TAKSHASHILA INSTITUTION

Space as a Geopolitical Environment

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TAKSHASHILA DISCUSSION DOCUMENT 2021 - 5

V1.0, 02 September 2021

Executive Summary

The ability to use space for commercial, military, and scientific purposes has become a vital determinant of national power. Yet space is a novel environment for human activity and the strategic implications of using it are poorly understood. This document seeks to understand how space functions as a geopolitical environment and provide a useful set of ideas for both scholars and practitioners. Focusing on orbital space, it looks at space as both a physical and strategic geography as well as a potential arena for military operations. It examines strategic theories of space, the structure and logic of space warfare, and the potential for putting in place legal and normative arrangements for space activity.

Introduction

In 1996, the Anglo-American academic and strategic thinker Colin S. Gray published a paper titled 'The Influence of Space Power upon History'. Evoking the title of A.T. Mahan's much-cited volume from more than a century earlier, The Influence of Sea Power Upon History:1660–1783, Gray threw down the gauntlet to future scholars by asking "Where is the theory of space power? Where is the Mahan for the final frontier?"[1]

In the years since, several scholars and practitioners have sought to take up Gray's intellectual challenge with varying degrees of success. Some of the key ideas on space power developed over the quarter century since Gray's paper are discussed in the pages below. However, any strategic theory of space must be anchored in a broader understanding of space as a physical and political geography. These must also be coupled with an understanding of space as a strategic arena as well as the underlying dynamics of space warfare.

Today, India is looking towards the heavens, and is beginning to craft space doctrines, strategies, and policies. It will need a common set of assumptions to work on in order for these to retain coherence and minimise contradictions. This document seeks to develop a set of principles and ideas that can form the basis of India's future doctrines, strategies, and policies for space.

A NEW URGENCY

Gauging economic dependence on space is a daunting task, and estimates can vary based on the definition of space-reliant activity. However, according to one estimate, the global space industry alone was worth $423.8 billion in 2019.[2] During that same year, the total number of commercial missions grew by nearly 50%.[3]

In the last few years, states have also begun to develop military capabilities in space. In December 2019, the United States (US) formally founded its Space Force as a separate branch of the military. Four years earlier, China's People's Liberation Army (PLA) created its Strategic Support Force (SSF), which is dedicated to space, cyber and electronic warfare. China has also tested kinetic anti-satellite weapons as well as developing non-kinetic counterspace capabilities.

India's response to these developments has been modest. In the last months of 2019, its Defence Space Agency (DSA) become operational, backed by a Defence Space Research Agency tasked specifically to develop the ability to wage space warfare.[4] Earlier that same year, India also demonstrated its anti-satellite capability when it launched a modified ballistic missile interceptor, the Prithvi Delivery Vehicle Mark-II, to strike at Microsat-R, a tiny satellite in sun-synchronous orbit at an altitude of 282 kilometres.[5] The Indian government has also begun opening up space to the private sector and has set up an independent regulator, the Indian National Space Promotion and Authorisation Centre (INSPACe), to facilitate this.[6]

While space has been militarised since the inception of the Space Age in 1957, the renewed interest in weapons of space warfare stems from greater military and economic reliance on space. Military-capable satellites increase the visibility of Earth-based forces and also enable military forces on Earth to disperse. In short, space-based reconnaissance, navigation and communications capabilities both necessitate and facilitate the dispersion on military forces on Earth to increase their survivability.[7]

These parallel developments in the military and commercial spheres are not coincidental. As the commercial sector drives down costs and develops new technologies, the use of space will be increasingly democratised. This means that a state's ability to use space will become increasingly important to its overall national power. A corollary of this is that a state's ability to harness new technologies to militarily deny adversaries the use of space will also become a measure of its power and influence.

As military planners around the world turn to space, some see it as an opportunity to establish dominance, while others see it as a way to cut a bigger rival down to size. While India has moved with impressive speed to develop the organisational structures for space warfare, there has been little discussion on the most crucial issues. How does the strategic geography of space connect to politics on Earth? What strategic theories are likely to be most useful for pursuit of India's space ambitions? What would be India's purpose in waging space warfare? How would it be connected with warfare on Earth?

The next few sections provide brief overviews of the physical and strategic geography of space, some of the key ideas concerning strategic theories of space, and the underlying logic and dynamics of space warfare. We will then discuss a series of conclusions that could potentially form the basis on which to build future space doctrines, strategies and policies. These are briefly presented below for the reader's convenience.

POSTULATES

Drawing from scholarship over the last 25 years, we postulate the following:

1. The geography of space is determined primarily by gravitational forces and radiation.
2. Space is a distinct environment. The character of orbital space fundamentally differs from that of Earth's stratosphere, troposphere, and so-called 'near space'. Therefore, space power cannot be extrapolated from the military term air power.[8]

3. Human activity in orbital space is shaped by the interaction between activities on Earth and the physical character of the celestial littoral, as defined by such phenomena as orbital mechanics and solar weather patterns.

4. Human activity in orbital space is heavily Earth-centric, with most orbital craft tasked with providing remote-sensing, communications, and navigation services on Earth.

5. Space power is the ability of a state to leverage its space-related activities to wield influence in international politics. It encompasses commercial, military and scientific activity in space, as well as all Earth-based activities connected to the use of space.

6. Celestial lines of communication (CLOCs) are the routes used for space-related activities, including orbital paths and communications links between satellites and Earth.[9]

7. The command of space is the ability to use space, deny it to others, or to do both.[10]

8. Space warfare is waged for the command of space. It can be waged both in space and on Earth.[11]

9. Orbital space has always been militarised, but new technologies and the diffusion of existing technologies will make it easier to contest the use of space in the near future.

10. The battlefield of space is characterised by vast distances, the lack of natural cover and concealment, the absence of atmospheric attenuation, the presence of radiation, and the mechanics of gravitation.

Physical Characteristics

DEFINING THE SCOPE

At its most extreme, the word “space” would refer to all the universe beyond the earth’s atmosphere, an expanse currently too vast to consider for human affairs. For the purposes of this document and its earth-bound concerns, we must drastically limit the scope of our consideration.

One solution would be to consider only our solar system. By the most conservative definition, the solar system has a diameter of 9.09 billion km,[12] compared with the earth's equatorial diameter of 12,756 km.[13] Still, unlike interstellar space, the solar system is likely to be traversed extensively this century, and parts of the inner solar system might also witness sustained human habitation. In less than seven decades of space travel, humans have already landed on the moon and dispatched unmanned probes to other planets and lunar surfaces. In the coming years, the laws and norms of exploring and exploiting celestial bodies will be set, both through political negotiations on Earth and through brute facts of possession and use in space. The norms established in these early years are likely to have far-reaching consequences.

As important as travel to other celestial bodies will be, orbital space will most directly and consequentially impinge on human affairs over the next decade. This is the portion of space that lies within a radius of about 40,000 kilometres from the Earth's centre, which is home to both artificial satellites and inhabited spacecraft like the International Space Station.

ORBITAL SPACE

There is no clear boundary between the earth's atmosphere and space. By one definition, space begins 100 kilometres from the earth's surface—the so-called Karman line. However, some satellites have orbited at altitudes as low as 80-90 kilometres for brief periods of time.[14]

A satellite's orbit depends on its altitude. The orbit, in turn, determines the relative velocity of the satellite in relation to earth. The lower the orbit, the greater the relative velocity of the satellite.

Orbits are also characterised by their inclination—the angle formed by a satellite's plane through the earth's centre and the equatorial plane. Therefore, a satellite orbiting the equator would have an inclination of zero degrees, whereas a satellite in polar orbit would have an inclination of 90 degrees. Most other satellites have inclinations between zero and 90 degrees.[15]

There are three major types of orbits. Low Earth Orbit (LEO) satellites are found at altitudes of 100 km–1,920 km. Medium Earth Orbit (MEO) satellites orbit the earth at altitudes of 1,920 km–35,680 km. Finally, Geosynchronous Earth Orbit (GEO) satellites are at altitudes of 35,680 km to about 35,800 km.[16]

Orbits and altitudes also determine the time it takes for a satellite to circle the earth. A satellite orbiting at 200 kilometres will travel at 7.8 kilometres per second and take 88.3 minutes to complete an orbit of the earth. On the other hand, a geosynchronous orbit satellite traveling at 38,800 kilometres travels at just 3.1 kilometres per second and takes 24 hours to circle the earth. This is also why geosynchronous satellites appear to hover over the same portion of the earth's surface.

Low earth orbit includes remote-sensing and reconnaissance satellites, and middle earth orbit includes navigation systems like the American Global Positioning System (GPS) or the Russian Glonass, which rotate around the planet at an altitude of about 19,000 kilometres. Satellites in geosynchronous orbits are useful for both communication (providing wide and reliable coverage with relatively smaller round station and tracking infrastructure) and for reconnaissance (allowing a particular patch of the earth to be continually monitored). Satellites in polar orbit move north-to-south instead of west-to-east.

There are other special orbits. Satellites in highly elliptical orbits change their altitudes and velocity to serve specific functions. The 12-hour Molniya orbit, for instance, helps maximise coverage during high-altitude phases. Satellites in this 12-hour orbit swing away from the earth to increase their time over the area to be monitored, before accelerating back to lower altitudes. At their apogee, Molniya orbit satellites are at 40,000 kilometres and at 1,000 kilometres at their perigee. A variant of Molniya orbits are Tundra orbits, which are focused on higher altitudes.[17] The sun-synchronous orbit is a variant of the polar orbit in which the satellite always covers any point in its ground track at the same local time.[18]

Mission	Orbit Type	Altitude	Period
Communication/ Nuclear Early Warning	Geostationary	35,780 km	24 hours
Remote Sensing Weather	Sun-synchronous Geostationary	150–900 km 35,780 km	1.5 hours 24 hours
Navigation	Semi-synchronous	20,232 km	12 hours
ISR Satellites, Space Shuttles	Low Earth Orbit	160–2,000 km	1.5–2 hours
Communication/ Intelligence	Molniya Orbit	7,971–45,170 km	12 hours

Figure 1: Orbits and their Applications[19]

Orbital mechanics allow satellites to rotate around the earth along complex (but predictable) paths with a minimal need for fuel to maintain orbit. Larger quantities of fuel are only needed to change orbits or evade threats. Unlike aircraft, satellites do not need to be designed to survive high windspeeds or rainstorms.

However, space is a hostile environment in its own right. Satellite makers face three key challenges. One is outgassing, which is the emission of gases from synthetic materials in a vacuum. The second is cold welding, which occurs when solid parts with only small gaps between them fuse together in extremely low temperature environments. The third is heat transfer via conduction, convection or radiation, causing temperatures to fall below required levels.[20]

Different orbits can also pose challenges. Satellites at altitudes less than 1,000 kilometres face a low-level drag that causes their velocity to increase and, therefore, their altitude to drop.[21] Lower orbits also contain atomic oxygen, which is more reactive than molecular oxygen, and can degrade sensors and other components.[22]

Ionising radiation from both galactic cosmic radiation (which originates beyond the solar system) and solar particle events (which are the results of solar flares and coronal mass ejections) envelops orbital space.[23] These take their toll on satellites, damaging delicate electronics and embrittling material.[24] Even the accumulation of electrostatic charge can lead to discharges strong enough to disable critical functions.[25]

Another challenge is posed by Van Allen radiation belts, which follow the lines of the earth's magnetic field and consist of trapped charged particles. Some LEO paths lie within a portion of the inner belt.[26] However, medium earth orbits are the worst-affected by this phenomenon. Satellites in these orbits need extra radiation and protection, adding to weight and cost.[27] This is one reason why only about 10% of satellites in operation lie in MEO.[28]

EARTH & SPACE

As of this writing, there are 44 landlocked states on Earth that lack independent access to the oceans. While all states notionally have access to space, the practical ability to carry out launches is determined by access to the right locations on Earth.

Satellites are easier to launch from close to the equator in an eastwards direction. This is because as the Earth rotates, the equatorial region moves fastest (at 1,670 kilometres per hour), allowing the launch vehicle to impart the required velocity to the satellite. Launching from around the equatorial latitudes also allows satellites to enter most orbits directly instead of having to carry out transfer manoeuvres.[29]

This fact explains the locations of major launch sites: NASA's Cape Canaveral, the European Space Agency's site in Kourou, French Guiana, China's Hainan Island site, and India's Satish Dhawan Space Centre in Sriharikota, Andhra Pradesh.[30]

Launch sites are also ideally located away from heavily populated areas and busy airspace, which is why they are usually set up with the sea to the east or in sparsely populated regions inland, such as the Baikonur Cosmodrome.

Despite this, the geography of human settlements and political relations can influence the manner of a launch. For example, Israel has to launch its satellites westwards instead of eastwards to avoid the territories of states with which it has troubled relations. These launches, which are against the direction of the Earth's rotation, force Israel to make several compromises and restrict itself to small-sized satellites.[31] While India does not face such severe constraints, for safety reasons, its Polar Satellite Launch Vehicle (PSLV) rockets launching from Sriharikota must conduct "dog-leg" manoeuvres to swing around Sri Lanka's heavily populated landmass.[32]

During launch and operation, spacecraft need to be monitored from ground stations across the globe. For example, during the launch phase, India's monitoring stations are located at Sriharikota, Port Blair and Brunei. Once launched, satellites and other spacecrafts are monitored from stations operated either by ISRO or by ISRO in collaboration with other space agencies. In the northern hemisphere, these include stations in Bengaluru, Brunei and Mauritius. In the southern hemisphere, ISRO uses a station on Biak island in Indonesia, along with the Alcantara and Cuiaba stations run by Brazil's space agency INPE, and the Hartbeestoek station run by South Africa's SANSA.[33] Besides these, ISRO also benefits from the Deep Space Network (DSN) operated by NASA's Jet Propulsion Laboratory. DSN is key to monitoring interplanetary missions and has facilities in Goldstone, California, outside Madrid, Spain, and in Canberra, Australia.[34] Ground stations in polar regions are also crucial for satellites in various polar orbits as well as for satellite navigation systems. India's Antarctica Ground Station for Earth Observation Satellites (AGEOS) gathers data from fast moving remote sensing satellites in LEO.[35] Norway similarly runs ground stations in both polar regions.[36] Russia and China maintain Antarctic ground stations that can improve the accuracy of their satellite navigation constellations, which are dual-purpose systems that can be used for both military and civil purposes.[37]

THE MOON & BEYOND

The Moon is 27% the size of Earth but only 1.2% of its mass. It has 16.6% of Earth's gravity and no atmosphere.[38] The Moon's rotational and orbital periods are roughly the same, at about 27 Earth days, which means one side of the moon is always facing away from Earth and cannot be observed directly. Daylight on any spot on the Moon lasts about 14 Earth days followed by an equal period of night. Temperature differences between day and night are drastic, ranging from 111 degrees to -193 degrees centigrade.[39]

Despite its inhospitable environs, the Moon is seen as an important launching pad for further exploration of the inner solar system and beyond. Its mineral composition is believed to be very similar to that of Earth's, with ores of titanium, aluminium, and magnesium present on the lunar surface.[40] The Moon's polar regions are likely to hold large quantities of water, an important source of both hydrogen (for fuel) and oxygen (for breathing).[41]

The moon is considered a crucial intermediate base or launching pad for further exploration of the inner solar system, especially journeys to Mars and the Near-Earth Objects (NEOs) of the Asteroid Belt.

Despite renewed interest in lunar exploration, there are formidable hurdles to be overcome before humans set up habitats on the Moon. Most of the requirements for a sustainable base, including construction material, fuel, and atmospheric gases would have to be produced on the Moon itself. Inhabitants would also have to grapple with myriad safety issues, including meteorites, radiation and moonquakes, not to mention the constant challenge of maintaining health in a low gravity environment.[42]

Geopolitics in Space

Can the word "geopolitics" be appropriately applied to human affairs beyond the earth's atmosphere? Some scholars use the term *astropolitics* to describe the continuation of geopolitics in space.[43] This term continues to be contested, reflecting Earth-bound debates over the ideas of geopolitics. For convenience, in this document we will extend the use of the word geopolitics to space.

GEOPOLITICAL FOUNDATIONS

The historian Geoffrey Parker defined geopolitics as "the study of international relations from a spatial or geographical perspective".[44] We draw on Parker to develop an expansive definition of geopolitics: human geography is the result of an ongoing interaction between human agency and physical geography. The politics that result from these interactions, whether foreign or domestic, are geopolitics. In other words, geopolitics is the politics of human geography.

While simple, this definition is rooted in the realities of history and is less encumbered by the ideological baggage that usually accompanies such an endeavour. It recognises that humans have constantly imparted new meanings to their geography through technological, social and political innovation. The domestication of grains and livestock eventually allowed for the rise of states. By building boats, humans changed the seas from barriers into highways, and by mounting complex sails on those boats, they managed to turn ecological phenomena like the monsoon winds into propulsion systems. Humans have similarly created sacred geographies of pilgrimage sites, holy cities, and holy rivers. By creating imagined communities of nations, human societies have also changed the meanings of territories and boundaries.

Over the last two centuries, industrial revolutions have not only shrunk geography but have also imbued it with new significance: regions with reserves of key mineral resources like coal, oil, or more recently, rare earth metals, have gained importance. This period of technological transformation has also opened up new geographies such as the deep-sea environment, sea-beds, and space.

A NOVEL ENVIRONMENT

Unlike harsh environments on Earth, such as the deep seas, there is no known life in outer space. Humans do not dwell in space on a permanent basis and even inside the confines of a spacecraft, humans must cope with weightlessness. Indeed, since direct exposure is lethal, the human experience of space is mediated. At the most intimate end of the spectrum, it is experienced through the translucent visor of a space helmet. Most of the time, space is experienced from Earth—from data and images sent back by uncrewed vehicles. There are no recognised claims of national sovereignty in space, no holy sites and no irredentist claims to lost territories. This means space itself is not an arena for the geopolitics of emotion, but the fear, humiliation, and hope felt by people back on earth could spur or contain conflict that extends into space.[45] The Space Race of the 1960s was the product of Cold War rivalries, and the commercial and military satellites currently orbiting the planet are potent symbols of national power that are also critical to economic activity and military capabilities.

Despite the radical differences between space and earth-based environments, there are some commonalities in how human agency has been exercised to impart new applications to natural phenomena. Humans have harnessed the earth's gravitational pull to establish useful orbits, have used gravity assist manoeuvres—the so-called gravitational slingshots—to accelerate spacecraft, and exploited solar radiation as a power source for those vehicles. In conclusion, the physical characteristics of orbital space gain geopolitical significance because of human agency.

Strategic Theory in Space

There are two broad conceptions of space as a geopolitical environment. One is that space power is simply an extension of airpower to higher altitudes. A second is that space bears closer resemblance to the maritime domain. A third, more recent conception focuses on the nearer reaches of space, and treats it as a littoral environment.

This document finds the first conception useful mainly to understand some military aspects of space power, while the second and third offers important insights that will find a place in the conclusion of this document.

AN EXTENSION OF AIRPOWER

The idea that space is a logical continuation of the atmospheric environment has found favour with air forces. A prominent US Air Force document called for the "synergistic application of air, space, and information systems to project global strategic military power."[46] The former head of the US Air Force Space Command, the predecessor to the US Space Force, once warned that "the potential of aircraft was not recognized immediately… until one day the full advantage of applying force from the air was realized, and the rest is history. So too [will it be] with the business of space."[47]

This line of thinking suffers from two problems. One, is that is appears to gloss over the differences between the two different domains of air power and space power. As noted above, vehicles in orbital space are built on very different principles from earth-bound aircraft and can continue to remain in flight without a fuel source. A corollary of this is that space forces are less manoeuvrable, more vulnerable to kinetic attacks and possess no proven capabilities to deliver large amounts of ordnance against land or sea-based targets.[48]

The second problem is that the aerospace power conjecture is entirely military.[49] Space is a realm of economic, military, and scientific activity, and any state's space power is a product of all three.

THE MARITIME ANALOGY

While the word "naval" refers to the armed forces on the seas, the word "maritime" refers more broadly to a society's relationship with the oceans and all the activity that entails: economic, military and even cultural. This maritime analogy is of utility in understanding space power not because space resembles the seas—it does not—but because both the seas and space are geographical territories used by humans for both economic and military purposes. A state's maritime power can be understood as encompassing all the ways in which it can leverage the seas to wield power. These may include not just activities at sea but also crucial shore-based capabilities ranging from maritime insurance to land-based anti-ship missiles.

Space power can also be thought of in this comprehensive manner as including the whole spectrum of space-related activities including communications, positioning, navigation, timing, remote sensing, reconnaissance and early warning, military counterspace capabilities, space-related businesses, and innovations in space technologies.

Maritime power can become central to the identity of a society and polity. Such thalassocracies have been a recurring feature of history. In a recent work, the historian Andrew Lambert defines a thalassocracy or seapower state as one that has chosen "to emphasise the sea, to secure the economic and strategic advantages of sea control to act as a great power, through a consciously constructed seapower culture and identity."[50] Phrased another way, the seapowers of the past, ranging from Carthage to Great Britain, were "maritime imperial great powers, dependent on the control of ocean communications for cohesion, commerce and control."[51]

Despite our pervasive dependence on space today, it will perhaps be decades before we see the outer space equivalent of a thalassocracy. However, maritime theory does provide insights into space power. John J. Klein has used Julian Corbett's 1911 work, *Some Principles of Maritime Strategy,* to "define a theory for space operations."[52] Klein makes the case that space strategy has to work within the context of broader military strategy and that warfare in space is unlikely to win wars by itself.[53] He goes on to add:

"The inherent value of space is the utility and access it provides—whether during peace or war—and this utility and access is enabled through space communications. Generally stated, space communications are those lines of communications in and through space used for the movement of trade, materiel, supplies, personnel, data and information, along with the means of doing so. By ensuring access to one's celestial lines of communication (CLOCs), a nation can protect its diplomatic, economic, informational and military interests."[54]

Klein's celestial lines of communications (CLOCs)—drawn from sea lines of communication (SLOCs)—leads him to conclude that warfare in space will be centred around securing one's CLOCs and denying them to the adversary.[55] While Klein does not seem to consider that a state might be content with just denying CLOCs to an adversary, this is a useful framework for developing a space strategy.

One final observation can be drawn from the idea of CLOCs: orbital craft do exchange goods with Earth, but they do so almost entirely in the form of electromagnetic radiation.

A CELESTIAL LITTORAL

Considering that the vast majority of space activity is still tied to orbital regions, the scholar Bleddyn Bowen has sought to use the analogy of coastal waters, with orbital regions being defined as celestial shorelines.[56] Bowen argues that the “routes of crucial satellites such as GPS, Keyhole, and Defense Support Program (DSP) constitute a part of the United States’ ‘space coast.’ Chinese Beidou and Yaogan satellites’ orbits likewise form parts of the Chinese ‘space coast.’”[57] To build on this, the objective for spacefaring states is not space itself but influencing events on earth.[58]

Building on the theories of Corbett and Alfred Thayer Mahan, Bowen states that “the command of space means that the strategic object of space warfare is always to secure and/or deny the use of celestial lines of communication”.[59] Bowen defines command of space as controlling space or denying its use to the adversary. A state may exercise command of space by just controlling or denying parts of space for periods of time. This control is not “inherently decisive” since “spacepower is a source of support for the primary theatre of a conflict and infrastructure on Earth”.[60]

Elsewhere, Bowen also helps clarify another limitation of using Corbett as an analogy. Corbett attributed to the sixteenth century statesman Francis Bacon the idea that those who command the sea are “at great liberty and may take as much or as little of the war” as they choose.[61] This aphoristic wisdom may have sometimes held true for an island kingdom but it has little relevance for celestial shorelines. For instance, an India engaged in border confrontations with either China or Pakistan cannot leverage orbital space to limit its involvement in the conflict.[62]

Space Warfare

THE BATTLEFIELD OF SPACE

Before we examine the offensive capabilities that might be used in space warfare, we turn briefly to the character of orbital space as a battlefield.

The first, most obvious point to make is that orbital space is vast. For instance, geosynchronous satellites orbit the earth at altitudes of about 36,000 kilometres, well out of the range of existing Earth-based kinetic weapon systems. However, more than 70% of all satellites are in low-earth orbit, making the immediate littoral crowded and the farther reaches of the littoral only sparsely populated by satellites.[63]
The second point to make is that satellites follow predictable orbital paths and only deviate from them because of purposeful movement, orbital degradation, or accidents. At present, purposeful deviations tend to be rare since they consume a limited on-board

fuel supply. This means that if a state is tracking an adversary's satellite, it can predict with some confidence exactly where the satellite will be in, say, an hour's time.

Space is sometimes referred to as the "ultimate high ground". US President Donald Trump used the phrase when addressing military personnel in 2019[64] and it has found its way into Indian military writing as well.[65] There is no question that space is an unmatched vantage point from which to observe the earth. However, the celestial littoral lacks the other attributes commonly associated with "high ground" on land. Orbital space offers no natural protection from enemy observation and attack. A satellite cannot "dig in". This means orbital craft do not enjoy natural cover (some protection from enemy fire) or concealment (protection from enemy observation, but not necessarily enemy fire). In short, satellites in low earth orbit are vulnerable to any adversary with adequate space situational awareness (SSA) and some offensive capabilities. Satellites can only achieve a form of concealment by deceiving adversaries into believing they are something else—a purely commercial craft or a piece of debris—or by being too small to detect, which usually means less than 10 centimetres in size. If the concept of "ultimate high ground" is taken to mean an extension of airpower theory, orbital craft are much worse off. Unlike combat aircraft, satellites cannot use terrain features to mask their flight paths and are much more limited in their ability to approach a target from a different direction or perform complex evasive manoeuvres.

Despite the vulnerability of satellites to kinetic attacks from weapons such as direct ascent ASAT missiles, orbital space presents would-be attackers with serious political dilemmas. The debris fields created by the collision of a satellite and kinetic kill vehicle (KKV) presents risks to friendly satellites. The 2007 Chinese DA-ASAT test involved collision at a relative velocity of 32,400 kilometres per hour, and resulted, three years later, in 3,037 pieces of tracked debris and an estimated 32,000 other smaller pieces that remained untracked.[66]

According to one estimate, if China and India were to target three low earth orbit satellites each with DA-ASATs, the resultant debris could cause up to 60-75 orbital collisions of varying severity in the first decade.[67]

While orbital space is a risky arena for the use of kinetic weapons, it is much more inviting of other kinds of offensive capabilities. Satellites remain vulnerable to electronic jamming from earth, and increasingly from other satellites in space. Directed energy weapons (DEWs) are difficult to field in space as of today, but these beams are much more effective in space without atmospheric attenuation. Rendezvous and proximity operation (RPO) satellites are potential dual-use tool.

One limitation for space-based weapons remains their relative lack of manoeuvrability—the ability to be in the right place at the right time—but not all space weapons need to be located in space or target space-based assets. Indeed, if space warfare is waged for the command of space, it need not always be waged in space.

MAPPING SPACE WARFARE

Any satellite system has three segments: the space segment (the satellite itself), the ground segment (the users), and the link segment (the ground station). Those waging space warfare will target these three segments, meaning there are both space-based and Earth-based target sets. Similarly, the tools with which these attacks are mounted can be based on both Earth and space. These tools, from both the present and near-future, are:

1. ASAT kinetic kill missiles
2. Co-orbital ASATs such as rendezvous and proximity operations (RPO) satellites
3. Space-based kinetic kill weapons
4. Conventional and nuclear weapons
5. Electronic warfare
6. Cyber attack
7. Directed energy weapons (lasers and high-powered microwaves)

	Earth-Based	***Space-Based***
Kinetic	ASAT Missiles Conventional & Nuclear Weapons Electronic Warfare	*Co-orbital ASAT* *Kinetic Kill Vehicles* DEWs
Non-Kinetic	Electronic Warfare Cyber Attack DEWs	Electronic Warfare DEWs

Figure 2: Earth and space-based means of waging space warfare. Systems that are not yet in existence are in blue.

One class of weapons not listed above are long-range ballistic missiles such as ICBMs, which enter space in their midcourse phase before their warheads re-enter the atmosphere. Ballistic missiles are not weapons of space warfare. However, to deny a ballistic missile the use of space is to exercise command of space and is an act of space warfare. This makes ballistic missile warheads the fourth target of space warfare after the three satellite segments noted above.

THE OFFENSIVE TOOLS OF SPACE WARFARE

ASAT Missiles: The first ASAT missiles were air-launched and used conventional or nuclear warheads. Most such missiles fielded today are ground or sea-launched direct-ascent weapons and are typically variants of existing ballistic missiles used to attack targets or intercept other ballistic missiles. Most do not carry explosive warheads, instead relying on kinetic kill vehicles (KKVs) to destroy the orbiting craft.

Besides the problem of debris, there are two limitations to ASAT missiles. One, the use of KKVs presupposes a high degree of space situational awareness (SSA).[68] Two, most satellites beyond low earth orbit, including global navigation satellite systems (GNSS) and geosynchronous communications satellites are out of range of existing ballistic missiles.[69]

Kinetic Kill Vehicles: Besides being mounted on ASAT missiles, kinetic kill vehicles (KKVs) are also used by ballistic missile defence systems such as the US Ground-Based Midcourse Interceptors.[70] These KKVs are designed to be able to destroy warheads that are made to survive re-entry and "use sensors, lenses and rocket thrusters to pick out warheads and steer into their paths."[71]

Fanciful proposals have been put forth for space-to-Earth KKVs that will essentially act like artificial meteorites. Such proposals—the most prominent being dubbed 'rods from God'[72] —have not quite managed to overcome the realities of orbital mechanics. To be able to get weapons on target quickly, the orbiting platforms would have to be in low earth orbit. This would make them vulnerable to Earth-based countermeasures such as ASATs. It would also mean that sizeable constellations of these platforms would be required for adequate coverage.[73]

Co-orbital ASATs: These are orbital craft that can potentially damage or destroy other orbital craft through kinetic means. It is not clear what particular co-orbital craft are actually ASAT weapons. Most are rendezvous and proximity operations (RPO) craft that can manoeuvre close to satellites and conduct repairs or collect intelligence.[74] However, these capabilities also make such RPO craft dual-use systems that can potentially disable an adversary satellite.

Electronic Warfare: Electronic warfare can take the form of either jamming or spoofing. Jamming can target the uplink signal from the link segment (i.e. the ground station) to the satellite or the downlink signal from the satellite to the link segment. The jamming system transmits signals of the same radio frequency as the uplink or downlink signal, thus disrupting regular transmission. Jammers have progressively become smaller and lighter, falling from size of a frisbee to "the size of a hockey puck."[75]

Rather than disrupt, spoofing is meant to deceive the end user with wrongly coded signals. This has been used so far against global navigation satellite systems (GNSS) such as GPS being used by merchant vessels at sea.[76]

Jamming and spoofing are largely Earth-based activities today, though satellites could be conceivably used to jam both uplink and downlink signals.

Cyber Attacks: These will target the link and user segments on Earth, and if successful, could provide the attackers access to the satellite itself. Cyber attackers are likely to exploit weak points including "the landlines that link ground stations to terrestrial networks, user terminals that link satellites, and antennas on satellites and ground stations."[77] The attackers could simply disrupt Earth-based facilities or find their way in the satellite itself. While this will require considerable technical understanding of the satellite, it is entirely possible. For instance, in 1998, hackers took control of a US-German satellite and turned its solar panels towards the sun, resulting in damage to the satellite's battery.[78]

The future prospects of offensive cyber operations are unclear and remain contested among expert observers. Some have argued that such cyber capabilities have revolutionary implications for statecraft[79] while others have maintained that it neatly fits older patterns of sabotage, espionage, and subversion.[80] Still others stress the difficulty and expense of mounting complex cyber attacks against industrial control systems as well the limited damage achieved.[81] The Stuxnet computer worm used against Iran's Natanz nuclear facility in 2010 cost at least $300 million and caused only reversible damage.[82]

Despite the healthy scepticism about cyber attacks, the Stuxnet worm is known to have caused physical damage. In orbital space, an equivalent attack could be devastating, allowing the attackers to potentially commandeer satellites and use them as kinetic kill vehicles against other satellites.[83]

Conventional & Nuclear Weapons: Both the ground and link segments of a satellite system can be attacked by regular Earth-based armed forces or non-state actors. The attackers could use conventional or nuclear standoff weapons or special forces. Nuclear weapons can also be used in an ASAT role to destroy multiple satellites, though any nuclear explosion in space will have a catastrophic effect on other satellites as well.

Directed Energy Weapons: These include lasers and high-powered microwaves. There are currently no DEWs capable of waging space warfare and much about the potential of these weapons is speculative.[84] At present, some solid-state lasers weapons have proven capable of intercepting small remotely piloted vehicles during tests[85] and similar experiments are afoot with high-powered microwaves (HPMs).[86] In 2006, a Chinese ground-based laser temporarily dazzled US spy satellites but it's not clear if the laser was in fact a nascent anti-satellite weapon.[87]

Whatever the fate of DEWs on Earth, lasers and HPMs are potentially effective non-kinetic weapons in the vacuum of space if technical challenges (including the need for power) are overcome.

	Earth-Based Destination	***Space-Based Destination***
Earth-Based Source	Conventional & Nuclear Weapons Electronic Warfare Cyber Attack	Electronic Warfare ASAT Missiles *Kinetic Kill Vehicles* DEWs Cyber attack
Space-Based Source	DEWs *Kinetic Kill Vehicles*	*Co-orbital ASAT* *Kinetic Kill Vehicles* Electronic Warfare DEWs

Figure 3: Earth and space-based weapons and the locations of their targets.

THE LOGIC OF SPACE WARFARE

Space warfare will be waged to exercise command of space by defending its use and/or denying its use to an adversary. For the near future at least, it follows that space warfare will be waged to maintain the advantages the use of space confers to the conduct of war on Earth and/or to deny these advantages to the adversary.

To protect its use of space, a state can either defend its space assets or deny an adversary the ability to attack them. To the extent that these capabilities (and the willingness to use them) are known to the adversary, and thus dissuade an adversary from mounting attacks, these capabilities constitute *deterrence by denial*.

A state may also develop the offensive tools to deny an adversary the use of space. To the extent that these capabilities are known to the adversary, and to the extent the adversary believes the state willing and able to inflict unacceptable damage in retaliation, and is thus dissuaded, they constitute *deterrence by punishment*.[88]

Space warfare capabilities are not necessarily about deterring attacks on space assets. These capabilities may be pursued to actively deny an adversary the use of space. However, this capability may, in turn, contribute to *overall deterrence* between the two parties.

Most of the offensive tools that can contest an adversary's use of space are presently Earth-based. The exceptions are co-orbital ASAT craft. This distinction helps highlight the primitive character of warfare in space. While space-based assets are part of sophisticated Earth-based systems for warfare, in space itself, satellites lack active measures to defend themselves, and weapons such as co-orbital ASAT craft are dual-use. In space, humans are still using their ploughshares as improvised weapons and have yet to convert them into swords.

Space has yet to see the "speciation" of weapons: the development of a diverse array of weapons, each evolved to fit into its niche in the battlefield ecology.[89] On Earth, militaries can draw upon a panoply of weapons to target Earth-based space assets. Earthly warfare offers abundant examples of speciation. A glance at the history of airpower over the last century shows us the evolution of fighters, long-range bombers, tactical bombers, as well as multi-role combat aircraft, transport and refuelling aircraft, and airborne warning and control planes. The logic of space warfare suggests that similar pressures may force the speciation of military platforms in orbit.

Conclusion

This is the best of times and the worst of times to attempt a document such as this. It is the best of times because states including India are turning to space with a mix of hope, concern and curiosity, giving it a relevance that would not be as evident a decade earlier. It is the worst of times because the present body of literature concerning geopolitics and space is both vast in quantity and in great flux, with few widely accepted texts available to guide scholars and practitioners.

Instead of attempting the Sisyphean task of surveying all the available literature in this emerging field, this document has focused on issues and ideas most relevant for policymakers. We conclude by once again summing up our postulates:

1. The geography of space is determined primarily by gravitational forces and radiation.

2. Space is a distinct environment. The character of orbital space fundamentally differs from that of Earth's stratosphere, troposphere, and so-called 'near space'. Therefore, space power cannot be extrapolated from the military term air power.[90]

3. Human activity in orbital space is shaped by the interaction between activities on Earth and the physical character of the celestial littoral, as defined by such phenomena as orbital mechanics and solar weather patterns.

4. Human activity in orbital space is heavily Earth-centric, with most orbital craft tasked with providing remote-sensing, communications, and navigation services on Earth.

5. Space power is the ability of a state to leverage its space-related activities to wield influence in international politics. It encompasses commercial, military and scientific activity in space, as well as all Earth-based activities connected to the use of space.

6. Celestial lines of communication (CLOCs) are the routes used for space-related activities, including orbital paths and communications links between satellites and Earth.[91]

7. The command of space is the ability to use space, deny it to others, or to do both.[92]

8. Space warfare is waged for the command of space. It can be waged both in space and on Earth.[93]

9. Orbital space has always been militarised, but new technologies and the diffusion of existing technologies will make it easier to contest the use of space in the near future.

10. The battlefield of space is characterised by vast distances, the lack of natural cover and concealment, the absence of atmospheric attenuation, the presence of radiation, and the mechanics of gravitation.

These conclusions are not exhaustive, nor must they be set in stone. Space is a novel environment in the history of humanity, and our conclusions must change as necessary along with new scientific understanding, technological developments, or phenomena in international relations.

The relative novelty of space means we still have limited understanding about its economic, social, and military potential. We cannot predict what new commercial applications may emerge from the orbits, or what the grammar of space warfare will be like. There are no history books to provide us direct precedents, and there is little institutional experience that can be passed on.

Novel environments can lead to both dangerously optimistic thinking and dire pessimism. One need only look back to the early days of airpower and the near-magical thinking about what aircraft could achieve in war.[94] The realities of geopolitics and strategy in space are likely to be complicated, combining the familiar with the new. India's policymakers must always keep in mind that Earthly concerns must drive decisions in space, that strategy is difficult in any environment, and that fog of war hangs as thickly in the vacuum of space as it does on Earth.

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