GLOBAL SPACE WARFARE TECHNOLOGIES:

INFLUENCES, TRENDS, AND THE ROAD AHEAD

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ABSTRACT: Set in an environment that lacks a modernized, enforceable, and effective space treaty regime, this forecast highlights for readers the potential bridges and sequels between various existing and emerging technologies in the years leading up to 2025 that might culminate in acts of space warfare. This piece also explores the relationships between critical dual-use technologies that assist in the development of both peaceful commercial and destructive military applications. Given how easily information can spread about the globe today, it is inevitable that space warfare technologies will proliferate. Once one country sets its sights on space domination, other countries are sure to follow, spurring a second arms race of sorts. The international community is in a race against time as technologies are evolving faster than ever before and will continue to accelerate exponentially in an almost biological fashion. If this process continues unabated, it will almost certainty result in the deterioration of peaceful collaborations, an increase in the creation of orbital debris, and the risk of an accidental or spasm nuclear event.

One has to look to beyond forefront military space technologies in order to begin to map the future of space warfare. This is partly due to the fact that in recent years, research and development partnerships related to sensitive military space systems and dual-use commercial systems have grown broader and more inclusive. This trend has resulted in greater access for the United States to talented minds from all over the world and low-cost scientific contributions from university-based researchers and small commercial operations. It has also resulted in a greater probability for technologies developed in the U.S. to leak outside its borders. The realignment of the global economy stands to further shift the international balance of space power in the years to come. For nations that possess the relative wealth, infrastructure, and knowledge to develop space warfare technologies, their ability to become a leading military space power requires only the will to do so. The “brain drain” that hampered the space programs of many nations in decades past is weighing less on them today. The stagnancy of foreign economies that resulted in a flood of scientific minds to the U.S. is slowly ebbing, as many are now returning home to profitable jobs in booming defense and space industries.

This situation is compounded by increased competition in the launch services industry, which has resulted in reduced costs to place assets into orbit, as well as a decrease in the size and weight of satellites and space systems—developments that are conducive to space warfare. Consequently, access to space is no longer limited to nations with massive military budgets. In this rapidly changing environment, the greatest influence on the development of space warfare may rest on our ever-growing dependency upon satellites—for both military and commercial purposes—and their inherent vulnerabilities. Furthermore, as we venture forward into a globalized security environment fueled by advances in technologies such as directed energy (DE) systems, artificial intelligence (AI), and nanomanufacturing, both the warfighter and the diplomat will be presented with new tools to respond to security crises.

Military space technologies currently in development are the precursor to a world where threats can be neutralized at the speed of light and conflicts may escalate at a rate too fast to curtail. Accordingly, adjustments will soon have to be made across the entire spectrum of diplomatic and military affairs. If we fail to draft international treaties now that are in line with the pace of advancements in military space technology, a global technology free-for-all could result. This could contribute to a climate in which a spacefaring nation such as the U.S. would be bound to engage in a constant race against itself in order to maintain an effective defensive capability. The purpose of the following military space technology forecast and analysis is to provide new insights and specific recommendations that might protect peaceful cooperation in outer space. This forecast assumes that there are no binding constraints from international treaties. It depicts the current and future state of science related to military space systems, specifically systems that could lead to scenarios that could be precursors to or causes of warfare in space.

In the years leading up to 2020, tensions among military space powers have been mounting. This has been due, in part, to broad-spectrum advances that have materialized internationally in the “Five Ds” of counter-space operations: Deception, Disruption, Denial, Degradation, and Destruction. Even as nations flaunt their military space abilities as a means of intimidating and deterring space rivals, instances of space systems failures, though still uncommon, are slowly rising due to space-warfare systems testing and the increasing amount of space debris. Space systems failures in this new era are triggering accusations of systems disruption and sabotage between nations. The means to achieve an offensive and defensive military space capability in this heady space environment can be found in various force-multiplying arenas of technology, which we will now discuss.

2020

We enter 2020 to find that the disparities that existed in decades past regarding global space warfare capabilities have been fundamentally and irreversibly altered. Many leading nations are now operating on a near-level playing field. Complementary technologies are driving one another’s progress; for example, as robotics concepts top out and undergo a momentary pause, they are soon catapulted ahead by explosive growth in the field of supercomputing. The arrival and subsequent establishment of strong artificial intelligence is approaching. Key strategists of military space warfare systems are chasing full-spectrum, real-time, and seamless situational awareness of sea, ground, air, and space. The world’s brightest minds are reaching new heights as human intelligence is fused with intelligent agents and neural networks. These are the systems that will deliver humanity to the next echelon as nations become increasingly reliant on AI systems and their ability to process a now humanly unmanageable stream of information–a torrent to which our military is now inextricably connected.

The five theaters of combat: Cyber, Space, Air, Land, and Sea, now resemble a unified battlesphere. The international space community is being led by drivers such as the still plummeting cost of computational power, the continued free exchange of knowledge, and the refinement of nanomaterials applications, which are resulting in stronger, lighter, faster and more responsive space systems. Featured most prominently in this transition process is the influence of the smaller commercial space systems companies and non-military R&D providers, such as universities. The roles of large military and governmental-based, space-systems providers have been challenged effectively by the private space industry. This challenge was inspired in part by successes in the fields of launch services, satellite development, and niche emerging systems. During this era, the commercial launch industry in the United States is now spending as much as four times the total annual budget of NASA, with wide spread commercial space travel seeming more plausible than ever.

The threat spectrum for potential space-attack scenarios is no longer a distant hypothesis, nor does it seem an abstract possibility because the technology is unknown–in 2020 various advanced space-warfare technologies are openly displayed and touted as offensive attack systems. For many nations there is an ominous and increased probability of sustaining a space asset attack; running in parallel with such concerns are increasing fears of worst-case scenarios related to the accidental launch of nuclear forces. This is also due to measurable increases in space debris and the confusion that could arise should space systems be attacked or time-out for extended periods without explanation. As more countries than ever are now realizing their mounting reliance on space, and as tensions run higher, the range of possible deterrents and responses to a space systems attack are increasingly severe and include the possible use of nuclear weapons. Full-scale attacks on space systems can now deliver catastrophic effects upon economies, societal functions, and military operations that would take decades to recover from–even limited acts of space warfare could result in rapid conflict breakout and light-speed escalation scenarios. Intolerable demands have now been placed upon the government and military officials of the leading space powers, as the remaining human factors across the entire spectrum of military space operations must come to terms with the prospect that their continued presence might only serve as an impediment to the realized potential of computational efficiency.

Artificial Intelligence & Cyber Warfare

In light of the convergence process that is now taking place between AI and cyber warfare systems and their corresponding areas of responsibility relating to military space systems and space warfare technologies internationally, their sections have been merged to reflect this evolution.

Human-machine interactions and interfaces are radically changing many aspects of the military space command and control structure. In many cases, specific combat operations are now being conducted by human and artificial operators working together in a virtual environment, which delivers a real-time view of the target area with semi-autonomous and autonomous attack options just a blink or a voice-command away. In 2020, AI-driven systems are now supplying consolidated information and refined military options to high-level decision makers, who are now unable to decipher and analyze vast data flows alone. The role of the war planner is now found to be most critical during the process of selecting war fighting strategies generated and provided by AI systems.

The entire sphere of global military operations in 2020 has the potential to be fully interconnected for those with the means and the desire to do so, as successful military operations are decided by this complex network of systems. Vast protection measures have been taken to guard these systems, including actions to greatly reduce the number of network access points into military and national security systems and to centralize individual architectures in an attempt to prevent unauthorized access and lessen the probability of cyber attacks. This will prove to be a critical decision for many advanced military powers. As governmental network access points are reduced and their decentralized layout is eventually integrated, the potential for security breaches is greatly decreased. However, should a cyber denial of service or brute force attack prove successful, a full or near-full spectrum catastrophic failure could result. Scenarios such as these must be considered before the complete consolidation of information architectures is achieved. Decentralized systems lead to an increased potential for vulnerabilities; however they defuse the effects of successful attacks, thus minimizing the potential for significantly debilitating operational effects.

Threats posed to computer networks that support critical military satellite systems are in 2020 becoming increasingly complex and are occurring more frequently. Specifically, attacks targeting ground stations and command centers threaten military connectivity and the seamlessness of the Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance systems (C4ISR). Such attacks have the potential to effectively induce a systems blackout. A military's ability to adequately secure C4ISR systems and protect ground segments ensures success not only in space, but in all dimensions of warfare. Advances in cryptology, quantum cryptology, and related technologies such as ciphers and crypto-keys for performing encryption and decryption of these data streams are vital to space-systems security. Specifically, the preservation of secure crosslink/uplink/downlink data transmissions will require constant enhancement efforts due to the availability of advanced computer processing capabilities and the adaptive nature of highly skilled adversaries. As with all military space-supporting computer systems, threat sources are not limited to code breakers and hackers trying to exploit weaknesses from outside government facilities in faraway lands, but from within the host government as well. In an environment where trust is everything, a weakness in the human element of security could jump all other protection measures. Additionally, if an attack were to succeed against the C4ISR supporting space systems, a self-healing capability or Self-Regenerative Systems (SRS) solution must be executed immediately in order to repair and secure the effected network. Such abilities to survive a debilitating space systems attack will be made possible by advances in AI.

Nanotechnology

In 2020 it is nearly impossible to find nanotechnology detractors as universal applications are benefiting countless industries in this multidisciplinary field. Up to this point, nanotechnology discoveries that improved space warfare capabilities had appeared mostly in the form of materials improvements, which enhanced solar power generation, survivability, and structural integrity. Now, micro-electro-mechanical systems (MEMS) and micro-opto-electro-mechanical systems (MOEMS) are beginning to lead to further improvements in sensors, such as Attitude Determination and Control (ADCS) and other components, such as actuators.

Meaningful research into the materials sciences has now been underway for nearly twenty-five years and novel applications are currently appearing and addressing key challenges. Specifically, developments made in the areas of carbon nanotubes (CNT) are resulting in materials capable of thermal and electrical conduction. Additionally, CNT in the proper configurations have led to the creation of materials with unprecedented ballistic protection and heat-shielding and load-bearing strength, including the ability to defuse and insulate against the effects of high-energy lasers. For example, 3D aerogels and xerogels are in 2020 capable of withstanding load-bearing pressures as extreme as 75,000psi. One can imagine numerous applications for such materials, especially when we factor in advances in oxide options. Nanocomposite materials such as those utilizing silica or polystyrene even demonstrate an ability to shield against the effects of high-power microwaves (HPM) and radio frequency (RF). This field of science is also delivering applications that provide the ability to blend an asset's thermal, visual, and radar appearance into its background. Through this research, advanced photovoltaics and power generation methods are evolving as well.

More elaborate, yet feasible, concepts are being pursued such as a Faraday Cage built on a nanoscale level, which would require doped and multi-walled carbon nanotubes (MWCNT). This concept uses carbon nanotubes to develop an enclosure for satellite subsystems and smaller satellite classes such as picosats and nanosats and would provide insulation against various DE threats. Such an enclosure could deter the effects of an electromagnetic pulse (EMP), electrostatic discharges and various other directed energy threats.

Also, self-healing materials are being researched by universities, industry, and militaries to develop self-repairing technologies to address damages such as those that could be sustained in space as a result of space debris or destructive space-asset attacks. Such impacts could lead to a satellite failure, and so a technology like this reaching the development stage would prove invaluable. These materials would use composite structures that contain nanoscale spheres, which encapsulate an unhardened polymer resin. When a satellite is hit, the resin would spread and then fill the cracks to prevent further damage. Such systems could also provide shielding.

Flexible nanoelectronic devices that are as thin as paper and mounted to a thin flexible substrate such a as a plastic would provide a flexible, conductive, and multiuse material, which could then be integrated into countless space systems. A very attractive manifestation of this application would be in the form of a substrate on which electronic circuits could be printed on demand. Such a nanomaterial would also be durable and could be rolled up and stored. Flexible substrates and the use of various conductors could lead to thin-film solar cells for space applications or thin-film semiconductors.

The next level: Molecular nanotechnology (MNT) promises to revolutionize countless products by engineering mechanical and electronic systems, including advanced materials, at the molecular scale. Such a capacity for discovery will touch upon every aspect of military technology in the realm of space warfare. This rearranging of individual atoms is an emerging technology with serious implications and will be discussed in the next section.

Satellites, Attack Satellites & Asset Defense Systems

In 2020 military satellites and, to a lesser degree, commercial satellites that perform functions critical to civilians, governments and militaries are now increasingly capable of performing active and passive defense, offensive interdiction and rendezvous operations, and covert and overt attacks, while simultaneously carrying out their primary missions. As a result of this trend towards a technology convergence, satellites, attack satellites, and asset defense systems will be included in the same section.

Advanced autonomous satellites systems, may include the following subsystems: laser communications systems, high-powered electronic propulsion systems, advanced pattern recognition software, earth-space energy transfer, and/or advanced photovoltaics. These discoveries, which originated in the fields of AI, nanotechnology, and DE are continually improving many other areas of satellite survivability and overall performance.

These advanced systems are in many cases complemented by elaborate suites of countermeasures including: aerosols, decoys, lasers, chemical munitions, high- and low-energy lasers, power-sapping methods, adhesives, adhesive materials, corrosives, destructive enzymes, charged projectiles, kinetic objects, kinetic collisions, cryogenically frozen micro-meteors, compact DE systems, jamming devices, electronic warfare (EW), high-powered microwave (HPM), RF, EMP, and electromagnetic interference (EMI), and various other methods to duplicate natural phenomenon. Countermeasure options also include thermal effects, foils, lures, methods to compromise sensors, crosslink/uplink/downlink transmission sabotage or interference, and, lastly, defense by an accompanying host/surrogate satellite or an independent escort/defense satellite. Such countermeasures could be employed to defend against attack or, in an offensive capacity, impose the 5Ds upon a rival satellite.

The satellites of leading nations may now be incorporating autonomous crash avoidance, self-monitored diagnostics utilizing low-cost sensors and plug-sense-and-play software, threat identification and reporting abilities, and even self-directed repair services. Satellites are now also incorporating advanced nanomaterials, which depending upon their configuration, can partly or fully insulate against many forms of DE attacks, EMP, charged particle beam (CPB), neutral particle beam (NPB), HPM, and RF, assuming that a significant blast wave does not take effect–though the effect of such pressure is being reduced during this period as well.

In the era of space warfare, nations with lumbering space systems that can be reached with ballistic missile capabilities are faced with two choices: Replace or defend. A prime example of such a vulnerability (both in 2009, and undoubtedly in 2020) would be a system like the European Union’s four Helios observational satellites, which each weigh in at 4 metric tons and are located in low earth orbit (LEO). In contrast, deployed formation-flying microsatellite constellations are beginning to evolve into pico satellite and nanosatellite swarms, providing an enhanced means to defuse the effects of space warfare against satellite systems. Such satellite configurations would also further upgrade the overall integrity of a global, seamless, real-time, and integrated data stream, which is the ultimate pursuit of the military war planner. Such systems would be equipped with versatile features such as electrical propulsion systems, multiple-agent-based autonomy, and laser communications systems–all technologies delivered via the fields of directed energy, artificial intelligence, and nanotechnology.

Directed Energy Weapons (DEW)

Various ground-based DEW platforms, which can deliver effects utilizing CPB, NPB, HPM, RF, and high-energy laser (HEL), have been deployed by various nations. Despite widespread successes in the fields of directed energy and adaptive optics, an ability to dispense a powerful space-earth, earth-space CPB or HEL weapons system has yet to be fully achieved due to atmospheric challenges.

With atmosphere-related challenges removed from the equation, many HEL systems could potentially release continuous wave and pulsed outputs reaching into the multi-megawatt ranges. Continued advancements in other subsystem-focused areas, such as beam control and pointing and tracking, will continue to improve overall beam propagation as well. Additionally, it has been shown in years past that it is possible to overpower atmospheric effects by phase-locking multiple DE sources, thus creating a combined energy source. When this is done accurately, the resulting power outputs are drastically increased when compared to a single source DE pulse stream. For this reason, research in refining methods such as this to reduce or eliminate weather-related challenges is rigorously underway.

Many other R&D programs are taking place internationally, across the university, commercial, and military-based scientific communities, to develop ways to improve DEW effects. Constellations of high-strength and thermal-effects-resistant relay mirrors, utilizing advanced nanomaterials, could in 2020 be installed in multiple locations. For example, when mounted to an unmanned aerial vehicle (UAV) or high-altitude airship (HAA), they could accurately direct a beam of energy to any target on earth, thus eliminating line-of-sight barriers. Contrary to the various levels of efficacy provided by such concepts, the deployment of a high-energy, space-based laser or other type of space-based DEW has already been undertaken by as many as three parties that are now capable of space-to-space anti-satellite (ASAT) operations–and, though slightly compromised, space-to-earth attacks. It is also important to note that atmospheric challenges do not degrade space-to-space DEW platforms and their potential. Furthermore, earth-space attacks can be carried out by lasers based on aerial vehicles.

With the help of high-powered supercomputers and AI systems working in concert with ground stations and weather satellites, militaries of the world can now accurately predict weather patterns like never before. Such an ability to predict weather and atmospheric changes allows war planners to accurately diagnose the time, location, and other related information necessary to channel the atmospheric windows of opportunity that would most empower HEL beams. Should these predictive methods be combined with long established research into weather modification techniques and advanced adaptive optics, it will not be long before many countries can unlock the full potential of DEWs.

Not only can EMP effects now be employed anywhere in the world without the need for a high-altitude nuclear detonation, the delivery of these effects can also be achieved with a reasonable level of accuracy. These non-nuclear electromagnetic pulse (NNEMP) generators, which have for decades been used to test hardened military and commercial equipment, have become yet another benefactor of the trend towards increased miniaturization of military systems. As a result of such size reductions, NNEMP systems can now be based terrestrially on mobile units, tactical aircraft, UAVs, space-based systems, and as fixed ground stations.

Ground Segments

The role of ground-based installations in the pursuit of space dominance has never been so significant. In 2020, attacks against the ground segments of a capable space nation are just as destructive as those committed against satellites in space. Cyber, Space, Air, Land, and Sea operations are equally vulnerable to these attacks, though for many nations, such a distinction no longer applies. Joint warfare is no longer a doctrine, it is no longer a practice or a military strategy - it is a constant; it is the only option. From special operations to ground forces, from space command to naval forces, there is no mistaking that there is only a military now–a singular, integrated, and fully-networked military force. And there is no denying the integral role played by ground segments in future wars.

Military space systems and related operations consist of three key components: the space-based segment (satellites), the ground segment (systems operations), and the electromagnetic links, which connect the two. These ground stations house information processing, fusion and dissemination facilities, command and control centers, and many other components that support essential military and intelligence functions. In the years leading up to 2025, advances in the fields of nanotechnology, AI, and DE will begin to redefine everything we thought we knew about the ground segment as the process of technological convergence continues.

Evolved Unmanned Aerial Vehicles & Launch Services

Developmental efforts in the field of unmanned, autonomous, high-endurance, near-space vehicles are coming into fruition as these systems are nearing full-scale production with various concepts having been proven flight worthy and even deployable. This revolutionary platform may feature: supersonic capabilities, quantum-encrypted data transmissions, and advanced nanomaterials that deliver superior ballistics protection, stealth capabilities, and integrated power generation. Weapons capabilities may include: near-space to space DEWs, RF munitions, electromagnetic pulse generators and various ASAT capabilities. It is not expected that such a system would require in-flight refueling, since various energy-generating and conversion methods may be applicable during this time frame; should such a technology not be available until 2025, hybrid propulsion systems would instead reduce the need for in-flight refueling. Such a system can also return back to its point of origin or change flight plans to another location in-flight, depending on the needs of the warfighter.

Other deployable configurations have also now appeared, such as unmanned, autonomous, high-endurance global strike platforms, which are delivered into orbit on a responsive launch system, maintain a stand-by position, and, when called upon, can reach hypersonic re-entry speeds to deliver a variety of weapons payloads.

Subsonic high-altitude, ultra-long-endurance, low-observable unmanned systems have now been deployed by multiple nations and are being used for various military operations, with multiple integrated weapons options. These autonomously-assisted strike platforms provide increased versatility compared to their predecessors. These applications, much like microsatellite systems, have been significantly enhanced in many other areas. Improvements in materials sciences, miniaturization methods, and energy-generation techniques have also improved reliability and survivability, while extending mission duration. It is now also possible that such systems have begun to receive integrated HEL weapons for military operations such as those related to: space asset attack and protection, air-to-ground engagement, and missile defense.

Caveats

As a result of widespread technology exchanges pertaining to space launch systems and the proliferation of long-range ballistic missile technology, coupled with the widespread availability of commercial launch services, virtually every nation on earth now has the potential to place military satellites into space. At the same time, an increasing number of nations now have indigenous ballistic missile and launch capabilities, which have dramatically increased their potential to commit offensive space systems attacks against blue-shirt assets.

Additionally, the continued trend toward cooperative space security has combined the launch capabilities of many national space programs. Such an outcome is due to: consolidation of the commercial launch and space systems industry on an international level, decades of abundantly available open-source technical information, loosely monitored multi-tiered collaborative environments, and industrial and military espionage. These influences mentioned above also apply to nearly every area of the military space systems industry, and are responsible for immeasurably enhancing red-shirt military space capabilities.

Adding to this, by 2020 emerging technologies have dramatically reduced the overall size of space systems and increased affordability while simultaneously improving upon strategic initiatives such as systems redundancy and interoperability. The resulting widespread access to military space technology has led to an exponential increase in the number of satellites, which has, in turn, heightened the potential for an act of space warfare.

Internationally, the convergence process is continuing as the standardization of space and related technical protocols among allies is ensuring that each nation involved in cooperative space security is on the same page. This process will also begin to become a polarizing force, making the existence of a red shirt-blue shirt space dynamic more clearly defined. In 2020 space access is power and not solely of the military sort. Now that we rely on space systems for trade, communications, imaging, intelligence gathering, military targeting and navigation, and other functions, the objectives of war planners are being achieved by attacking, compromising, or temporarily rendering inoperable a nation's space assets – and by doing so, economies and societal functions of the targeted nation or nations could as a byproduct be brought to a grinding halt.

Given this unprecedented level of space access, combined with smaller payload weights, advanced satellite development programs, and proliferation of military space systems, one can be reasonably confident that most conflicts between industrialized nations will incorporate some methods of space warfare, even if in a limited, nondestructive fashion. Regardless of the level of taboo associated with such an act, countries that are engaged in conflicts against a more advanced military space power will have to either accept defeat or commit to attacking the systems that are devastating their forces. As with other space warfare scenarios, the probability an attack against a nation's space systems increases as the deterrent decreases; this deterrent factor is greatly reduced in the case of nations with a minimal space presence, especially when under attack or in a position of desperation.

There are very few reasons not to incorporate space warfare attacks in an attempt to deliver lights-out warfare effects that would avoid unnecessary death and destruction while also potentially reducing the duration of the conflict. Such an action would be an extraordinary and irreversible step towards space warfare tactics becoming an acceptable force multiplier. Such a sense of acceptance could be further compounded by internationally-approved military space operations conducted under the banner of peace keeping and sanctions employment and enforcement. Space warfare could become a means to reduce the probability of war–to be able to silence and deafen a military before the first human casualty takes place.

To imagine such a scenario, however, one must ignore a world armed with thermonuclear weapons and the potential for space warfare to result in a debris field so dense that it could serve to preclude the possibility of future space colonization. And as the approach of Strong AI systems looms on the horizon, perhaps a more immediate concern would be this: In an era of increasingly seamless, high-speed military operations and a reduced human presence in the data stream, will this ever-evolving computational capability reduce or increase the probability of accidental nuclear warfare?

2025

By 2025, space warfare systems have been used numerous times both covertly and overtly by various nations, during limited space-specific attacks and in support of larger military operations. These technologies can deliver destructive effects that are physical, societal, and/or economic, in many cases with varying levels of overlap. Such space-specific attack scenarios are conducted in a space-to-space, space-to-ground, and ground-to-space fashion. What has not occurred and is highly unlikely to occur for many decades, if ever, is a dedicated war in space or space war. This is a direct result the intrinsic inability for modern militaries, regardless of partial or complete command of space, to separate military space functions from other areas of military operations. Space has been and will continue to be used as a force multiplier and as part of a larger military operation. Should a nation pursue a dedicated space war scenario, it likely would be capable of only an individualized or limited act of war against space systems, an act that, if committed, would require supplemental attacks and support provided by the remaining four theaters. Therefore, the phrase "space war" is more of a cultural term, describing a scenario that could not in reality be conducted between nations, as either a war of space systems attrition or as a means to achieve a decisive victory against a nation or nations alone. Wars per se can not be fought and won solely in space, though for nations engaged in conflict against a capable space adversary, they are nearly impossible to win without some act of space warfare.

Military space systems, which were once viewed as consisting of distinct or virtually independent elements, are in 2025 progressively appearing unified in many fundamental ways as the converging trajectories of various scientific fields drive the space industry forward. Over the years, technologies that were once referred to by many as merely emerging concepts and theoretical possibilities have by a rapid and consistent pace of development challenged contrarian expectations; today, they transcend and defy their once predefined and now abandoned limitations. We witness this phenomenon in a similar light to what unfolded in the previous century with computer processing technologies. As computational demands increased, relays became vacuum tubes, then transistors, and on to semiconductors. In 1965 Moore's Law charted an exponential growth pattern in the complexity of integrated semiconductor circuits and computer processing. The unprecedented explosion of computational potential, and, in turn, affordability that Moore accurately predicted drove widespread discoveries in the field of computer science, such as the creation of the Internet.

In 2001 Kurzweil's Law of Accelerating Returns extended the growth pattern described in Moore's Law to transcend computers and reach into many other areas of science. Most remarkable is that this scientific and technological growth, which Kurzweil revealed, is not linear but exponential; and it is not limited to the technological, as humanity accelerates its potential in cadence. The way that one technology seems to max out and then suddenly converge with another to become something greater was also observed with the marriage of early of genetics research and advanced computer processors. According to Kurzweil's Law, this would constitute an example of two technologies having pushed and pulled with one another, engaging in almost evolutionary fashion to become more than just the sum of their parts, but rather something superior. The result in this case was the mapping of the genome, improved health care, and longer human life expectancy.

Converging technologies driving one another in parallel as humanity realizes a collective need to meet the next challenge – in 2025 this phenomenon has now set its sights on military space technology. Due to the nature of the sciences that will drive future military space systems advancements, the military space systems industry is now experiencing its exponential growth cycle. The primary influence leading to advanced arms racing and evolved methods of warfare that reach destructively into space is the integration of nanotechnology, robotics, and artificial intelligence technologies (NRai).

Nanotechnology/Robotics/Artificial Intelligence (NRai)

As the arrival of Strong AI draws ever closer, along with it comes the realization that computing on such a scale and breadth is beyond our human ability to maintain and monitor, even with the assistance of the machines themselves. We will begin to turn over keys to the IT department to the computer within it, as the pending arrival of Strong AI will drive its own evolutionary cycle, with human oversight existing from afar, at specific points in the data stream. This is the liftoff for military space systems, and our final approach towards a victory over the Turing Test.

During the span of this analysis we have seen the devices for human involvement in netcentric warfare leave the point-and-click mouse behind in exchange for voice-command and evolved human-computer collaboration, under the banner of intelligent and Human-Machine Interfaces (HMI). In 2025 HMI takes a step further towards Brain-Computer Interfaces (BCI), also known as Brain-Machine Interfaces (BMI). Working, but limited, examples of this technology, such as the Berlin Brain-Computer Interface (BBCI) have exhibited proven results as far back as 2002. Such technologies to command cyberspace and, as a result, the five theaters of combat including space have been driven by AI. This is specifically through advances in the field of neural networks, a computational data-analysis method that is based upon the architecture of the neuronal connections within the human brain. Such a system will eventually allow human integration into the data stream and in time will not only allow interaction via one single human function, but instead BCIs will be comprised of central nervous system connections, alpha and beta brainwaves, eye movement, and voice and facial recognition. The first manifestations of this technology have been dual-use and have led to tremendous improvements in freedom and mobility for the severely disabled; additional limited civil applications are mostly in the area of video gaming. Military and national security applications of BCI in 2025 include the control of logistics, supply chains, terrestrial-based weapons systems, unmanned aerial platforms, and space systems.

BCIs will exist in parallel with a virtual world, though they will not be the virtual boxes developed many years prior such as Cave Automatic Virtual Environments (CAVEs). BCIs have combined with a technological ability to create 3-D stereoscopic images direct to the eye, located in interpupillary distance of the warfighter. These virtual domains when fully integrated with Strong AI and connections to the central nervous system, alpha and beta brain waves, and voice and facial recognition, will provide far more than virtual theaters for war gaming and interactive displays for pilots and troop training–we will have effectively and irreversibly fused human intelligence (HI) and AI.

To play ping-pong on a personal computer utilizing a BCI interface that reads alpha and beta brainwaves is impressive in 2009, however in 2025 when BCIs are integrated with optical interpupillary interfaces that transmit a netcentric warfare systems display, combined with central nervous system connections, and voice and facial recognition, we begin to realize its optimal potential. Such a system could ultimately combine with real-time, secure uplink and downlink data transmissions to a satellite in space which, in turn, could direct a small scale UAV or unmanned ground vehicle (UGV) utilizing advanced MOEMS/MEMS-derived sensors and optics delivering streaming video of the battlefield. The truly transformational role of these merged technologies will be difficult to imagine until we first witness the warfighter speak, think, or signal the fire command and neutralize an enemy target.

A specific military application of these technologies that is more likely to be available in 2025 would be those which are used to automatically target objects on the ground from space with hyperspectral imaging integrated into a microsatellite platform. This imaging capability would be combined with principal component analysis (PCA), used to reduce the volume of data to a manageable size for analysis, and a multi-layer perception (MLP) neural network, which uses multiple layers of neurons to turn vast amounts of data into a consolidated form. This could lead to a system capable of educating neural networks on how to execute a specific task, such as delivering strike options in real-time to the war planner via satellite communications to a comprehensive BCI interface.

On a much smaller physical scale, military robotics programs have been enhanced by advances in the field of molecular nanotechnology (MNT), resulting in devices such as molecular motors. This development has spawned numerous concepts which are in the R&D programs of leading NRai nations. These concepts, with molecular scale systems that measure less than a few centimeters, might range from miniature flying vehicles with numerous applications to ground-based robots, both of which, with the help of AI can collectively combine their effects in a swarm-like fashion.

The continued reductions in the size of technology will span all industries and countless military systems, including space systems. For instance, such small flying devices could be contained within a relatively larger rendezvous capable satellite, which would then release the smaller molecular devices or bots to execute acts of sabotage against rival space systems, with a reduced chance of being detected or targeted. Advancements in the field of MEMS-driven micro-thrusters would provide propulsion as reductions in the size of computer systems would allow for control of the devices, either autonomously or remotely via downlink to a ground segment, then onto the device itself.

Microscale and nanoscale UGVs acting alone or in swarms, could eventually mimic biological entities such as insects through MNT processes and be used in military- or intelligence-related operations–as will also be the case with the flying systems. Like nearly every program contained in this analysis, this forefront technology is being pursued by various nations, in multi-tiered collaborations that may include military researchers, university students and professors, and private companies. Such systems would someday be available for deployment as military off-the-shelf (MOT) systems and as commercial off-the-shelf (COT) systems. Additionally, each platform would be field programmable and exhibit Strong AI characteristics. Such technology could be powered by one of a myriad of emerging, nanotechnology-generated energy systems, such as those that use: electromagnetic force, solar energy, microwaves, electricity, magnetism, transistors, and lasers. Furthermore, developments made to gyroscopes for navigation systems also will be realized.

Other combinations of MEMS/MOEMS, (which it should be mentioned, offer features and benefits which at times overlap one other so much so that the individualized acronyms may in time become integrated under a single designation,) can also be used as sensors, inputs, outputs, or serve other internal processing functions in larger space systems. Such far-reaching technology is leading to entire computer systems on a single chip that could potentially replace silicon chips, adding a further dimension to the forecast beyond 2025. In the more immediate future, innovations in the field of lithography and multi-gate processing, such as double- and tri-gate transistors, may also contribute to dramatic increases in processing speed, especially when compared to the traditional and increasingly more archaic silicon chip.

The role of ground segments in 2025 continues to remain a critical area of military and national security operations. In corresponding fashion with the steps forward witnessed by many other areas of military space systems, the ground segment is reaping the benefits of NRai as well. The vulnerabilities that weakened this bridge between earth- and space-based military functions have been significantly reduced, thanks to improvements in the areas of: miniaturization, maneuverability, survivability, and redundancy. The ground segment of the past has become the unattended ground sensor (UGS), a transportable and affordable, small box-on-the-ground. Deployable in large numbers, providing multiple layers of redundancy, and effective terrestrial-based communications and space-to-earth uplink/downlink, this device has effectively mitigated the threat to ground stations, for now.

Directed Energy: Weapons and Next Generation Launch Systems

Ground-based (GB) DEWs are in 2025 abundant and can be found in the arsenals of many nations, as they have by now achieved adequate power levels and have clearly demonstrated an ability to strike space assets. For the few nations that have the ability and choose to deploy in space (covertly or overtly), ground targets can be reached from the heavens as well. DEW has redefined warfare, with speed-of-light attack capabilities and a psychological factor second only to nuclear, biological, and chemical (NBC) weapons. It can be expected that the number of nations with deployed DEW weapons will continue to grow exponentially, as the methods to develop such tools of war and the means to reduce the challenges that hamper development-ready systems will find their way to virtually any nation that seeks to acquire their awesome power.

A thought-provoking combat scenario surrounding GB-DEWs in 2025 begins with the fact that many GB-DEW installations are fixed stationary systems with a large foot print. These fixed systems will likely require massive amounts of energy to provide an effective beam strength that can be capable of sustained offensive and defensive effects. Because of such constraints, many GB-DEWs are directly wired into nuclear plants and municipal power stations. Accordingly, it should be noted that in 2025, should a nation be faced with a threat to their military forces or space systems by GB-DEWs, there will be few options but to attack these power sources. Clearly then, it is difficult to deny that DEWs powered by fusion sources place a very unique set of challenges upon the war planner.

By 2025 military DE efforts are not only limited to directly improving weapons effects, but rather innovations in the field of DE are also advancing areas such as propulsion. Examples of promising systems in this field include, solar thermal propulsion (STP), which could provide a highly efficient alternative to hydrazine for micro-scale (and larger) space systems that require high Delta-V maneuvers. Another method is based on the concept of using energy generated by a laser to heat a gas, such as hydrogen for example, to a very high temperature. As a result of this interaction, the gas then rapidly expands and delivers thrust. At this time, lasers have a demonstrated ability to reach the power levels required to deliver this concept to the military in a truly beneficial sense. Just as affordability, reductions in weight, and sheer innovation drove the satellite industry forward in prior decades, those same satellites and their dramatically reduced size and cost has, in turn, provided new opportunities for discovery in the field of space exploration.

In keeping with this spirit of innovation, other methods of propulsion that have been in the R&D stream for many years, such as the Lorentz force ion thruster, are now coming into full fruition. This method delivers a lift capability via the energy created when an electric current is combined with magnetic energy to generate thrust. In 2025, this concept may be already integrated into various space crafts. Other DE propulsion methods such as plasma-based, pulse-detonation engines (PDE), which received much attention in the past, may now be seen regularly preparing for take off.

The rapidly growing threat spectrum against space systems is further expanded by the increasing number of nations and non-state actors with access to ballistic missile technology. At the same time, the ballistic missile defense (BMD) methods deployed in decades past are in some cases now seen as unable to fully respond to the challenges presented in 2025 and beyond. In particular, BMD systems such as the kinetic energy interceptor (KEI) and the miniature kill vehicle (MKV) require elaborate sensor suites, such as infrared, radar, and optics to ensure an accurate trip to the threat. Additionally, components that add weight and systems complexity such as thrusters and guidance systems can now be avoided with the aid of DE missile defense solutions.

Other methods for ballistic missile intercepts such as ground-based lasers (GBL) and space-based laser (SBL) programs have now existed for many years and have proven to be successful for the few nations that possess the resources to employ DE as a BMD system. Though also welcomed are complementary alternatives that help meet the increasing challenges while at the same time preventing threat leakage caused by advanced countermeasures, maneuverable in-flight warheads, and hypersonic global-strike platforms.

One such DE system that may emerge as a complementary BMD application involves a laser-propulsion system named Lightcraft, which could by 2025 deliver a Kinetic Kill Vehicle (KKV) to a target at hypersonic speeds. Such a KKV could be ground, air, or space launched, though its effectiveness is reliant on the overall quality of the DE source that propels it. The structure of the KKV resembles a parabolic-like shape, with an interior consisting of highly reflective mirrors that channel heat away from the laser, resulting in explosive energy that ultimately generates thrust. Such a technology could theoretically be used to deliver lightweight space systems into LEO, without a launch vehicle, resulting in immeasurable cost reductions.

Integrated Satellites & Conventional Launch Services

Over the past ten years there has been a steady progression towards integrating asset-attack/defense systems, maneuverability-enhancing technology and redundancy measures into individual military and commercial satellites with distinct strategic operations and industry roles. The threat environment, regardless of whether ASAT strikes are common or highly uncommon, dictates that such measures should be integrated into all spacecraft as the potential security and economic effects of downed networks and partial netcentric blackouts outweigh the cost of this integration process.

As large satellites are now perfectly placed in an era that will complete their descent into obsolescence, autonomous formation-flying microsatellite constellations continue to be seen as the most ideal and reliable space-asset platform of choice in an environment plagued with risks directed at space-based operations. Microsatellites such those described in 2020 will continue to be a primary method to ensure netcentric continuity, though the most remarkable advancements are now centered on nanoscale systems. Nanosatellites integrated into microsatellite platforms are in 2025 capable of supporting asset defense and committing acts of sabotage via stealth attack to permanently or temporarily disable a larger satellite or weapons platform. These systems deployed in swarm formations in LEO could provide excellent levels of coverage, with revisit times as good as or better than their larger hosts and counterparts.

This trend towards size reduction and redundancy is setting another revolution into motion as the unmanned, autonomous high-endurance near-space vehicle begins to perform military space roles, and not just in a backup capacity, but one that overlaps and empowers the services delivered by assets in space. As space continues to become an increasingly dangerous place during times of international tensions, the UAV and the satellite will begin to work together regularly to meet the threat. It can be expected that from this trend of satellites and UAVs working together, that a hybrid UAV/Satellite system will emerge. This would be made possible with the help of integrated power generation and compact DE propulsion systems. The first manifestation of this may be satellites launched into orbit from near-space UAV platforms. What is most remarkable though is that through further technology convergence, we in 2025 may be the first to witness a satellite launching itself into space.

Conclusion

It is a societal constant spanning the history of warfare that military technology can only remain a secret for so long. From the rocket to the hydrogen bomb, information once proven to contain awesome technological powers spreads like wild fire–secret or not. For generations past, it took years and sometimes decades for leaks to take their toll. Inside the global information network, there are fewer limitations placed upon the flow of ideas, and many nations appear as if they are without borders.

It is important to mention once again that discoveries such as those mentioned in this forecast and analysis are the byproduct of dual-use systems with clear military and commercial applications, many of which have been developed in concert with commercial- and university-based contributors worldwide. These systems, for example, are openly talked about by professors, scientists, company representatives, foreign nationals, and patent holders at academic conferences and emerging technology trade shows, effectively undermining the purpose of developing systems to enhance national security. At the same time, in a global economy where collaborations in the commercial space industry lead to individual success, an environment of secrecy is sure to lead a nation towards isolation and subsequent suffocation.

Nations that wish to possess an effective defensive posture against all existing threats to their space systems face an open-ended investment. They should consider alternative solutions that could be developed in concert with the international community, and they should act quickly. It is inevitable that the drafting of clearly defined arms control measures and/or treaties regarding legitimate actions in space will be more difficult in the future because of the growing ambiguity that will result from military space systems that have evolved in dual-use fashion.

Additional Resources

1 - DARPA Defense Sciences Office: http://www.darpa.mil/dso/

2 - Information Processing Techniques Office http://www.darpa.mil/ipto/thrust_areas/thrust_ep.asp

3 - Foresight Institute http://www.foresight.org/

4 - Militarily Critical Technologies List (MCTL) http://www.dtic.mil/mctl/MCTL.html

5 - Developing Science and Technologies List (DSTL) http://www.dtic.mil/mctl/DSTL.html

6 - Joint Ground Robotics Enterprise Library http://jointrobotics.com/

7 - Artificial Intelligence: A Modern Approach http://aima.cs.berkeley.edu/

8 - Institute for Defense and Government Advancement http://www.idga.org/

9 - Small Business Innovation Research (SBIR) Information http://www.sbir.gov/
