AIR POWER

Journal of Air Power and Space Studies

Vol. 17 No. 2 • Summer 2022
(April-June)

Contributors

Air Marshal Daljit Singh • Air Marshal Diptendu Choudhury
• Dr Joshy M Paul • Group Captain TH Anand Rao
• Mr Abhishek Saxena • Air Marshal Sukhchain Singh

CENTRE FOR AIR POWER STUDIES, NEW DELHI

THE CHANGING SPACE ENVIRONMENT

TH ANAND RAO

The space environment has undergone dramatic changes in the past two decades of space exploitation. The outer space domain is no longer a domain accessible to a few space-faring nations. Today, more than 83 nations have access to space or space services. The limits of human activity in space have expanded at both ends of the outer space domain. From the extreme ranges of Earth orbit, human activity has gone beyond the Earth orbit towards exploration of celestial objects like the Moon, Mars and deep space exploration. At the closer orbital ranges, satellites are being positioned for Very Low Earth Orbits (VLEOs) and pseudo satellites are being used for exploiting near space. This expanding space domain has not only diminished the demarcation between air space and outer space but has also removed the distinction between outer space and deep space. However, the utility of space for humankind and all activities benefitting civil or military users remains in the Earth orbit.

The limits to the extent of space and Earth orbit, though a physically defined entity, has many variations and interpretations. The genesis of these varying interpretations is the absence of any legally backed and internationally accepted definition of where space begins. The Outer Space Treaty (OST) of 1967 has been found deficient in defining many such terminologies. There

Group Captain **TH Anand Rao** is Senior Fellow at the Centre for Air Power Studies, New Delhi.

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are also no laws which regulate human activity beyond the Earth orbit into deep space, barring the Moon Treaty of 1979 which in itself is ambiguous and ratified by only a handful of countries. The resulting situation is the overlap between air space and outer space, leading to a clash of interests in sovereignty on the fringes of air space and space.

WHERE DOES SPACE BEGIN?

Since the beginning of space is not defined in any legally verifiable document, different countries and space agencies use different distances from the Earth's surface as the beginning of space. The US military, Federal Aviation Administration (FAA) and National Aeronautical Space Administration (NASA) have all set the boundary of space at 50 miles (80 km) above the Earth's surface. The Fédération Aéronautique Internationale (FAI), an international record-keeping body for aeronautics, defines the Kármán Line as the space boundary, at an altitude of 62 miles (100 km). Despite these numerical differences which are based on convenience, space would be deemed to exist above an altitude where flight can no longer be sustained and near zero gravity exists. This would include the 'near space' region which is closer to the Earth and extends from 20 km to around 80-100 km above the Earth's surface. Anything beyond this will be outer space.

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DELIMITATION OF OUTER SPACE

The absence of clear lines of demarcation among air space, near space and outer space has allowed states to exploit the ambiguity in sovereignty with impunity. Specifically, the space surveillance applications of satellites have proved to be a boon for their military value. Both the US and Russia took to space in the Cold War years to gather intelligence on each other's nuclear and ballistic missile facilities without violating the sovereignty of their air spaces and risking the loss of reconnaissance aircraft. In 1960, an American U2 spy plane was shot down over Russian territory. Later, in 1962, another U2 was shot down over Cuba. The risk to high altitude reconnaissance aircraft was reason enough for the US to explore satellite-based reconnaissance platforms.

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Today, the ambiguity between air space and outer space is even more predominant with pseudo-satellites and high altitude drones operating in the near space region which could be in an air space, yet would not be violating the sovereignty of the adversary's air space. It could be operating in the region of ambiguity—near space. Suborbital rockets, trans-atmospheric rockets and orbital rockets all transit through near space which adds to the confusion. Furthermore, it is in the near space that critical phases of space flight like reentry take place, which may cause fragmentation or explosion during uncontrolled reentry. Commercial as well as military interests have begun to develop for space systems which can operate in near space. Such space systems-suborbital vehicles, stratospheric balloons, pseudo-satellites and high-altitude drones fly with durations ranging from a few hours to several days or more. Most of these space systems do not follow either the air space regulations or the existing space laws, and pose a potential threat to air traffic.

HIGH GROUND TO WAR-FIGHTING DOMAIN

The emergence of the traditional "high ground" as a means to observe the enemy was recognised centuries ago. The high ground transitioned into

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observations made from the medium of the air through hot air balloons used by the French in the battle of Fleurus in 1794 and from aeroplanes in the World War years, to eventually reconnaissance using satellites from outer space since 1957. While reconnaissance and communication were the primary objectives of military space utilisation during the post-World War years, the other end of the spectrum of space utilisation was offensive and started with ballistic missiles transiting through the medium of space. The V-2 achieved the distinction of becoming the world's first ballistic missile reaching an altitude of 60 miles in its ballistic flight. This feat marked mankind's first step into the space age.[1] The Cold War years comprised a period of Intercontinental Ballistic Missiles (ICBM) with long ranges. The destructive potential of ballistic missiles was countered with Anti-Ballistic Missile (ABM) weapons or Ballistic Missile Defence (BMD). This BMD concept was such that the same weapons could be used as Anti-Satellite (ASAT) weapons with minor modifications. The first kinetic ASAT weapon was tested in 1959 (Bold Orion) by the USA. The period from the 1960s to the 1980s saw many ASAT tests being conducted by the USA and USSR. The debris issue was a concern even in those days. The USSR was the pioneer in co-orbital ASAT development and had operational co-orbital capability in the 1970s. China entered the ASAT arena in 2005 with its first ASAT test. Its destructive ASAT test of 2007, which blew up its own satellite at 860 km, attracted global condemnation due to the largest debris cloud created in outer space. Since then, the focus of the US, Russia and China has shifted to other forms of non-kinetic counter-space technologies like proximity operations, electronic interference, Directed Energy Weapons

1. Rajat Jairath, *Quest for Space: The Indian Context* (New Delhi: KW Publishers, 2014), p. 40.

(DEWs) and cyber attacks on space systems. However, testing of kinetic ASATs didn't cease by any of these space powers.

Today, the strategic situation in space is changing at a faster pace than ever before. Outer space—regarded as a global commons, and meant for peaceful use for the benefit of mankind—is witnessing a shift towards offensive use of space for military advantage. This is in the backdrop of the many technological advances in space in the past two decades which have increased military dependency on space services. From remote sensing, reconversion and communication satellites to global positioning systems, space has transformed human life and the military in the 21st century. Space security is, therefore, a fundamental national security interest. Potential adversaries understand the high degree to which space systems enhance conventional war-fighting capabilities, and a growing number of nations are acquiring the ability to destroy or degrade these systems. Strategic ambitions and a craving to dominate the 'high ground' have opened a new front for the military. The dependence on space for our routine functioning and for military advantage has grown to such an extent that there is now a dependency which has exposed vulnerabilities in space systems. These vulnerabilities are the precise target for counter-space technologies and weapons. These counter-space technologies and ASAT weapons have developed high precision capabilities over the years and can be used in such a manner that outer space becomes a battlefield. More recently, in 2019, the North Atlantic Treaty Organisation (NATO) allies declared space as an operational domain amid growing threats from Chinese and Russian counter-space developments. This implies invoking Article 5 of the North Atlantic Treaty for a collective response to counter any attack on space assets. A year prior, the US president had declared outer space as a "war-fighting domain", much to the anguish of the global space community.[2]

2. Hitoshi Nasu, "NATO Recognizes Space as an 'Operational Domain': One Small Step Toward a Rules-Based International Order in Outer Space", March 4, 2020. https://www.justsecurity.org. Accessed on January 9, 2022.

The advantages of aerial reconnaissance without infringing on the sovereignty of the adversary's air space was a lucrative option for the Americans as well as the Soviets. Satellites were used extensively for military communication and reconnaissance before the other space services and commercial applications caught up.

EXPLOITATION OF EARTH ORBIT

Outer space began to be used as a military enabler during the Cold War years. The advantages of aerial reconnaissance without infringing on the sovereignty of the adversary's air space was a lucrative option for the Americans as well as the Soviets. Satellites were used extensively for military communication and reconnaissance before the other space services and commercial applications caught up. Even though the world's first artificial satellite, the Sputnik, was launched in 1957, the world's first commercial communications satellite, Intelsat-1, or Early Bird, was launched only on April 6, 1965.[3] The focus on satellites for power projection and technological one-upmanship began to give way to putting humans in space in the 1960s as both superpowers of the Cold War era—the US and USSR—sent humans into space in 1961. Later in the decade, however, both countries nurtured divergent views on the exploitation of outer space. While the US was successful in sending humans to the Moon and created the space shuttle, the Soviet Union constructed the world's first space station, Salyut-1, which was launched in 1971. Later, other stations followed such as the American Skylab and the Soviet Union's Mir. Soon, many countries joined the space club by launching their own satellites as the benefits rippled through society. The space applications and services which were then mainly for communication and reconnaissance expanded vastly into remote sensing, navigation, internet services, weather, television broadcasts, etc.

Miniaturisation of computers and other hardware, as well as new generation software have made it possible to send up much smaller satellites

3. Intelsat-1 at https://www.britannica.com/topic/Intelsat-I. Accessed on November 15, 2021.

that can provide all the services that larger satellites could. Smaller satellites also meant more satellites per launch which enabled a new era of mega constellations. These mega constellations could have hundreds of satellites in each orbit and are set to dominate the Low Earth Orbit (LEO) region. These along with the growing debris count and increasing traffic in the near space region are a growing cause of worry for the stability and sustainability of the space environment.

Space activities have reached a defining moment, with a dramatic increase in the numbers of satellites launched, the remarkable role of new technologies and the appearance of space entrepreneurs in large numbers.

Space, as we know it, is changing. Space activities have reached a defining moment, with a dramatic increase in the numbers of satellites launched, the remarkable role of new technologies and the appearance of space entrepreneurs in large numbers. The overcrowding of the Earth orbit is calling for new regulations and management techniques for space activities.

GLOBALISATION OF SPACE

The phrase "globalisation of space" was coined in the 1990s in California, USA, in lectures and presentations by Marilyn Dudley-Flores in a sociological context.[4] Now, the term "globalisation of space" is referenced by a host of organisations connected to the aerospace community. Globalisation is essentially the growing interconnectedness of all people and their societies on a worldwide scale. In reference to space, globalisation is a phenomenon which has been seen in the past two decades. It involves accessibility to space by an increasing number of nations leading to a democratisation of space. It has also been fuelled by the entry of private entities into the space sector for not only research and development, but also for making profits. This has

4. Marilyn Dudley-Flores* and Thomas Gangale, "The Globalization of Space: The Astrosociological Approach", SPACE 2007 Conference & Exposition, September 18-20, 2007. https://www.researchgate.net/publication/269160949_Globalization_of_Space_-_The_Astrosociological_Approach. Accessed on October 1, 2021.

Today, there are more than 83 countries which have access to space or space services. This has been made possible by the lowering of the financial cost of access to space and access to space technology.

also been termed as space 2.0 by the growing space industry, which rests on manufacturing of satellites and launch vehicles and the bigger space applications market. Globalisation has brought space access, which was once the preserve for the developed countries, to many more states across the world. Today, there are more than 83 countries which have access to space or space services. This has been made possible by the lowering of the financial cost of access to space and access to space technology which is, in turn, an offset of the revolution in the Information Technology (IT) software domain and miniaturisation of hardware as well as the growing dependence on space services for civilian applications as well as for the military.

SPACE ECONOMY AND SATELLITE POPULATION

The growth of industry and commerce in the space sector is an important indicator of the growing demand for space services. Utilisation of space services has seen steady growth across the world for various applications like communication, Direct to Home (DTH) television, navigation, banking, weather prediction, remote sensing, and many more. The requirement of satellites to support these ever-increasing space services has grown manifold over the years: 12,480 satellites have been launched since 1957, of which 7,840 satellites are still in orbit, while about 4,900 are operational satellites.[5] Between 2010 and 2020, the number of operational satellites orbiting the Earth jumped from 958 to 3,371, an increase by three and a half times. The current decade will see a much larger increase. By 2030, it is estimated that the satellite population will reach 100,000.

The global space economy thrives on the satellite industry, space application services industry and launch vehicle industry. The $400 billion

5. "Space Debris by the Numbers", January 4, 2022. https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers. Accessed on January 5, 2022.

space industry by annual revenue is set to become a trillion-dollar industry by 2040.[6] This growth will be fuelled by the mega constellation revolution as well as the entry of private players in the 'new space' revolution. The term 'new space' represents the decentralisation and liberalisation of the space sector. This has led to the evolution of a new generation of companies, including start-ups, besides the well-established larger players like Boeing, Raytheon, Northrop Grumman, etc. The insurance sector has also benefitted as a spin-off by insuring satellites and services, especially for the upcoming private entities. Commercial space transportation has also seen a big boom with private players like SpaceX capturing a large market share. Profitability in the space sector is set to boom and the rush to gain a significant market share is on. Major developments in commercialisation of the space sector are being seen in LEO. The net result is crowding of the LEO region and a competition to gain access to the useful orbital slots and frequency spectrum. Today, there are around 10,000 space tech companies globally. India has 368 space firms, most of which are start-up companies dealing with space application services, space ancillaries, satellite fabrication and small satellite launch vehicles, which is already more than China, Russia and Japan, putting India in the fifth place globally—after the US, UK, Canada and Germany—in commercialisation of space. India's share in the global space economy, though, is 3 per cent which is set to grow to 10 per cent in the next few years.[7]

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6. Irene Klotz, "Burgeoning Satellite Industry Paving Way To $1 Trillion Space Economy", August 24, 2021. https://aviationweek.com/aerospace/program-management/burgeoning-satellite-industry-paving-way-1-trillion-space-economy.
7. Chetan Kumar, "With Over 350 Private Space Companies, India in Fifth Place", June 3, 2021. http://timesofindia.indiatimes.com/articleshow/83186207.cms. Accessed on November 29, 2021.

The advantage GEO has is a constant visibility at the ground stations, large area of coverage and relative safety from conventional kinetic ASAT weapons.

Notwithstanding the Outer Space Treaty (OST) of 1967, which strikes a middle ground on the development and use of resources in space which are to be treated with a 'global commons' approach, the US has upset the status quo in the regulatory framework by facilitating the growth of asteroid mining activities by passing the Commercial Space Launch Competitiveness Act in 2015. This is a US legislation that grants property rights to the resources extracted from a planetary body (though not to the body itself) to whoever gets access first.[8] Development of asteroid mining technology is progressing at a rapid pace with the successful sample return of Japan's Hayabusa-2 in 2020 and the ongoing American OSIRIS-Rex mission.[9] Such exploitation of space resources will eventually extend to the Moon's surface and to other planetary objects. The disparities in space exploration and exploitation of resources are likely to widen further across nations in the times to come.

THE COMSAT REVOLUTION

Communications Satellites (CoMSATs) traditionally relate to the Geostationary Earth Orbit (GEO) where they have been orbiting for decades. The advantage GEO has is a constant visibility at the ground stations, large area of coverage and relative safety from conventional kinetic ASAT weapons. These satellites are also made heavier to carry larger antennae, have higher power requirements and carry more fuel, giving them a longer life as compared to the LEO satellites. GEO satellites are expensive to manufacture and launch but have a life of around 15 years. The trend in the recent years has seen a shift towards COMSATs being put in LEO. The

8. Weinzierl, Matthew, "Space, the Final Economic Frontier." *The Journal of Economic Perspectives*, vol. 32, no. 2, American Economic Association, 2018, pp. 173–92. http://www.jstor.org/stable/26409430.
9. Elizabeth Howell and Meghan Bartels, "The Greatest Asteroid Missions of all Time!". https://www.space.com/41052-best-asteroid-encounters-ever.html. Accessed on November 29, 2021.

orbital dynamics in LEO necessitates multiple satellites in the same orbit spaced out in time to achieve uninterrupted signal relay. This concept has caught the fancy of many private companies which have planned large constellations of satellites in the LEO region mainly for global high-speed internet. SpaceX and One Web have already launched a sizeable number of satellites in the 500-1,200 km range of orbits. Many more satellites are to follow from these companies and many more companies are entering the fray, not just for internet services but for other applications too like Earth Observation (EO), Internet of Things (IoT) and other data services. A tabular depiction of the proposed and approved satellite constellations is given below:

Table 1: Planned Communications Satellite Constellations[10]

FCC Approved/Application in Process Constellations		
Constellation	**Company**	**No. of Satellites**
Guowang	China Satellite Network Group	12,992
Starlink	SpaceX	11,943
Project Kuiper	Amazon	3,236
OneWeb	OneWeb	648
Lightspeed	Telesat	298
Spire Global	Spire Global	175
Boeing	Boeing	147
	Total	**29,439**
Future Expansion / Proposed Constellations		
Starlink	SpaceX	30,000
Astra Constellation	Astra Space	13,620
OneWeb	OneWeb	6,372
Boeing	Boeing	5,670
Project Kuiper	Amazon	4,538
Hughes Network	Hughes Network Systems	1,440

10. Douglas Messier, "Planned Comsat Constellations Now Exceed 94,000 Satellites", November 8, 2021. http://www.parabolicarc.com/2021/11/08/planned-comsat-constellations-now-exceed-94000-satellites/. Accessed on November 12, 2021.

Lightspeed	Telesat	1,373
SpinLaunch	SpinLaunch	1,190
Intelsat	Intelsat	216
Kuiper Systems	Kuiper Systems	199
Inmarsat	Inmarsat	198
	Future Planned	**64,816**
	FCC Approved	**29,439**
	Total	**94,255**

The figures do not include constellations operated or planned outside the US, for EU, the IoT, or other purposes.

Geostationary Orbits (GEOs) which were once the preferred orbital slots will soon have a limited utility. The concept of LEO constellations for internet and data services has already caught public attention. LEO constellations can also be extended to communication services, with sufficient satellites in orbit. LEO is being seen as the future of communication networks. Eventually, in the foreseeable future, GEOs will empty out, and LEOs will be overpopulated. The growth of LEO traffic will be akin to a web of satellites around the Earth which will become a barrier to onward space traffic.

SPACE TOURISM

Space tourism is no longer just leisure travel, but is now being associated with a combination of adventure sport and an experience of weightlessness at the edge of space. It is now an extension of the aviation industry but is very rapidly integrating with space exploration. Space tourism is an activity that gives humans the opportunity to have an experience like astronauts and travel in space for recreational, leisure, or business purposes, albeit at a very exorbitant price. Space tourism can be classified into broadly four types viz., high altitude flights, zero gravity flights, short duration suborbital flights, and longer duration orbital trips into space. Presently, only the first two categories have been explored in the flights of the 'Virgin Galactic' and 'Blue Origin'. Both these pioneering space tourism ventures reached altitudes of 86 km and 100 km respectively for a few minutes.

Sub-orbital flights will follow soon. Trips to the Moon and, eventually, to Mars, will take some time. While these developments do seem fascinating and the space tourism industry will eventually flourish as prices decrease over the years, the concern here is the additional unregulated traffic that is being added to an already crowded LEO.

Rendezvous and Proximity Operations (RPOs) were being tested since 2005. This is a primary capability required for automated docking of capsules to a space ship.

GAME CHANGER SPACE TECHNOLOGIES

Space technologies of the 21st century, aided by miniaturisation and enabled by a software revolution have facilitated the accessibility to space, thus, fuelling the rapid growth of space objects in the Earth's orbit. These technological developments, being of dual use, will also find their way for military utility and, thus, the fears of vitiating the space environment would always remain. Despite the deep military underpinnings of many of these space technologies, the reduction in costs for space companies has meant more commercialisation of space and a potentially booming space economy. Some major game changer technologies are given in the subsequent paragraphs.

Rendezvous and Proximity Operations

Rendezvous and Proximity Operations (RPOs) were being tested since 2005 by the US under the Demonstration of Automated Rendezvous Technologies (DART) project[11]. This is a primary capability required for automated docking of capsules to a space ship. Besides docking with space ships, the RPO has multiple utility. This one single game changer capability has enabled multiple options for civil and military satellite operators. RPO has been used for satellite-on-satellite approaches by Russia and China for unknown reasons.

11. DART, Gunters Space Page. https://space.skyrocket.de/doc_sdat/dart.htm. Accessed on December 25, 2021.

The US too has exercised this activity with its own satellites. The known purposes are for repair and servicing, refuelling of satellites and for satellite inspection. RPO, being a dual use phenomenon, the unknown activity could be for military purposes which varies from a fly-by inspection to electronic jamming, lasing or even causing physical damage. This capability is also being planned for experiments to attach with dead satellites and bring them closer to the Earth's atmosphere for a burn up.

Satellite Servicing

RPO is also the primary capability required for satellite repair and servicing. This will include robotic repairs, replacement of solar panels and even refuelling of the target satellite. These activities—especially refuelling—give a fresh lease of life to the satellite and can increase the satellite's life much beyond the design life of 7-8 years in LEO. Satellite servicing is set to change the economics of the space industry, the mantra being "*Reduce, Reuse, Recycle, Repair, Refuel in space*!"

Reusability

Reuse of space rockets has been the major factor in bringing down launch costs. From being able to reuse the first stage rocket engine, successfully being done by SpaceX for the Falcon 9 boosters, we are now on the verge of fully reusable rockets under trial. SpaceX's 'Big Falcon' rocket and Blue Origin's 'New Shepard' rocket are set to be the first fully reusable rockets. The small rocket manufacturer 'Rocket Labs' is promising a game changer rocket called the 'Neutron' which will have full reusability and is expected to have a first launch in 2024.[12]

Space-Lift

Space transportation is being envisioned in a novel concept which would entail passengers and logistics being space-lifted—not only to planetary

12. Loren Grush, "Rocket Lab Unveils Details of New Reusable Neutron Launcher", December 2, 2021. https://www.theverge.com/2021/12/2/22813819/rocket-lab-neutron-launch-satellite-reusable-mega-constellations. Accessed on December 24, 2021.

destinations like the Moon and Mars—but from one place to another on the Earth. This will be made possible with fully reusable rockets like the Neutron becoming a reality. Space-lift is akin to air-lift, the difference being in the mode of transport. A rocket with load and passenger carrying capacity could be launched, orbited, and made to land at a destination across the globe in a matter of a few minutes. Space-lift could be particularly useful for strategic transportation of military equipment and personnel.

Launching satellites on demand or responsive launch is a critical capability for enhanced national security requirements. This capability basically involves the ability to launch satellites at short notice or within a quick turnaround time.

Responsive Launch Options

Launching satellites on demand or responsive launch is a critical capability for enhanced national security requirements. This capability basically involves the ability to launch satellites at short notice or within a quick turnaround time. Such quick launches are used for tactical military reconnaissance, replacing lost satellites or even restoration of services caused by unserviceable satellite payloads. The responsive launch can happen from conventional land-based launch facilities, ship-based launch facilities or air-launched from a mother aircraft releasing a rocket at high altitude. The 'Virgin Orbit' of the USA has demonstrated this capability with the 'Launcher One' rocket released from a modified Boeing-747 at 35,000-40,000 ft altitude, and the facility has been operational since January 2021[13]. A more recent development in responsive launch capability is the concept of rockets orbiting in space for a payload release on requirement. The trend, therefore, is moving towards reduction in timeframes between launch preparation to 'on orbit'. While this is a positive development for the space industry and military space

13. Robert Cardillo, "A Responsive Launch Capability will Deter Enemies, Boost National Security", September 3, 2021. https://www.defensenews.com/opinion/commentary/2021/09/03/a-responsive-launch-capability-will-deter-enemies-boost-national-security/. Accessed on January 4, 2022.

strategists, it is a nightmare for the ever-increasing burden on air space and orbital space, as the current air and space traffic regulating environment and surveillance technologies are not conducive to such short notice space launches. Unless there is a coordination at a global level for managing space-bound traffic, with corresponding tracking sensors, responsive launch will be a safety hazard with the present rate of growth in the satellite population.

Innovative technologies have assisted in bringing down launch costs to affordable levels. Additive manufacturing is one such practice which has converted large multi-piece assemblies into a single part, leading to a reduction in volume, weight, cost, and lead time.

Cost Reduction

A major driver for the growth of commercial space exploration is the cost factor. Innovative technologies have assisted in bringing down launch costs to affordable levels. Additive manufacturing is one such practice which has converted large multi-piece assemblies into a single part, leading to a reduction in volume, weight, cost, and lead time. Similarly, use of simulation systems has reduced the development time by several months. Software has been used to study the 3D flow of the rocket engine exhaust plume which has enabled reduction of exhaust temperatures by an order of magnitude.

REVOLUTION IN MILITARY AFFAIRS IN SPACE

The Revolution in Military Affairs (RMA) in space has been made possible by the evolution in technology which has made space applications the backbone of modern military strategy. The use of the space domain for the military has expanded into multiple disciplines like space surveillance, signal intelligence, strategic communications and data links, tracking and data relay, navigation and precision strike, weather prediction, missile launch warning, etc., each of which has developed into a specialised military activity, with the availability of precise spaceborne sensors. Technology has also extended the war-fighting options into the space domain with the development of various counter-space weapons options. Space weapons and space-based Ballistic Missile Defence (BMD) are set to alter the spacescape altogether, necessitating a much higher degree of the space surveillance regime.

Space weapons would comprise not only weapons launched from the Earth but also weapons hosted in space and weapons that transit through space.

SPACE WEAPONS

The ambiguities generated by Article IV of the Outer Space Treaty (OST) and its inadequacy in dealing with rapid proliferation of ASAT technologies created a situation wherein space weapons have become the predominant threat to security and sustainability in space. Though there have not been any confrontations in space in which space weapons have been used, there have been kinetic ASAT tests, many of which have resulted in generation of space debris. Space weapons would comprise not only weapons launched from the Earth but also weapons hosted in space and weapons that transit through space. The former variety of weapons launched from the Earth are a reality. Now, we are increasingly seeing a shift towards hosting weapons in space under the garb of the dual use conundrum. These are in the form of lasers and electronic jamming equipment that could be hosted on satellites. These soft kill counter-space technologies may not destroy a satellite by fragmentation, but can make it dysfunctional, causing it to become unresponsive and move out of its orbital slot. This, in turn, will become debris in space and a potential hazard for other space traffic. Weapons transiting through space are presently of the ballistic missile variety or even hypersonic missiles. These are objects entering space without any notification and a serious threat to orbital assets in both VLEO and LEO. Additionally, BMD engagements which occur in the mid-course phase would hamper the safety of spacecraft besides increasing the debris in the region.

As for the testing of kinetic ASAT weapons, there was an initial boom in the Cold War era, followed by a lull between 1995 and 2005. China's arrival as an ASAT weapon state in 2005 changed the scenario and there now seems to be a resurgence in kinetic ASAT tests. The pointers are towards a renewed space race for gaining an edge in the quest to dominate the space domain.

SPACE-BASED BMD

The space layer for missile defence and space-based weapons were first envisioned in the Star Wars Project of 1983 of former US President Ronald Reagan. Extensive research in this direction is said to have been done, however, these weapons remained far from reality, but the research done in the Star Wars project doesn't seem to be futile. Ballistic missile defence as it exists today has many deficiencies. The missile technologies being developed by Russia and China are designed to circumvent the missile defences and, thus, are becoming more unpredictable. On October 17, 2021, the *Financial Times* had reported that China had tested a nuclear-capable hypersonic missile that circled the globe before heading towards its target, demonstrating an advanced capability that surprised the US intelligence. Though not much evidence is available, a Chinese Foreign Ministry press briefing on October 18, 2021, clarified that it was a test of a reusable space vehicle. This gave rise to speculations of China possessing the capability to release a Hypersonic Glide Vehicle (HGV) from a missile that could travel around the globe, much like the Fractional Orbital Bombardment Systems (FOBS) of the erstwhile USSR in the 1960s. Russia, on the other hand, already has hypersonic weapons called the 'Kinzhal' that it claims can reach a speed of Mach 10, and the 'Avangard' that can go up to Mach 27 using rocket boosters. In December 2019, Russia's Defence Ministry announced that a nuclear-armed HGV had been inducted into combat duty, making Russia the first country armed with hypersonic weapons.[14]

14. Sujay Bhattacharyya, "Hypersonic Hyperdrive: China and Russia Ahead of US in Next-Generation Weapons Race". web article in Indiatoday.in, October 21, 2021. https://www.indiatoday.in/world/story/rocket-boosted-hypersonic-glide-vehicle-uk-russia-china-1867271-2021-10-21. Accessed on December 18, 2021.

The US has recognised the vulnerabilities of its existing missile defences like the Aegis BMD, Terminal High Altitude Area Defence (THAAD) and Patriot Advanced Capability (PAC-3). It has a system for missile launch detection on space-based sensors, called the Space-Based Infra-Red System (SBIRS), which has been operational since 2001.[15] However, there are gaps in detection, which can be exploited. The development of HGVs and warheads with Multiple Independently Targetable Reentry Vehicles (MIRVs) and Manoeuvrable Reentry Vehicles (MARVs) necessitates a space layer for detection in missile defence. Over the past few years, the US has focussed its Research and Development (R&D) on space-based missile defences. The effort may see a new generation of missile detection satellites in space, called the Overhead Persistent Infra-Red (OPIR) which could be launched in 2025[16] as a replacement for the SBIRS.

Missile defence technologies are also moving towards an intercept layer in space. Space-based missile defences involving kinetic interceptors or non-kinetic technologies, such as Directed Energy Weapons (DEWs) are capable of addressing some of the deficiencies of terrestrial missile defence systems, particularly the HGVs. Space-based defences are capable of engaging a missile in its boost phase as well as during the mid-course phase. In particular, DEWs offer the potential to engage large numbers of incoming warheads (and decoys).

Space-based missile defence will see a renewed thrust towards ASAT weapons to counter these systems. These missile defences could be the pre-emptive strike targets in any future war; the aim being to get the missiles through to their terrestrial targets.

The larger fear is the increase in the orbital population hosting missile defence payloads in LEO. To engage ballistic missiles during their boost phase, a missile defence system in space would need to be designed such

15. Web article on '*SBIRS*', https://www.airforce-technology.com/projects/space-based-infrared-system-sbirs/. Accessed on December 18, 2021.
16. Theresa Hitchens, "Next-Gen OPIR Missile Warning on Schedule for 2025 Launch". web article on August 25, 2021. https://breakingdefense.com/2021/08/next-gen-opir-missile-warning-on-schedule-for-2025-launch/. Accessed on December 18, 2021.

The proliferation of missile defences into the realm of space and the possibility of creating debris due to an interception will pose an additional risk for air and space traffic in the coming years.

that interceptors were always located relatively close to all potential missile launch sites. Satellites, being in constant motion relative to the Earth's surface, hundreds of satellite platforms would be needed to cover potential launch sites.

The proliferation of missile defences into the realm of space and the possibility of creating debris due to an interception will pose an additional risk for air and space traffic in the coming years. This situation must be prevented by a freeze on the offence-defence spiral through a bilateral/multilateral treaty forbidding placement of any weapons in space.

EFFECTS OF GLOBALISATION AND THE RISKS OF ORBITAL CROWDING

Earth orbits will continue to be used for orbiting satellites for generations, till such time alternatives are developed. The growing density of objects in LEO, coupled with the presence of debris poses the hazard of collisions. While rare, collisions do happen, and the frequency of such collisions is set to increase. In February 2009, a Russian military satellite, the Kosmos-2251, collided with the American Iridium 33 communications satellite. This was a major debris creating event. Ever since, there has been an increased vigil and many near misses have been reported. In 2020, a Soviet navigation satellite—the Parus—narrowly missed a Chinese rocket booster launched in 2009. In April 2021, a defunct US meteorological satellite and a rocket body launched in 1971 by the former Soviet Union came within 21 metres (m) of each other, narrowly avoiding a major collision. Even though the 'Starlink' and 'OneWeb' constellations in LEO are a more recent phenomenon, there have already been instances of collision avoidance manoeuvres due to these small satellite constellations. In 2019, the European Space Agency's (ESA's) Aeolus satellite raised its orbit in order to pass safely over the Starlink 44. This was the first reported collision avoidance related to the Starlink mega constellation. The International Space Station too has made collision avoidance manoeuvres on several occasions.[17] While these are examples of near misses, there are at least five recorded accidental collisions between objects in space.[18] With the increasing number of players in space and the rapid growth of satellites and debris population creating potential collision hazards, there is a need to change the manner in which traffic in space is managed. Some options that emerge and need further deliberation are listed below:

With the increasing number of players in space and the rapid growth of satellites and debris population creating potential collision hazards, there is a need to change the manner in which traffic in space is managed.

(a) Saturation of orbital capacity could be prevented by limiting the numbers of satellites that could be placed in orbit. This would certainly have repercussions for states and companies which are yet to explore the opportunity.
(b) Tracking potential collisions, notifying concerned parties and coordinating their response is still an archaic process and needs to evolve. As the traffic in space increases, automation of tracking and collision avoidance manoeuvres seem to be the only way ahead.
(c) The inadequacy of regulations governing launch and operation of orbital platforms needs urgent redressal. This involves revamping the organisational deficiencies for enforcement of regulations.
(d) Space situational awareness and space traffic management have to evolve as a joint effort without stakes, and implemented on a global scale. This will necessarily involve sharing of inputs from tracking sensors without censorship.

17. Dan Swinhoe, “Satellite Boom Demands Better Space Traffic Management”, July 2, 2021. https://www.datacenterdynamics.com/en/analysis/satellite-boom-demands-better-space-traffic-management/. Accessed on January 8, 2021.
18 “Accidental Collision of YunHai 1-02”, *Orbital Debris, Quarterly News*, vol 25, issue 4, December 2021. e-bulletin of NASA. https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv25i4.pdf. Accessed on January 5, 2022.

THE DEBRIS ISSUE

Space debris colloquially called 'space junk' has for long been a matter of concern. The vastness of space had been a consolation for every piece of debris knowingly added, be it rocket bodies, dead satellites or even remnants of space experiments. The debris figures became a concern after the Chinese ASAT test of 2007 which created more than 3,000 pieces of trackable debris. Collisions in space and ASAT tests in later years by other countries added to this debris count. The numbers of debris objects as estimated by statistical models to be in orbit are given below (Table 2):[19]

Table 2

Objects greater than 10 cm	36,500 objects
Objects measuring from 1 cm to 10 cm	1,000,000 objects
Objects measuring from 1 mm to 1 cm	330 million objects
Debris objects regularly tracked by Space Surveillance Networks	30,610

Updated as on January 4, 2022

Space debris is caused due to multiple reasons, both natural as well as a result of human activity in space. The major contributors of space debris are the remnants of human space activity like dead satellites, spent rocket stages, fragmentation of objects and debris created by collisions and ASAT tests. Debris-on-debris collisions can have a cascading effect and result in an exponential increase in debris which is also known as the Kessler's Effect. Any deliberate creation of debris by the use of kinetic weapons in space like the ASAT tests done by China, Russia, the US and India will increase the probability of collisions further, triggering the Kessler's Effect in space and result in making space operations unsustainable in the future. There have been around 74 kinetic ASAT tests done till date at varying altitudes by the US, USSR and China. The Russian kinetic ASAT test on November 15, 2021, which generated around 1,500 pieces of debris, is said to have

19. n. 5.

increased the probability of collision by 5 percent based on mathematical modelling[20]. Debris created by kinetic ASAT tests is avoidable, and can be stopped by negotiating a test ban treaty, however, the mission related debris, defunct orbital payloads, fragmentation and collisions are uncontrollable, and technologies need to mature for preventing any long life debris from remaining in space. The debris retrieval technologies under development like the Active Debris Removal (ADR) missions, though challenging, are promising and need global support and funding to be successful.

The real concern of existing debris is its location and not the quantity. It is the LEO region where most of the satellites are concentrated, particularly the 600-1000 km height band. By virtue of this band having most of the useful orbits, there is bound to be orbital crowding. The debris concentration is also the highest in this region. Most orbital debris is found within 2,000 km of the Earth's surface. The greatest concentrations of debris are found near 750-800 km.[21] Future debris generation is also likely to increase the debris concentration in this band as more satellites get placed in this region. The mega constellations of SpaceX and One Web have chosen the 550 km and 1,200 km orbital heights respectively. All transits to the geostationary region and beyond the Earth orbit have to pass through this region, which bears a potential risk of collision. Moreover, debris is being created at a pace which is more than the debris elimination rate. Orbital decay of debris may take months to centuries depending on the orbital height. Space debris, being an irreversible phenomenan, congestion in this LEO region needs to be avoided.

LONG-TERM EFFECTS OF SPACE DEBRIS AND SATELLITE CROWDING

Our biggest fear will obviously be the loss of access to space though it may be decades away. Nevertheless, there are other consequences of cluttering

20. "Russian ASAT Test Debris Will Threaten Space Missions for Years, Say Scientists", November 18, 2021. https://science.thewire.in/spaceflight/russia-asat-test-debris-threaten-space-missions-years/. Accessed on November 21, 2021.
21. FAQ's published by Orbital Debris Program Office, Astromaterials Research & Exploration Science. https://orbitaldebris.jsc.nasa.gov/faq/. Accessed on January 8, 2022.

up space with satellites and debris. Some of these are described in the subsequent paragraphs.

Space Junk and Climate Change

The long-term effects of space debris are much worse than can be imagined. Besides the known fear of losing unrestricted access to space and the threat of collisions, the Kessler's syndrome has the potential of an exponential increase in debris to an extent that could obscure the skies, preventing adequate sunlight on vast portions of the Earth's surface. Also, the existing climate change phenomena could possibly add to this problem by lowering the density of the upper atmosphere. This will result in increasing the debris decay period and also altering the reentry dynamics of space objects. In a worst-case scenario, we may see partial burn-up during reentry causing space objects like debris to enter the atmosphere, posing a threat of collisions in the air as well as a risk to life in inhabited areas. Besides, a shrinking atmosphere will also keep the debris for a longer time in the closer reaches of LEO, thereby increasing the orbital decay time.[22]

Effects on Space Observations

Astronomical observations through telescopes form an integral part of the Space Situational Awareness (SSA) information gathering mechanism. The only limitation faced is by conventional telescopes where observations must be made in the night sky, as objects in space shine by reflecting light and can be clearly seen against the dark background of the night sky. Most telescopic observations are done at night. In the best stargazing conditions, the human eye can perceive about 3,000 twinkling stars overhead[23]. But

22. Jonathan O'Callaghan, "What if Space Junk and Climate Change Become the Same Problem?", *New York Times*, May 19, 2021. https://www.wionews.com/science/what-if-space-junk-and-climate-change-become-the-same-problem-386124. Accessed on November 1, 2021. Also see, Victor Tangermann, "Climate Change May Be Making Space Junk Worse", May 13, 2021. https://futurism.com/the-byte/climate-change-making-space-junk-worse. Accessed on January 11, 2022.
23. Joshua Sokol, "The Fault in Our Stars". https://www.science.org/content/article/satellite-swarms-are-threatening-night-sky-creating-new-zone-environmental-conflict. Accessed on November 10, 2021.

now, with thousands of small satellites finding their way into space, the night skies are witnessing an unnatural illumination by way of lighting up of the skies. This makes telescopic observations extremely difficult and will affect the way astronomy is done. By default, SSA observations through optical telescopes will also get affected.

CONCLUSION

Space activity is on an upswing. With countries and companies racing to put satellites in orbit and explore space for resources and habitation, the sector is likely to see massive changes in the coming years. Space activities are catching the headlines every week. Major events have unfolded—China has become the second nation to plant its flag on the Moon, the space company 'Blue Origin' plans to take the first woman to the Moon, Japan's Hayabusa-2 capsule has returned safely to the Earth with asteroid samples and SpaceX's Starlink constellation is set to cross a figure of 2,000 satellites in orbit. This buzz of space activity is unlikely to abate. Under such circumstances, the critical issue at hand is to resolve the problem of deconfliction of space traffic and prevent collisions in space. This issue needs to be addressed at a global level under the stewardship of a neutral organisation like the United Nations at topmost priority. The urgency stems from the fact that the active satellite count will touch a figure of 100,000 in the next decade and the debris count will continue to increase. Current levels of SSA are inadequate to manage the current space object population and Space Traffic Management does not exist for the emerging scenario. In this new space environment, routes frequented in space must be managed efficiently to avoid surprises, mistaken identity, and accidental collisions.