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HOW TO WIN(G) A WAR IN SPACE: ENABLING RAPID SURGE SPACE CAPABILITIES

by
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PREFACE

There are two sayings among space operators: "military space doctrine and spacepower theory in 2024 has about the same maturity as airpower doctrine and theory did in 1924," and "Space has yet to have its Pearl Harbor moment."* While the first is very much up for debate, the second is true – there has yet to be a mass attack of such profound gravity that it radically changes the course of American Spacepower. While the aftermath of Pearl Harbor saw a herculean effort to rapidly establish a massive air enterprise, this project is dedicated to the hope that with the development of a mature doctrine, spacepower theory, and forward-looking policies, the U.S. space enterprise can avoid having to grow up quickly under hostile fire.

In giving credit for this effort, I owe my first thanks to my airmen, whose many questions and observations drove this line of inquiry – most tellingly, "What would military space look like if World War III happened tomorrow?" My peers in the Space Electromagnetic Warfare community further sharpened these ideas through hundreds of conversations, and for this, I am grateful and look forward to many hundreds more. My instructors and course mates in the OLMP program provided immense assistance in editing this final volume, I am grateful for this support, and must emphasize that any residual errors in facts or analysis remain mine alone.

Finally, and most importantly, I would like to thank my beautiful bride, Becky, whose infinite grace and patience enabled me to pursue research and writing through a deployment, two babies, and innumerable life events. Thank you, Love, for the infinite support!

* These sayings, or equivalents thereof, largely originated in the report of the Rumsfeld Commission – more correctly the "Report of the Commission to Assess United States National Security Space Management and Organization" (Rumsfeld, Donald, et al, 11 January 2001)– while the expressed dates and the exact phrasing has evolved over the years, the sentiment remains constant.

ABSTRACT

Space has now become a primary driver of modern warfare. The ability to sense, shoot, move, and communicate in all domains is predicated upon a robust space infrastructure, itself dependent upon space superiority. The resulting space center of gravity, with space at once being a hard-to-defend vulnerability and all-domain force multiplier, presents a challenge in a global all-domain conflict.

As success in every domain requires robust space operations, the ability to rapidly restore lost capability and surge space operations in the face of lost and attritted space capabilities is necessary for operational success. This research posits that on a timeline when an expansion of forces through conventional material acquisitions and personnel accession is infeasible, the equipped, organized, and trained force needed for short-notice expansion of space operations may still be obtained. Qualitative analysis and quantitative assessment of other-domain solutions, analyzed through the lens of specific counter-space threats, suggests that employing unconventional space capacity, as well as leveraging emerging doctrine, training, materiel, and personnel leadership, provides an actionable path to rapid surge of space forces.

INTRODUCTION

"Military history is replete with examples of combat forces employing maneuver warfare to move quickly, sidestep defenses, achieve surprise, reorient quickly in the battlespace, and hold centers of gravity at risk to achieve victory. As in domains of human endeavor on Earth, the advantage in space will go to the force capable of sustaining maneuver on a scale previously unknown to a domain dominated thus far by Keplerian and Newtonian thinking." – Lt Gen John Shaw[1]

The Department of Defense should be prepared to rapidly surge space capabilities in days or weeks because space capabilities have become vital enablers of ground and maritime maneuver, air and cyber operations, and the joint intelligence that informs the command and control of joint all-domain forces. In a major conflict, increased demand for space capabilities can be expected to coincide with battlefield losses to the same, exacerbating a gap in available capacity.

Throughout history, the outcomes of wars have hinged on the victor's ability to rapidly develop and field forces lost to attrition and ensure that no component of the presented forces is weak enough for an adversary to exploit to the point that it renders the other warfighting components ineffective.[2] This was the case during the opening days of the Russian invasion of Ukraine, where a much smaller Ukrainian force used space-derived services, specifically commercial imagery, communications, and precision navigation, to punch above its numerical weight, disrupting the early critical phases of Russian incursion.[3]

Additionally, as a theater of conflict expands, for example, covering all of East Europe or the Western Pacific, demands for space services such as missile warning and counter-ISR will be seen at a level far beyond those experienced during the geographically limited conflicts in Iraq and Afghanistan.

This research effort is divided into four sections, each addressing a different logical aspect of rapid space replenishment, restoring lost capability, and presenting additional operational capacity, referred to as force surge.[*] Part I of this effort relies on existing threat literature to establish what space capability needs will likely be most pressing in a global conflict through parallel analyses of expected attrition and increased demand. Shortfalls are assessed in terms of major space mission areas,[†] with augmentation emphasized for those mission areas most likely to suffer both an increase in demand and a decrease in operational capacity.

Part II informs potential solutions from a service perspective. This is warranted due to the American structure of armed conflict, where forces are presented by the services, such as the Space Force or Army, and conflict is executed under the direction of Joint Force Commanders, such as the commanders of U.S. Space Command or U.S. Forces Korea.[4] Consequently, separate analyses that address the interests of these equal, interrelated, but legally separate parties are warranted. In evaluating potential solutions from a service perspective, specifically, the need to organize, train, equip, and deploy or employ fieldable forces, the assessed needs of Part I inform what non-traditional solutions can plausibly enable these service responsibilities on an expedited schedule.

Similarly, Part III explores solutions enabling a Joint Force Commander (JFC) to best meet command objectives with presented space forces. Recognizing that employment from the

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[*] While this work is written to a military professional audience with limited space background, the author recommends Air University's AU-18 Space Primer as an excellent reference for those interested in increasing their general military space acumen, or who are interested in exploring space warfare concepts to a greater depth than is permitted here.
[†] As defined in Joint Publication 3-14 "Space Operations"

JFC level is principally a concern of human behavior, rather than materiel, this analysis focuses on the capability management considerations of doctrine, organization, training, leadership, and policy needs to enable rapid surge.

Finally, Part IV combines the most promising solutions from Parts II and III into consolidated recommendations, prioritized by needs assessed in Part I. As the means by which services present forces and the JFCs employ forces are ideally synergistic, emphasis is placed on those solutions that 1) meet a prioritized need, 2) enable a service to more effectively organize, train, or equip, and 3) provide a path towards greater JFC lethality. Given the rapid pace of technological change in the space arena and the enduring constancy of human nature, behavioral solutions such as improved organization, training, leadership, or doctrine are emphasized.

PART I - THE NEED FOR TIMELY SPACE SURGE

"All armies prefer high ground to low . . . With regard to precipitous heights, if you are beforehand with your adversary, you should occupy the raised and sunny spots, and there wait for him to come up." - General Sun Tzu

In a conflict creating significant increases in demand for military space capabilities concurrent with battlefield losses of the same, how could U.S. joint space forces achieve a "days to weeks" surge capability? An emerging multi-front war would be challenging enough, especially if the U.S. enters into a global conflict with limited and degraded space capabilities and a joint force that has grown accustomed to reliable space-enabled effects.[5] While all domains would see an immediate need to surge capabilities and massively mobilize forces, how would the military space enterprise meet an expected demand increase while minimizing the impact of attrition-reduced capabilities and forces?

KEY ASSUMPTIONS

Central to this question is a recognition of two assumptions: first, once directed to engage in military action, Joint Force Commanders (JFCs) will need to seize the tactical initiative as soon as the operational environments allow them to do so,[6] and second, relying on purely material solutions to bridge gaps in space capability would be too slow (months to years) to meet increased demand for space capacity alone.[7] Examining the first, military victory often comes down to decisive actions taken at the right window of opportunity, a window often as short as hours or minutes.[8] Success in de-escalating global conflict scenarios to a diplomatically resolvable condition will likely require significant military action - in an instance where a NATO partner has been kinetically aggressed upon, this is an almost certainty.[9] To achieve a state of military dominance that would enable political de-escalation and resolution, those JFCs entrusted to bear the Military Instrument of National Power would seek to seize the initiative of action from an adversary quickly. The critical benefit of holding the operational initiative is being the first mover who creates operational dilemmas for an adversary through posture, maneuver, and successful delivery of massed effect. Dilemmas that limit and ultimately deny their decisional space eventually force said adversary to expend resources and effort without operational gain or seek political de-escalation.[10] Key to this is the ability of the JFC to deliver effects at a time, place, and domain of most significant operational benefit. Consequently, restoration and a surge of space forces too late in a conflict could be of little benefit or worse – the resources expended to gain a "too much, too late" surge scenario could impose opportunity costs that harm efforts in other domains.

Addressing the second assumption, while the U.S. enjoys a large and technologically advanced aerospace industry, a solution predicated upon delivering exquisite new capabilities in any domain is highly unlikely to meet the immediate operational needs of a Joint All-Domain force. Similarly, an assumption of timely replacement in weeks of capabilities that were years in their initial delivery is overly optimistic at best and a poor use of available resources at worst. For example, space vehicle manufacture is an inherently time-consuming proposition: even with technological advances, critical paths in fabrication, assembly, and testing of spacecraft[*] make appreciable reductions in timelines unlikely in the near term.[11] While the Department of the Air Force and commercial space industry have made strides to speed steps such as test and

[*] Space Force and Joint Doctrine differentiate between "Satellites" – any object in a stable orbit around the Earth, and "Spacecraft" – a human-made object performing a specified task in the space domain. Where possible, the doctrinal "Spacecraft" terminology is used here unless referring to a proper name, e.g. "Satellite Control Network" or "2d Satellite Operations Squadron" – Reference Raymond, John, 2020, Space Capstone Publication, 4

inspection, many manufacturing techniques are unlikely to accelerate, barring technological breakthroughs beyond this analysis, and almost certainly not forthcoming by chance during the opening days of a global conflict. Launch vehicle preparation is similarly time-consuming, and barring a few designs built on decommissioned missile boosters, a ready backbench of launch vehicles is not typically kept on hand. Finally, exquisite ground systems (or, as often billed by Space Systems Command – "systems of systems") take years to design, integrate, and field. For example, the NAVSTAR Global Positioning System Next-Generation Operational Control System (OCX) required over a decade from contract award to fielding of the initial ground segments and has years to go before completion.[12]

To meet these competing requirements – massing space-enabled forces and effects at critical moments without reliance upon traditional acquisitions, other techniques for providing space effects without reliance on purely material acquisition solutions are needed. Replacing lost frontline capability with bought, commandeered, or repurposed commercial, academic, or adversary capability is only a first step. Recognizing that the success of any ad-hoc solution rests on human capability and behavior - and that behavior can change rapidly with sufficient motivation (such as national survival), emphasis on behavior-centric solutions, such as modifications to doctrine, training, or leadership, should be emphasized over material acquisitions where time is of critical essence.

HIGHER ORDER EFFECTS

Loss of space assets due to direct attacks may profoundly affect the orbital domain. China, Russia, and India have all successfully tested direct-ascent anti-satellite weapons (ASATs), and Russia and China are suspected of having fielded experimental co-orbital ASAT spacecraft.[13] Strikes on low earth orbit (LEO), or the threat of strikes, present a dilemma as the short time from launch to engagement (15-20 minutes) allows a minimal window of defensive response. Further, the effects of a kinetic weapon may be compounded by the orbital debris resultant from a successful strike, rendering an entire orbital plane and altitude* unusable and creating conjunction hazards to all spacecraft transiting the debris field.[14]

Denial and disruption of space assets may be limited not only to kinetic damage but also to direct cyber-attacks, cyber isolation, and denial of the electromagnetic spectrum, the latter being a predicate for all spacecraft communication. Additionally, while only a few select nations have anti-orbital capabilities, all countries and many non-state actors can attack ground infrastructure. This denial of the ground segment, cyber capabilities, and the electromagnetic spectrum can be just as effective at denying U.S. and coalition ground forces the effective use of space assets.[15]

Key to an analysis of what needed space surge should look like and could look like is an exploration of where specific space mission areas will likely fall short in a rapidly escalating global conflict. Many, but not all, space capabilities will see an increase in demand. More precisely, an increase in demand that can only be met with a proportionate increase in capacity. For example, doubling Satellite Communications data throughput requires (plus or minus some small technological margin) a doubling of available on-orbit SATCOM capacity.[16] Conversely, since the major Positioning, Navigation, and Timing constellations† can serve a theoretically infinite number of users without modification, a surge in demand would not necessarily require

* For circular and near-circular orbits, " orbital period, " the time required to complete a full path, and “altitude, " the height above the Earth’s surface, are functionally synonymous. To provide consistency for an Air Force audience, “altitude” is used throughout, though in the referenced literature both metrics are used.
† Poetically, a group of common-purpose or cooperative spacecraft is referred to as a “constellation”

additional on-orbit capacity. While demand for PNT would almost certainly increase dramatically in a major conflict, minimal additional capacity is needed to meet that demand*.[17]

Finally, many space capabilities will see a reduction in capacity, either through direct battlefield attrition or incidental loss. In either case, loss of space capability may have an immediate and direct effect on operational effectiveness (loss of a U.S. Intelligence or Missile Warning asset) or more delayed onset driving second-order multi-domain consequences, for example, loss of Space Domain Awareness leading to increased exposure of surface maneuver to adversary reconnaissance assets. In formulating needed surge and replenishment options, those assets that will see both an increase in demand and a decrease in capacity, along with the most far-reaching higher-order effects, will drive the greatest need for rapid surge and replenishment.

HAZARDS TO SPACE ASSETS

In categorizing the acts of malice that might befall U.S. spacecraft, the Defense Intelligence Agency (DIA) defines a "counterspace continuum," where threats are arranged by profundity of harm and reversibility of effect. Military deception operations, electronic warfare jamming, cyber-attacks, and non-destructive directed energy weapons are at the less impactful end of this spectrum. Destructive capabilities include kinetic energy weapons, attacks on ground sites, as illustrated in the preceding scenarios, and nuclear detonation, the last having historically had dramatically destructive effects on spacecraft.[18]

* Scenarios where PNT spacecraft are damaged or destroyed drive a far different conclusion.

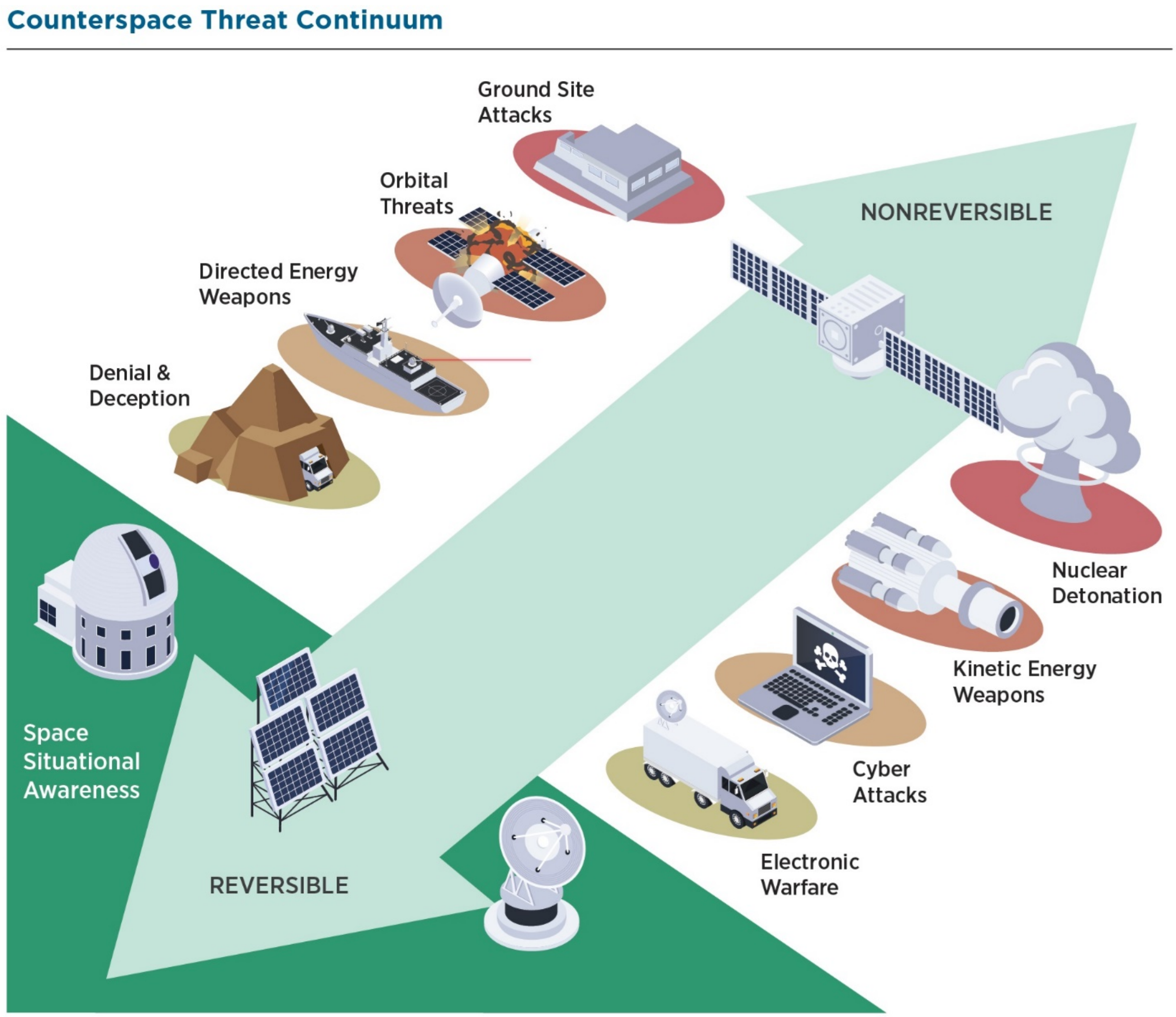

Figure 1: Counterspace Threat Continuum per the Defense Intelligence Agency (DIA, 2022)

Within these broad threat categories, the Center for Strategic & International Studies (CSIS) further divides threats to spacecraft and space systems into counterspace weapons families – Kinetic physical, non-kinetic physical, electronic, and cyber.[19] For surge requirement analysis, both perspectives are helpful. DIA's focus on reversibility informs the need for excess capacity: for example, recovering a capability that is temporarily unavailable due to overwhelm, electronic jamming, or cyber-attack allows for potential solutions centered on lessening denial impact or speeding post-attack recovery. Conversely, destructive attacks may drive reliance upon excess capacity or alternative capability since post-attack recovery may be substantially more time and resource-intensive, if possible at all. Analysis within CSIS' counter space weapons framework allows for assessing vulnerability on a per-space-mission-area basis.

CSIS subdivides into ground segment attacks, direct ascent ASAT missiles, and co-orbital ASAT spacecraft to address kinetic physical threats.[20] The most immediate and pervasive are attacks on ground infrastructure, a mechanism within the capacity of all adversaries, both Nation-State and non-state actors. Compounding this risk are inherent vulnerabilities of U.S. architectures. For example, all U.S. launch facilities, 71% of Spacecraft Control Network nodes, and roughly 50% of surface-based SDA sensors[*] are located on a coastline at hazard of maritime fires.

While theoretically, Direct Ascent (DA) or Co-orbital ASAT threats could impact any orbital regime, in practice, DA-ASAT weapons pose a more significant hazard to LEO orbits, which can be reached quickly by a launch vehicle indistinguishable from a theater ballistic missile.[†] As a spacecraft in LEO orbit will pass within sight of most points on the earth's surface in a given day, a single DA-ASAT battery could theoretically hold most LEO spacecraft, and all above an altitude of 600km, at hazard over a given 24-hour period.[‡] Medium Earth Orbit (MEO), Highly Elliptical Orbits (HEO), and Geosynchronous Earth Orbit[§] (GEO), while still at hazard to DA-ASAT attack, would require substantially larger launch vehicles, the ability to launch from a narrower set of locations or both.

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[*] Reference Appendix A-1 for analysis

[†] At the smallest end of the DA ASAT size scale, the experimental ASM-185, developed and tested by the U.S. in the mid-1980s, was a 3,000lb, telephone pole-sized two-stage missile. Attaining sufficient velocity to reach LEO required launching from an F-15 fighter in a near supersonic, high-altitude climb. Surface based munitions must be substantially larger – lacking the altitude and velocity of the F-15! Reference Glenshaw, Paul, 2018, "The First Space Ace", Smithsonian Air & Space Magazine, April 2018

[‡] Reference Appendix A-2 for analysis

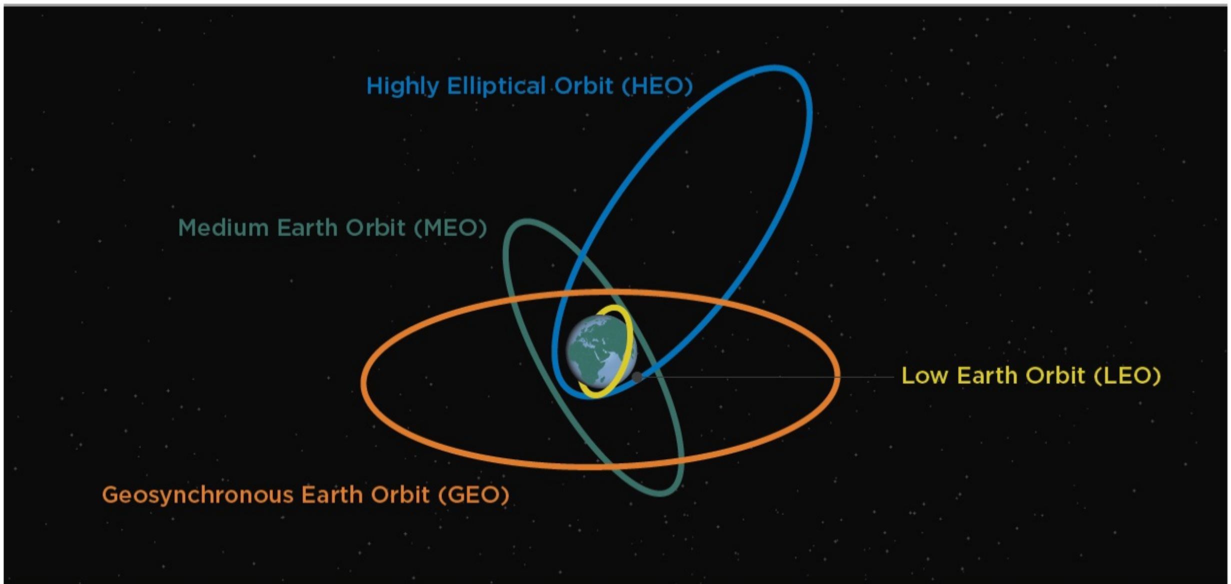
[§] While central to modern satellite communications, Geostationary Orbits will be treated as a subset of GEO, with "GEO" terminology understood to refer to both Geosynchronous and Geostationary orbits.

Conversely, GEO orbits are at most significant hazard from co-orbital ASAT weapons. Due to the immense rotational inertia of a spacecraft's orbit, changes in the orbital plane are much more propellant expensive than almost any repositioning within the plane.* As GEO spacecraft effectively orbit at the same orbital plane and altitude, an ASAT spacecraft within the GEO orbit could select between many targets and engage with limited warning. This lack of predictability is complicated by investment in micro-satellite architectures and the inherent difficulties of observation at a distance of 36,000km.[21] Co-orbital ASATs in other orbital regimes must possess significant maneuverability to make substantial changes in orbit, making their use unlikely. DA-ASATs are typically presumed to use a high-velocity impact as their destructive means,† an option also available to co-orbital ASATS. However, co-orbital ASATs can present a wider variety of effects through controlled rendezvous, from reversible electronic jamming or forced repositioning (hijacking), to non-reversible directed energy attacks or contamination of sensors or solar arrays through chemical spraying.[22]

* For example, in GEO, a 1° change in an orbital plane requires over 25 times more propellant than a similar 1° change in a specific anomaly – or spacecraft position within the orbit track.

† This is described in the popular press as "hitting a bullet with another bullet." The author feels this analogy is unfair: each object in a DA-ASAT collision is traveling over ten times the speed of a rifle bullet, and the "guns" are aimed from hundreds of kilometers away and must be fired with microsecond accuracy – this is a much harder problem than hitting a bullet with a bullet! (ref Hebert, et al)

Orbit Types and Uses[37,38]



Orbit	Altitude*	Uses
Low Earth Orbit	Up to 2,000 kilometers	- Communications - ISR - Human Spaceflight †
Medium Earth Orbit	Approx. 2,000 to 20,000 kilometers	- Communications - Positioning, Navigation, and Timing
Highly Elliptical Orbit	LEO altitudes at perigee (nearest to Earth) Approx. 40,000 kilometers at apogee (farthest from Earth)	- Communications - ISR - Missile Warning
Geosynchronous Earth Orbit	Approx. 36,000 kilometers	- Communications - ISR - Missile Warning

** The advantages of higher orbits for communications and ISR are near-persistent coverage of most of the Earth in view of the satellite, with the exception of Earth's polar regions where it is limited. LEO satellites cover all parts of the world, including the poles, but for shorter periods based on the speed of the satellite.*

† With the exception of nine U.S. Apollo missions to the Moon, all human spaceflight has been completed in LEO.

Figure 2: Orbit Types and Uses (DIA, 2022)

Non-kinetic physical threats also span the DIA spectrum from temporary, reversible disruption to spectacularly destructive. The most pervasive and least destructive threat is the use of moderate-power lasers to blind or distort the optical sensors of ISR payloads, known as dazzling. While potentially denying photographic collection over an affected geography, these attacks would essentially leave a spacecraft intact and functioning once beyond the dazzler range.[23] Higher-powered microwave or laser beams could potentially permanently damage sensors, solar arrays, or radio receiver hardware, and finally, the intense electromagnetic waves and ionized radiation particles associated with a High-Altitude Nuclear Detonation (HAND) would likely destroy most spacecraft electronics within the field of view of the detonation.[24]

Electronic attacks are typically temporary and reversible. However, since all spacecraft depend on the radio spectrum for control, telemetry, and payload communication, electronic attack is a viable threat to all spacecraft. Typically, electronic jamming is achieved through one of three mechanisms: uplink jamming of ground-based signals to spacecraft, downlink jamming of ground receivers, or spoofing.[25] In this last, a convincing signal is generated to propagate false data, for example, an inaccurate position signal from a NAVSTAR GPS spacecraft. Electronic attack is by far the most accessible means of counterspace effects. While Co-orbital ASATs require spacecraft capable of sophisticated rendezvous maneuvering, Direct Ascent ASATs require precise ballistic missile navigation and exquisite space domain awareness, and destructive lasers require volatile chemicals accelerated at near-supersonic speeds through optics chains the size of semi-trucks,[26] an effective SATCOM jammer requires the hardware and technical expertise available in any given local television station.[27] Consequently, an electronic attack on spacecraft control, communications, positioning signals, or space-based radars is highly likely in a large-scale conflict.[28]

Finally, cyber threats provide a predominantly reversible and often difficult-to-attribute attack mechanism. Cyber effects may be used to directly disrupt spacecraft or control infrastructure, corrupt data, or seize control of spacecraft in extreme cases. More covertly, cyber effects open the door to potential data intercept and monitoring of spacecraft or ground infrastructure, vulnerabilities that may be exploited for higher-order effects, such as the insertion of deceptive communications.[29]

ANALYSIS OF DEMAND AND LOSS

Joint Publication 3-14, Space Operations, identifies ten space mission areas: Space Domain Awareness (SDA); Offensive and Defensive Space Operations; Positioning, Navigation, and Timing (PNT); Intelligence, Surveillance, and Reconnaissance (ISR); Satellite Communications (SATCOM); Environmental Monitoring; Missile Warning (MW); Nuclear Detonation Detection (NUDET); Spacecraft Operations; and Spacelift.[30] Offensive Space Operations (OSO) and Defensive Space Operations (DSO) will be analyzed as separate mission areas to better align with operational practice. Similarly, Environmental Monitoring may be considered a Geospatial Intelligence (GEOINT) subset of ISR, and Nuclear Detonation Detection is a subset of Missile Warning. However, the relevant sensors are hosted on different constellations in both cases. Finally, while heterogeneous in operations and facilities, Spacecraft Operations and Spacelift are analyzed concurrently as the second and third-order effects of capability loss in these areas are similar.

Several noticeable trends emerge when evaluating these through the lenses of increased demand, decreased capacity, or higher-order effect. First, several capabilities inherently or directly enable surface maneuver or airpower. For example, Satellite Communication, Offensive Space Operations, and Defensive Space Operations (in previous doctrine iterations collectively known as “Space Control,” in conjunction with certain Space Domain Awareness missions) provide or enable layered effects for which a fully equivalent air or surface-based substitute does not exist within current technologies. For example, when evaluating remotely piloted aircraft, no current medium-altitude, long-endurance remotely piloted ISR platform can force project beyond a few tens of kilometers using only terrestrial communications techniques.

Beyond these, a second tranche of space capabilities emerges, those that have a primary use of enabling surface maneuver or airpower but do have a ready non-space analog. Specifically, NUDET, ISR, PNT, MW, and Environmental Monitoring (particularly weather observation) have surface or air analogs that can cover some of the capability gaps exposed due to space capability degradation. Referencing these particular missions, seismic monitoring, airborne collection, inertial navigation, ground-based radars, and surface observation sites and buoys provide a remaining capability during the loss of space-based services. None of these gap fillers restore full mission capability on their own - if that were the case, the multi-billion-dollar space capability would likely not exist. Still, they can ease some of the impact a space capability loss presents to the forward Joint Force.

Finally, Space Domain Awareness, Spacecraft Operations, and Spacelift underpin the ability to project all other space effects. There may be a few immediate first-order effects to diminishing these capabilities, for example, the ability to project Satellite Reconnaissance Advance Notice (SATRAN) or Satellite Vulnerability assessments (SATVUL) that enable a surface maneuver force to minimize their exposure to observation from adversary satellites.[31] However, most of the U.S. operational edge lost due to the degradation of these capabilities stems from the second-order effects of degraded space operations in other mission areas and third-order effects due to adversary outmaneuvering of U.S. capability in the Space Domain.

Examining specific mission areas for potential loss requires some inherent generalization. For example, the November 2021 destruction of Russian ISR satellite Kosmos 1408 with an A-

235 Nudol missile at roughly 500 km altitude would suggest that any satellite at or below that altitude would be at hazard to similar missiles.[32] However, an inherently limited inventory of missiles, intermittent launch opportunities due to orbital mechanics, and the political and operational restraint imposed by orbit pollution suggest that not all satellites at or below the hazard altitude would be targeted, even if operationally advantageous to do so. Following this logic, the following analysis assumes that destroying, degrading, or denying a single U.S. Satellite or ground site is easily within adversary capability. However, successfully attacking an entire constellation or collective network of assets becomes increasingly difficult and unlikely.

Space Domain Awareness (SDA) is the active tracking of orbital objects, including active spacecraft, natural debris, and non-maneuvering humanmade objects, to inform situational awareness and operation in the space domain. The data from SDA sensors informs orbital maneuvering, warns of imminent conjunction,[*] and indicates potentially hostile or destructive on-orbit acts. Additionally, SDA data informs non-space forces of ISR collection opportunities, enables integration with space assets (through an antenna pointing towards a communication satellite, for example), and, as previously mentioned, can inform air and surface forces of exposure to adversary ISR.

Typically, SDA is performed through two parallel processes: first, the collection of orbital observations via a global network of sensors, principally large aperture radars for near-earth objects and optical telescopes for further deep-space observations, and second, the processing and dissemination of accurate orbital trajectories (“ephemerides”) gleaned from these

[*] A conjunction is an intersection of orbits at a time where the collision of space objects is high. It can involve both collisions between multiple controlled spacecraft, as well as collisions of a controlled spacecraft with an inert object.

observations. This last is non-trivial, as the U.S. has volunteered to lead peaceful SDA efforts for the globe, including Great Power Competition adversaries.[33] This goal requires the active tracking of over 40,000 space objects and continuous analysis for conjunction hazards amongst orbital objects.

In a large-scale conflict, the demand for SDA data will likely scale in proportion to the increase in space domain maneuver and the introduction of new orbital objects, whether through launch, release from existing satellites, or debris-producing events. Concurrently, many SDA sensors may be held at hazard of physical ground-segment attack, electronic jamming, or spoofing due to their strategic value as missile warning or non-space domain radars or proximity to other operationally valuable targets. SDA processing and dissemination is primarily performed by a single Squadron strength unit in a central location adjacent to an operationally valuable command and control node, presenting a possible bottleneck should this processing and dissemination node be degraded.[34]

Spacecraft Operations and Spacelift underpin the continued delivery of space effects and space-enabled capabilities across the joint force. Spacecraft operations provide both the control of the spacecraft vehicle, providing correction to desired orbit and ensuring the continued health of its systems, as well as control of payloads, be they sensors or communications transponders. Spacelift provides the only means of orbital replenishment, whether delivery of a new spacecraft or, in recent developments, refueling an existing one. This last is significant, as effective spacecraft lifespan is typically a function of propulsion available rather than component failures. Excess orbital maneuvering, such as avoiding a co-orbital ASAT threat, carries a real cost of shortened mission life.* Should defensive maneuvering increase, spacecraft operations would likely see a proportionate increase in demand. However, as mentioned above, any unnecessary maneuver or fuel expenditure shortens spacecraft service life, making whole constellation maneuvers unlikely – at least with 2024 technology.

As space launches are sporadic, and spacecraft maneuvers are often minimal and rare, interruptions to these capabilities would likely not be fully felt until days or weeks into a conflict for Spacecraft Operations and weeks to months for Spacelift. Demand for these services may increase in the medium term, especially to execute defensive maneuvering or reposition spacecraft to fill a desired field of view better.

The ground segment of launch and control facilities is often poorly postured for defense. For example, all three major U.S. launch ranges, Vandenberg Space Force Base, Cape Canaveral, and NASA's Wallops Island Launch Range, are immediately adjacent to the open ocean, as are five out of seven USSF Satellite Control Network (SCN) Remote Tracking Stations and all five NAVSTAR dedicated control stations.† Maritime fires could easily damage or destroy any of these nodes in a conflict with questionable maritime superiority. Additionally, electronic downlink jamming or cyber-attacks could render an SCN node (or nodes) inoperable. This last is not an idle concern, as intentional cyber actions against commercial spacecraft control sites have already been suspected during the Russian Invasion of Ukraine.[35]

While SDA provides situational awareness of the space domain, Offensive Space Operations provide the mechanisms to shape, deter, and limit adversary action within the

* If a refueling option is available, this can appreciably extend mission life without the need for full vehicle replacement – though this requires the expense of launch and operation of refueling vehicles
† See Appendix A-1 for a quantitative analysis of ground installation threats

domain. While this theoretically may be done through kinetic means, such as the direct ascent ASAT missiles the U.S. has tested or operationally employed on two occasions, the current U.S. policy of not pursuing or employing debris-producing effects makes future use of kinetic anti-satellite capabilities unlikely. Conversely, the USSF has acknowledged the fielding of reversible electronic warfare capabilities[36] and, by extension, could be reasonably assumed to employ offensive electronic warfare effects in a conflict. Though not as impressive as kinetic destruction, as radio communication is the only means to informationally access a space asset, hypothetically denying the electromagnetic spectrum could deny an adversary the ability to leverage beyond-the-horizon satellite communications, obtain satellite-derived imagery or signals or provide command signals and instructions to spacecraft.

In a major conflict, the required offensive space operations capability will likely increase proportionately to adversary use of the space domain. The degree of adversary space dependency for coordinated maneuver will primarily be a function of terrain and geography – the larger the beyond-the-horizon force, the more space-enabled capability is required. Similarly, the space dependency of adversary kill-chains, conceptually consisting of the sensors that detect a target, the control elements that direct fires, shooting units that engage, and sensors to update the target and assess effects (or the multi-dimensional "kill-web" analog) drives the complexity and span required of U.S. offensive space capabilities. The Offensive Capabilities that have been fielded are inherently expeditionary, able to relocate to geographic locations with the most significant ability to impact adversary space capability. Consequently, these forward forces may be at higher risk of ground segment attack or isolation by disrupting cyber or communications capabilities.

Defensive Space Operations preserve the ability of U.S. forces to continue leveraging space capability, either through proactive protection of space assets or by speeding the resolution of reversible degradation of space capability. For example, the USSF's Bounty Hunter weapon system allows for rapid resolution of electronic attacks on U.S. spacecraft through detection, characterization, and geolocation of interfering energy.[37] This capability enables the rapid restoration of spacecraft services through interference mitigation or intelligent reallocation of remaining capacity.

Much like space Domain Awareness, the value of Defensive Space Operations lies in the higher-order effects they deliver to other domains. Consequently, Defensive Space Operations will likely see an increase in demand proportionate to the Mission Areas enabled, such as SATCOM or PNT. To an even greater extent than Offensive Space Operations, Defensive Space capabilities employed through expeditionary force projection are at elevated risk of ground segment attack, cyber isolation, or communications isolation. Defensive Space Operations are helpful because they inform the greater all-domain conflict and allow for more rapid maneuvering within the space domain. Their usefulness wanes as the ability to communicate and synchronize in near-real-time with operational control nodes diminishes.

Over the history of 21st Century Conflict, the capabilities presented by positioning, navigation, and timing (PNT) are often held as the most significant contributors to enhanced ground maneuver and airpower through enhanced positioning and precision munitions.[38] While an immense enabling effect, modern PNT architectures work through the broadcast transmission of timing signals (of varying degrees of accuracy and security) to theoretically infinite users.

Consequently, while demand for PNT services will likely increase dramatically in a peer conflict, the space segment required to deliver additional capacity is arguably already in place.

By astrographical coincidence, PNT systems enjoy some of the more secure orbits – with greater medium earth orbit altitudes avoiding the congestion and DA-ASAT risks of LEO, and dispersal of spacecraft amongst many orbital planes mitigating the co-orbital threat risk seen in GEO. However, PNT systems have amongst the greatest vulnerability to ground-based or orbital electronic attacks. Electronic ground-based PNT denial, though often limited in geographic area, is now a common tactic for protection against precision munitions, as witnessed in the Russian Invasion of Ukraine.[39] Similarly, the proliferation of inexpensive, off-the-shelf PNT[*] jammers has placed counter-PNT capabilities (and enabled tactics) in the hands of even rudimentary adversaries. At the same time, academic teams have publicly demonstrated the ability to spoof PNT signals with false timing information.[40] Consequently, while PNT systems may not see a surge in demand or appreciable space-segment loss – demand for Defensive Space Operations capabilities associated with PNT protection and resolution will almost certainly increase in proportion to adversary denial of PNT signals. In regions where spoofing is a concern, ground-based navigation augmentation may be required to maintain mission surety.

Intelligence, surveillance, reconnaissance (ISR), and environmental monitoring provide information on features and human behavior on the earth's surface.[†] This can be through observing the visible or infrared light spectrum (electro-optical imagery), using spacecraft-based radar to measure surface features, or collecting human-made electromagnetic radiation from

[*] See Appendix A-3 for an analysis of commercial counter PNT technology.
[†] While spacecraft are also used to observe other spacecraft and satellites, this is traditionally considered a Space Domain Awareness activity.

radar or communications sources.[41] This collection can and does take place across all orbital regimes, with low earth orbits especially preferred due to the better resolution or signal strength afforded by lower-altitude observation.

In any conflict, the demand for ISR products will likely increase quickly and dramatically, with an insatiable thirst from fielded forces to reduce the fog and friction of war with technological illumination. Alternately, while demand for Environmental Monitoring products, for example, weather forecasts, will likely increase in a conflict, the raw space-based collection required to meet this demand will probably remain near-constant, with demand for raw Environmental Monitoring data remaining at stasis as a conflict escalates.

ISR assets are inherently at high risk of adversary action. The low orbits of many of these assets place them at hazard of both direct ascent ASAT and directed energy weapons, the latter potentially made more effective by the sensitive optics or receiver electronics required for primary ISR missions. As the collection of ISR data is only as useful as the ability to relay observations to an end user, the radio links used by ISR assets are inherently vulnerable to electronic attack and interference.[42] Attempts to mitigate this last vulnerability, through storing and forwarding collected data later and suitable overflight geography or relay through other spacecraft, create communications bottlenecks that limit available ISR collection.

Perhaps the greatest combination of inherent vulnerability and increased demand is in the Satellite Communications (SATCOM) mission area. SATCOM provides the ultimate resource in beyond line-of-sight communications – allowing truly mobile communications from any point on the earth's surface to any point on the earth's surface. Most advancements in enhanced command and control, remotely piloted vehicles, and intelligence sharing depend on satellite communications. Consequently, increased beyond line-of-sight activity, such as increased airborne ISR orbit or posturing forces beyond operable terrestrial communications nodes, will increase SATCOM demands.

Within DoD Doctrine, SATCOM is managed as a Joint capability, divided into three capability families: narrowband, wideband, and protected. Narrowband SATCOM (operated by the U.S. Navy in the lower frequency UHF bands) provides low data rate communications to tactical-level users of mobile services; commercial telephony is functionally included in this category. These technologies have limited protection; even very technologically unsophisticated actors (including petty criminals) have succeeded in disrupting and hijacking these services.[43] The second tier, wideband SATCOM (recently acquired by the U.S. Space Force, previously managed as a service by the Army, typically in the higher SHF frequencies),[44] offers high data throughput to operational and tactical users through predominantly fixed base stations. Most commercial SATCOM services provide wideband-like services and are managed as such. Finally, protected SATCOM is provided by the U.S. Space Force to deliver high reliability and low data rate communications for strategic command and control. Very few commercial or civil analogs provide the high-frequency, highly interference-tolerant services these spacecraft provide.[45]

SATCOM services operate from every major orbital regime, with military narrowband, military wideband, and commercial wideband services provided from GEO, commercial narrowband from LEO and MEO, and military-protected SATCOM from GEO and HEO. Consequently, SATCOM spacecraft are vulnerable to all counterspace threats. However, inherent to the mechanisms of SATCOM payloads, wideband and narrowband services are at very high risk of electronic attack, and while Military SATCOM (MILSATCOM) payloads can provide some additional protection over their civilian counterparts, non-protected services of all operational origin are inherently at hazard to electronic jamming.

Missile Warning and Nuclear Detonation Detection provide real-time notification of launches through either on-orbit observation of infrared light or radar screening of missile vehicles transiting low earth orbit. Nuclear Detonation Detection from orbit measures spikes in x-ray radiation, though the wideband radio pulses created by a nuclear detonation would be apparent to many payloads. Current Overhead Persistent Infrared (OPIR) Missile Warning constellations provide continuous launch detection across the planet from high orbital vantages (GEO and HEO), able to meet increases in demands for missile warning without a proportionate need to increase on-orbit assets. These same orbital advantages make these spacecraft more challenging targets for DA-ASAT or ground-based dazzler attack, and due to the strategic nature of these assets, they tend to use more ruggedized communications waveforms and have multiple layers of redundant, hardened ground segments. The most significant protection these assets enjoy is the U.S. policy, mirrored by that of other major nuclear states, that attacks on nuclear warning or strategic command and control infrastructure are viewed with the same gravity as an attempted nuclear strike. Consequently, the extraordinary political and diplomatic consequences likely to be visited upon an adversary who intentionally damages Missile Warning, NUDET Detection, or the protected SATCOM associated with them serve to dissuade potential attacks.

From the above observations, mission area dependencies are subjectively and qualitatively assessed. Demand increase and likely loss are evaluated on a three-point scale of High, Moderate, and Low. High is an almost certainty of increased demand or lost capacity, Moderate is a high likelihood, and Low is an even chance of the same. Higher-order effects assess space and other domain dependencies on a given mission area, rated on a three-point scale of Significant, Moderate, and Minimal. Significant dependencies indicate a critical reliance on this service, for which non-space alternatives do not exist or are unsatisfactory. Moderate indicates other domain alternatives may allow continued operations at a reduced capacity, and Minimal that space effects are either secondary or can be readily augmented through other domain capabilities. Table 1 summarizes this analysis on a per-mission area basis:

Table 1: Demand, Loss, and Second Order Effects by Space Mission Area

Space Mission Area	Increase in Demand	Attrition and Loss	Second-Order Effects
Space Domain Awareness	MODERATE Added maneuver of both surface and orbital forces drives increased observations	MODERATE Primarily performed by a small number of exquisite, ground-based sensors, at risk of kinetic or non-kinetic attack	SIGNIFICANT All other space effects and services are reliant upon accurate and timely SDA
Offensive and Defensive Space Operations	HIGH Demand will increase linearly with U.S and adversary SATCOM and electronic attack on U.S. assets	MODERATE As expeditionary assets, OSO & DSO are at increased risk of kinetic attack, high impact from communications loss	SIGNIFICANT DSO provides protection to other space capabilities, such as SATCOM or PNT. Loss of DSO implies additional loss of these services.

Positioning Navigation and Timing	LOW Existing architectures scale infinitely, and multi-constellation receivers reduce the risk of single-constellation failure	HIGH Low-density MEO orbits are at reduced risk of direct attack. However, all PNT user segments are at risk of electronic attack.	SIGNIFICANT Denial of timing and positioning has direct effect on SATCOM and SDA capacity
Intelligence Surveillance and Reconnaissance	HIGH Planning and operations in all domain require timely and accurate ISR	HIGH Low orbits, radio spectrum dependencies, and sensitive optics make ISR assets desirable targets	SIGNIFICANT ISR informs and enables all military operations – loss has profound tactical and strategic impacts
Satellite Communication	HIGH Demand will increase with added beyond-line-of-site capabilities or forces	HIGH SATCOM is at high risk of electronic attack, including from unsophisticated adversaries	SIGNIFICANT Almost all beyond line of sight or remote operations have a SATCOM dependency
Missile Warning	MODERATE	MODERATE	MODERATE

	Demand for missile warning historically increases with conflict escalation, but current sensors can meet global coverage demand	GEO and HEO based constellations are harder to target, strategic nature drives many layers of ground redundancy and hardening	Loss of Missile Warning or NUDET Detection has profound diplomatic implications
Nuclear Detonation Detection	LOW Worldwide monitoring of nuclear detonation remains constant regardless of escalation	LOW Seismic monitoring and PNT constellations provide layered NUDET monitoring	MINIMAL NUDET events can be determined from seismic or RF events without benefit of space assets
Spacecraft Operations	MODERATE Demand will increase proportionately to defensive maneuver, which may not be substantial	MODERATE Many tracking sites are on islands or otherwise OCONUS, often not located within larger protected installation	SIGNIFICANT Continued delivery of space service and orbital evasion requires continuing Spacecraft Operations
Spacelift	LOW Additional spacecraft unlikely available for	MODERATE Space launch facilities located on	MODERATE Destroyed or permanently

	launch until later in conflict	coastlines with limited defense	degraded on-orbit capability cannot be fully replaced without Spacelift

Based on this analysis, Mission Areas will be prioritized for surge options based in the following descending order of priority:

1) SATCOM

- High U.S. demand increase drives a surge requirement for SATCOM capacity
- High loss requires fielding additional replacement capacity
- Communication dependencies of far-flung forces and remote capabilities increase the importance of SATCOM restoration

2) ISR & Environmental Monitoring

- All military planning and operations are predicated on timely and accurate ISR dramatically increasing demand
- Low orbits, sensitive optics, and high strategic importance make ISR assets particularly vulnerable to attack

3) Positioning, Navigation, and Timing

- At immense risk from ground or air-based EMI – but likely transitory
- Many terrestrial analogs allow for redundancy in event of local loss

4) Offensive and Defensive Space Operations

- An increase in U.S. space use drives a proportionate increase in DSO

- Similarly, an increase in adversary space dependency drives an increase in OSO

5) SDA

- Predicates the ability to execute all other space operations
- Reliant upon a small number of exquisite, often specialized sensors

6) Missile Warning

- Global need can be met with current sensor set and radar augmentation
- Attacks on strategic warning sensors have profound political implications

7) Spacecraft Operations

- Drives defensive maneuver and continued vehicle and payload operations
- Inherent redundancy of tracking sites reduces risk

8) Spacelift

- Critical for eventual on-orbit replenishment, but not in the medium or short term

9) Nuclear Detonation Detection

- Space based NUDET has substantial terrestrial backup systems
- Directly attacking NUDET Detection has profound political consequences

PART II - SPACE SURGE AND REPLENISHMENT OPTIONS

"We're not figuring out the next lunar landing. This is a pistol. Two years to test? At $17 million? You give me $17 million on a credit card, and I'll call Cabela's tonight, and I'll outfit every soldier, sailor, airman and Marine with a pistol for $17 million. And I'll get a discount on a bulk buy." – Gen Mark Milley[46]

The core of a Military Service's function is to organize, train, equip, and present operational forces to the Combatant Commands and subordinate Joint Force Commanders.[47] Towards this end, an analysis of space surge and replenishment options is presented through the lens of these major service functions. Inherent to its core missions, the U.S. Space Force is likely to shoulder much of the demand for both baseline and surge space capability. However, the following analysis is presented as service agnostic: many repurposed capabilities, such as maritime radars, microwave transmitters, or overhead collection capabilities would be organic to the Space Force's Sister Services, and potentially best employed as a space enabling capability under a non-Space Force Service's auspice. Further, the dynamics of maritime and ground maneuver, as well as the access and penetration of non-conventional warfare assets may provide opportunities for space effects and space enabling activities that simply cannot be accomplished by a largely garrison-based Space Force. Finally, many of the most crucial space capabilities, such as SATCOM ground terminal services, are the responsibility of non-Space Force services. As a consequence, throughout the remainder of this analysis the phrase "space forces" will refer to those service members from any branch who are engaged in space operations as a primary or secondary mission, rather than Guardians specifically, unless noted otherwise.

As the previous analysis began with loss of physical plant and associated capability, this section addresses the potential options of re-equipping first. While some comparison of technological capacity is necessary to gauge the extent to which an ad-hoc solution can bridge those gaps predicted in the previous demand-loss analysis, this section will avoid proffering recommendations for any technologies or materiel not readily available on 1 January 2024. While future technological breakthroughs and commercial advancements in space are a near certainty – which specific emerging capabilities will meet the dreams and hopes of their creators, and on what timeline, is uncertain and makes tying an effort of national survival to an entrepreneur's promises a foolish proposition. Similarly, while the Department of Defense likely possesses developmental capabilities in all domains that offer substantial technological advancements over currently fielded systems, the assumption that these experimental "silver bullets" could be quickly transition from laboratory or test range to the field, in appreciable numbers, and with a crew force that can operate them to satisfactory tactical effect is an unreliable at best. As a consequence, while the public and private efforts by organizations like the Defense Advanced Research Projects Agency or Space Rapid Capabilities Office may inform technological trajectory, the laboratory specimens that result from them are unlikely to meaningfully factor into a capability analysis.

EQUIP

By almost tautological definition, replenishing orbital capability requires some capability beyond the terrestrial domains. Terrestrial analogs exist for almost all space-based capabilities, ranging from technologically sophisticated high-altitude ISR collection aircraft like the U2 Dragonlady; to the simplicity of replacing GPS navigation with a collection of charts, timepieces, compass, and sextant that Horatio Nelson would find familiar. That said, virtually all space capabilities have inherent advantages over their terrestrial counterparts; substantial enough to justify the multi-billion-dollar investments required to establish functioning space systems to begin with.

While perhaps no terrestrial analog can fully replace lost space capability, several tactics for ameliorating the gap between space capability demand and actual space capacity are available. First, more efficient use of existing or remaining capability can extend remaining space capability further into a fight. This may entail a simple change in tactics, or may require fielding Commercial Off the Shelf (COTS) capabilities in concert with a doctrinal shift in space employment. Second, non-traditional capabilities may be brought to bear, leveraging commercial, academic, or even adversary on-orbit capability. Doing so may require rethinking policy, legalities, and how space forces are staffed. Third and finally, augmentation through other domain capability can be used to soften the blow or largely replace lost space capacity and capability. This will likely have leadership and doctrinal implications as nexus of action is refocused into alternate domains.

In the spirit of "waste not, want not," some capabilities could endure through degradation by more efficiently leveraging remaining capacity. For example, military SATCOM relies heavily on single channel per carrier (SCPC) modem schemes, where a given user leverages dedicated bandwidth to broadcast a signal to a specific receiver (or receivers). The bandwidth used for this one transmitter is effectively occupied, whether the full data requirements of a stream are present or not, and they usually are not.[48] In instances where data is relayed via terrestrial lines to a central transmit facility, as in the case of the Global Broadcast Service,[49] the ability to efficiently multiplex* multiple data streams together help to limit this inefficiency. However, in tactical use, bandwidth is usually apportioned based on each user's peak need. If a user requires a download rate of 1 Megabyte per second (MBPS), for example, suitable bandwidth must be apportioned for 1 MBPS. Conversely, modern commercial Very Small Aperture Terminal (VSAT) satellite communication architectures are built to a business or consumer internet service market, requiring the most spectrally efficient means of delivering an equitable throughput of data in a constrained bandwidth.

While the technical mechanisms of achieving this are almost as varied as the many commercial architectures available, all are more efficient than the single-channel-per-carrier (SCPC) schemes traditionally used by tactical and operational forces. These commercial capabilities are largely off the shelf, providing end-application agnostic internet-protocol (IP) communications and in many cases an ability to flexibly re-use front end radio hardware, enabling integration into existing DOD communications architectures with relative ease. Further, many emergent systems use large, proliferated, constellations in orbits not traditionally leveraged by DOD SATCOM, for example SES' Medium Earth Orbit (MEO) mPOWER, Eutelsat's Low Earth Orbit (LEO) OneWeb,[50] or SpaceX's LEO-based Starlink, which potentially dilutes the DOD's threat surface through dramatically increasing the spacecraft and orbits an adversary would have to hold at hazard.[51] However, while these systems are available to purchase and field today, they are still in their operational infancy, and a full understanding of their true capability and vulnerability will not be known for some time. This risk blunts currently circulating propositions that, for example, proliferated LEO (pLEO) architectures will

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* In telecommunications terminology, combining multiple independent data streams onto a single communications channel, like a radio broadcast is referred to as "Multiplexing." The reverse process, distilling a single data stream from a larger combined channel, is 'De-Multiplexing"

rapidly supplant traditional GEO-based architectures whose strengths and vulnerabilities (such as cyber threat exposure) are well understood.[52] By augmenting forward surface forces with more bandwidth efficient VSAT terminals, limited transponder space can be shared amongst more users – improving the ability of space and cyber professionals to fight through electronic interference, cyber disruption, and loss of on-orbit transponder capacity.

Space Domain Awareness and Offensive Space Operations can also benefit from more effective use of existing sensors and processing capacity. Current SDA missions, like almost all pre-planned space operations, are directed via a global Combined Space Tasking Order (CSTO), typically published on a weekly execution cycle, with fragmentary orders disseminated as needed.[53] This process affords an effective means of efficiently allocating scarce sensor resources in peacetime. However, a multi-week planning cycle is inherently too brittle for wartime tasking and carries a real risk of misallocating sensing and processing capacity.[54] By entrusting a more significant role in SDA observation and processing to forward, Geographic Combatant Commands or subordinate Joint Force Commanders, observations and processing can be accomplished on much tighter timelines, efficiently addressing emerging threats and requirements as they occur. For example, allowing a fleet to adjust their scheme of maneuver in response to a change in adversary ISR spacecraft overflight.[55]

In addition to more efficient use of available resources, Non-traditional capabilities can be leveraged to meet space operational needs. For example, the U.S. has the opportunity to exploit commercial SATCOM more fully by implementing a Civil Reserve Airlift Fleet (CRAF) like program for Satellite Communications bandwidth. The CRAF program allows the U.S. government, through Air Mobility Command, to commandeer the aircraft and flight crews of participating passenger and cargo airlines, in times of declared war or national emergency. To incentivize commercial participation, the airlines who enter into the program receive preferential treatment on peacetime airlift contracts with the DoD. Consequently, virtually all U.S. passenger and commercial airlines participate in this program.[56]

As commercial SATCOM provides a substantial portion of the U.S. military's wideband SATCOM capacity[57], and the U.S. Government is one of the largest lessors of SATCOM bandwidth in the world[58], the implementation of a CRAF like program is likely palatable to both Government and Commercial entities alike. A CRAF program for SATCOM would provide an advantage of presenting both the immediately desired transponder bandwidth towards military applications, as well as transferring the commercial crews and ground station capabilities required to manage the providing spacecraft. This further save saves U.S. Military the added burden of spacecraft control and space domain awareness, with participating commercial operators providing those services for their constellations. This concept brings added complexity over its aeronautical counterpart with the need to redirect existing non-military SATCOM users. In the airlift implementation, this is less of a problem - if Air Mobility Command needs to commandeer an aircraft from United Airlines, its next flight is canceled, with the same aircraft and crew being redirected as the Department of Defense requires. However, in the commercial SATCOM marketplace, long-term leases often preclude redirecting existing users. Both the legalities of this concern, as well as the practical difficulties of reconfiguring large commercial networks would need to be taken into account in both overarching policy and individual contracts - ensuring potential provision for relocating users, or potentially dropping users in favor of DOD usage. Finally, whereas aircraft are typically registered in the United States, whether by operational origin or as a flag of convenience, most spacecraft are registered abroad, notably in countries like Luxembourg, which provides substantial tax benefits for spacecraft operators. Under the Registration Convention, this complicates the diplomatic and treaty demands of implementing a CRAF like program.[59]

Similarly, the U.S. could potentially leverage adversary assets, notably analog SATCOM transponders, to its own use. Despite advances in space electronics, the vast majority of wideband communication is performed over analog transponders[*]. As a consequence, no signal processing beyond simple changes in frequency occurs on the satellite: whatever signals are received are what gets rebroadcast to earth, without change. By using the bandwidth spreading techniques employed by Protected SATCOM signals, the U.S. could leverage an adversary's SATCOM transponders for low data rate communications. This transponder hijacking, as described above presents an inherent dilemma to an adversary: leave a transponder in operation, knowing that doing so allows U.S. to utilize it along with their own forces, or negate the transponder, for example by powering it off, denying both their own use along with U.S. communications.[†]

Other nontraditional capabilities exist in the intelligence, surveillance and reconnaissance mission area. For example, commercial imagery, although lacking some of the fidelity of its military or intelligence community counterparts, still offers fairly exquisite geospatial products with 30 cm resolution imagery across the entirety of the globe.[60] Services that were only the providence of the most advanced nation states not long ago, such as hyperspectral imaging[‡],

[*] Or their newer, but still very much analog, high throughput channelizer payloads

[†] See Annex A-5 for an analysis of adverse transponder throughput

[‡] A technique that divides an image into more colors than can be seen by the human eye and can support useful analysis, such as discriminating synthetic camouflage netting from surrounding foliage.

synthetic aperture radar imaging*, or precision location of radio transmitters[61†] can now be purchased from a staggering array of companies.[62]

In a surge scenario, space forces could utilize these commercial capabilities through two distinct means. First, through outright purchase of sensing as a service, or commandeering commercial sensing spacecraft and crews as described previously. Legitimate purchase of complete imagery products through existing providers has been a historically successful model, and as these services do not have existing users to preempt, is an easy strategy to legally and contractually implement. The other means by which space forces could leverage commercial ISR is through military operated ISR downlinks, as was the case in the Air Force's legacy Eagle Vision program.[63] Under this construct commercial ISR operators would provide forward military forces with the encryption keys needed to directly communicate with commercial spacecraft. When tasked through forward ground sites controlled by military forces, the commercial ISR spacecraft would downlink imagery directly to military antennas.[64] In both constructs the commercial owner operators continue to provide spacecraft operation of their own spacecraft.

The greatest advantage of direct military receipt of relatively high-resolution imagery is the timeliness with which it can be analyzed, interpreted, and used to inform operational decisions making. By pulling a commercial or intelligence community middleman out of the processing cycle, imagery obtained this way can enable much faster and more agile decision making and U.S. operational response.[65] In either instance, moving a greater portion of ISR needs onto commercial remote sensing spacecraft allows intelligence community and military spacecraft to focus on more challenging collection problems.

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* A useful technology that can collect terrain data at night, in inclement weather, or through smoke

† A commercial service used for search and rescue or tracking of maritime vessels or shipments, for example

Positioning navigation and timing has several non-traditional capabilities that can be leveraged to soften the blow of lost Global Navigation Satellite System (GNSS) service, most likely through surface based electronic attack. One of the most promising is the use of alternative constellations, a practice already widespread in the civil world, where most GNSS receivers marketed for aviation or precision surveying use are capable of resolving two or more PNT constellations, including the U.S. NAVSTAR-GPS, European Galileo, Russian GOLNASS or, increasingly, the Chinese BADOU systems.[*] With the most common arrangement is a three-constellation system, utilizing GPS, Galileo, and GLONAS. Use of multi-constellation receivers, as allowed by Air Force policy,[66] carries an inherent advantage that like transponder hijacking, fully denying these devices requires electronic jamming or space segment denial that would collaterally affect adversary users, presenting a dilemma for wider area electronic attack.

Figure 3: A portable tri-constellation GNSS receiver abord a USAF C-17 (author photo)

[*] Multi-constellation PNT citation

As previously discussed, Offensive Space Operations, specifically counter-SATCOM jamming is within the realm of any actor who has access to the technical knowledge and equipment found in most civilian television stations.[67] By extension, most commercial-off-the-shelf SATCOM transmission hardware could be theoretically repurposed for a potential offensive electronic warfare use. Should the U.S. elect to exploit this, the DOD could potentially field a large number of small, lightweight jamming systems. Doing so carries an operational advantage in that a large number of smaller, dispersed forces presents an adversary with an inherently harder targeting problem, as well as requiring greater monetary and personnel investment in Defensive Space Operations capabilities to resolve.[68] Theoretically, this would also allow the U.S. to leverage other fielded forces to proliferate jamming systems. For example, an Expeditionary Communications Squadron, Infantry Brigade Combat Team, or Naval Surface Action Group could be equipped and tasked to perform counter-space electronic warfare as a secondary mission. Similarly, Defensive Space Operations could be proliferated through inexpensive software defined radio processors, programmed to evaluate well understood signal processing algorithms to characterize and geolocate electromagnetic interference received by U.S. spacecraft.[69]

Space Domain Awareness could be enhanced through a number of nontraditional means. For example, almost all radar sensors that are capable of performing a missile warning or missile detection function, including most ship-board phased-array radars such as the U.S. Navy's SPY-1, or dedicated tactical missile warning radars such as the AN-TPY 2 used in the Army's Terminal High Altitude Area Defense (THAAD) are capable of observing objects in LEO[*]. As

[*] See Appendix 1-4 for analysis of these radars.

these radars perform their primary missile or aircraft search function, they could easily be used in a secondary mission to detect and track low earth orbit objects.[70]

Similarly, academic and scientific telescopes are equally capable of detecting spacecraft - to the point where proliferated constellations have become a nuisance to many astronomers.[71] By analyzing collateral space object observations in scientific data, or by directly tasking scientific telescopes towards space domain awareness observation, the U.S. could gain additional deep space sensing. As these instruments are relatively inexpensive, with a cluster of 1 meter-class telescopes and associated electronics equivalent to the U.S. GEODDS[72] costing less than $5 million, inclusive of their operating facilities, it would be inexpensive to further proliferate deep space observation sites.[*] This could be done through the establishment of reserve component units who operate mobile SDA sites, or as an inexpensive option for partner nations who wish to participate in SDA activities.[73] Finally, as more commercial operators begin to provide SDA as a service, or SDA data as a byproduct of other activities, such as spacecraft signal processing or spacecraft deconfliction, SDA data may be purchased from commercial entities on an as needed basis, with the resulting data centrally aggregated by the DOD.

Spacecraft operations may benefit from commercial teleport capability purchased as a service. In the civil space industry, teleport control of spacecraft is often operated by third-party vendors, who already possess the large S-band antennas and powerful amplifiers required for satellite commanding at sites around the globe.[74] Though these commercial sites do not currently connect to the U.S. Satellite Control Network, by dispatching small teams with the required secure communications equipment to these facilities, they may be utilized for additional spacecraft commanding and tracking.[75] Additionally, improvements in solid-state amplifier

[*] See Appendix A-4 for cost analysis

technology and the commoditization of large aperture antennas has resulted in several manufacturers offering low cost S-band Tracking, Telemetry, and Control (TT&C) antennas. Like previously described proliferate capabilities, these could be deployed as a secondary mission with non-space forward forces, or by a dedicated reserve component force as a standalone, protected mission to geographically distribute spacecraft control capabilities.

Recently, an increase in the number of commercial launch operators have seen the repetition-rate of space launches fall from a proposition of months to weeks or even days. However, the manufacture and preparation of spacecraft themselves remains a stubbornly slow process. While public efforts like Air Force Research Laboratory's Operationally Responsive Space[76] or the Defense Advanced Research Projects Agency's Project Blackjack[77] have made promising strides in developing technologies for shelf-stable spacecraft, maintaining a backbench of ready to launch vehicles remains out of reach as of early 2024. However, in an interesting swords-to-ploughshares strategy[*], the DOD has elected to reserve most of its decommissioned Peacekeeper Inter-Continental Ballistic Missile (ICBM) boosters, as well as many operationally expired Minuteman-III boosters, creating ready supply of Minotaur[†] launch vehicles. These rockets can be assumed to remain in supply in medium term, as the Minuteman-III fleet is replaced with the Ground Based Strategic Deterrent ICBM missile architecture. By prioritizing shelf stable or reusable launch vehicles, such as Space-X's Falcon-9 booster, the U.S. can expedite spacelift requirements[‡]. This may be accomplished by developing LEO spacecraft

[*] Or in this instance, swords-to-less-apocalyptic-swords

[†] Amusing historical note: the "Minotaur" name is space-operator humor: the original versions used decommissioned Minuteman boosters for the first (bottom) stage, and Taurus missile boosters for the second (top) stage. Bull on top, man on the bottom: Minotaur.

[‡] While strictly speaking air-launched boosters, notably Northrop Grumman's Pegasus could also fill this niche, however as of 2024 none meet the "ready-off-the-shelf" intent of rapid launch.

specifications that are compatible with the use of Minotaur launch vehicles, allowing the U.S. to maintain a backbench of ready boosters available within weeks or months, rather than the traditional years required to manufacture a new launch vehicle.

In exploring augmentation from other domains, one needs to accept inherent operational limitations. For example, while few options can fully replace the beyond-the-horizon capabilities afforded by SATCOM, proposed architectures leveraging manned or unmanned aircraft or aerostat balloons as repeaters can provide SATCOM like services over a fixed geographic area.[78] Assuming these capabilities are able to reuse the radio spectrum allocated towards SATCOM, these vehicles could in theory fully replace the communications capability lost due to SATCOM denial, albeit within a much smaller field of regard. Theoretically, purpose-built relay aircraft could augment a broader area through large networks of interconnected aircraft, though over sparse regions like the Pacific Ocean this becomes difficult to achieve. Easier to achieve, however, is the addition of repeater payloads on existing aircraft. While the size, weight, power, and cooling requirements of additional electronics can be at a premium on mature airframes, and the time required to flight test new hardware non-trivial, the time required to do so is still substantially shorter than that required to manufacture and launch of new spacecraft.[79]

Similarly, as seen over North America in February 2023, high-altitude balloons can traverse many thousands of miles, with long loiter times over a desired area. While the payloads and purpose of the 2023 balloon are unknown, DOD research into aerostat high-altitude vehicles and operational experience in West Asia has proven them to be reliable camera and radar platforms and potential candidates for radio relay.[80] Using these platforms, with ranges in the hundreds of kilometers, can fill geographic gaps in communication coverage left by the degradation of SATCOM. Consequently, this capability becomes particularly useful over regions like the Western Pacific, where the limitations in range and loiter time of heavier-than-air aircraft inherently restrict usage for long-range relays.

Positioning and navigation have been accomplished via celestial objects for thousands of years, with accurate timekeeping as a primary means of establishing longitude since the 18th century. In the 21st century, however, advancements in optics and semiconductors have resulted in inexpensive, very small form-factor inertial navigation systems, which determine accurate position via precise timekeeping and fine acceleration measurements. Similarly, reducing the cost of highly accurate quartz and rubidium clocks has allowed for both commercial and military navigation and timing systems whose accuracy is on par with the best celestial-based capabilities.[81] The U.S. can fill localized gaps in GNSS coverage caused by the jamming denial of GPS or other satellite-derived PNT sources by augmenting these services with ready ground-based navigational aids. Off-the-shelf hardware, such as thousand-plus kilometer-range Non-Directional Beacons (NDB) or kits currently in USAF inventory, including hundred-plus kilometer-range rapidly-placeable tactical air navigation beacons (TACAN)[*] and terminal guidance systems, including expeditionary microwave landing system[†] can further provide capabilities deployable on short notice.

[*] Such as the DOD's AN/TRN-48 TACAN rapidly deployable navigation set, which can be deployed in a few hours at an expeditionary site

[†] Similarly, the DOD's AN/TRN-45 MLS, which is also deployable in less than two hours

Figure 4: AN/TRN-47 TACAN (CWO Bryan Nygaard)

TRAIN

Perhaps the most challenging component to mass during a force surge are the airmen, guardians, soldiers, sailors, and marines who will operate space systems. Just as surging forces on the ground or air are dramatically more involved than just machining more rifles or molding more fiberglass UAV fuselages, successfully surging space forces will potentially require a dramatic increase in the personnel to operate them.

Historically, a significant reserve component is the most common strategy for ensuring a ready back-bench of expertise. Three methods for presenting an operational reserve are presently practiced in the DOD, each offering potential opportunities for enabling space surge. First, a militia model, where forces are organized into standalone units, which are in turn equipped with weapons or equipment under their own operational control. The Army and Air National Guard are the primary examples of this model, with current space-presenting militia units providing missile warning, electronic warfare, and protected SATCOM.[82] The second model, a traditional reserve, provides troops organized into standalone units that typically mirror the regular force with whom they share weapons, equipment, or operational control. Most of the Air Force, Army, Navy, and Marine Corps reserves operate within this construct, and most space-presenting reserve forces are organized in this model. Finally, reserve troops may be presented absent reserve unit organization, assigning individuals or small groups to regular units or staffs as needed. In addition to existing instantiations of this last model, such as the reserve individual mobilization augmentee or military personnel appropriation programs, the U.S. Space Force intends to create a reserve force based primarily on this concept. However, the exact implementation details of this proposed single-component model have yet to be published. By maintaining a sizeable ready reserve, the DOD can synergistically ensure a ready force knowledgeable on existing space mission areas and able to exploit knowledge gained through civilian experience and education. By emphasizing continuing and early integration, maintaining a large core of reserve bodies ensures a well of ready forces that can be rapidly mobilized if a space surge is required.[83]

Assuming that the services can activate and fully employ the entirety of their regular and reserve component forces, a likely shortfall in staffing will still need to be addressed. One solution seen throughout U.S. history is accelerated accession of recruits. Using the Space Force as an example, initial training for a newly enlisted Guardian can take over a year. Even with no delays in obtaining school seats, a new Guardian can currently expect to spend two months in Basic Military Training, followed by six months or more at Space Gateway Training (more widely known by its previous name: Enlisted Undergraduate Space Training), concluding with four to six months of initial and mission qualification training – all at different installations. This paper does not offer any specific curriculum recommendations to reduce basic training timelines, as this core training impacts every career field within a service and changes would have higher-order effects far beyond space-presenting forces. However, it is worth noting that in recent military history, the time required for initial accession schools has been reduced substantially, and with limited adverse effect, to meet the force surge demands of Operation Iraqi Freedom. For example, the National Guard's Academy of Military Science reduced the time required to train a new Lieutenant to 42 days from 90, largely by eliminating non-training days (e.g., weekends) and providing academics over an extended 14-hour to 16-hour duty day.[84] While this particular model runs contrary to accepted military pedagogy, which holds that retention diminishes substantially after a few hours, experience with highly driven candidates, such as aspiring officers, special forces selectees, or reactor operators, has shown that a sufficiently motivated student can maintain attention and retain newly presented skills and knowledge over daily training periods longer than typically employed by Air Education and Training Command or sister service equivalent formal schools.

Currently, Enlisted Space Gateway Training seeks to provide a broad-based education for newly assessed space operators and guardians; however, to get troops to a front-line tactical position quickly, subject matter depth could be emphasized in a shortened course, with broad space background knowledge presented later during in-garrison follow-up training. By shifting more training material toward in-garrison study, undergraduate space training (or sister service equivalents) could be curtailed into a one-month (or shorter) course, potentially delivered by detachments co-located at major space bases[*], eliminating the need for mass training at

[*] The National Security Space Institute successfully delivers online and hybrid equivalents to these accession courses for the federal civilian workforce. However, the inability within a public venue to easily discuss sensitive or

Vandenberg space force base as well as shortening follow-on mission-specific specialty space training. This model is already proven with the success of the National Security Space Institute's space-100 qualification course, provided to non-space sister service forces and acquisition or intelligence professionals tasked with space responsibilities, and Introduction to Space and Space Familiarization courses offered to the DOD Civilian workforce engaged in space missions. These courses are relatively short, at 50, 40, and 32 instruction hours, respectively, and are currently offered either wholly or partially remotely via internet-based delivery.[85]

In this construct, newly accessed troops would focus on the specific space mission area most relevant to their first duty assignment during their first post-basic training course. For example, electromagnetic spectrum operations would be emphasized for those tasked with electronic warfare or orbital mechanics for those with a focus on space domain awareness. While a broad-based space education is ultimately essential, this can be delivered concurrently through self-study courses like the Air Force's long-practiced and well-understood career development courses.[86] This allows newly accessed troops to report to front-line tactical-level units much more quickly, speeding up the time required for mission-specific qualification training. Later delivery of broader space and military professional education, while less than ideal, allows first-assignment tactical troops to focus on their crew-floor duties, presenting more abstract "bigger picture" content closer to a troop's first leadership or operational staff assignments when knowledge beyond specific mission procedures becomes vital.

In an additional break from current practice, any newly delivered training or courses should refocus from the historical, missile community-derived culture that emphasizes the

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classified space system capabilities, assessed adversary threats or military planning considerations makes a purely online or remote course unlikely.

memorization of checklists and adherence to fixed procedures and broaden to emphasize a greater understanding of core space concepts.[87] This is not to discount the value of checklist discipline - for established systems, it is a vital tool that allows experienced operators to manage complexity. However, detailed procedures are unlikely to be available when repurposing commercial hardware or adapting sister service capabilities for employment in a secondary space capacity. At this point, tactical success with improvised or repurposed equipment is incumbent on the depth of theoretical understanding of the operators tasked with operating them rather than their ability to faithfully follow an established and proven procedure.[88]

Figure 5: 1st Space BDE Soldiers provide secondary space missions attached to maneuver forces (SSGT Dennis Hoffman)

A commissioned officer is present on most operational space crews, which are typically small, to conform to certain legal authorities. Consequently, the U.S. Space Force has the highest officer-to-enlisted ratio in the DOD, with the number of Commissioned Guardians exceeding their Enlisted counterparts by some calculations based on congressionally authorized end strength.[89] While not as extreme, the space-presenting forces of non-Space Force sister services tend to have an Officer to Enlisted ratio much higher than their service average. However, by taking a closer view of what must be within an officer's legal purview and expanding to an on-call model, one or two commissioned duty officers can provide 24-hour a-day oversight and positive control of multiple ongoing missions.[90] Reducing the needed officer-to-enlisted ratio reduces the need to assess and field new officers, a time-consuming proposition. It frees the officer cadre for employment on operational and strategic staffs, for example within an air and space operation center. Finally, junior officers freed from space operations floor tactical employment could be employed to significant effect as space liaisons to expeditionary forces, enabling expeditionary or maneuver elements, such as a Naval Surface Action Group or Marine Air and Ground Task Force, to more optimally provide space effects as secondary missions.[91]

Finally, in the event a conflict grows to the point that Congress authorizes a general draft or the use of conscription powers by the DOD, space-presenting forces could seek shorter accession times through targeted conscription of citizens with a professional or academic background relevant to space, as is currently the practice with health professionals.[92] By focusing on those who, for example, have civilian experience in the electromagnetic spectrum, such as radio engineers or communications technicians, a broader theoretical knowledge of these domains could be gained without the time investment required for recent high school graduates. While the training avenues described previously will ultimately still be necessary, reducing the number of newly assessed members requiring in-depth technical training can reduce the demands placed on initial training pipelines and reduce the time needed to go from draft notification to presentation of a capable space warfighter at a front-line squadron.

ORGANIZE

Presenting battle-capable forces requires a triad of operational systems and weapons, troops capable of operating them, and a means of directing their activities toward a common operational end. Consequently, the presentation of humans and machines is meaningless if their activity cannot be efficiently controlled or integrated with a more substantial force. Organizing a service's forces requires a hard look at who, how, and where of space capability presentation.

As a first observation, surprisingly little space activity is inherently governmental, and even less is inherently military. As established previously in our discussion of equipping a surge force, most space mission areas have a commercial analog and, by extension, commercial operators - contractors who can operate and maintain space systems. This remains true when broadened to both primary space missions and those systems with a secondary space application that could be used to augment space-presenting forces. Within these activities, few actions are inherently governmental functions, that is, activities that must be performed by a representative or employee of the U.S. Government by law or policy.[93] These activities, such as management of federal funds, legal control of presented military forces, direction of contractors, or certain intelligence collection activities, must be performed by federal civilian employees or military members. Similarly, even fewer space activities are inherently military; that is, they consist of an act of controlled violence intended to impose national will upon an adversary.[94] Of these actions, for example offensive electronic attacks or spacecraft maneuvers that might be interpreted as affrontive, may be performed by any uniformed member of the U.S. Military whose orders authorize them the authority to perform these actions, and who need not necessarily be a member of the U.S. Space Force.

By pivoting more space capability presentation to a contractor-focused surge model, where commercial elements both provide and operate spacecraft as well as limited space domain awareness and defensive posturing of their activities, military members can be made available for those duties inherently governmental or military. For example, expeditionary assignments with innate hazards that make them difficult to staff with government civilian or contractor personnel or staff and liaison roles that rely on fusing space domain knowledge with more generalized military expertise possessed by uniformed military members. Organizationally, this requires revisiting contract management, as the lines between service acquisition and operations blur. To meet the responsiveness and flexibility needed for successful operation in a global conflict, the contracting mechanisms by which these services are procured must allow some measure of positive control by the operational echelon of the presenting service, for example, Space Operations Command, Pacific Air Forces, or III Marine Expeditionary Force, without the need for time-intensive contract modifications, or requiring operational direction to pass through an acquisition organization. Historically, flexible contracting models, such as indefinite quantity-indefinite delivery, blanket purchase order arrangements, or other transaction authorities have allowed operational and tactical echelon representatives to manage the presentation of contractor services without time consuming modification. However, the drafting and negotiating of these vehicles require more care than traditional rigid firm-fixed-price or cost-plus arrangements.[95]

Similarly, while a substantial portion of U.S. government civil space operations remains within military control, this is primarily due to historical inertia rather than legal or operational logic. For example, the Department of the Air Force and U.S. Space Command provide the vast majority of Space Domain Awareness products to spacecraft operators from all nations, military or civilian.[*] While providing this "space traffic management infrastructure" has obvious safety benefits, much as deconflicting air and maritime traffic makes maneuver in the air and on the seas much safer, and U.S. leadership of such an effort may make technological and diplomatic

[*] Because of the shared interest in conjunction resolution shared by all spacefaring nations, commercial operators, and militaries, US policy requires that this data be made available to all requestors – including traditional US adversaries, foreign militaries, and Great Power Competitors

sense, there is no particular reason this must be a primarily military-led effort. Consequently, efforts are underway to move much of this mission to the Department of Commerce,[96] begging the question of what other missions may be better suited to non-DOD control. Several space-enabled activities, such as maintenance of timing standards and operation of assured satellite communications, likely fall into the category of inherently governmental but not inherently military. In these cases, the transition of these missions to a non-DOD department or agency may be as simple as policy change, transferring authority rather than physical plant or infrastructure.

While much of the discussion thus far has presumed dedicated space professionals, logically, space effects provided as a secondary mission could be executed by forces qualified for space operations as an additional or secondary duty. The Army, for example, uses Functional Areas to demark those officers with specialized training or experience in areas like strategy or space, the latter being functional area-40. These FA-40s are drawn from any primary Army career field or military occupation series. They may continue to provide tactical or staff leadership within their primary area of specialization, with space expertise forming an additional, ancillary skillset.[97] This model allows for a rapid increase in military members available to execute space missions, space support, or integrate space effects into their primary force, an Infantry Brigade Combat Team. These individuals could remain operationally and administratively attached to their primary mission and command relationships, with space effects and integration controlled through geographic space commanders, such as the USSPACEFOR-INDOPAC or USSPACEFOR-KOR. Finally, the training pipeline for these individuals could theoretically be much shorter than that for new space accessions since basic military and career field training is already accomplished for another non-space area of specialization, requiring only space-specific courses, some as short as two weeks long, to provide a secondary space skillset.

Single centralized command and control present a particular hazard within current space organizations. By the nature of their responsibilities within the Unified Command Plan, the Commander of U.S. Space Command controls the vast majority of activity beyond the atmosphere.[98] Similarly, a single Coalition Space Forces Component Commander (CFSCC) operating out of the Coalition Space Operation Center (CSpOC) provides the tactical control of most of the forces operating within this domain. Presenting two consolidated centers of gravity, the CSpOC floor in California and the U.S. Space Command Joint Operations Floor with its collocated activities in Colorado exposes an attack surface where loss of communications due to cyber or infrastructure attacks could render forward space forces rudderless. Distributing control and delegating support and forces to non-space Joint Force Commanders as much as practicable dilutes these centers of gravity and opens the possibility of more responsive space actions. For example, should a Joint Force Commander need to exercise additional SATCOM requirements, reallocate SATCOM bandwidth, or request support from space assets such as missile warning, doing so directly through a regional command center substantially shortens the time required to task, rather than having to prioritize requests on a global scale.

Similarly, within the U.S. Space Force, the model of a single squadron per primary mission or weapon system creates inherent centers of gravity. While some missions will have additional operating locations through detachments, the vast majority operate under a single squadron per mission, such as NAVSTAR GPS or SBIRS missile warning, themselves under a single Delta per mission area, such as electronic warfare or space domain awareness. As the operational control authorities for space missions become more Numbered Air Force-like in span and intent, distributing control responsibility away from a single Delta model to potentially multiple Deltas, divided amongst geographic Areas of Responsibility (AORs). Indeed, the dispersal of tactical missions across numerous geographically diverse Squadrons can avoid operational bottlenecks and the centers of gravity presented by the centralization of missions. Even within non-Space Force sister services, such as the Navy or Marines, space as a primary or secondary mission tends to be highly concentrated within a single command and a single global tactical tasking chain of command. Normalizing mission command of distributed space-presenting forces can minimize the impacts felt due to the loss of operational echelon control.

As previously established, a robust reserve force activated during surge operations directly increases trained personnel, and this augmentation frees additional subject matter experts for staff or liaison projection. For example, to be the space liaison to a Surface Action Group performing SDA as a secondary mission or a Brigade Combat Team that needs to integrate PNT and SATCOM tightly with ground maneuver.[99] However, the organization of these reserve forces bears consideration. For example, the U.S. Space Force's single reserve force is suitable for increasing guardians attached to existing space-presenting units. By closely coupling the reserve and regular force, on the same operations floors and equipment, transition to full-time operations is straightforward. This model, however, does not present a separate reserve of hardware or weapon systems, for example, SDA sensors, electronic warfare equipment, or satellite spacecraft control nodes that can be forward deployed. A militia model, such as the National Guard's unit-equipped missions, provides assets and personnel for the proliferation of expeditionary forces.[100]

DEPLOY AND EMPLOY

Many space assets are controlled from a single operating location, as described in the threat assessment of Part I, which is unrealistic in a global conflict where it is likely necessary to distribute assets around the nation and globe. Currently, most space activities are tasked through prescriptive space tasking orders (CSTOs), published at roughly weekly intervals.[101] While highly efficient at providing synchronized and organized effects, this mechanism is far too slow and lacks the flexibility required in a rapidly changing, multi-front conflict. To avoid the brittleness of prescriptive and infrequent CSTOs, assets distributed globally should be tasked through more flexible Mission Type Orders, emphasizing tactical echelon decision-making and initiative. A mission command-empowered forward force, which would almost certainly have greater relevant situational awareness of the operating environment than a centralized C2 activity, can provide more timely and nuanced decision-making.[102]

Additionally, forward deploying teams in small elements rather than the traditional squadron-strength units can present right-sized mission packages to Joint Force Commanders. Through force tailoring, composite elements presenting multiple space capabilities, for example, space domain awareness sensors combined with offensive space operations jammers and spacecraft operations TT&C antennas, could be leveraged to provide flexible expeditionary employment.[103] This model, similar to the mosaic warfare concept where small, independently organized forces are combined to form ad-hoc task forces under a flexible mission type directive, easily expands to incorporate maneuver or surface forces who provide space effects as a secondary mission.[104] Organizing forces into small teams inherently provides a greater magazine depth of both humans and material, that is, teams can be assigned across more locations or maneuvered with much greater rapidity than the traditionally deployed larger squadron-strength forces.

When evaluating forward space operation sites, small teams should be prioritized for Goldilocks locations that are not so small that logistics or local security difficulties stifle operations or maneuver yet not co-located with other valuable targets that present large centers of gravity, regardless of space presence. This concept, coupled with the ability to complicate adversary targeting and decision-making through constant, dynamic maneuver, forms Agile Combat Employment's core.[105] Space-providing forces should also seek to use rapid mobility and diffusion of forces to avoid creating persistently soft targets and complicate adversary operations. This goal makes space as a secondary mission an attractive proposition, as it is likely easier to add space capability to a maneuver force than make traditional fixed space forces maneuverable.

PART III - CAPABILITY MANAGEMENT SOLUTIONS

"If you don't like change, you'll like irrelevance even less." – GEN Erik Ken Shinseki

The previous analysis was written from the perspective of the services: the Army, Navy, Marine Corps, Air Force, and, most relevant to a space warfight, the Space Force. While the service interest lay in optimally training, organizing, and equipping a force that can forward present to conduct warfighting, the services, under law, do not themselves lead or direct the warfight. This is the job of the Joint Force Commanders.[106]

Under the Goldwater-Nichols Act, Combatant Commanders (CCDR), each responsible for an area or function of responsibility, conduct primary military actions on behalf of the United States with the forces presented to them by the services. These CCDRs may further delegate Joint Force Command (JFC) of a portion of their AOR to a subordinate, for example, a Sub-Unified Commander or a Joint Task Force Commander (JTF-C). They will further delegate specific responsibilities and authorities to Functional Component Commanders (FCC) responsible for a single capability, such as special operations or domain, such as air or space.[107] Historically, space-providing forces have been presented under the command of a Joint Force Air Component Commander, with non-directive space coordination accomplished through a Director of Space Forces, or DS4[*]. Most Combatant Commands (CCMD) have transitioned to a Space Forces Commander model, or SPAFOR, where a senior Guardian has FCC-like authorities over those space forces presented within their AOR. Complicating this picture is the inherently global and extra-global nature of space conflict.[108] As alluded to previously, the majority of space-

[*] Old AFDP 3-30 citation

relevant tasking falls underneath the Commander, United States Space Command. By extension, tactical control of the majority of space-presenting forces accomplishing said tasking flows through CSpOC's Space Forces for Space (S4S) as the controlling FCC.[109] The relationship between these entities and their non-space AOR counterparts will inform much of the behavioral changes needed.[110]

Integration of space forces under a JFC during a days-to-week space surge is best presented within a context of non-materiel capability management. As defined in CJCSI 3010.02, "Guidance For Developing And Implementing Joint Concepts," these non-materiel solutions consist of those changes in doctrine, policy, force structure, or force employment that constructively enhance joint-force presentation.[111] The rationale behind this analytical emphasis is twofold: first, JFCs do not themselves develop, train, or equip forces, as the services provide these functions. Second, any changes or additions a JFC feels are needed to a fielded capability are driven through documented operational needs or emerging operational requirements. These are, in turn, provided to the services to modify accession, training, acquisitions, or materiel. Solutions pursued in this manner could not plausibly be executed in the days-to-weeks timeframe analyzed in this paper.[112] Consequently, solutions rooted in changes in human behavior or leveraging readily available off-the-shelf materiel will be highlighted here. In the spirit of "Joint Concepts," capability management solutions available to the JFCs are analyzed within doctrine, organization, training, on-hand equipment, leadership, facilities and infrastructure, and policy.

DOCTRINE

To meet the needs of a rapid surge in space forces, changes are advisable to both service and joint doctrine. Joint space doctrine is driven by or derived from Joint Publication 3–14 "Space Operations" and its international counterparts. Additionally, every service maintains one or more volumes of space-specific doctrine, ranging from simple tactical guidance in the case of the Navy and Marine Corps to an entire body of operational and tactical doctrine from the U.S. Space Force. Harmonizing these volumes should flow from the recent modernization of joint doctrine, reflecting changes incorporating more pervasive application of offensive and defensive space capabilities and emphasizing the importance of dynamic space domain awareness and spacecraft control.

Enabling the mission command concepts examined previously requires unambiguous guidance on space effects application from owning CCDRs.[113] This guidance could potentially conflict when a geographic CCDR's or subordinate JFC's requirements or guidance is contrary to that of the Commander U.S. Space Command. Resolving these potential conflicts will require doctrinal clarification of how space effects requirements are derived from the CCDRs and under what circumstances the geographic CCDRs could directly task space forces. This problem is complicated by space operations' inherent ability to cross geographic boundaries.[114] A given geographic CCDR could plausibly require effects from forces within their defined AOR, from within another geographic AOR, or even from astrographic orbital forces. Previous concepts that partially resolved these conflicts, such as the "space C2 forward" construct relied upon assumptions that a forward JFC possesses the ability to positively control presented space forces. Historically, this has been interpreted as possessing a staff capable of providing nuanced and thorough space command and control and a requirement that those space effects provided would not have meaningful extra-theater consequences.[115] This latter assumption has become increasingly unrealistic as space technologies and associated space warfare practices have matured in the 21st century. A more realistic doctrinal concept may be a mechanism by which non-USSPACECOM CCDRs may add additional clarification and requirements to the intent and direction provided by the Commander of USSPACECOM. Through a trickle-down model, the commander of USSPACECOM implements the strategic guidance of civilian leadership and imparts direction through published intent, which is then expanded through regional space FCCs for further theater guidance. This model captures both the intent of the Commander of USSPACECOM, who would have the most detailed situational awareness of the space domain and the political and military implications of actions therein, and the regional situational awareness of the geographic CCDRs or their subordinate JFCs, who would have the most detailed understanding of their geographic AOR. By providing guidance filtered through both perspectives, the tactical echelon would be empowered to make rapid and informed decision-making through mission command and mission-type orders, utilizing their exquisite awareness of their local space battle picture.

Further, the mechanisms by which forces may be allocated to objectives, targets, or tasks deserve a similar examination. A single-point-of-control model, like a single global (and extra-global) FCC, allows for an ideal spread of capability against global tasking, where the needs of all competing JFC and AORs may be balanced against the available global force laydown.[116] However, this global tasking process is inherently brittle and slow. Brittle, in that a worldwide tasking authority forms a single point of failure, and slow, in that the need to process extraneous requirements, such as balancing the needs of adjacent geographic CCDRs, results in many more days or weeks required for order development.[117] The mosaic warfare concept provides an attractive doctrinal model by which these limitations could be alleviated. Rather than relying on a centralized operational staff to allocate tasks to the tactical units through monolithic, prescriptive tasking orders, the operational planners and execution staff should provide mission-type descriptions of tasks and desired outcomes to be performed and then allow the tactical echelon to lead allocation through a bidding process.[118] This optimally pairs a needed task or objective with the tactical force that assesses it to be most suited to its operation, location, and capabilities. For example, in a space domain awareness mission, a set of spacecraft desired for immediate observation could be provided to the SDA sensor community, with sensor operators evaluating which spacecraft are most suitable to their sensor capabilities, geography, and available time of collection. This model allows the tactical echelon to balance concerns as varied as local meteorological conditions, natural lighting, equipment maintenance status, and communications capability against the list of available tasks. A bidding-based model presents an advantage over centralized weaponeering and allocation. It can be much timelier than developing a single, global prescriptive order and provides flexibility if the operational echelon becomes unavailable due to communication outages or other adversary actions. If an FCC staff is unable to generate tasking orders, the tactical echelon, through mission command empowerment and bid-down allocation practices, would still be able to meaningfully allocate targets amongst themselves under the standing guidance provided by the Commander USSPACECOM and clarified by other geographic CCDRs and subordinate JFCs.[119]

Joint and service doctrine is still primarily built around primary space missions performing the bulk of space activity. As discussed previously, this may not necessarily be a warranted assumption, though it is a logical one: the Air Force does the vast majority of aerial bombardment, and the Marine Corps does the vast majority of littoral warfare - why wouldn't the Space Force execute the vast majority of space operations? However, just as the other services perform substantial aerial operations, non-Space Force services will continue to provide space effects, largely as a secondary mission. Given the massive relative size of non-Space Force services to the Space Force, even small space capability footprints embedded in naval SAGs, Carrier Strike Groups, Marine MAGTFs, or Army maneuver units could quickly provide a substantial portion of space effects, and in some space mission areas a majority of presented space providing forces. Harmonizing these secondary-mission space-presenting forces with robust space command and control infrastructures offers the opportunity to quickly expand the footprint of available space-presenting forces.

ORGANIZATION

While every service organizes its forces per the demands of presented capabilities - the effective organization of aircraft carriers carries different demands than that of Marine Corps Combat Engineers, the concept of service organization has several common themes and an overall structure that would not have seemed out of place in the Napoleonic army. Though doctrinally joint force presentation is planned around large primary units, such as Air Expeditionary Task Forces, Brigade Combat Teams, or the Naval Group, as Air Force Chief of Staff Dave Goldfein pointed out, the squadron still forms the "beating heart of the Air Force."[120]

Focusing on organization from a JFC perspective, subdividing forces into finer granularity force packages -like Goldfein's squadrons, may have inherent planning benefits. Revisiting the mosaic concept: rapidly assembled task packages, being able to subdivide a single force-presenting unit, such as an electronic warfare squadron, into multiple concurrently executed mission sets allows the JFC the opportunity to task that element with multiple objectives concurrently.[121] For example, a squadron-strength element operating a defensive space control system may have a primary mission of friendly SATCOM monitoring. However, this unit could also allocate personnel, attention, and mission system bandwidth to concurrent tasks, such as blue-force-tracking, without substantially degrading their primary task. This divisibility enables the same squadron-strength element to provide effects to multiple JFCs concurrently, expanding available space capacity across multiple AORs.

The mosaic model allows the composition of small teams tailored to specific JFC objectives. For example, a composite unit consisting of a special operations platoon, coupled with an airborne ISR platform and a fraction of a space team, could lean forward to meet a JFC's specified task without meaningfully detracting from the other tasking meaningfully required from the broader squadron strength element.[122]

TRAINING

While the services are primarily responsible for training their forces, the Combatant Commanders maintain a role in establishing joint training standards.[123] Training has been standardized through joint tactics for troops such as the medical core, aviation, and combat arms. Standardization for space-presenting forces should be established and expanded to meet the needs of those forces who present space as a secondary mission. The Space Force training standards provide a de facto joint standard because they have the most significant investment and detail in space-presenting forces. However, this standardization should be revisited with an eye towards optimization towards those non-Space Force sister service forces who, though presenting space effects as a secondary mission, may present most space effects near the forward line of troops. These sister service forces will likely need to be trained to present those secondary-mission effects quickly. Across current training standards and curricula are a few consistent themes: first, space training, and by extension, space training standards, are very procedure-oriented, a historical artifact from the days when space and nuclear operations were one and the same.[124] Those forces who will employ space as a secondary mission may use one of dozens, if not hundreds, of different hardware sets or tools. Consequently, fixed procedures are unlikely to transfer between different weapons, tools, or hardware. However, detailed theoretical knowledge of the principles by which space systems operate should transfer well. For example, a maritime radar repurposed for SDA purposes is unlikely to be well-trained by rehashing the tactical procedures for the Cobra Dane space radar site. However, knowing how space domain awareness radar operations differ from the air control or surface observation radar roles that the radar operator is likely familiar with can empower that operator to better provide space effects as a secondary mission.[125]

OFF-THE-SHELF MATERIEL

Historically, space planning has been built around a model of well-established bases, typically a large installation operated by the Department of Air Force, with space operations being present as a small operational footprint with a more extensive base infrastructure. However, the emergent need to provide additional survivability and complicate adversary targeting through asset mobility, maneuver, and disaggregation of forces drives a shift in operational philosophy to space as an expeditionary force.[126] Inherently, as expeditionary space forces can be rapidly deployed to austere environments, they should possess some self-sustaining means should attacks on broader forces or installations render base operations support integration unreliable.

Towards this end, investment in off-the-shelf materiel, such as tents, generators, and other expeditionary force-support equipment, as well as the previously mentioned commercially available small footprint space systems such as small telescopes, VSAT systems, or radio transmitters, should be investigated to robust those space forces that currently present from expeditionary forward locations.

LEADERSHIP

While some Combatant Commanders and at least one Sub-Unified Command have an appointed Space Force officer with Functional Component Commander (FCC) authorities, many AORs and most subordinate Joint Force Commands still operate without a senior space commander. Some may have a Director of Space Forces (DS4), who does not have command authority and essentially serves as a liaison.[127] Expanding the FCC role across all JFCs, whether that FCC is a formally nominated officer, as would be appropriate in a Combatant Command, or whether that individual is the ranking Space Force or primarily space forces presenting officer within a JTF's AOR, allows for more granular command of space presenting forces with a JTF's area of responsibility.

Additionally, space liaison officers (LNOs) should proliferate beyond the operational echelon where they are currently employed and be emphasized for their role at the tactical echelon. As an example, a space LNO presented to a Naval Surface Action Group (SAG) could not only best inform the SAG commander how space capabilities may best be employed to meet the SAG requirements but also how the SAG's inherent capabilities, such as missile defense and maritime radars, or space communications capabilities, may be employed as a secondary space presenting missions. In doing so, the technical expertise and space operational insight required for integrating these secondary mission areas are provided by a primary space officer rather than naval officers whose training and experience may emphasize space as a distant secondary concern to naval surface warfare.

PERSONNEL

Much as transportation and strategic action inherently cross AOR boundaries, space is an intrinsically global and extra-global activity. However, within many Air, Maritime, and Land Operation Centers, space is either an ancillary activity that is coordinated through a geographically removed specialized staff, such as a Director of Space Forces, or through a small liaison team who may or may not have tight incorporation into the operations and planning staff of the operations center. Ideally, space should be included in more tightly coupled coordination and planning within operation centers. For example, it would be logical to have a Space Operations Division, analogous to an Air Mobility Division representing USTRANSCOM, as an ancillary to combat plans and operations divisions. This ensures that operational level planning and execution consider space needs and best leverage available space capability.[128]

FACILITIES AND INFRASTRUCTURE

While typically presented by the services in the form of installations, basing, and lines of communication (such as roads or railroads), some infrastructure, for example, global communications networks, inherently affects all Combat Commanders and AORs. Space capabilities are at once an enabler of infrastructure, for example, communications or ISR collection, and significantly reliant upon them. Given the many threats to space assets and SATCOM's inherent exposure to attack, the wise Joint Force Commander would create a requirement across all Service Component Commanders to proliferate communication infrastructure within their AOR as much as possible. By providing numerous communications and data-sharing modalities across their AOR, combat commanders and their subordinate joint force commanders can both ensure successful space mission execution and best leverage the products provided by their assigned space forces.[129]

POLICY

Significant changes in U.S. space policy could greatly enhance the ability of space-presenting forces to surge and present effects to the Joint Force Commanders rapidly. A first and profound change would be reducing the security classification of space activities, typically classified at the top-secret level and controlled within sensitive compartments or special accesses. While the exposure of some space activities would meet the legal threshold for this classification, to wit "resulting in exceptionally grave damage to national security,"[130] the vast majority of space activities could be protected at a level commensurate with their air or surface analogs, without degradation to security practices. Since vetting personnel and accrediting facilities for higher classification activities are often the most time-consuming propositions during mission expansion, reducing classification levels for tactical space missions can create a virtuous cycle of mission acceleration. Finally, reduced security requirements allow for an enhanced ability to inter-operate with allies, commercial partners, and the civil space enterprise, expanding the options for non-traditional space capabilities discussed in part II. [131]

Changes in acquisition policy, such as establishing CRAF-like programs for SATCOM and ISR that allow contractual compulsion of DOD use of commercial assets on pre-negotiated terms, can significantly smooth the acquisition of surge assets. Similarly, acquisition frameworks that emphasize obtaining common space services like SDA or DSO acquired as a service can synergistically allow rapid purchase of space capability without the associated need for military infrastructure to manage it. When these services are purchased through scalable

Indefinite Delivery – Indefinite Quantity or Blanket Purchase Agreement arrangements the DOD pays by the product, be it an image, orbital element set, or hour of SATCOM monitoring, to maximize the flexibility of contracting during surge operations.[132]

PART IV - CONSOLIDATED RECOMMENDATIONS

"…we will be leaders within government to achieve greater speed in decision-making and action. We will partner with and lead others to further responsible actions in, and use of, space to promote security and enhance prosperity. Should an aggressor threaten our interests, America's space professionals stand ready to fight and win." – Gen John "Jay" Raymond[*]

OPPORTUNITY 1 – ROBUST SATCOM

To ensure continued delivery of reliable SATCOM, assessed to be the most critical mission area in terms of projected loss, increased demand, and shortfall impact to the all-domain force, the DOD should add additional COTS VSAT capabilities to expeditionary communications inventory and plan to aggressively purchase COTS SATCOM capabilities in the opening days of a major conflict. Bandwidth to operate this increased communications foot-print can come from traditional owner-operator providers, as a lease agreement associated with the VSAT terminals (a likely solution for proliferated constellation capabilities), or potentially pirated from adversary capabilities – this last creating decisional dilemmas for an adversary.

To ease bandwidth procurement, a CRAF-like Civil Reserve Space Fleet should be pursued at the national policy level, with the added commandeering of commercial crews and operations infrastructure easing the Spacecraft Operations, Defensive Space operations and Space Domain Awareness burdens associated with commandeered spacecraft or payloads.

[*] Raymond, John, 2020, "Chief of Space Operations Planning Guidance – 1st Chief of Space Operations", 3

Empowering a multi-capable Guardian crew force flexible enough to best leverage COTS SATCOM technologies and non-traditional orbital capability requires a pivot in training emphasis from mastering established procedures to developing in-depth knowledge of radio theory. To best allocate SATCOM capacity, communications architecture, bandwidth, and force allocation decisions should be delegated to the regional Space Component Commander. Finally, to rapidly and flexibly inform force package fielding decisions, operational and tactical planning doctrine should emphasize including SATCOM capacity as a distinct node within larger Mosaic warfare flexible force presentation constructs.

OPPORTUNITY 2 – LEVERAGE NON-TRADITIONAL ISR

Addressing the second most impacted Space Mission Area - Intelligence, Surveillance, and Reconnaissance, several opportunities become apparent for providing non-traditional capability and maximizing existing ISR assets. First, emphasizing commercial overhead capabilities ahead of exquisite orbital national assets and airborne ISR platforms allows both of the latter to focus on more specialized tasking. While military assets might provide capabilities that commercial spacecraft cannot, for example, aircraft can provide full motion video or loiter over a target for an extended period, most tactical land and maritime maneuver elements could meet most of their geographic intelligence needs from commercially derived imagery.

Expanding analysis and space-derived product interpretation can similarly be accomplished through commercial service providers or where inherently governmental or inherently military activities are concerned through a robust operational reserve force. Finally, embedding direct receive capabilities amongst tactical forces would allow processing and dissemination of overhead geographic intelligence within seconds of spacecraft overflight, allowing exploitation of space-derived ISR products even in an environment where intercontinental communications and intelligence support were unavailable.

OPPORTUNITY 3 – AUGMENT CELESTIAL PNT

At immense risk from ground or air-based Electromagnetic Interference, regional loss of PNT services is an almost certainty in a major conflict. While losses due to jamming are transitory – PNT service resumes once the jammer ceases transmitting, the reliance of U.S. joint forces on accurate and precise PNT makes these outages potentially profound. Augmenting these services with ancillary constellations such as the European GALILEO, Russian GLONASS, or Chinese Baidou allows for robust PNT services through added frequencies and bands of PNT reception. This diversification also potentially forces an adversary dilemma, where complete denial of U.S. PNT receivers requires degrading their services. Many terrestrial analogs allow for redundant air, surface, and maritime navigation or self-sufficient timing in the event of local loss of celestial PNT services. By proliferating existing COTS tactical navigation aids with forward deploying units, a network of ancillary navigation systems capable of withstanding local PNT jamming can advance along the forward line of troops.

OPPORTUNITY 4 – PROLIFERATE OSO AND DSO CAPABILITIES

Increased U.S. space usage and reliance drive a proportionate increase in Defensive Space Operations. As the greater joint force expands its dependence on space capabilities, the Guardians must live up to their name by ensuring that SATCOM, ISR, SDA, and spacecraft operations continue uninterrupted. Given the inherently defensive nature of these missions, they need not be performed by military forces or even government personnel. Consequently, dedicated commercial operators, or the providers of commercial SATCOM or teleport services, can assume much of the DSO burden. Providing this first civilian line of defense allows uniformed DSO forces to focus on higher-priority threats or more complex defensive operations. Additional military depth can be created through an expanded operational reserve force capable of leveraging DSO to counter complex threats. Finally, leveraging inexpensive commercial hardware and well-understood signal processing algorithms would allow adding DSO as a secondary mission for those forces possessing SATCOM receivers.

Similarly, an increase in adversary space dependency drives an increase in Offensive Space Operations. Unlike most capabilities, OSO is an inherently military endeavor, requiring military solutions to meet joint requirements. Fortunately, by expanding offensive space operations to a large and robust operational reserve and assigning OSO as a secondary mission to non-space presenting forces, an immense depth of OSO capacity can be fielded rapidly along the forward line of troops.

OPPORTUNITY 5 – EMBRACE NON-TRADITIONAL SDA

Space Domain Awareness predicates the ability to execute all other space operations and informs space-affected activities in other domains. Historically reliant upon a small number of exquisite, fixed sensors and centralized data processing, SDA provides a prime candidate for further robustness. Fortunately, many non-traditional sensors, from maritime radars and academic telescopes to a new wave of commercial entities providing SDA as a service, can rapidly fill the gap left by the loss of an exquisite asset. By expanding SDA sensing to non-traditional assets and exploiting commercial data processing, SDA collection, processing, and dissemination can be preserved during surge operations. Finally, operational reserve units equipped with SDA sensors, for example, telescopes or signal processing equipment, can forward deploy to fill capability holes in the global SDA network.

OPPORTUNITY 6 – FULLY EXPLOIT MISSILE WARNING

Global needs for theater missile warning can be met with an overlapping array of space-based sensors and ground-based radars. While physical and political terrain largely dictate the placement of ground missile warning radars, the ability of these assets to concurrently provide missile warning, space domain awareness, and inform political discourse makes them useful beyond missile warning. By carefully selecting tactical radar placement, missile warning assets can synergistically meet the needs of multiple mission areas.

As attacks on strategic warning sensors have profound strategic implications, these assets have an added layer of political consideration in their employment that could further dissuade attack, and by extension provide collateral protection to both their secondary missions as well as resources co-located near them.

OPPORTUNITY 7 – DISAGGREGATE SPACECRAFT OPERATIONS

Dynamic space operations seek to complicate adversary targeting of U.S. space assets; however, the success of these endeavors is predicated on reliable global spacecraft operations. Many constellations operate from a single operations floor, and telemetry and commanding requirements potentially exceed available capacity should an operations floor or tracking site become isolated or degraded. Expanding spacecraft operations through commercial teleport services and multi-mission operations floors allows for disaggregation of spacecraft operations should any single site or capability become isolated or degraded.

CONCLUSION

"First, the present extent of U.S. dependence on space, the rapid pace at which this dependence is increasing and the vulnerabilities it creates, all demand that U.S. national security space interests be recognized as a top national security priority. The only way they will receive this priority is through specific guidance and direction from the very highest government levels." – Donald Rumsfeld[*]

On December 7, 1941, the United States was attacked with little warning and, within days, thrust into a conflict on a global scale. The U.S. National Defense Space Enterprise has limited ability to control the outbreak of a global conflict; however, the U.S. can adjust policy, doctrine, and organization to surge space forces most advantageously should that conflict arise with little notice.

By embracing non-traditional providers of space services, the front-line space capability available to the DOD can be rapidly expanded in a matter of days. These non-traditional sources may consist of commercial entities delivering SATCOM, ISR, and SDA services, civil space capabilities such as civil environmental monitoring, and non-space military capabilities such as maritime radars, which provide space effects as a secondary mission. Further, by emphasizing space as a secondary mission provided by surface forces and expeditionary capabilities presented by reserve forces, the DOD can ensure that space-presentation projects move forward along with the advancement of the forward line of troops. Permissive doctrine for space forces integration and policy that eases classification burden and smooths acquisition of commercially available capability.

[*] Conclusions of the "Rumsfeld Commission"

Embracing the principles of mission command and mosaic warfare, non-traditional force providers can be brought to bear swiftly and flexibly. With associated mission-type orders, mission command presents as much decision impetus as is practicable to the tactical echelon. As practiced under a mosaic warfare construct, objective bidding and composite task teams allow for considerable expansion of effects for a given tactical space capacity and optimization and speeding of objective allocation and weaponeering. These innovations will enable the presentation of right-sized forces, even when most of those forces may present space as a secondary mission.

Finally, maintaining a healthy operational reserve force is the greatest asset for providing a robust and rapidly expandable military space enterprise. To meet the needs of an imminent surge, the ability to rapidly activate an already trained, organized, and expeditionary-equipped force reduces the proposition of expanding space-presenting forces from years to days.

APPENDIX A – QUANTITATIVE ANALYSES

Analysis 1 – Vulnerability of DOD Space Infrastructure

Threats to ground segment are as varied as adversary weapons. They can be in the form of kinetic strikes from air, land, or sea, cyber or electronic attack, or sabotage by non-conventional forces. In analyzing risk to a given facility, the questions of defense in depth – is the facility within the protected confines of a larger secured installation, attack proximity – how close can an adversary get without interception, and collocation – does the facility's proximity to other valuable targets increase likelihood of collateral attack?

During analysis, adversary conventional forces' likelihood of land attack seemed universally remote. These facilities were either located within the United States, on islands or territories firmly controlled by the U.S. or close U.S. partners, or on difficult to access terrain, such as arctic tundra. Similarly, all facilities had fencing and security elements, if not enclosed within much larger installations possessing these same attributes. However, many installations had substantial coastline, suggesting a more plausible attack vector from maritime fires, or maritime incursion – for example weapons fire from a civilian-appearing vessel. Consequently, posture on a coastline is used as a proxy for conventional force risk, with location inside a larger, well patrolled and secured installation serving as a control for attack from non-conventional forces. Finally, collocation with a substantial operational target informs the likelihood of being collaterally damaged during attacks on other nearby targets.

Space Launch Facilities:

Table 2: Space Launch Facilities

Facility	Littoral?	Inside Larger Installation?	Collocated with other operational targets
Vandenberg SFB	Yes – on coast	Yes – but very large and sparse	Yes – Primary Space C2 Node
Patrick SFB	Yes – on coast	Yes	No
Wallops Island	Yes – island	No	No

Conclusion: All U.S. Launch facilities are at hazard of maritime attack, and moderate risk of non-conventional attack. Vandenberg carries additional risk as a Command-and-Control center of gravity.

Satellite Control Network

Table 3: Satellite Control Network Major Facilities

Facility	Littoral?	Inside Larger Installation?	Collocated with other operational targets
Schriever SFB	No	Yes	Yes – Primary C2 Node
Diego Garcia Station	Yes – island	Yes	Yes – Naval Support Facility Diego Garcia
Guam Tracking Station	Yes – island	Yes	Yes – Anderson AFB
Hawaii Tracking Station	Yes – on coast	No	Yes – Proximity to Joint Base Pearl Harbor Hickam and Naval / Air C2 nodes
New Hampshire Station	No	No	No
RAF Oakhanger Telemetry &	No – but near coast	Yes	No

Command Station (U.K.)			
Pituffik Tracking Station (Greenland)	Yes – on Coast	Yes	Yes – radar early warning

Conclusion: 71% of SCN nodes are at hazard of maritime attack, and 29% are at increased risk of non-conventional attack. Most, also 71%, are collocated with or near other desirable operational targets.

Space Surveillance Network

Table 4: Space Surveillance Network Major Facilities

Facility	Littoral?	Inside Larger Installation?	Collocated with other operational targets
Maui Space Surveillance Complex	No – mountain top	No, but remote	Yes – Maui Optical and Supercomputing Observatory
Space Surveillance Telescope, Exmouth (Australia)	Yes – on coast	No, but remote	No
GEODSS Socorro	No	Yes – within White Sands Missile Range	No
GEODSS Diego Garcia (UK)	Yes – island	Yes – within Naval Support Facility Diego Garcia	Yes – naval Support Facility Diego Garcias
Pituffik SFS (Greenland)	Yes – on Coast	Yes	Yes – early warning radar
Shemya SFS	Yes - island	No, but remote	Yes – early warning radar
Cavalier SFS	No	No	No

Clear AFS	No	Yes	Yes – early warning radar
Beale AFB	No	Yes	Yes – airborne ISR assets
Cape Cod SFS	Yes	No	No
Lincoln Labs LSSC	No	No	No
Eglin AFB	Yes	Yes	No – R&D Range
Ascension Island (UK)	Yes	No, but remote	No
Fylingdales (UK)	No	Yes	Yes – early warning radar
GLOBUS (Norway)	No	No	No

Conclusion: roughly half of observation sites are on a coastline, with far more near a coast, presenting an increased risk of conventional maritime attack. Similarly, half are at increased risk of non-conventional attack, and half are near operationally desirable targets.

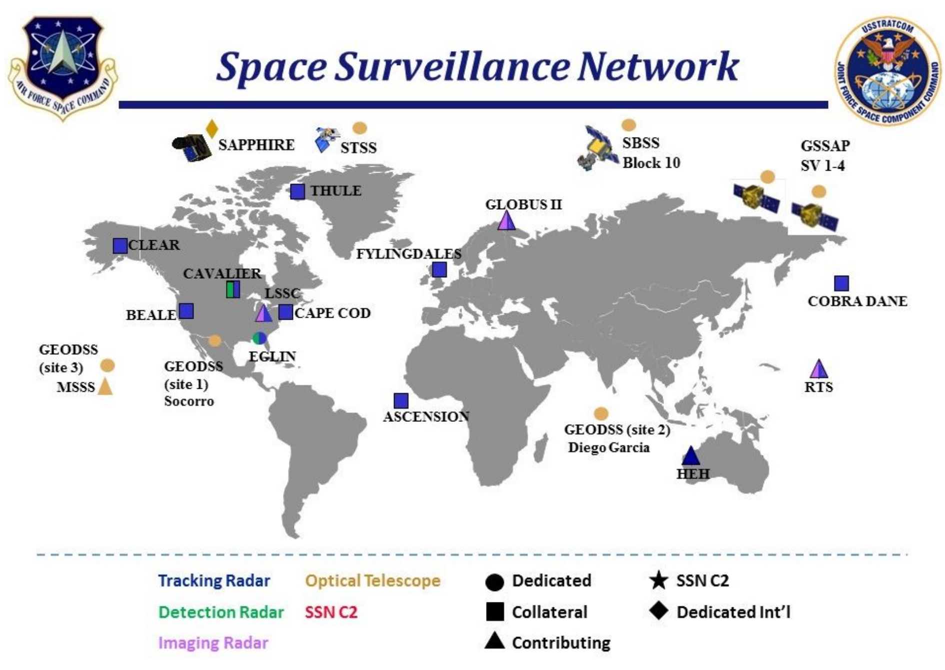

Figure 6: Space Surveillance Network Geographical Locations (USSTRATCOM Graphic)

Analysis 2 – Low Earth Orbit Exposure

For this analysis, the most common low earth orbit case, polar orbit, will be analyzed at varying orbital altitudes[*]. The field of hazard will be defined as the area of the earth's surface observable from the spacecraft, which reciprocally is the area in which an optical or radar observer could plausibly locate and target the passing spacecraft.

From trigonometry, the apparent horizon, or lateral distance visible to an observer is approximately $Dist = 6371 * \text{acos}\,(\frac{6371}{6371+Alt})$, with both distance and altitude expressed in kilometers[†], and 6371 being the mean radius of the earth.

Revisit rate is a function of orbital period, with period, in minutes described as:

$$Period = 2 * \pi * 1.05x10^{7}\,\frac{Alt+6371}{\sqrt{\frac{1}{Alt+6371}}}$$

(note: again, 6371 is the mean radius of the earth, in km, 1.05x10^{7} is a constant consisting of the product of the earth's mass, the universal gravitation constant, and conversion from seconds to minutes)

A worst-case revisit time will be over an equatorial point (a polar orbit, by definition, will overfly each pole every orbit, with moderate latitudes falling somewhere in between), with the equatorial distance between orbits being a function of the earth's rotation: 15 degrees per hour, or 27.8 km per minute at the equator. For the reader not accustomed to visualizing orbital mechanics – the plane of the orbit actually stays (relatively) fixed due to inertia, and the earth "moves" underneath as it rotates!

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[*] Note that special retrograde cases, such a sun synchronous orbits, will pass over every point on the earth surface in 24 hours by tautological definition. Lower inclination prograde orbits will, if anything, have more frequent revisits within their latitudes of regard.

[†] Derivation of this simplified identity is beyond the scope of this paper, but available from the author on request.

Tabulating LEO polar orbits provides the following observations:

Table 5: Risks profiles of common LEO Polar orbits

Altitude (km):	Orbital Period (min):	Field of Regard (km):	Equatorial Distance between orbits (km):	Max hours between views:
200	88.4	1575.9	2455.8	37.4
300	90.4	1917.9	2512.1	31.4
400	92.4	2200.8	2568.8	28.0
500	94.5	2445.5	2625.9	25.8
600	96.5	2662.7	2683.5	24.2
700	98.6	2858.8	2741.4	23.0
800	100.7	3038.1	2799.8	22.1
900	102.8	3203.6	2858.5	21.4
1000	105.0	3357.3	2917.7	20.9
1100	107.1	3501.1	2977.3	20.4
1200	109.3	3636.2	3037.3	20.0
1300	111.4	3763.6	3097.6	19.8
1400	113.6	3884.1	3158.4	19.5
1500	115.8	3998.6	3219.6	19.3
1600	118.0	4107.5	3281.1	19.2
1700	120.3	4211.3	3343.1	19.1
1800	122.5	4310.6	3405.4	19.0
1900	124.8	4405.6	3468.1	18.9
2000	127.0	4496.8	3531.2	18.8
2100	129.3	4584.3	3594.6	18.8

From this data, any object above 600 km can be assumed to "see" - and be seen from, every point on the earth's surface at least once per day. These orbits can be assumed to be at hazard of ground-based weapons from any point on the earth's surface, within any given 24 hours period.

Analysis 3 – Availability of GNSS jamming equipment

Counter GNSS equipment is prolific. A Google search engine query for “gps jammer”, for example, returns over 4 million results. More tellingly, legitimate online merchants, whether resellers of a myriad of things, such amazon.com, or specialized radio hardware vendors who typically provide more legitimate products.

At the low end, roughly 25 USD can procure a 12v DC powered, 1 watt GPS L-1 jammer advertised as capable of denying an area ten of meters around a vehicle, though employment of a similar device in 2022 was sufficient to disrupt flights into the Dallas-Ft Worth airport.[133]

Approximately 800 USD can purchase more sophisticated units with multiple frequencies and constellations covered, roughly 25 watts of transmit power, and potential ranges against aviation targets in the tens to hundreds of kilometers. It’s safe to assume that a relatively sophisticated non-state adversary could add additional transmit amplification for increased range, for about the price of a high-end smartphone.

The sophistication of Jamming waveform plays a role in range and effectiveness, with those jammers capable of recreating the GPS, GALILEO, or GLONASS spreading codes much more effectively and presenting a longer range per watt of transmit power than simple noise jammers. However, as open-source tools for creating these waveforms for peaceful purposes are prolific and easily obtained, it’s plausible that a determined adversary will be able to perform matched waveform jamming of published GNSS waveforms.

Analysis 4 – Suitability of tactical radars and academic telescopes for SDA use

Case 1 – Radar suitability

The ability of a given radar to sense an object is a function of the radar equation, which will be simplified assuming a common transmit and receive antenna to $SNR_{RX} = \frac{0.00633 * P_{TX} * G * \sigma_{Tgt}}{N * Dist^4}$ where P_{TX} is transmit power in watts, G is total antenna gain*, σ_{Tgt} is target radar cross-sectional area (RCS) in square meters, N is noise power, also in watts, and distance is range from the antenna to the target in meters. The constant 0.00633 allows for treating a far-field target in square-meters instead of angular area. In a radar processor, if a return signal to noise ratio (SNR) exceeds the radar's detection threshold, the radar can track the objects. Important takeaways from the radar equation are that SNR increases linearly with target cross-section and decreases with the fourth power of distance to target. For example, if target distance is doubled, received SNR decreases by a factor of 16! These observations allow us to extrapolate the performance of missile warning radars with known ranges and target RCS to space objects.

Given that a tactical missile nosecone may have an effective RCS of $0.1m^2$ when directly approaching the radar set†, and that most satellites per 18 SDS' spacetrack.org catalog have an RCS greater than $1m^2$, we can add a range increase of 1.78 for moderate sized objects, or 3.16 for objects with an RCS of $10m^2$. The U.S. Navy's SPY-1 maritime radar, with a published range of 370km, could be expected to detect moderate sized spacecraft to 660km and larger spacecraft to altitudes of up to 1,170km. The more powerful AN/TPY-2 missile warning radar can track missile sized objects to 870km,[134] suggesting spacecraft could be tracked between

* Note that in the spirit of gross simplification, this paper combines numerous gain terms into a single function. For out purposes, what's important is not antenna design, but to what distances existing antennas could be extended.
† From a radar operator's perspective this is the most concerning positioning of a missile!

1,550km and 2,750km. While these ranges incorporate altitude and distance from the radar set, even a case where an AN/TPY-2 radar tracks an object at 1,900km altitude 2,000km away laterally still provides meaningful LEO coverage.

Case 2 – Telescope suitability

Much as radar detection is a function of object cross-section, optical detectability is a function of spacecraft size, reflectivity, and relative angles between the sun, spacecraft, and observing telescope. This last, "camera-angle-to-sun" or CATS, is one of the fundamental considerations for the observability of satellites. Due to atmospheric illumination and poor CATS, optical observation during daylight hours is typically not possible.

CATS for ground viewing peaks during the period around morning and evening twilight – during this time, many LEO objects are visible to the naked eye. However, as the night progresses, many objects remain illuminated for sufficient observation with hobbyist-grade telescopes (<30cm aperture). Reliable observation into deeper orbits, such as GEO and HEO near apogee, require large apertures; the U.S. GEODDS sites use 1m class telescopes coupled with low-light cameras.[135]

These technologies are available on the open market, making procurement of a GEODDS-like observation site consisting of 3ea 1m telescopes, low light cameras, and support infrastructure conceivable. An internet survey of laboratory supply companies and telescope manufacturers provided a median price for a 1m telescope of approximately 750,000 USD. With a tracking mount (50,000 USD), low-light optics (100,000 USD), and a protective dome (100,000 with HVAC), a three-telescope site could be built for roughly 3M USD. With buildings, power, and communications infrastructure, a highly functional deep space observation site could be constructed for less than 5M USD.[136]

Analysis 5 – SATCOM efficiency

An upper limit on communications throughput, expressed as bits of per second, is provided by the Hartley-Shannon Noisy Channel Theorem. This observation is driven by the ability of a receiver possessing a perfect radio and theoretically perfect signal processing equipment to recover transmitted data from a noisy background. In its simplest form, the maximum possible data rate is $C = B * LG(1 + \frac{S}{N})$, where B is available bandwidth in Herts, S is signal energy in Watts, and N is noise energy over the relevant band, also in Watts. "LG" denotes a logarithm-base-2 operation. Evaluating several use cases over a 36 MHz commercial transponder equivalent with varying Signal-to-Jammer and noise ratios yields the following results:

Case 1: Undisturbed Communications, SJNR = 15 dB

In this example a traditional SATCOM signal is operating 15dB above the noise floor, and the energy collected by the receiver is about 30-parts signal to every 1-part noise. Across our 36 MHz receiver, our users could theoretically communicate 180 million bits per second, or 22.5 Megabytes / second, roughly the throughput of a mid-tier commercial internet connection. Note that these are theoretical maximums for perfect communications hardware; in practice, real users might see half that data rate for the same bandwidth.

Case 2: Jamming Resistant Communication, SJNR = -3 dB

This waveform assumes a jammer roughly twice as energetic as the targeted signal, with 1-part signal energy to 2-parts jammer or noise energy. In this case, the available data rate across the same transponder drops to 21 million bits per second, or 2.6 Megabytes / second. This data rate would be fine for several hundred voice calls or asynchronous communications such as email but would struggle to support services like full-motion video.

Case 3: Sub-signal transponder hijacking, SJNR = -15 dB

In a final case a friendly waveform is placed near the noise floor, and underneath adversary signals. This technique would be almost impervious to jamming, as the addition of further energy does not meaningfully reduce the 1-part signal to 30 parts jammer and noise. However, this scheme sees a data rate of 1.6 million bits per second, or around 0.2 Megabytes per second. This data rate, close to that of 1990's dial-up services, could support a small handful of voice calls or textual communications, but would struggle to communicate graphical information in a timely manner.

ENDNOTES

(Note: recurring sources are listed in short form here, with longer citations in the bibliography)

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