knowledge from 12 years of satellite operations experience.
[67] Nichols, Thomas, Author Interview with True Anomaly Cofounder, March 27, 2023.
[68] Jon Harper, "AI Agents Take Control of Modified F-16 Fighter Jet," DefenseScoop (blog), February 14, 2023, https://defensescoop.com/2023/02/14/ai-agents-take-control-of-modified-f-16-fighter-jet/.

where operators have little control and require the contractor to develop specialized code for every maneuver.

Rapid reduction in the launch cost will continue the trend toward autonomy for satellites exponentially. If launch costs drop dramatically and exponentially increase the number of satellites, autonomy becomes more and more of a requirement. The US Space Force is considered a relatively small military service and is not likely to gain additional personnel soon, which will catalyze autonomy. Instead of having operators watching the satellites 24 hours daily, the engineers get text messages only when the software needs human intervention. When the Space Force needs a squadron of 60 people to operate 25 satellites and the commercial gold standard needs zero to operate tens of thousands of satellites, questions will come quickly from senior leaders.

Autonomy does not necessarily mean mission command or detailed control. Either of these control principles can be programmed into the underlying weapon system. However, autonomous operations will likely become a massive point of effort within the space industry. Space will likely be the first domain to take advantage of the improvements in software, mainly because of the rapid improvement in launch capability. Understanding the level of autonomy and how to program it will drive the conversation about the spectrum of control.

Conclusion

Autonomy and control are inextricably interlinked. Due to the nature of satellites, the Space Force will likely be the first service to move toward impressive levels of autonomy. The extent of autonomy will likely be determined by the amount of control the service wants. Each approach has positives and negatives, though the Chief of Space Operations intends to drive to a mission command. Cultural inertia may impede the nascent service's ability to achieve that control, and its worth considering the entire spectrum in alternate futures. The following four chapters discuss those futures and what each may look like.

“RESILIENT MEGA-CONSTELLATIONS”

The future of “Resilient Mega-constellations” may come to pass sooner than outlined in this paper. Mega-constellations describe satellite formations that reach a vast quantity: hundreds to thousands of satellites working in concert to provide an effect. The constellation by quantity is resilient to attack by the adversary. The scenario is a logical outcome of the compound effect of all the trends described in the paper but shies away from weaponization. Acquisition and procurement are rapid and iterative, control is mainly autonomous, and weaponization is defensive if it exists. Below, each of the spectrums will be elaborated upon, and a short scenario will be given to explore the benefits and drawbacks of this future.

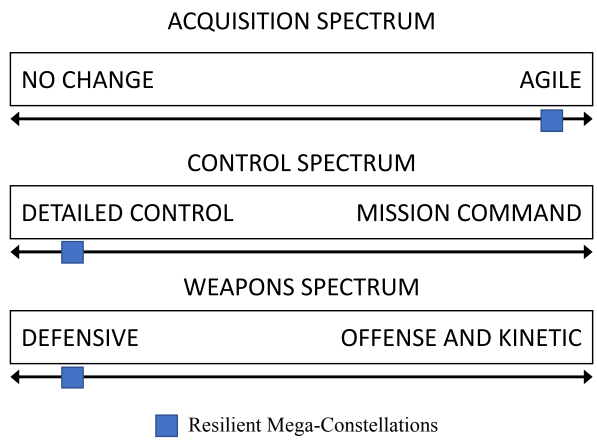

Figure 6: Scenario 1 spectrum layout.

Acquisition

In this future, the acquisition and procurement arm can leverage the fast-moving pace of the commercial space industry to budget for, contract, and buy small and iterative satellites. Each piece of that puzzle is in place based on fundamental requirements from combatant commanders, and more satellites are delivering more effects than ever before.

Concerning speed, satellites are contracted, built, and launched within two years. Instead of having a multi-year contract period, contracts are regularly scheduled to support a steady and advancing constellation pace. Likewise, numerous bidders are awarded multiple contracts to increase competition and ensure the satellites are on time. Given the high flight rate of the Starship vehicle, satellites and rocket ships are traded frequently to preserve manifest and pace.

Iteration and size become critical to reaching maturity and gaining an incremental advantage. The manufacturing and design speed needed to maintain the above pace may require some trade-offs upfront, but those trade-offs may be replaced over time as the constellations grow. Likewise, designing smaller satellites with fewer functions can improve the manufacturability and the quantities available for launch.

Weapons

This future sees little to no advancement in weaponization. Instead, it focuses on resilience as a form of defense. The passive nature of resilience becomes interesting in its own right. The speed of manufacturing of the vehicles ensures that consistent replacements are available. Constant flight rates of Starship allow for replenishments of lost pieces of the constellations.

While improvements for offensive non-kinetic or kinetic activities do not improve, minor enhancements to defensive capabilities are notable. Indeed, the small size of the satellites proves useful for defense in the proportionate increase in maneuverability.

Those improvements also drastically impact the cost reduction of the satellites and complicate adversary targeting. Coupled with a cost reduction is an increase in resilience. The cheaper the satellite, the less of an impact this has on costs to the owner, in this case, the U.S., but it also impacts the adversary's calculations. The effect of the loss of a satellite to the U.S. would be measured in terms of cost and the impact on the mission. For a mega-constellation, the loss of any one satellite would be minimal to the effect of the mission because the remaining satellites would still provide the service. For the adversary, a direct attack on the constellation becomes challenging due to the quantity and relative importance of any one satellite. In this case, raw numbers become defensive. Space warfare ceases at the individual satellite level and moves to the constellation.

Control

Control for resilient mega-constellations would default to detailed control but autonomous. Autonomy would be required for the operations of the mega-constellation due to its size. Any single satellite would not be individually controlled as the numbers within the constellation would rapidly outpace the available Guardians to manage them.

Control is likely detailed as the autonomous features present less of a need to decentralize and allow for a global perspective on the constellation. Higher-level officers can control the constellation and understand impacts as reported to them. Because any individual satellite can be lost and replaced on a whim, communications at the individual satellite level would likely cease. Instead, constellation and effects-based health status would replace normative communication up the chain of command.

Additionally, rules and orders are likely planned for scenarios requiring pre-programmed autonomous decision-making. Space Debris and collision avoidance maneuvers would likely become automatic and function as part of a system to maximize the health and effects. Advances in artificial intelligence have opened swarm technology to guide the constellation to maximize health and safety and provide more significant effects to the warfighter.

Scenario

With the build-out of U.S. Space Force mega-constellations, the force multiplication from space has never been higher. Data rates, position, navigation, and timing signals have never been more robust, enabling advanced and semi-autonomous drone warfare. Gone are the days of complaints about data caps and the internet that's too slow on the ship. Surveillance and reconnaissance satellites provide an almost real-time common operating picture of the globe, ensuring live updates on the positions of the adversary's most dangerous weapons.

U.S. Adversaries have realized the futility of attacking individual satellites directly. Global pundits have acknowledged that the mega-constellations have notably increased peace and deterrence. However, public calls for government and military oversight have never been higher for fear of a 'watchdog' state. Adversaries, thinking more practically, have pursued other avenues for manipulation. Terrestrial-based spoofing and jamming of signals have become the tactic of choice. However, more subtly awaits a sleepy Space Force.

The swarm technology used to avoid collisions with space debris has worked flawlessly since inception and reduced the hours required by Guardians. China has recognized the reliance on this system. Over a few weeks, Chinese operators have maneuvered a formation of satellites close to a significant swath of surveillance and reconnaissance satellites. The latest maneuver has forced an autonomous swarm maneuver to higher altitudes and put a temporary blind spot in the global operating picture.

The Space Force reacts rapidly by attempting to override the autonomous software and launching replacements. The latest Starship launch will occur within the next twelve hours, and due to the recent events, the manifest swap protocol option was implemented between SpaceX and the USSF. The Space Force took government priority over the next commercial launch. The software is another issue. Though autonomous once in orbit, ground controls have come a long way and provided flexibility. However, the override was inconveniently frozen for a 45-minute interval during the Chinese maneuver. Later details from cyber defense teams would reveal that an exploit was used to freeze the monitors in the background of the computer interface. The attacker is unknown.

The damage is already done. The rift in intelligence provided an opportunity for a missile attack on a critical new semiconductor factory in Taiwan. Though intelligence sources cannot confirm Chinese involvement, the disruption to the ISR constellation leaves little to the imagination. Without the semiconductor factory, conditions are set for an invasion of Taiwan.

Conclusion

In some ways, the future presented here is already in progress. The Space Development Agency just launched its first tranche of satellites forming a new constellation of satellites with even more to follow. This launch sews the first seeds of what could be the future of mega-constellations in the Space Force.

Resiliency is actively called the best defense, being so strong that the adversary chooses not to attack. However, a willing adversary always finds a way. Consider the resiliency and defense of the Maginot Line in France between world wars. Instead of attacking the defensive positions of the French, the Germans bypassed them entirely.[69] Relying on resiliency should not be the default defense for future Space Force architectures.

[69] J. E. Kaufmann and H. W. Kaufmann, *The Maginot Line : None Shall Pass* (Praeger, 1997).

"PEACEKEEPER GUARDIANS"

This scenario encompasses a future with an increased pace of acquisition, mission command type control, and weaponization to include non-kinetic activity. Though the US Space Force has weaponized to the degree that its willing to deny the adversary its ability to create effects, the US has not weaponized the domain kinetically. Fear of the political backlash of weaponizing has prevented the development of such weapons, but geopolitical realism remains strong within the government. Acquirers have been able to leverage commercial partners but have been unable to replicate them. The personnel limitations of the fledgling service have forced mission command and culture change has occurred to allow for junior commander decision-making.

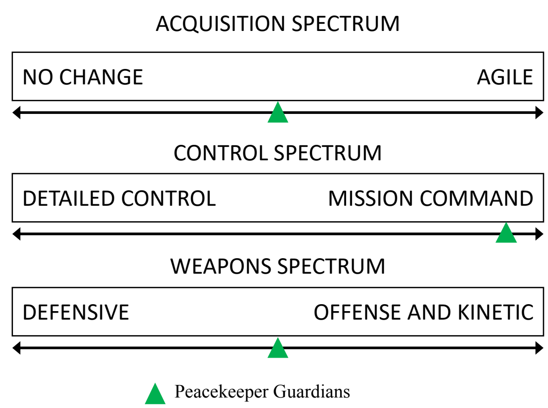

Figure 7: Scenario 2 Spectrum Layout.

Acquisition

The acquisition community can increase speed in some activities, but not to the scale seen with commercial space companies. Instead of thousands of satellites, tens to hundreds would be used to create effects for the warfighters on the ground. Quantity increases allow for more options in orbit to create effects on Earth.

Iteration capability improves, but not a rapidly limited lifecycle like the commercial sector. Instead of decades-long satellite procurement programs, shorter three to five-year programs have become more regular. Needs addressed within a given fiscal year are appropriately budgeted and executed within a nominal budget outlook.

In the previous scenario, increases in acquisition pace correlated to a satellite size reduction. In this scenario, the correlation between the weaponization of non-kinetic weapons has the opposite effect: an increase in the size of satellites for more power and payload capability. The desire for greater power coupled with only a minor increase in speed guides the increase in size—greater-sized solar panels to match power requirements.

Weapons

In this scenario, non-kinetic weaponry normalizes, especially reversible effects and effects that do not cause additional space debris. Lasers and electromagnetic spectrum jamming systems are launched regularly. To create a significant impact in the electromagnetic spectrum, quantity, and power requirements increase with the growth of adversary capability. Additionally, given the distances in space, similar increases in fuel and maneuver technologies work in tandem to create highly maneuverable weapon systems. This capability minimizes range requirements for the jamming weapon systems but requires closer approaches of the satellites to the targets.

Electromagnetic spectrum denial occurs not only in space-to-space engagements but also in space-to-ground or space-to-air engagements. Communication disruption, radar disruption, and other techniques control the "airwaves." Targets include direct military weapon systems but also intelligence assets, command and control units, and civil-government agencies of the adversary. The breadth of capability launched enables individual electromagnetic target folders to be produced for each target, providing electromagnetic precision for all units involved.

Control

The increased complexity from both an increase in satellite quantities and weaponry options creates the need for a greater focus on mission command. Precisely, control authority and responsibility move down the chain of command. While control is still higher than that of a single pilot in a single jet, commanders control squadrons of satellites that work in tandem. To produce an effect.

While lower-level commanders now have more responsibility, the maneuverability and additional fuel make the satellites available for "worldwide" operations, increasing the area of responsibility for a squadron of satellites. In turn, some aspects of control are still at the higher levels. However, understanding the increased capability, more rule sets are made for troops to follow in times of combat. The rules of engagement are complex and untested but based on a fundamental understanding of orbital mechanics, the physics involved, and a similar assumed knowledge from the adversary.

Scenario

As tensions rise in the South China Sea, USINDOPACOM has asked the Space Force to provide options to support an Integrated Air Defense System attack operation across the major island chains, manufactured or otherwise. The joint force commander is in a dilemma. Both aircraft and naval vessels are at extreme risk, and significant lives could be lost without some changes made to the plan. Initial planning involves regular sorties of wild-weasel fighter aircraft taking incremental islands with expected casualties of greater than fifty percent. Naval forces cannot proceed through the area until the air defense system is disabled. Stealth bombing seems out of the question as the manufactured island chains have extensive radar systems to negate the stealth options. However, the Space Force options may change that.

The focus on electromagnetic dominance for the newest service has provided many capabilities to the space domain, including space-to-ground radar jamming systems. The latest plan begins to take shape, now involving stealth aircraft and the combined arms of the space domain.

The threat picture for the space force planners involves the protection of radar jamming satellites. Two squadrons are formed, a Suppression of Enemy Air Defenses team, which will attack the abovementioned problem, and a Defensive Counter Space team. Chinese anti-satellite missiles are not expected to be used as the debris problem is already too severe. Still, orbital attack satellites quickly move “toward” the Space Force satellites. Fortunately, rules of engagement previously established have clear lines based on orbital mechanics that, if breached, allow the defensive team to engage.

However, as execution time draws near, the adversarial satellites straddle the previously determined engagement line, causing rapid discourse amongst defensive team members. The rules are clear. However, the rules were made before the significant enhancement of maneuverability of the satellite systems. The choice: either take control outside the ROE or allow the aggressor satellites to disrupt the radar jammers, likely leading to a loss of terrestrial stealth capability. Saving lives is the easy choice, and mission command wins the day.

Breaking the rules of engagement was not without cost. Though the bomber flight made it to the targets, the adversary now knows the combined nature of the attack. Too many coincidences have created a clear picture and knowledge of the threat from orbit and escalated the conflict in orbit. Adversary anti-satellite missiles are likely on the table for the duration of the next phase of the South China Sea conflict, but mission command in the space domain has saved the day.

Conclusion

Out of all scenarios, this future seems most likely. Progress by industry will continue to advance, and the Space Force will capture as much as possible. Leaders from both acquisition and operations are pushing for change in their arenas. This scenario seems highly possible unless adversarial actions push the new service to a more weaponized state.

"FORTRESS IN THE STARS"

This future extends current practices for acquisitions into the future. Weaponization has advanced significantly but remains tightly controlled due to its political ramifications. The control spectrum has remained tight and at the highest levels. This future explores the potential of kinetic weapons with little-to-no other change with the other variables.

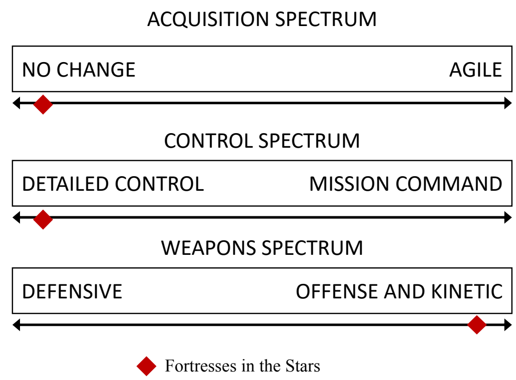

Figure 8: Scenario 3 Spectrum Layout.

Key Characteristics

Acquisition and Procurement: In this future, no significant changes will be seen in the acquisitions variable from current methodologies. This looks like more extensive programs focused on one primary objective. Block-buys of low double-digit quantities of more capable weapon systems. Speed and cost take a back seat to performance in primary objectives. The military dictates requirements instead of the commercial sector providing options. Cost-plus contracts are the norm, with a steadily inflating budget over time.

Weaponization in response to potential threats from adversaries, the USSF focuses heavily on developing and deploying advanced space-based weapons. This includes kinetic and directed-energy weapons and advanced satellite jamming capabilities. However, given the relative lack of speed increase from the acquisition and procurement, weaponization is not all-encompassing but relatively focused on a few minor challenging targets or problem sets.

Control Spectrum: In this scenario, tight control is maintained over the weapon systems. Strikes against targets must first be discussed at committees and thoroughly and meticulously planned. Decisions on strikes are likely made at the general officer and above level as part of a key option within a strategic campaign. Likely, some discussion revolves around whether to use various capabilities and the implications of doing so.

Scenario

China continues to advance its presence in space at a rapid pace. Additionally, China has continued developing and building anti-access area-denial (A2AD) weaponry to deny the U.S. and its allies' freedom of maneuver within territories claimed by China. While the US Navy has continued its efforts to build counter-A2AD weaponry, the adversary has forced a multi-domain solution that includes space assets.

The rapid decline in launch costs has opened options never thought realistic by force designers but has offered a solution: space-based bombing. Previously thought impossible due to the constraints on mass, the Space Force pursued the technology to crack the complex A2AD network in place by China.[70] Specifically, the persistence and overflight capabilities of the space domain have made it the perfect choice for this problem set.

While a permanent and persistent overflight presence would be ideal, the overflight of space-to-ground weapons is fraught with controversy at the highest levels. Still, the solution is better than the alternative. Previously, a naval carrier strike group would be forced to enter a contested sea space relatively slowly. With more than 5,000 souls aboard a single ship, the risk for the carrier and crew is high. The Space Force's weapon, though not actively overhead to prevent escalation, a simple change in orbit could position the weapon overhead in hours.

The initial vision of kinetic bombing from orbit did not entirely explore the range of the possible. Visions of this weapon from the past included massive 20-foot long by 1-foot diameter fully metallic rods that 'dropped' from orbit. These rods would produce the equivalent of a nuclear blast in TNT.[71] Previously, due to its size and mass, the weapon was thought to be impossible to launch. Launch costs have decreased to the point where lifting such a device is now possible. While fantastic in capability, the political ramifications of such a weapon were all too much to swallow.

However, the latest developments have modified the design for more practical use. The high launch rate from the rocket industry has provided many opportunities for test and refinement. The weapon decreased in size significantly. Instead of nuclear in scope, the bombs are much more tactical. They maintain the original draw of the program, however: persistence, overflight, and surprise. Space-to-ground weapons seem like the perfect counter to A2AD systems placing US naval assets at risk.

Even though the adversary has anti-satellite missiles, the preference for 'at risk asset' becomes an uncrewed spacecraft instead of the carrier strike group. Not only are no lives at risk, but the bombing satellite also becomes a debris risk if destroyed, a sound political and scientific deterrent to the adversary. Previously, the A2AD system may have

[70] "Rods From God," New York Times (Online) (New York, United States: New York Times Company, December 10, 2006).
[71] Ibid.

deterred the US from conducting freedom of maneuver activities in waters near China. No longer. Instead, the system flips the deterrence on its head.

Conclusion

The scenario and force design depicted above studied a potential future where progress happened mainly in the weaponization of space. Tight control of weapons and a steady application of known acquisition principles lead the service down a path of traditional, larger weapon systems with political ramifications. Though seemingly fantastical in design, the dramatically lower cost of space access brings fantastical weapons and thoughts borne out by the pure physics of the possible. However, the scenario shows that with more power comes more responsibility. This scenario can help paint a vision of that future.

“COMMANDER’S DREAM”

This scenario has weapons in space, mission command, and an improved acquisition pace. Development in Cislunar space has also begun as the race to capture the moon’s resources is in full force. Though seemingly unlikely, a firm realist foreign policy from China and the US could push the world in the direction captured here.

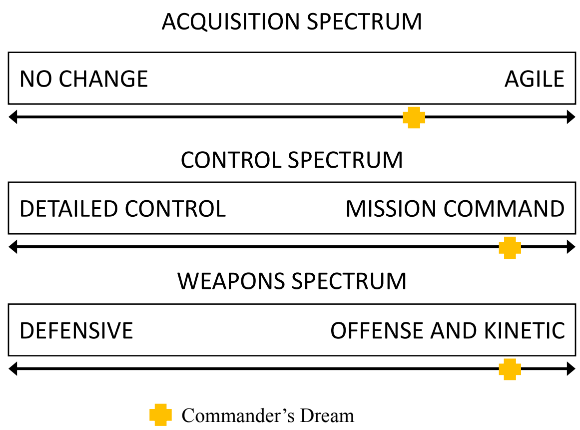

Figure 9: Scenario 4 Spectrum Layout.

Weapons

This scenario sees a weaponized orbital regime’s full realization from space-to-space and space-to-earth. Extreme focus on “low-to-no debris-generating” platforms has changed the political conversation around weaponization from risk to domain to risk to the coalition and its partners. The USSF can hold adversary assets at risk and conduct routine patrols of key orbital terrain. Reusable launch vehicles have given rise to weaponry.

Satellites can create engagements with other satellites. Squadrons of satellites flying together and working cooperatively to develop effects create unique opportunities for tactics development. Combining uplink jamming, sensor confusion, and kinetic activity allows the Space Force to cause a range of denial options against the adversary directly.

Though the maneuverability of satellites has increased due to the limitless launch mass, Key Orbital Terrain remains essential due to the physics of changing between orbits. Like the US Navy has Task Groups in various waters across the world’s oceans, the Space Force does the same with multiple orbits. For example, the US Navy has the 7th Fleet based in Japan, with upwards of 70 ships for a significant presence in the Pacific. Likewise, the Space Force now has a Low Earth Orbit equivalent with tens of satellites conducting freedom of operation exercises on a routine basis.

Goals from the CSO have been achieved with a relative balance toward achieving joint effects. The theory of success is realized by producing weapon systems that provide force application and not just force enhancement.

Acquisition

This scenario sees improvement in the acquisition but not to the entire end of the spectrum in all cost, schedule, and performance areas. Though each has improved, Guardian acquisition officers cannot match the pace of commercial development but can capture many gains.

Performance sees the most notable increase relative to the big three acquisition areas. Instead of fully diving into mega-constellations like commercial entities, the Space Force has continued to push performance within satellites. Though the satellites are not massive mega structures like in the ‘90s, systems have steadily improved in maneuver, power, sensor, and weaponry.

Improvements to schedule are notable and harken back to the ‘60s. Instead of program lifetimes of 40 years, systems are programmed for ten years with planned obsolescence with improvements factored in the design. Starship has created a platform for testing hundreds of times cheaper than the current day equivalent X-37B.[72] It has allowed commercial and military research groups to rapidly advance space technology. Cost has declined on a performance and per unit basis. While overall budgets remain at 2024 levels, relative performance has significantly increased.

Control

Out of necessity, control has dropped down the chain of command to effects-based commanders. Each subset of satellites, even if different, works to achieve a similar function with a mission director commanding a group. This enables coordination amongst similar weapon types and across entire satellite battle groups.

Squadrons have day-to-day control of their vehicles, but systems are mainly autonomous. Training and exercising tactical operations become routine. Instead of daily tasks of just keeping the satellites alive and gathering status updates, Guardians are training for the most potentially challenging missions. Exercises at the operational and strategic levels become routine, where multiple geographic commands work together to achieve effects and project American military power across the globe.

Scenario

The growth within the space industry has led to a massive increase in competition between the US and China in the push to the moon. The new space race is in full effect, but instead of racing to see who can get to the moon first, it becomes about who can exploit it first. US commercial companies are establishing footholds on the planetary body to bring low-gravity manufacturing and resources back to Earth. USSPACECOM is readily prepared with multiple task groups across key orbital terrain.

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[72] “X-37B Orbital Test Vehicle,” United States Space Force, accessed April 17, 2023, https://www.spaceforce.mil/About-Us/Fact-Sheets/Article/3263321/x-37b-orbital-test-vehicle/.

Tensions are on the rise on the dark side of the moon. Sites now use communications relay satellites orbiting the moon as the central relay between Earth and Moon operations. Suspicious activity is mounting with an increasing pace of faults at a US-based commercial site, faults at a rate far beyond typical. This site is shared with a Chinese-based entity describing itself as commercial. Intelligence gathered in the past two years has led the US to believe kinetic weapons designed for terrestrial targets are in development at the Chinese base. These kinetic weapons could be launched without warning and be masked for the whole trajectory until entering Earth's atmosphere.

The Cislunar Task Force Bravo (CTFB) is a moon-bound group of 15 satellites with various capability options. Its counterpart, Alpha, is on its fortnightly return from the moon.[73] Bravo has been tasked to deviate from routine Cislunar transfer orbit to investigate the relay satellites in orbit. Additionally, permission has been granted by USSPACECOM to conduct lunar bombardment demonstrations as part of weapons testing.

CTFB has spent the last few years conducting orbital inspection operations and training. The suite of capabilities includes satellites with diverse space domain awareness sensors, including infrared, electro-optical, and radar systems. Additionally, electronic warfare satellites have intelligence platforms for electromagnetic spectrum collection and assessment and jamming capabilities across the commonly used frequencies in this orbit. Refueling capability exists as part of the task force, though it has yet to be used as the CTFB typically remains within its orbital regime. Multiple kinetic options exist as well. The task force has mechanical repair capability with a dual purpose as mechanical disabling. The CTFB's newest satellite also has ten lunar warheads that seek to destroy lunar targets, such as weapons facilities. The fragility of lunar structures requires little force to cause destruction, and even minor gravity prevents major debris concerns.

The plan is for combined tactics as the CTFB approaches the relay station. First, the jamming satellites will disrupt the relay station for a twenty-minute window, immediately followed by the demonstration of the new lunar weapon. No adversary engagement is expected, as CTF Alpha was in a similar terrain two weeks ago. However, the adversary gets a vote.

Launching the lunar bombardment weapon was no secret due to its role as a deterrent. Chinese orbital engagement satellites waiting in hiding on the lunar surface are waiting to intervene and show presence. The adversary has surprised CTFB's commander; the units maintain discipline. Without time to communicate the 'surprise' to senior leaders, training and mission command comes to the forefront. The mission commander decides to prevent war and cancels the jamming portion of the plan, though the demonstration still commences.

[73] M J Holzinger, C C Chow, and P Garretson, "A Primer on Cislunar Space," n.d. 2021.

Though derided by Chinese Communist Party leadership in the public domain, the US has expressed its voice as an advocate for freedom of action in space. In back-channel talks, lunar-based weapons development has ceased… for now.

Conclusion

"Commander's Dream" exists in various forms in many junior Guardians' minds. Younger Guardians see the potential of the service if the lessons of the past can be combined with the technology of the future. Mission command combined with the weapons of today's terrestrial domains would make a mighty force for freedom in space. Though it may feel fantastical, everything described here is within the realm of technology today, if required and selected for that future.

IMPLICATIONS AND RECOMMENDATIONS

This chapter will highlight some implications and recommendations for the Space Force senior leaders to consider. Similar to the structure of the scenarios, short recommendations will be given for each of the variables: acquisitions, control, and weapons.

Implications

The rapid manufacturing, iteration, and launch capability gained with a drive toward mega-constellations will have a long-lasting impact on the effects brought from space. Data rates may finally keep up with demand, and intelligence to the warfighter will only improve.

While mega-constellations have colossal potential, relying on numbers and autonomy for defense seems short-sighted and unrealistic. Resilience may be helpful from the perspective of a direct attack. But resilience is not prevention. Without a similar increase in focus on weaponization, even if tactical only, the resilient constellation will be at risk just like any other system.

Autonomous systems can remove a significant workload from Guardians. Routine orbit keeping and collision avoidance by software could mean more operators used for warfighting thinking and planning. This could lead to substantial organizational changes, or drastic drawdowns in the Space Force.

An overhead weapon of destruction may enflame tensions between the US, its Allies, and its adversaries. Persistence overhead, choosing targets at any time, long durations, and failure potentials may drive fear in any nation that flies under the device. Decades of experience within the nuclear and air domains have created regulation and understanding not yet present in the space domain. The governing document on space weapons may confuse. The UN's Outer Space Treaty (OST) is nebulous on specific space weaponry. In particular, the treaty states that weapons of mass destruction may not be used in space.[74] The weapon outlined in this scenario would not be classified as such.

However, as seen in some scenarios, the greater the space domain's impact, the greater the space debris risk. The advantages the US gains from space provide an asymmetric advantage. Denying or destroying this advantage would increase an adversary's odds of winning in conflict. Anti-satellite missiles are a known method of achieving that destruction. Following the logic, increasing space-based weapons may increase the likelihood of space targets, thereby increasing the likelihood of space debris. The US must ensure some level of debris mitigation through active or passive measures.

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[74] United Nations, *Outer Space Treaty,* 1967.

Recommendations

Acquisition:

Space launch dollars only on reusable vehicles. Space launch has come a long way since the Evolved Expendable Launch Vehicle program. Reusability has proven cost reductions that are of strategic value to the joint force and the U.S. Any dollars spent on launch vehicles that do not have a goal of reusability are dollars spent on backward-looking programs. Given the large percentage of the Space Force budget being spent on launch, focusing on reusability to get those dollars will go a long way toward creating competition in the launch market.

Prioritize investments that leave the optionality open, like space-based capability in the following key areas: power generation, maneuverability (engines, reaction thrusters, fuel, etc.), cross-domain weaponry (Electronic Attack, Kinetic Bombardment).

With rare exceptions, the lowest levels of mission assurance categories should be used. Mission assurance provides value, ensuring the most critical space assets get to space and work. During an era of massive fundamental change, risk must be taken to capture that change fully. Slowing the process to mitigate risk may allow the adversary to catch up.

Control:

Miniaturization, resiliency, and disaggregation can lead to an autonomous future. Autonomous and self-healing operations create opportunities to decrease the number of space force personnel attached to the service providers. Those services, like GPS and satellite communications, could even reasonably be contracted out. What, then, should be done with Guardians on those systems? Higher-order decision-making.

The higher-order decision-making, commanding, and complex operations are left to the more ‘warfighting complex’ futures where a human-in-the-loop is more likely desired. Likewise, highly technical and complex pieces of operating spacecraft need to be delegated to software functions and outputs that any operator can understand. “Maneuver by committee” cannot be an effective strategy in conflict.

Each Guardian’s highest and best use is using them to their fullest potential. While detailed control has its place, each Guardian can be an asset to the fight if given the initiative and ability to do so. The Space Force could do this by creating opportunities for mission command with the newest iterations of satellites. Ensure that the newest satellites have their organization at the squadron level. This would allow Guardians operating the new satellites to thrive in a new environment outside the traditional satellite model. Due to the absence of a risk-averse culture, more initiative could begin in a grassroots manner creating mission command within Guardians.

Weaponization:

Due to the vocal nature of those wishing to keep space a domain of peace, calls for weaponry seem dramatic. However, from a realistic international competition perspective, weaponization of space becomes a requirement. Advantages can be gained from even the most minor progression into weaponization. Defensive methods provide an advantage to the US and its Allies where none previously existed.

The architectures unlocked by huge increases of mass to orbit are unknown. The most significant change could be the creation of orbital bombardment weaponry. Starship's entry onto the launch vehicle market should warrant a revisit to this fantastical idea due to the benefits it could provide the joint force and the national security options it could provide the U.S.

Conclusion

A significant challenge for a non-imperial and democratic nation is staying ahead of the adversary without appearing imperial. Understanding the realm of the possible and working toward positive outcomes is the only helpful goal. Doing nothing may be the worst outcome of all.

CONCLUSION

The research here has proposed alternate futures based on exploring control, acquisition, and weaponization changes. First, a brief overview of the research methodology was presented, describing the use of variables and the possibilities matrix as the tool for selecting futures. Then a brief overview of the history of launch vehicles, the future of Starship, and "known" trends were covered. These were used to set the stage for the variables and the future scenarios.

Then each variable was made into a spectrum where each end would be a wholly different take on that variable. Within the acquisition spectrum, cost schedule and performance were lumped together for a holistic look at improving all three vice stagnating current practices. For the control spectrum, mission command was compared to detailed control, and the rise of autonomy was contemplated for additional analysis. Weaponization was explored as it is today, little to non-existent, to full weaponization of the domain to include full destructive capabilities.

Each scenario attempted to look at unique perspectives in the matrix of possibility. "Resilient Mega-Constellations" explored the promise and peril of abundance within classic orbital military services. "Peacekeeper Guardians" explored the potential of radically increasing electronic warfare capability. "Fortresses in the Stars" looked at how Space Force design may look after Starship without significantly changing the main variables. Finally, "Commander's Dream" sought the potential that many Guardians can envision of the future of the service: combined arms in space beyond just Earth orbit.

One item noticeably absent from this paper is the strength of the adversary. The US has been historically reactive and not imperial. Though there have been many times of conflict, the development of weaponry has typically been responsive to the threat and the intelligence on that threat. The absence of the adversary was deliberate to highlight the range of possibilities despite what the adversary does. However, that is not representative of how the US will respond. Currently, China is continuing its efforts as a copycat state. Currently in development are a Chinese Starship and a Chinese mega-constellation.[75] The Chinese Starship looks eerily like SpaceX's.[76] The adversary gets a vote in determining the future of the Space Force.

This paper carries with it the potential of Starship and low-cost access to space. But it mainly carries the potential of a young service. What is becoming more and more sure is that Starship is coming, and that the commercial world is rising to take advantage. The US Space Force can match the pace and exciting potential of the commercial sector, but only if it seeks changes in some key areas.

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[75] "China Gears up to Compete with SpaceX's Starlink This Year | Reuters," accessed May 7, 2023, https://www.reuters.com/business/aerospace-defense/china-gears-up-compete-with-spacexs-starlink-this-year-2023-03-02/.

[76] Andrew Jones, "Chinese Startups Conduct Hot Fire Tests for Mini Version of SpaceX's Starship," SpaceNews (blog), January 19, 2023, https://spacenews.com/chinese-startups-conduct-hot-fire-tests-for-mini-version-of-spacexs-starship/.

This paper has focused on areas within the control of the nascent branch of the DoD: acquisition, command and control, and weaponization. These areas will shape the service for years to come, just like the previous generation shaped years past. Even if Starship does not live up to the promise described here, the potential for change can still shape the future of the service.

The outcomes presented within this paper are all theoretically possible and take no significant leaps to reach. Assuming SpaceX achieves its goals with Starship, a new era of spaceflight will be ushered into existence. The purpose of this paper is to highlight the possibilities of that era. If the US wants to leverage this new technology fully, it is time to start planning now. Starship has taken flight. Regular flights will be here in less than the time it takes to create a new program to leverage the enhancements. Fully leveraging this American space innovation will supercharge strategic competition in the space domain for years.

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