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14. ABSTRACT

How will the development of cheaper, reusable space rockets by private industry affect the militarization of space? This paper will answer the question by analyzing a future scenario that looks at three technologies that can proliferate with cheaper, reusable rockets: improved rocket modules for logistics and mobility, small, light-weight satellites for surveillance and communications, and space-based weapon systems. The feasibility of these systems and their possible use will be evaluated by looking at the anticipated reduction of cost of rocket technology in the next 15 years (private companies are currently aiming for 10% of current costs) and the effects this will have on who is able to access space, what (and how much) can be put into space, and how this will change the military approach to space as an operational domain.

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FUTURE WAR PAPER

The 21st Century Wright Flier:
Rocket Technology and the Military Implications of Affordable Access to Space

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR A DEGREE OF
MASTER OF OPERATIONAL STUDIES

Major Cole F. Petersen, Canadian Army

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The 15 years between the first successful flight of an aircraft and the end of the First World War featured the development of most facets of modern air power and the establishment of the world's first independent air force, the Royal Air Force.[1] The space age began shortly after the Second World War, but it is only now, with recent developments by civilian industry, that the costs of access to space will be reduced to the point were rapid advances in space power will occur to the scale similar to the experience of airpower between 1903 and 1918. Over the next 15 years, the development of cheaper, reusable rockets by commercial industry will lead to rapid expansion of military presence in space, establishing the economic feasibility of space-based military operations for state and non-state actors.

The rapid expansion of military presence in space portended by cheap, reusable rockets represents what theorist Jim Oberg describes as the fourth and final phase of a maturation process for technology, namely *ubiquitous use*. In this phase, the technology becomes so pervasive that it is regarded as simple and routine. In that regard, Oberg contends that space power went through its first phase, *discovery*, in the late 19th and early 20th centuries with the work of rocket pioneers such as Tsiolkovsky and Goddard. The second stage, *application*, was ushered in with the development of rockets as military tools during the 1930s to 1950s. The current stage, *acceptance*, has been the norm since the 1960s with the establishment of satellites and Intercontinental Ballistic Missiles (ICBMs) as not merely a novelty, but an integral part of the superpower military arsenal.[2]

The dawn of the acceptance stage followed shortly after the Soviet Union, in attempting to overcome the U.S advantage in long-range bombers, succeeded in developing rocket technology and placing the *Sputnik 1* satellite into space.[3] Subsumed by Cold War politics, space technology was quickly developed by both the United States and the Soviet Union to deploy an array of satellites and intercontinental ballistic missiles to support their strategic concepts and operational capabilities. Today, space operations in the form of satellite support to surveillance and communications are considered so essential that a former US Air Force Chief of Staff claimed their loss would mean "you go back to the Industrial Age."[4] Space operations are therefore accepted as the norm for those states that can afford to generate and sustain them.

This norm is restricted and limited by what Oberg terms the "impediments to the exercise of space power," which he sees as launch costs, launch bottlenecks (physical facilities to launch from), hazards of the space environment, and socio-political attitudes towards the use of space for military purposes.[5] Of these, launch costs are the "primary inhibitor of expanded commercial, private, and even governmental activities in space."[6] The Space Shuttle program, designed to make travel to and from space a routine affair, cost some $500 million dollars per launch, or a cost to weight ratio of about $50,000 dollars per pound. With the retirement of the Space Shuttle program, however, both government and civilian organizations now rely upon large commercial firms for rocket services, with costs remaining high at $42,000 dollars per pound.[7]

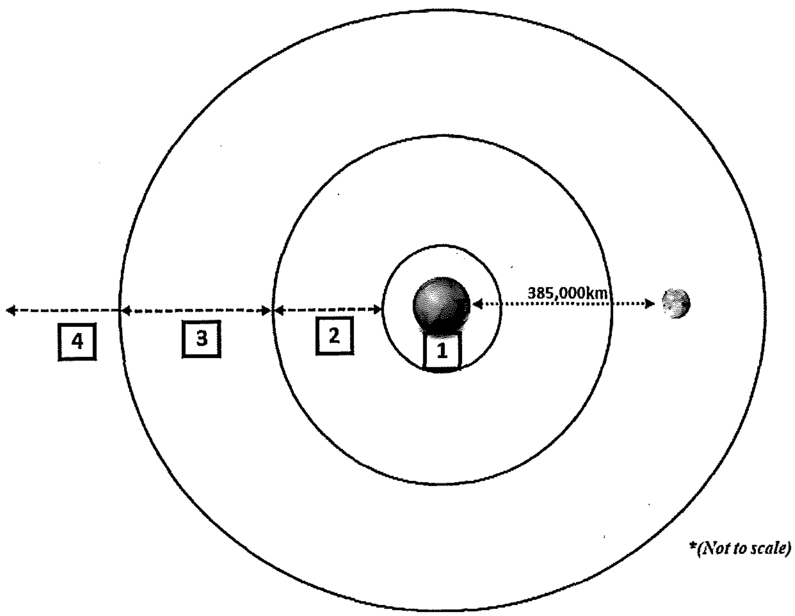
That said, in the next 15 years, emerging technological developments have the potential to undercut this high cost to weight ratio, changing the concept of the norm and moving military space technology into the fourth phase of ubiquitous use. SpaceX, the current industry leader, founded in 2002, has achieved numerous milestones in its efforts to revolutionize rocket technology. Indeed, it is the first commercial enterprise to send a rocket into orbit (2008), the first to return a spacecraft from low-earth orbit (2010), the first to service the International Space Station (2012), and produced the world's first rocket capable of returning to earth and being relaunched into space (2015-16).[8] Other companies in the civilian sector are following the lead of SpaceX, including Rocket Lab and Vector Space Systems, which are in the midst of developing lightweight rockets capable of sending smaller payloads into orbit with higher frequency at a reduced cost.[9] These and other companies are developing technologies that will push the weight to cost ratio for travel into space to about $10,000 per pound and perhaps lower, or 10% of the cost of the Space Shuttle program and about 20-25% less than the current market's space service corporations such as United Launch Alliance or Orbital ATK.[10]

In the next 15 years, general availability of rockets that move material into space at a cost 10% or lower than current prices will eliminate a barrier described by Oberg as "easy access to space by second and third-tier players, whether governmental or non-governmental, whose presence would at the very least complicate, and at worst endanger, current activities."[11] The high cost of space access has generally restricted the scale of military activities in space to those states with fairly predictable policies and agendas. As costs go down, however, and launch facilities increase, the conditions for ubiquitous military use of space by state and possibly non-state actors will flourish.

The projected future state of expanded military use of space creates security issues for states, in particular for those states that rely on the stability of the current paradigm of how space is used (and by whom) to support terrestrial military operations. For example, this future state will greatly expand the ability of actors to neutralize or defeat their adversary's space-based satellites networks by putting anti-satellite systems into space with ease. Moreover, this future state will promote greater use of space due to the proliferation of cheap delivery systems. What takes sealift days and airlift hours to do will be economically possible in minutes by cheap, reusable rockets. The future state will also create increased competition for dominance of key areas of the Earth-Moon system to provide assured access for space systems. If this future state becomes a reality in 15 years, then what will a future conflict scenario look like and how can countries prepare to deal with it?

<u>The Future State</u>

Any discussion of the future state of the military use of space must begin with an understanding of the space environment, how it is currently used, and how changing technology will affect future use. For military purposes, the area of space that the Earth-Moon system occupies can be divided into four regions.

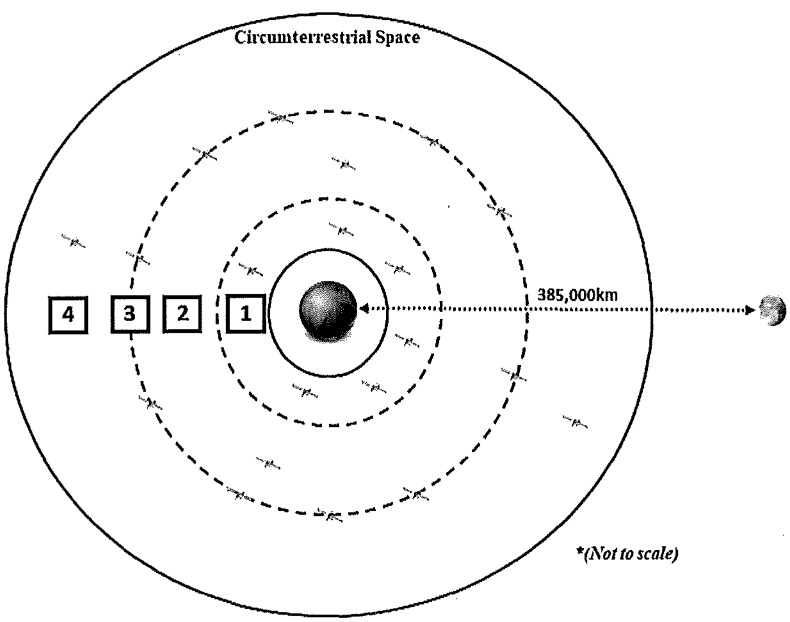


1. Earth and Atmosphere: Surface to 100km
2. Circumterrestrial Space: 100km to 80,000km
3. Moon and Environs: 80,000km to 770,000km
4. Outer Envelope: 770,000km+

Diagram 1 – Regions of Earth-Moon System[12]

The first region is the Earth and its atmosphere, which reaches from the Earth's surface to 100km above, or the distance where frictional heat strongly affects movement and re-entry to Earth. On top of this region is circumterrestrial space, reaching from 100km to 80,000km from Earth and encompassing an area heavily influenced by Earth's gravitational and magnetic fields. The third region, the moon and its environs, stretches 80,000km to 770,000km from earth, and defines an area where the dominant aspect is the interplay of the gravitational aspects of the sun, the moon, and other space bodies. The final region of space, the outer envelope, encompasses anything beyond 770,000km, an arbitrary distance set at twice the distance from Earth to the moon, where the dominant physical forces become those of the sun and other solar bodies.[13]

Within these regions satellite operations, the principal form of space operation, currently occur almost exclusively in the second, circumterrestrial region, which can be subdivided into four orbital zones (see Diagram 2). Low Earth Orbit lies between the end of the Earth's atmosphere (100km) and the inner edge of the Van Allen radiation belts (480km). Medium Earth orbit stretches from the start of the Van Allen radiation belts to Geosynchronous Orbit (480km to 35,700km). Geosynchronous Orbit fills a very small area where orbiting satellites can match the rotation of the Earth's axis, making it possible to lock them into a geosynchronous (passing the same location at the same time each day) or geostationary (remaining over the same location) orbit. Anything beyond Geosynchronous Orbit is considered High Earth Orbit, which extends to limit of the circumterrestrial space (80,000km).[14]



1. Low Earth Orbit (LEO): 100 – 480km
2. Medium Earth Orbit (MEO): 400 – 35,700km
3. Geosynchronous Orbit (GEO): 35,700km
4. High Earth Orbit (HEO): 35,700-80,000km

Diagram 2 – Earth's Orbital Zones[15]

Satellite operations primarily occur in the Low Earth and Geosynchronous Orbits, and these regions are already quite cluttered. The Union of Concerned Scientists tracks commercial and military activity and has identified 1,738 active satellites orbiting the Earth as of late 2017. Of these, just under half (46%) are American owned, with 309 of these being military or government satellites. China operates 204 active satellites while Russia has 142.[16] Along with these operational satellites is over 20,000 other pieces of space debris larger than a softball, such as inoperative satellites or pieces of used rockets, that further clutter circumterrestrial space and threaten to damage or destroy operational systems currently in orbit.[17]

Satellite operations in this cluttered environment are critical to terrestrial military operations for their ability to enhance reconnaissance, early warning, communications, and remotely piloted vehicle operations. Consequently, militaries are conceiving of ways to degrade adversary satellite networks as part of war planning. In response to what former American Deputy Defense Secretary Robert Work called a "big, expensive, enormously capable, but enormously vulnerable" American satellite network, the U.S. has recently undertaken efforts to strengthen its defenses against potential anti-satellite (ASAT) attacks.[18] Nevertheless, there is nowhere to hide objects in space from observation, and with ASAT capabilities proliferating, protecting military satellite networks may prove to be a serious challenge.

While militaries must consider how to work around degraded satellite capability, civilian satellite operations are equally vulnerable and, perhaps, less resilient.[19] Many civilian functions are dependent on the American Global Positioning System (GPS), the world's principal Global Navigational Satellite System (GNSS) network, for precise time tracking ability to drive commerce, traffic control, and communications at a global scale. A loss of GPS/GNSS timing could affect stock markets, automatic bank machines, cellular phone towers, traffic light systems, air traffic control, and power distribution, potentially grinding critical civilian infrastructure and financial transactions to a halt.[20]

Cheaper, reusable rockets will expand access to the circumterrestrial region to more actors, making the civilian and military satellite networks more vulnerable to intentional or unintentional interference. While ASAT operations are traditionally envisioned as the launch of missiles to physically destroy satellites, there are other ways to attack satellite networks, such as using space vehicles to interfere, subtly damage, or jam adversary satellites.[21] Interference does not even need to be intentional, or require the use of purpose-built ASAT platforms. Increased activity in orbit creates increased chances of mishaps and the creation of space debris which, travelling at high velocities, can damage satellites and create a cascading effect of debris. With the lowering cost of space access, the capability to interfere with satellite networks can conceivably proliferate to second and third-tier space powers, or even non-state actors.

While cheap, reusable rockets will open circumterrestrial space to more actors, thus increasing the vulnerability of satellite networks that operate there, it will also reduce the costs and difficulty of maintaining their satellites, providing resiliency to networks. Along with low cost rockets, miniaturization and cheaper access to space will reduce the costs of satellites. For example, the newest Iridium Next communication satellites weigh almost 1,900 pounds each and cost over $27 million per copy.[22] Satellites of this size and cost are gradually being replaced by what are termed small satellites, weighing under 400 pounds, which are increasing in capability and are the fastest growing share of the satellite market.[23]

In a future state where circumterrestrial space is more cluttered and the prospect for satellite network interference is greater, small satellites launched from cheaper, reusable rockets offer users a cheaper, easier way to sustain operational capability and capacity. The big, expensive, and vulnerable networks described by Robert Work will become small, inexpensive, and easy to replace. In the future, when faced with a compromised satellite network due to willful attack or unintentional mishap, a state will be able to quickly regenerate its GPS/GNSS, surveillance, or communications network by the launch of rockets with dozens, if not hundreds of small satellites to "reseed" orbit and bring operations back on line. The implication is that, in the future, states will possess, or contract, ready reserves of small satellites to be launched into space by military or corporate rockets to maintain critical, vulnerable satellite networks. Cheap, reusable rockets will enable states to "regenerate" their satellites as fast as adversaries could take them out.

While rocket technology will mean increased flights of cargo from Earth to space to sustain satellite networks, the same technology also provides for the possibility for using Low Earth Orbit as a highway for orbital mobility. Cheaper rockets that can land and be reused can become rockets which can be loaded with supplies, equipment, or personnel, launched through Low Earth Orbit and accurately and safely landed, all in a more cost-effective manner. Low Earth Orbit will become a new orbital line of communication, to be used by military forces in conjunction with the traditional ground, air, and sea lines of communication, and will take only minutes to move large amounts of materiel around the globe.

Surface-to-surface rocket transit through Low Earth Orbit is being pioneered by SpaceX and its Mars Rocket program, currently designated as the "BFR." The BFR is the follow-on development to the Falcon Heavy rocket, which recently conducted its maiden flight in February 2018. The Falcon Heavy rocket, capable of lifting 54 metric tons (just under 119,000 pounds) into space, will be the most powerful rocket in operation by a factor of two.[24] The BFR's capability will dwarf the Falcon Heavy and SpaceX owner Elon Musk announced in September of 2017 that he intends to land a BFR-supported spacecraft with human explorers on Mars by the year 2022. The BFR will dwarf any rocket ever built, with the ability to be continuously refueled and reused to move 300 metric tons or over 660,000 pounds into orbit for each launch.[25]

Musk also advertised the ability of the BFR to conduct surface-to-surface transit on Earth. By moving through Low Earth Orbit at a speed of 27,000km per hour, the BFR could deliver cargo or passengers anywhere on the Earth in under one hour. Space pioneer and commentator Sam Dinkin conducted a cost analysis of Musk's concept of moving almost 900 passengers and crew, a number similar to the Airbus A380 that Musk claimed his BFR-powered shuttle could hold. While reduced costs for the proposed BFR won't materialize until a mature industry can develop over the next 10-20 years (the timeframe of the future state being examined), Dinkin estimated that a BFR could be procured at costs similar to a A380 and could move passengers for just over one million dollars per trip, or $1,200 per customer.[26] Use of an orbital line of communication with maturing rocket technology will enable terrestrial movement that takes days by ship and hours by plane to be completed in minutes by a rocket.

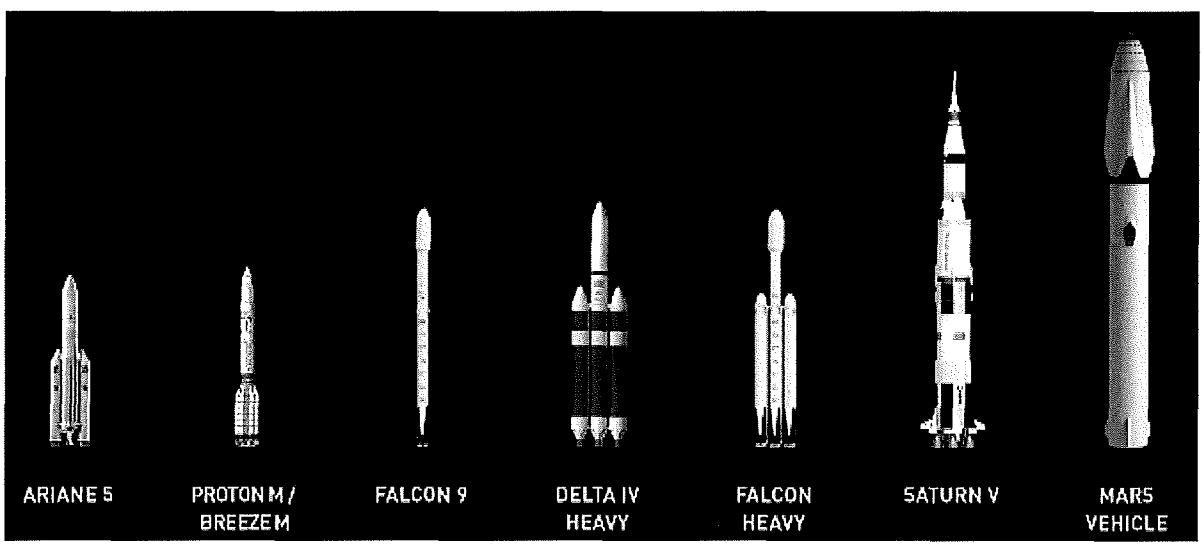


Diagram 3 – SpaceX Rockets Compared to Other Successful Rockets[27]

The military implications of this technological development are self-evident. As SpaceX's pioneering work matures, military forces will be able to conduct logistics through Low Earth Orbit. The BFR is planned to be capable of moving 300 metric tons (660,000 pounds) of cargo. 300 metric tons is the equivalent to just under four C-17 Globemaster loads or two and a half C-5 Galaxy loads.[28] A RAND study looking at airlift requirements to deploy a US Army Stryker Brigade Combat Team (SBCT) estimated that 239 C-17 equivalents would be required to deploy an SBCT, three days of supplies, and debarkation sustainment.[29] In the future state, rocket replenishment could deploy a similar sized formation anywhere on the planet with 54 flights, each with a flight time of 30-45 minutes. While 54 flights are likely an excessive demand, the movement of a medium-weight armored brigade provides a useful reference point for movement capacity. Using the previous example of 900 personnel, deployment of the personnel of an infantry battalion to its prepositioned equipment stocks can be accomplished in a single lift. This illustrates how reusable rockets such as the SpaceX BFR can transform surface to surface movement of materiel through Low Earth Orbit.

While using rockets for administrative movement of personnel and material is one possible avenue of development, the tactical deployment of combat forces is another possibility. This is not a new or novel idea, as the concept of orbital deployment of soldiers has long existed not only in science fiction but in military concept organizations. The US Marine Corps launched the Small Unit Space Transport and Insertion (SUSTAIN) project in 2003, which aimed to move a 13-Marine squad with equipment anywhere on the Earth on a small tactical landing craft.[30] It conceptualizes the launch of a landing craft from another vehicle, moving through sub-orbital space to get to its objective, and by-passing national airspace issues to get to its objective area. Although conceptually different than the orbital travel enabled by reusable rockets, it is conceivable that a tactical landing vehicle could be designed for mounting on a rocket, to be deployed from space and landing dozens if not hundreds of soldiers or marines in a form of "orbital assault." Orbital quick reaction or special operations deployments could be made around the globe in thirty minutes.

In a future state where the utility of orbital lines of communication for surface to surface travel and the increasing density of circumterrestrial space for satellite operations and maintenance, space control will become an essential element in military planning, just as air control is now. Like areas on the Earth, the Earth-Moon system has some "key terrain," or areas that give the force occupying them a marked advantage in a confrontation. While space has no cardinal directions or terrain, there are key points in the Earth-Moon system that could be considered distinctive, if not decisive, due the impact of gravity. These are known as the liberation points, or the points at which the gravitational forces of two bodies balances out to create a stable orbit, of which there are five for any two celestial bodies.

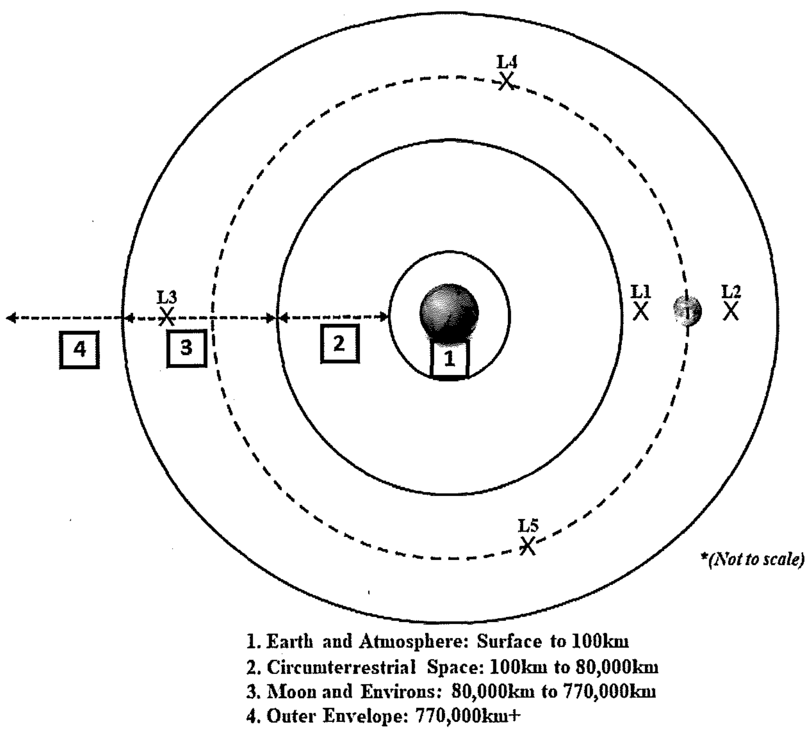


Diagram 4 – Lunar Liberation Points (L)[31]

Among these five points, the fourth and fifth points of liberation (L4 and L5) which exist at a 60°ahead of and behind the moon in its orbit, are considered to be potentially key terrain. Their decisive impact stems from the fact that objects located at these points can maintain a stable orbit with minimal energy, observe the "flanks" of both the Earth and the Moon, and occupy the exit of the gravity wells of both the Earth and the Moon.[32] By "looking down" the gravity well of both bodies of the Earth-Moon system, a weaponized satellite or station theoretically holds the "high ground" of that system, for it expends less energy and can gain greater acceleration with equal input than an adversary approaching from the someplace within the gravity well.

Control of this "high ground" in the exoatmospheric space would be exerted by denying access to the Earth-Moon system by "attacking from above" any space vehicle trying to move up from the surface of Earth (or, conceivably, the Moon). Weapons located in the L4 and L5 positions have the advantage of detecting movement and launching some sort of attack with, as opposed to against, gravity's pull. They are also above the most useful orbits, Low Earth and Geosynchronous, for satellite networks. To date, the pursuit of space weapons has been relatively latent: the concepts exist, but the desire to execute them has not. A recent study by Wilson Wong and James Sullivan determined that, so far, "the great cost involved with turning the orbit-to-surface concept into a credible deterrent" and "the ease at which a low orbiting satellite may be found (and attacked)" has meant that most weapons are better off (and cheaper) if maintained on the Earth.[33] Anticipation of an increasingly busier circumterrestrial region of space could lead to a change in outlook on space weapons, with the L4 and L5 points representing the ideal location to overlook activity in the Earth-Moon system.

Space weapons to secure gravitationally key terrain, along with traffic along orbital lines of communication and an increase in satellite operations, represent aspects of a projected future state caused by expanded military and civilian use of space. This change in potential future warfare is driven by lower-cost, reusable rockets currently being pioneered by companies like SpaceX and have serious potential to create new security issues and changes to the paradigm of how space is used and who uses it.

Implications

Nothing in the changes in how space is used and who uses it described here is based on new or novel concepts. Commercial rocket services, satellite miniaturization, space stations, civilian space travel, space weapons, and the belief of a progressively greater presence of humanity outside the confines of Earth are all ideas that have been present in the literature of space for decades. What is new is SpaceX's achievement of a reusable space vehicle atop a rocket with the potential to vastly reduce the costs of accessing space. This advance essentially serves as the platform for future space development, as the practicality of ubiquitous use, in both engineering and financial terms, now exists in the near future. SpaceX's lower-cost, reusable rockets are the hub around which other concepts and technologies can be realized, exploited, and further developed. As humanity moves towards a greater presence in space, the effects on future war and military theory and practice will be as profound as effects on all other aspects of the human endeavor.

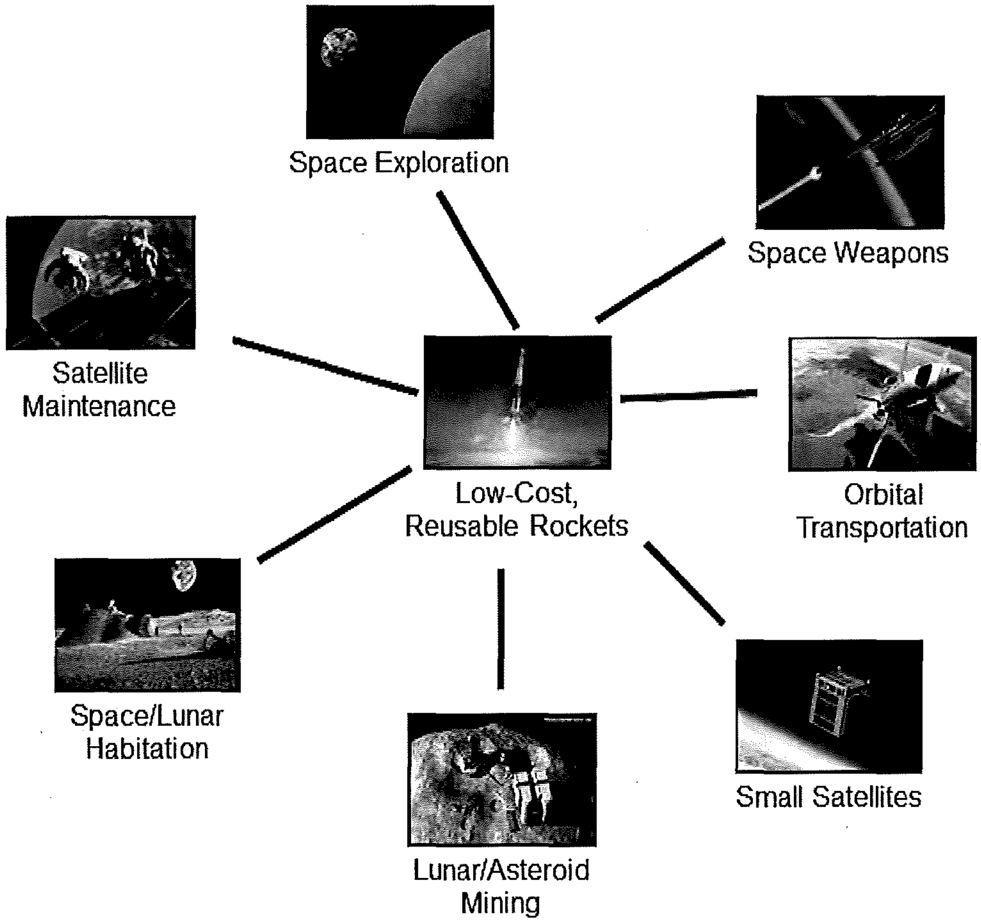


Diagram 5 – Low-Cost, Reusable Rockets as the Hub for Future Space Development

If cheap, reusable rockets as the hub to enable future space development represents the future state 15 years from now, then three critical implications and their effects on military space operations must be considered now. First and foremost, the "genie is out of the bottle" and the Earth-Moon system will lose its 70-year status as the preserve of governments and a few large corporations. Just as the Spanish claim to the Caribbean as a sort of "Spanish Lake" was broken by the official and unofficial seafarers of rival nations in the 16th and 17th centuries, SpaceX has created the conditions where smaller states and companies can access, compete, and develop their potential in space. Countries and corporations that currently operate in space must start considering now how they will handle new actors in the region while those that do not must consider how they can best unlock the potential of their emerging access. For militaries, planning considerations concerning the concept of control of space or space superiority, and the possibility of being forced to win it or not being able to exercise it, will become as essential as those concerned with airpower.

New actors in space leads to the second implication for states to consider: tension, both interstate and intrastate, between what Scott Pace has termed the cultures of the merchants (focused on competition and profit) and guardians (focused on order and protection).[34] A busier, more crowded Earth-Moon system will mean that the clash of Merchant and Guardian interests will occur at the state and global levels, increasing the requirement for accommodation and coordination on space policy. Traditional political, defense, and economic alliances need to start considering today how to coordinate their affairs on the orbital highways of circumterrestrial space. New methods of cooperation between states and alliances can build the necessary redundancy of essential capabilities to respond to cases of satellite network failure due to intentional attack or inadvertent mishap. New forms of traffic control will require implementation as the volume of traffic into and around the circumterrestrial region overwhelms current Earth-based monitoring systems. Much like the oceans today, the tension tomorrow between space as an economic development concern and space as a national security factor will affect how all of these coordination issues are addressed.

Further complicating coordination is the final implication concerning military operations in the future state, which is related to the change in infrastructure requirements for space operations in the face of evolving rocket technology. Under the current paradigm, military operations are conducted through large, fixed installations with established government agencies and contracted companies. These are easy to monitor and act as bottlenecks for access due to throughput of launches. Smaller, lighter rockets and smaller payloads require less infrastructure.

This is already occurring, with launches from rocket Transporter-Erector-Launcher (TEL) vehicles and submarines putting small satellites into low Earth orbit.[35] The reduction of logistics required to support a launch will mean that rocket support facilities or vehicles could devolve from national assets to theater or even tactical assets. Military planners must take this into account as they organize to support and defeat future space operations.

In conclusion, over the next 15 years the development of cheaper, reusable rockets by commercial industry will lead to rapid expansion of military presence in space, establishing the economic feasibility of space-based military operations for state and non-state actors. Low cost, reusable rockets being pioneered by SpaceX will serve as the hub for a host of other existing technologies and concepts to be developed and employed in space. If the future state of warfare sees space in 15 years as an expanded, but more cluttered, region to be contested by state and non-state actors, then it is essential to determine how to manage the implications now. As we observe SpaceX and other companies continue their drive to improve their creations, we are watching the 21st century's Wright Flyer take off, and like that modest flight, the potential of cost-effective, reusable rocket technology offers to change the parameters of space power within the next generation.

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[5] Jim Oberg, *Space Power Theory*, 67-68.
[6] *Ibid*, 69.
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[11] Jim Oberg, *Space Power Theory*, 69.
[12] Diagram adapted from John M. Collins, *Military Space Forces: The Next 50 Years* (Washington, D.C.: Pergamon-Brassey's, 1989), 7.
[13] *Ibid.*, 6-22.
[14] The division of orbital zones in the circumterrestrial region is arbitrary, and the convention used here is from John M. Collins, *Military Space Forces*, 15-16. Also see Wilson Wong and James Fergusson Eds, *Military Space Power: A Reference Handbook*, (Santa Barbara, CA: ABC-CLIO LLC, 2010), 21-24.
[15] Diagram adapted from John M. Collins, *Military Space Forces: The Next 50 Years*, 17.
[16] Satellite database at Union of Concerned Scientists, "UCS Satellite Database," *UCSUSA.org*. <http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.Wgtxp0qnGUl > (accessed November 14, 2017). Satellite distribution currently sees 92% (1602) of all satellites in either low earth or geosynchronous orbit.
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