NASA astronaut Jack Fischer photographed the SpaceX Dragon capsule as it reentered Earth's atmosphere 3 July 2017 at 8:12 a.m. (EDT) before splashing down in the Pacific Ocean west of Baja, California. Fischer commented, "Beautiful expanse of stars-but the 'long' orange one is SpaceX-11 reentering!" (Photo courtesy of NASA)

Space-Land Battle

Trevor Brown, PhD

Digital nations have centers of gravity (COGs) that are critical to their functioning: space-based assets.[1] For example, the GPS enables the digitization of national economies. The timing signal of the GPS has become ubiquitous for ATM time stamps across digital nations, and the GPS positioning capacities have become vital for a vast array of other commercial activities as well, "ranging from just-in-time logistics, international air and maritime traffic control, and the functioning of cellular telephone networks."[2]

To state Carl von Clausewitz's famous dictum, "One must keep the dominant characteristics of both belligerents in mind. Out of these characteristics a certain center of gravity develops, the hub of all power and movement, on which everything depends. That is the point against which all our energies should be directed."[3] One example of this is the electronic intelligence that U.S. space-based assets are able to gather. One of the most vital aspects of U.S. capabilities "is the ability to detect" enemy activity through the manipulation of the electromagnetic spectrum.[4] In this regard,

> A kindred class of satellites monitor the Earth, not in the optical portion of the electromagnetic spectrum but through the radio and radar atmospheric windows. These electronic intelligence (ELINT) gathering satellites listen patiently to the radio and radar emissions of ground, air and sea emitters. For example, the detection and location of emissions of the search and tracking radars of mobile air defense units provide valuable assistance to the planning of tactical air strikes. Likewise, the interception of communications may disclose not only the contents of the messages, but also the locations and identities of the communicators. Together, these types of information permit the construction of an electronic order of battle (EOB) which would influence the conduct of an engagement.[5]

Because of these capabilities, U.S. forces are "able to develop high rates of change in battle that cannot be outpaced, while sharply narrowing the strategic choices of the enemy."[6] The United States is now able to "emphasize precision firepower, special forces, psychological operations, and jointness—as opposed to the purported traditional dependence on overwhelming force, mass, and concentration—and the resultant qualities of speed, maneuver, flexibility, and surprise."[7] The first Persian Gulf War was a manifestation of the power of space-based assets. Space-based assets for command, control, communications, and intelligence made possible tremendous "quality and quantity of information," which proved decisive to the successful operations of that war.[8] The United States "structured its campaign around the free flow of information at the tactical, operational, and strategic levels" and obtained an invaluable advantage that led to the utter annihilation of Iraqi forces.[9] The famous flanking maneuver of the United States through the desert was made possible by the GPS. This movement only strengthened the position of the United States that it must control space at all costs.[10] Indeed, according to Colin Gray,

> Most of the information that fuels the alleged information-led RMA [revolution in military affairs] is collected by, or is transmitted via, space vehicles. Of course there are alternative platforms on which sensors can be deployed, but the highest of high "ground," which is to say outer space, offers dramatically superior performance over rival geographies for most intelligence-gathering missions. If space control is lost, an information oriented RMA will not work. In the view of this school, even if space systems themselves are not the real revolution, at the very least they constitute the key contributing element. If one loses the war for space, or in space, one loses the war (on land, at sea, and in the air) as a whole.[11]

> Space power enables the United States to plan, coordinate, and deliver overwhelming firepower and dominant maneuver in the conventional operational environment.

The capabilities that space-based assets provide—from precision movement and precision strike; to meteorology; to photo, signal, and electronic intelligence that help to determine enemy orders of battle—shift the terrestrial balance of forces heavily. The United States has significantly reduced the friction and fog its forces face by linking its space, air, and ground assets into an intelligent sensor web that allows warfighters to zoom between a picture of a larger battle, or theater space, to narrowly focused views that then enable warfighters to sense and react as a coherent organism.[12] Space power enables the United States to plan, coordinate, and deliver overwhelming firepower and dominant maneuver in the conventional operational environment.[13] Enemies of the U.S. military must successfully knock off-line the GPS and other space-based assets or be forced into an insurgent or terrorist strategy. With space capabilities in play, no enemy can withstand a conventional assault on U.S. forces due to the American ability to sense, move, and strike with precision.

However, the space-enabled land dominance of the Army is increasingly threatened by the missile and other anti-access/area denial capabilities of adversaries, and it must have missile defense capabilities of its own to protect its forces from those threats. The missile batteries of adversaries, especially those that possess tactical nuclear weapons, could impede the movements of the Army's columns, or indeed, destroy the main forces of the Army. The ground-based kinetic interceptors that the U.S. military has focused its missile defense development efforts on are woefully inadequate. They cannot reliably stop the missile forces of adversaries, especially if the adversary attempts to overwhelm the U.S. military's kinetic missile defense capabilities with an intense barrage of numerous missiles. Also inadequate would be any effort to move kinetic ballistic missile defense assets into space. (At the same time, the financial dynamics of moving kinetic ballistic missile defense assets into space would require that the size of the Army be drastically reduced.) The U.S. military's air-to-air kinetic interceptors as well as its airborne lasers are also not entirely reliable. However, a new and nonkinetic missile defense capability in the domain of space with a large variety of uses has recently emerged that can effectively neutralize all missiles and hypersonic weapons of all adversaries while simultaneously minimizing the expenditure of significant resources. This new and nonkinetic space-based missile defense capability is the inflatable spherical solar power satellite (SPS). The inflatable SPS, when combined with other American enabling satellites, will provide the U.S. Army with complete dominance in space-land battle.

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The Inflatable Sphere Solar Power Satellite—the Power Star

A revolutionary new design for space solar power has emerged; it is called the Power Star. This design for space solar power is inflatable, enabling it to overcome the mass and volume constraints of existing and future rockets. It is spherical, reducing the complexities of station keeping and attitude control in orbit, especially with respect to larger classes of the satellites. Power Star satellites will require no mechanical motions in orbit, and they can do station keeping as well as boost and lower their orbits with the radiation they generate.

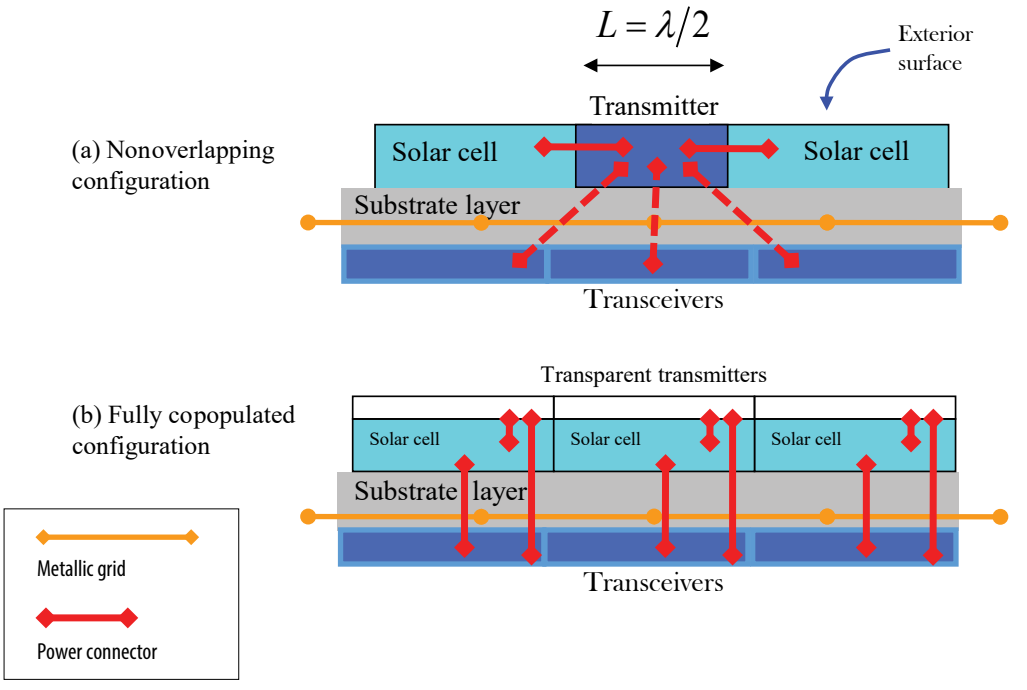
The satellites will have their photovoltaics and microelectronics 3-D printed onto flexible fabrics. Also 3-D printed onto the fabrics will be transparent patch antennas printed over the collecting solar cells. Such a configuration is intended to resolve intrapower distribution issues and eliminate the need for large wires. It will also allow the full surface area of the satellite to be illuminated for the maximum amount of energy generation while simultaneously alleviating the need for cover glass. A transceiver will line the inner surface of the inflatable sphere and will coordinate the pointing of beams with energy collection sites on the surface of the Earth. Therefore, the inflatable spherical SPSs will both collect and beam solar energy across the entire surface of the sphere with the solar-microwave fabric, alleviating the need for more traditional, massive, and cumbersome transmission equipment.

Indeed, the strategic situation prevailing since both the United States and the Soviet Union acquired atomic bombs has been similar to the Clausewitzian concept of an equipoised play of forces, where both sides in the contest maneuver for advantage without actually engaging. The inflatable spherical SPS will collapse the deterrence regime based on mutually assured destruction with nuclear weapons and intercontinental strike capabilities and revolutionize warfare.

> The Power Star is already fully developed: The design concept discussed here carries modularity and multiple-functionality several steps ahead of all other SPS designs. The concept combines a technology that is so new it is often overlooked with a technology that is so old it is almost forgotten. The new technology is the printing (via photolithography, ink-jet processes, etc.) of solar cells interspersed with microwave patch antennas on thin, flexible sheets (Mylar, Kapton, paper, fabric, etc.). The printed sheets are produced in mass quantities. The old technology is that of the Echo satellites. Large, thin sheets are assembled into a spherical balloon. For launch, the sphere is compactly packaged in a small container that fits into the launch vehicle payload faring. Once on orbit a volatile material is made to sublimate to provide the gas pressure for initial inflation. Metallic layers within the printed sheets are forced into yield to provide rigidification and the Power Star sphere is then evacuated. Electromagnetic propagation theory shows us that a completely decentralized control algorithm allows us to coordinate the numerous (printed) microwave antennas to transmit multiple beams to any desired ground-based power collection locations. The system is a single, very simple structure and no slewing or mechanical motion is required. Further, the power distribution technique involves power transmission within the "skin" only over distances of a few centimeters. Thus power transference is localized and requires neither complex and high voltage power distribution and management systems nor large power-conducting wires. The system has no moving parts, requires no slewing or rotating elements, can be deployed from a single launch vehicle, is extremely robust to component failures and is composed of material that can be manufactured in great quantity.[14]

One of the most critical aspects that will enable the technology will be its solar-microwave fabric:

> The very new and rapidly advancing element of Power Star technology is the solar-microwave fabric. Large scale production of inexpensive solar arrays is well underway. Printed microwave antennas are also well known and are being advanced at a rapid rate for numerous communication applications. Solar-Microwave Fabric combines these two components on the surface of the same flexible substrate. The solar cells and patch antennas are interspersed (without overlapping) with a randomized tessellation in order to eliminate grating lobes. This pattern is printed on what is to become the exterior surface of the substrate sheet or "skin." In the full system, there may also be an array composed solely of microwave transceivers (dual transmitters and receivers) printed on the opposite surface (due to become the interior surface of the sphere). Patch antennas on the exterior surface draw power from half of the immediately adjacent solar cells (a few centimeters distance) or from the interior transceivers, through the thickness of the skin.



(Figure by David C. Hyland)

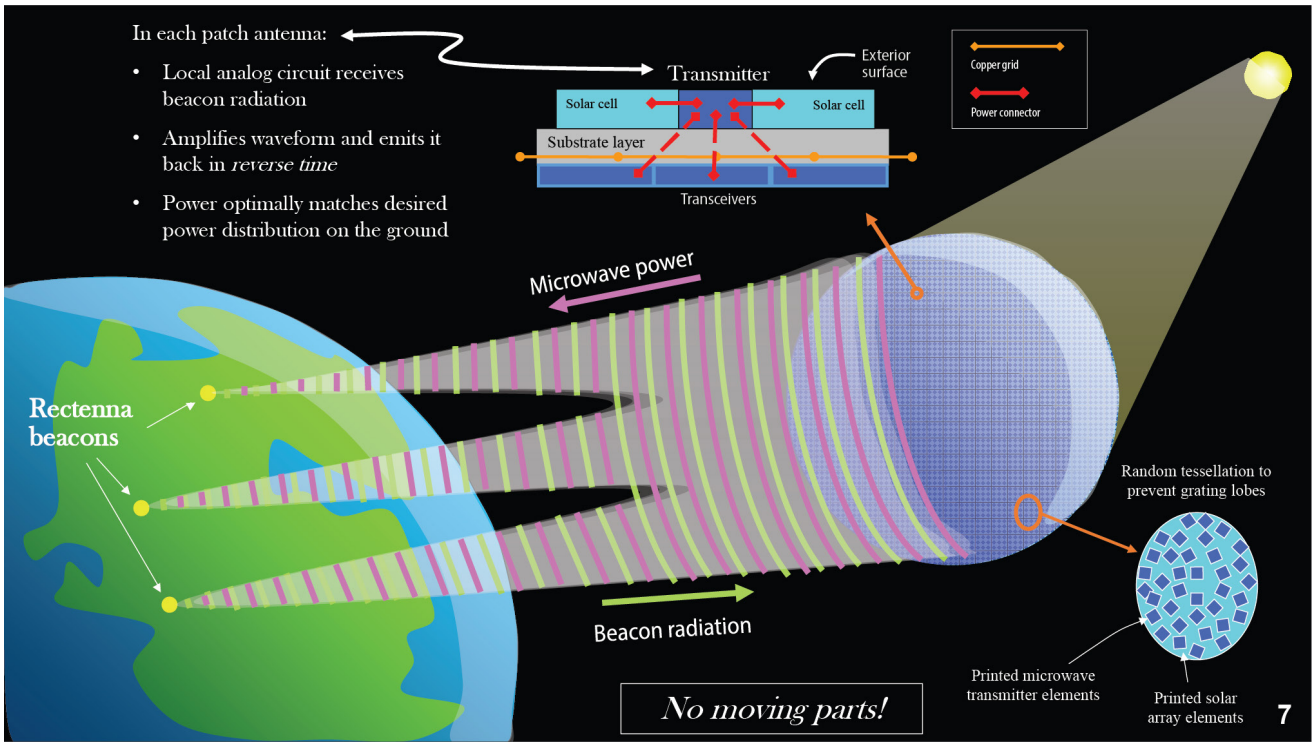
Figure 1. Cross Section of the Power/Communication/ Transmission Embodiment

> Besides the short power leads there is a grid of conducting wires for electrical ground and for rigidizing the sphere prior to evacuation.[15]

However, and again, the true configuration for the fabric in orbit will be transparent patch antennas 3-D printed over the solar cells. Such a configuration will allow the entire surface of the asset to be illuminated for the maximum amount of energy generation, while the transparent patch antennas printed over the solar will eliminate the need for the assets to have cover glass (see figure 1). Proceeding with the dynamic functions of the satellite in orbit, figure 2 (on page 125) sketches the overall composition and method of operation.

Perhaps one of the most ingenious aspects of the design is the intrasatellite power distribution arrangement:

> Since the directions of the sun and the beacons are not coincident, a mechanism for distributing power within the satellite is needed. Figure 3 (on page 126) shows the geometry of irradiation from the sun and the beacons, where we assume that the angular separation of beacons is small so that a single, representative beacon direction may be considered. The quantity ϕ is the angle between the sun direction and the beacon direction. Recall that the interior surface of the sphere is coated with transceivers operating at a higher frequency (to reduce diffraction effects). These transceivers are to be oriented so that the resonant axes of each diametrically opposite pair are parallel. As illustrated in figure 3, the surface of the sphere is divided into four sectors: The sector exposed to both sunlight and beacon radiation (denoted by S,B); that receiving beacon radiation but no sunlight ($\tilde{S},B$); that exposed to sunlight but not beacon ($S,\tilde{B}$), and the region where neither sun nor beacon are visible ($\tilde{S},\tilde{B}$). Clearly, sectors ($\tilde{S},B$), and ($S,\tilde{B}$) are mirror images, such that each point on ($\tilde{S},B$) has a diametrically opposite point on ($S,\tilde{B}$), and *vice-versa*. The same remark pertains to (S,B), and ($\tilde{S},\tilde{B}$). The sector that a particular transmitter and its adjacent solar cells are located is indicated by their output signals. Given this information, the power supply algorithm is indicated in the table (on page 127). Note that no processing is needed for this algorithm. In essence, the transmitters that need to be active because they receive a beacon signal are powered by either the proximate solar cells or by the proximate internal transceivers, whichever is actually producing power. No beacon signal means



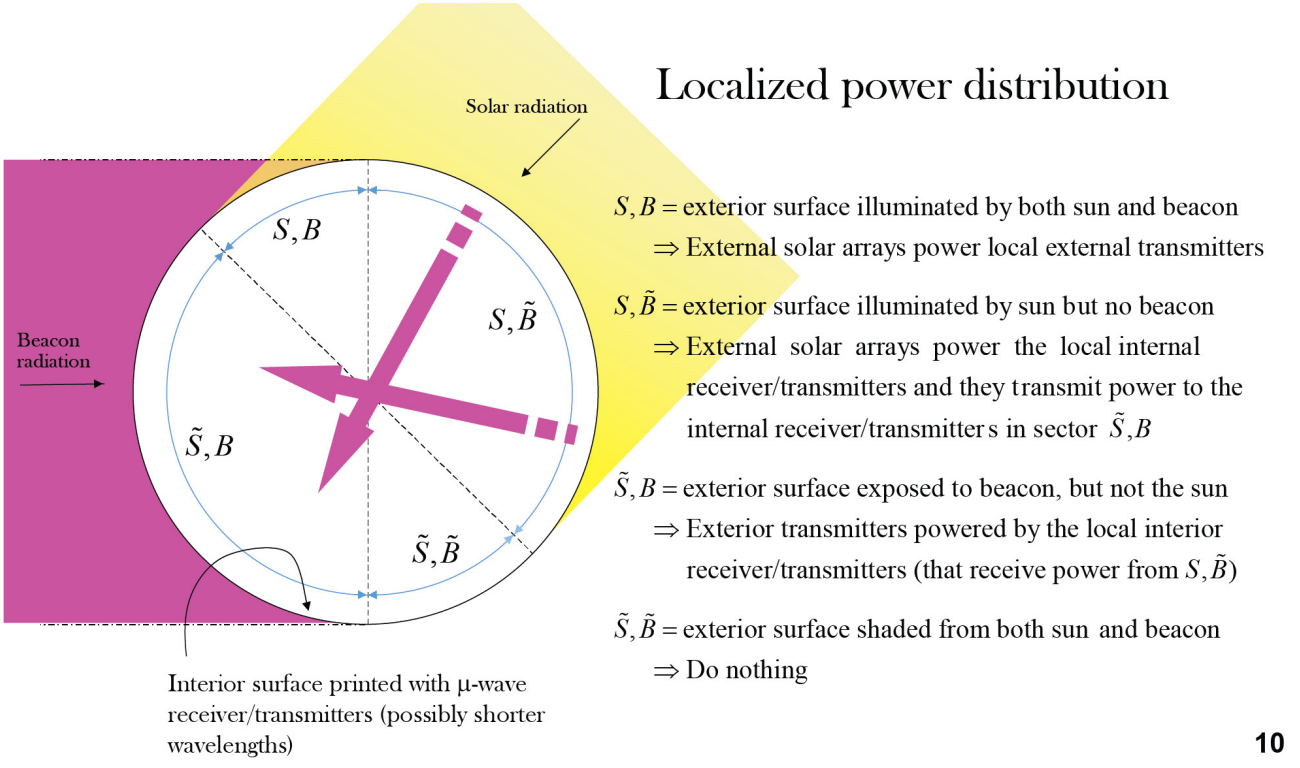
(Figure by David C. Hyland)

Figure 2. Overall Power Star Operation Once Deployed

the transmitter is blocked. Each transmitting antenna draws power from the solar cells in its immediate vicinity (within a few centimeters), or through the thickness of the skin. Each transmitter receives just a few watts, so there are no high voltages or large wires. This localized architecture means ***robustness*** against partial damage.[16]

The Power Star is almost undefeatable in space warfare. Any laser, interceptor, or co-orbiting asset that attacked the Power Star would not be able to disable it due to the distributed and localized nature of the power configuration. Therefore, if a laser preemptively attacked a Power Star in an attempt to disable or defeat it, the Power Star could easily return fire. The Power Star can fire multiple beams in all directions simultaneously even after it has been damaged. The only presently known ways (according to its inventor) to defeat the Power Star is the destructive blast of a nuclear weapon in orbit or an electronic or cyber attack to scatter the beaming algorithm. A five-kilometer-diameter Power Star would generate in excess of 8.5 gigawatts in orbit and could be launched with a single Space Launch System with zero on-orbit assembly required. A one-kilometer-diameter Power Star would generate three hundred megawatts in orbit and could be launched with a single Delta IV rocket with zero on-orbit assembly required. A one hundred-meter-diameter Power Star would generate three megawatts in orbit and could be launched in the air off of an F-35 aircraft with zero on-orbit assembly required.[17]

Not only will the Power Star effectively neutralize all enemy antiaccess/area denial capabilities, but another potential niche dual-use terrestrial application for the inflatable sphere SPS is also the provision of energy to the Army's forward operating bases. By beaming over fifty megawatts of power on demand from space to a forward operating base, the Power Star will dramatically reduce the tooth-to-tail ratio of the Army's forces, making them far less dependent on logistical support. Indeed, with just one five-kilometer-diameter asset placed in a geostationary orbit, the joint force will be able to beam at least fifty megawatts to fifty forward U.S. military bases from the western Pacific through the Middle East all



(Figure by David C. Hyland)

Figure 3. Geometry of the Power Distribution System (Angle ϕ denotes the angle between the directions to the sun and a beacon)

at the same time—fifty beams to fifty bases simultaneously—without requiring any mechanical motions from the spacecraft.

In this regard, electric ground vehicles have more torque than do ground vehicles powered by petrochemicals. If the Army's ground forces were to transition to a force composed almost entirely of electric ground vehicles, while American space forces were simultaneously launching Power Stars, then the land force could mostly eliminate the need for convoys to resupply the power needs of its bases as well as refuel its vehicles. Such a dynamic would result in far fewer soldiers and marines going into harm's way to defend resupply convoys while, at the same time, the quality of life at forward operating bases would improve dramatically. A single one-kilometer-diameter Power Star could supply almost the entire operational power needs of a forward operating base manned by thousands of soldiers. Thus, the Power Star will enable the Army to remove fossil fuels as a major supplier of energy and replace the internal combustion engine in war operations. In the process, the Army will become far more mobile and lethal, and will then be in a position to truly realize "supply-less" logistics from an energy standpoint. The Power Star is the innovative idea that will make logistics from 2018 forward, including the period between 2030 and 2050, supply-less and render forward bases more logistically secure.

What is more, the Power Stars will support "space-based radars and imagers of unprecedented size, powerful spaceborne jamming capabilities, and advanced communication architectures—particularly for aperture-limited users."[18] Indeed, a fleet of five-kilometer-diameter Power Stars would possess thirty-nine square kilometer phased arrays for each satellite; their combined effects could overpower an enemy in electronic or cyber warfare. The Power Star fleet could jam all communications and engage in electronic warfare on an unprecedented scale. This would be in addition to neutralizing all missiles of the enemy with the millions-of-megawatt beams that could be broadcasting in all directions simultaneously.

Shifting the Terrestrial Balance of Forces

With respect to space-land battle, unless a decision for the whole war can be obtained by victory in space in a way similar to the wars of the Dutch and English at sea in the seventeenth century, the action in space must necessarily be subordinated to the action on the ground. Although, as has been stated, if a complete command of the space domain is obtained, it is likely that it would shift the balance of forces on Earth so heavily as to decisively determine a terrestrial war's outcome. "For example, if one state or coalition could secure and hold the truly exclusive 'command of space,' the enemy might elect to surrender as a direct consequence (space could be blockaded against passage by an enemy's missiles)."[19] In any event, if control of the space domain is obtained, either through direct battle or by effectively exercising control when a battle cannot be had, significant options are then opened for shifting the balance of forces on the land.

Space-based kinetic and nonkinetic weapons can strike at targets on the earth, perhaps much easier than they could at targets in space. Merely a few dozen space-based kinetic-energy weapons against terrestrial targets could threaten the means of power projection of a maritime power like even that of the United States, and these capabilities are within reach of countries such as China and India.[20] They would work just as well against land forces—with the requisite radar and fire control, they could strike at tanks and other armored vehicles.

Nonkinetic weapons such as lasers were more difficult to field before the Power Star due to the necessity of keeping them adequately fueled, but their ability to strike at light speed on very short notice made them very attractive. Indeed, "space weapons may be the only ones that can reach fleeting targets in time."[21] And, before the Power Star, considerations were for whether "the value of the target was worth expending the weapon."[22] Obviously, following the invention of the Power Star, the magazine for space-based direct-energy weapons is virtually unlimited and free.

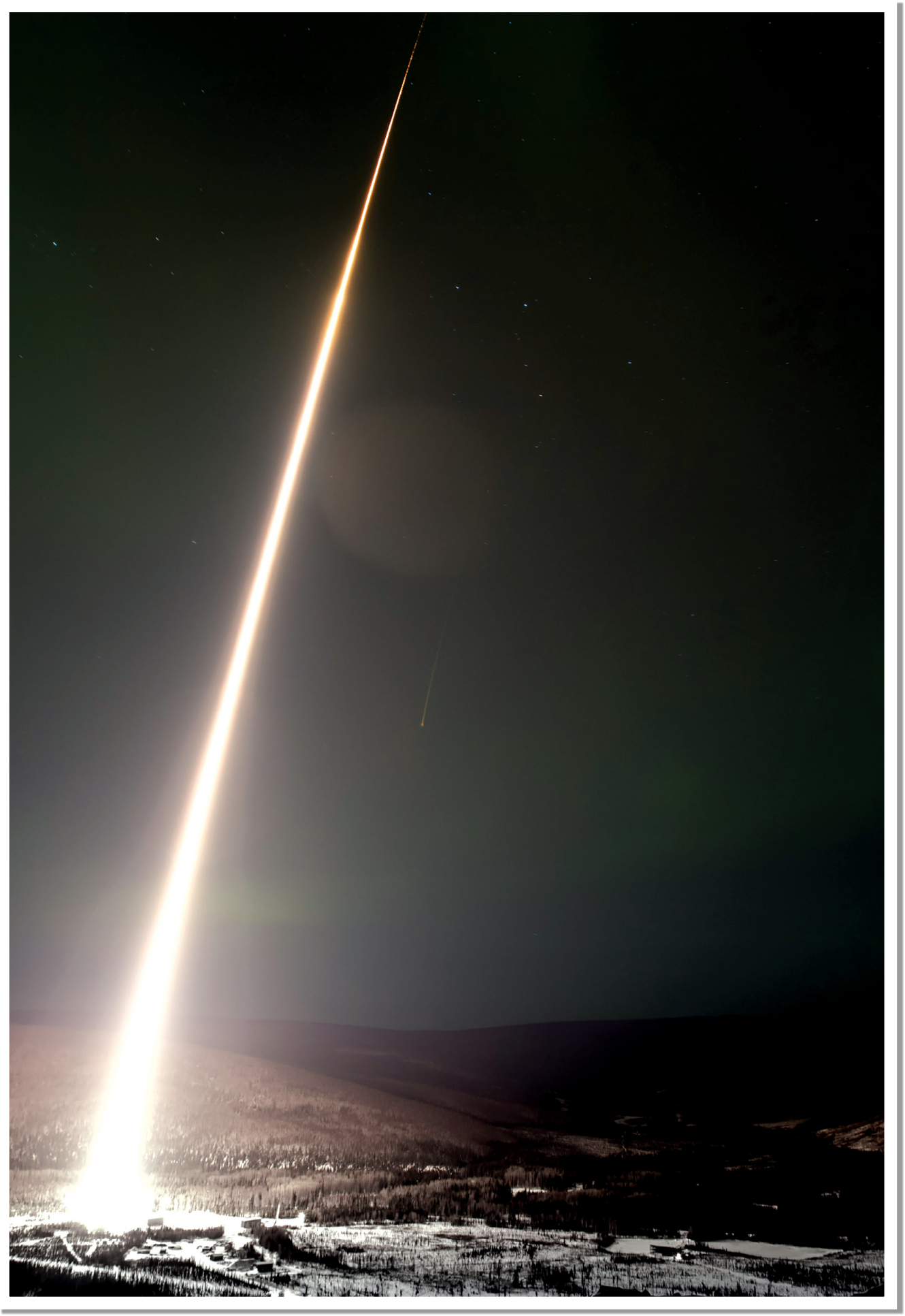
Regardless, the major economies of force that space-based assets have achieved by their complementary effects on friendly weapons systems are tremendous. Again, "one of the salient features of the U.S. Armed Forces is the ability to detect hostile military operations through exploitation of the electromagnetic spectrum":[23]

> Data received from ELINT satellites would add another dimension to the battlefield picture. The movement of radio and radar sites would permit an electronic order of battle which could then be compared with photographic intelligence. For example the relocation of command posts and electronic

Table. Power Transfer Algorithm

Sector	Power Transfer
(S,B)	External surface transmitter draws power from the adjacent solar cells.
$(S,\tilde{B})$	Solar cells transfer power through the skin to their immediately proximate internal surface transceivers. The internal transceivers emit power beams through the center of the sphere to fall on the internal transceivers in sector $(\tilde{S},B)$.
$(\tilde{S},B)$	Internal transceivers transfer received power through the skin to their immediately proximate external surface transmitters.

(Table by David C. Hyland)



> … it is space capabilities that are the gulf between the knowledge of information forces and the ignorance of industrial forces.

> jammers might foreshadow a weakness along the forward edge of battle or a redirection and new push elsewhere along the front. The interception of enemy communications might yield valuable intelligence data.[24]

Indeed, space-based assets are the backbone of information-oriented forces. They have made the operational environment far more transparent and increased the speed and access of U.S. forces in such a way as to profoundly alter the initial conditions of conflict. In space-land battle, U.S. forces are able to develop high rates of change in battle that cannot be outpaced while sharply narrowing the strategic choices of the enemy.[25] Without real-time visuals of operational environments and a variety of sensory images, all linked at the theater level, U.S. forces undoubtedly would not have the same ability to dominate the decision cycles of enemy leadership.

By 2008, even off-the-shelf technology that utilized space-based services for space-land battle had a very large impact on the operational environment. An author writing at that time observed,

> With an iPhone, you can access a map, convert it to satellite photography, and overlay embedded information like addresses and telephone numbers and soon all kinds of additional data like property values and even crime statistics. Eventually this kind of power is going to reach the average soldier in the field, drawing upon satellite data like GPS signals, near-real-time reconnaissance imagery, and weapons performance for enemy targets.[26]

A Black Brant IX sounding rocket launches 22 February 2017 at 5:14 a.m. (EST) from the Poker Flat Research Range in Alaska. This was the first of two launches planned in NASA's In Situ and Groundbased Low Altitude StudieS (ISINGLASS) mission to study the structures of auroras. (Photo courtesy of NASA)

Due to these capabilities, in space-land battle, the United States is now able to "emphasize precision firepower, special forces, psychological operations, and jointness—as opposed to the purported traditional dependence on overwhelming force, mass, and concentration—and the resultant qualities of speed, maneuver, flexibility, and surprise."[27] Space forces shift the balance on Earth so heavily that insurgency and terrorism are forced upon the enemy as its only course of action. Satellite-guided drones enable Americans to reconnoiter enemy positions and drop weapons from a hemisphere away. "With GPS satellites, automated aerial craft can sweep over a target and emit a huge burst of electrical energy into the atmosphere. This pulse of electromagnetic energy acts like a lightning bolt, frying an enemy's computers, radios, telephones, and critical communications devices."[28]

In space-land battle, space power was the critical enabler of concepts such as operational net assessment, effects-based operations, and rapid decisive operations during the second Bush administration (concepts created to facilitate operations during the RMA). In short, it is space capabilities that are the gulf between the knowledge of information forces and the ignorance of industrial forces. However, space-based assets are soft and may be the very first to be targeted in wars to come. "Space technology has become so integrated with tactical military operations" that many now question what the target is: "Is it the weapon on the battlefield or the satellite high above that is dramatically enhancing the weapon's power?"[29] As the COG of information-oriented militaries, enabling doctrines such as rapid decisive operations and effects-based operations, space-based assets must be considered primary targets in any war fought by forces that have entered the information age.

In space-land battle, "modern warfighting does not depend simply upon having information, but rather upon moving it from place to place, from weapon system to weapon system."[30] What would be the consequences for an information-oriented military if their celestial lines

of communication were wiped out? The consequences would be grave indeed, as it would mean that not only was the COG of their military wiped out, but the COG of their entire society was wiped out as well. Although only an all-out hostile attack on the ground stations and on the satellites would significantly harm American constellations, the U.S. military should not become complacent in the past performance and strength of U.S. systems, as more and more nations and political entities, from Russia and China to India, are investing in systems to be instruments of space warfare.

Industrialized Conventional Warfare

In space-land battle, the most prudent strategic course is for the land force to be strategically and tactically on the defensive until the space force is able to gain control of the space domain and barricade it. With the space force in control of the space domain, the joint force will then be in a position to bring all of the enabling assets and fires from space-based weapons systems to bear on the terrestrial battlefield. The fires and enabling effects from space will then give the land force decisive advantages when it goes on the offensive.

When deterrence based on nuclear-tipped intercontinental ballistic missiles breaks down, the U.S. Army must be trained and equipped to engage in conventional warfare against all industrialized opponents, as great power war will once again be on. In such a strategic dynamic, warfare may again become somewhat symmetrical and typified by front lines where forces are arrayed in formations against each other. The Army should excel at this mode of warfare, especially given the tremendous advantageous that all of the enabling effects from the space domain can provide, as well as the full-spectrum information dominance they should possess. The Power Stars will shield the Army's forces from enemy missiles, especially those carrying tactical nuclear weapons.

In any event, the Army's space-enabled land forces could potentially conquer entire regions by rapidly defeating enemy armed forces, perhaps under the cover of unlimited beams from space. Power Star artillery and air power could be used to channel or impede the movements of the enemy, disrupt communications, suppress forward defensive fires, and mask the advance of the Army's main land forces. Direct-energy weapons and tungsten bolts from space could support the movements and fires of air, armored, and infantry units to open breaches in the enemy's front. Enhanced by fires and intelligence from space, mobile and armored units could rush forward at tremendously high speeds to penetrate the interiors of the enemy. The action on the ground will be executed in close coordination with space and air support, including space and air reconnaissance as well as air transport. In this way, the space-enabled land forces will achieve defeat of the enemy.

Industrialized, symmetrical space-land battle will continue to be important in the twenty-first century after the Power Stars collapse the dynamic of mutually assured destruction with their ability to neutralize missiles and hypersonic weapons, especially intercontinental ballistic missiles.

Conclusion

The advantages of inflatable spherical solar power satellites are obvious: precise and overwhelming firepower, exceptional survivability, ground force protection, enhanced communication and intelligence collection capabilities, and tremendous cost effectiveness.

Sophisticated space forces help their terrestrial comrades in arms dominate on the ground—with the GPS and communication satellites in play—and enemies of American forces have been placed in insurgent or terrorist predicaments because they cannot withstand conventional warfare with U.S. ground forces due to the American ability to move and strike with precision. The nature of warfare has effectively changed. Space-based assets have allowed American terrestrial forces to take maneuver warfare to the next level. ■

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