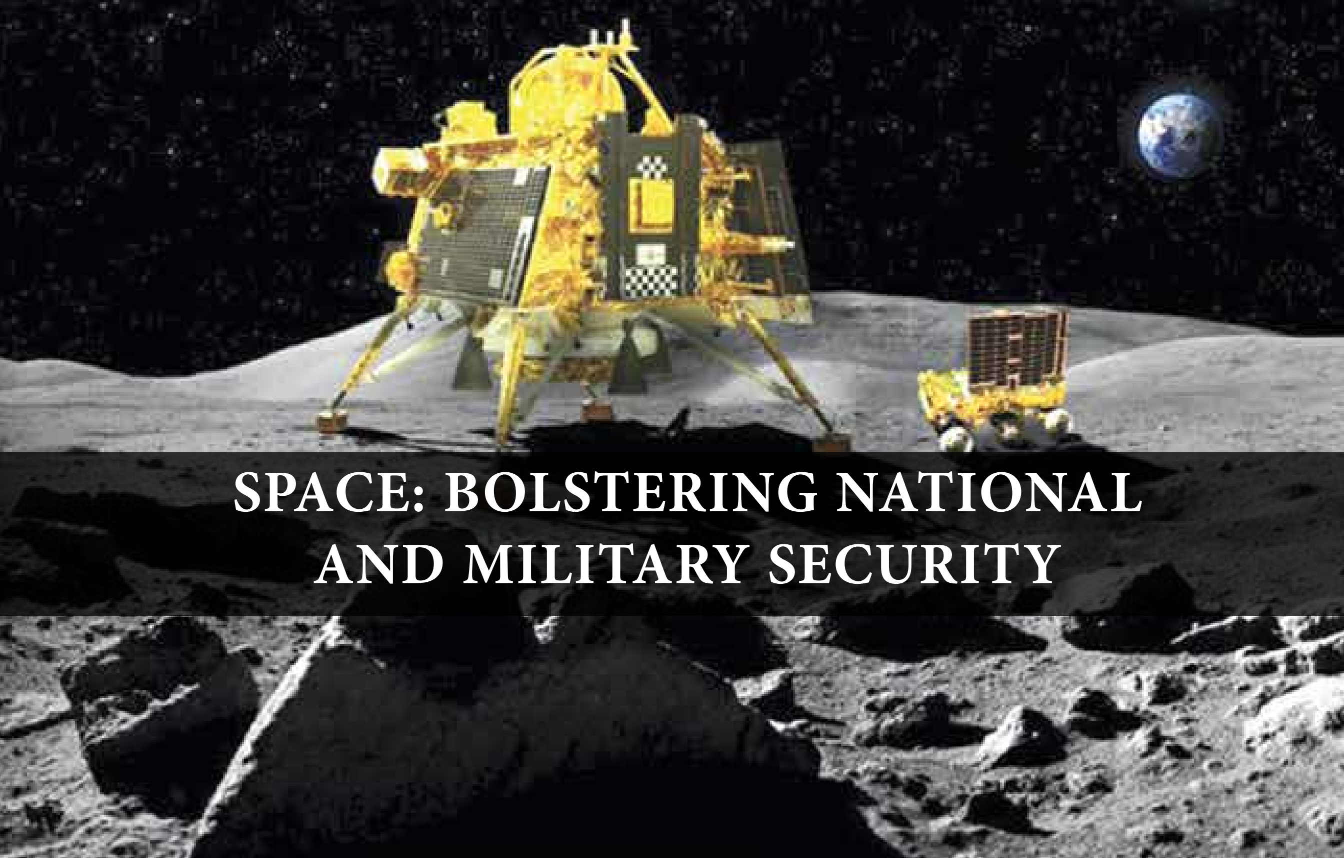
Volume 3 Issue 1 ISSN: 2583-536X February 2024

SYNERGY

CENTRE FOR
JOINT WARFARE
STUDIES
(CENJOWS)

Journal of the Centre for Joint Warfare Studies (CENJOWS)



SPACE: BOLSTERING NATIONAL AND MILITARY SECURITY

SYNERGY

JOURNAL OF THE
CENTRE FOR JOINT WARFARE STUDIES

Volume 3 Issue 1 ISSN : 2583-536X February 2024

CENJOWS
(Established : 2007)
Room No. 301, B-2 Wing, 3rd Floor
Pt Deendayal Antyodaya Bhawan
CGO Complex, Lodhi Road
New Delhi – 110003 (INDIA)
Telephone Nos : 011-24364881, 24366485
Fax : 011-24366484
Website : www.cenjows.in
E-mail : cenjows@cenjows.in, cenjows@yahoo.com

ABOUT US

CENJOWS was raised in 2007 as an independent think tank, registered under the Societies Registration Act, 1860. This aims to promote Jointness as a synergistic enabler for the growth of Comprehensive National Power and provide alternatives in all dimensions of its applications through focused research and debate.

Year of Publication	:	2024
Frequency	:	Bi-Annual
Language	:	English
Publisher	:	Maj Gen (Dr) Ashok Kumar, VSM (Retd) Director General, CENJOWS 301, B-2 Wing, 3rd Floor Pt. Deendayal Antyodaya Bhawan CGO Complex, Lodhi Road New Delhi-110003
RNI Number	:	DELENG/2022/82424
Editor	:	Maj Gen (Dr) Ashok Kumar, VSM (Retd) (dg@cenjows.in) 301, B-2 Wing, 3rd Floor Pt. Deendayal Antyodaya Bhawan CGO Complex, Lodhi Road New Delhi-110003

All correspondence may be addressed to:
Editor
Centre for Joint Warfare Studies (CENJOWS)
301, B-2 Wing, 3rd Floor
Pt Deendayal Antyodaya Bhawan
CGO Complex, Lodhi Road
New Delhi-110003
Telephone: (91-11) 24366485/Telefax: (91-11) 24366484
e-mail: cenjows@cenjows.in/cenjows@yahoo.com
Website: http://cenjows.in

Price : **Rs 750/- INR or US 25$**

RNI No: DELENG/2022/82424

Print ISSN : 2583-5378
Online ISSN : 2583-536X

SPACE: BOLSTERING NATIONAL AND MILITARY SECURITY

CONTENTS

Notes:

- Views expressed in articles are individual opinions of the writers, and not of CENJOWS.
- Contributors to Synergy Journal are requested to visit the website for the theme of the next issue and guidelines.

MESSAGE

1. In the past few decades, the Indian Space Sector has grown manifold. The successful landing of Chandrayaan-3 Lander (Vikram) and Rover Pragyan near the Southern Pole of the Moon on 23 August 2023 is a historical milestone for the Indian Space Sector. The recent selection of first four astronauts for India's human spaceflight programme Gaganyaan, scheduled for takeoff by the end of 2025, with fully indigenous technology stack for its space infrastructure, is expected to put India on the global map of human space-faring nations.

2. Space capabilities are inherently dual use and diverse requirements of the armed forces need to be factored in our space missions. India's Space Policy released in April 2023 provides adequate opportunities for utilization of space-based capabilities for our socio-economic development, protection of environment and lives, peaceful exploration of outer space, scientific quest, as well as national security and military needs.

3. In addition to the existing land, sea, air and cyber domains of warfare, space is rapidly developing as the foremost frontier in the emerging multi domain warfare. Space is pivotal to meet the military needs, in terms of communication, navigation, provisioning of intelligence, surveillance and reconnaissance, besides supporting the network centric warfare. As the growing space technology makes inroads into sectors such as aviation, marine applications, agriculture, energy, telecom etc, the expertise attained from these technological developments need to be optimally utilized and their military significance exploited.

4. The need for synergy and integration of various evolving technologies in national security issues related to space is critical and demand optimum collaboration and cooperation and calls for convergence in various domains, integrated approach, collaborative and international cooperation for our space missions. Space based cutting edge technologies need to provide us the opportunities to meet the challenges related to information, surveillance, information based warfare and other defence based capabilities. It provides unique opportunities to Indian private sector space start-ups to innovate, create new space technological thresholds and contribute to India's national security.

Contd 2/-

प्रमुख रक्षा अध्यक्ष

CHIEF OF DEFENCE STAFF

5. In future, the space is expected to become vital for strategic superiority. Therefore, the timely development and evolution of space defence capabilities and its integration in the national security apparatus is essential. Protection of our assets in space will be critical with increased activities of our adversaries in space.

6. I am sanguine that this issue of 'Synergy Journal' will trigger innovative ideas for bolstering India's national and military security through emerging space related issues.

Jai Hind !

(Anil Chauhan)
General
Chief of Defence Staff

Lt Gen Johnson P Mathew,
PVSM, UYSM, AVSM, VSM
Chief of Integrated Defence Staff to the
Chairman, Chiefs of Staff Committee
& Chairman CENJOWS

FOREWORD

Though the launch of rockets by ISRO began in the early 1960s, India ventured into space with the successful launch of Aryabhatta in 1975. The Indian space sector has witnessed remarkable growth over the past few decades, including impressive strides in space exploration, with the successfully launching Mangalyaan, Chandrayaan, Aditya-L1, and Gaganyaan (TV-D1) missions in recent times. India created history with the path breaking landing of the Chandrayaan-3 Lander (Vikram) and Rover (Pragyan) near the South Pole of the Moon on 23 August 2023. India's latest space policy has been formulated as an overarching, dynamic and composite framework to implement the space reform vision of the Government of India. The policy will develop space industry standards, promote identified space activities, and work with academia to widen the space ecosystem and enable industry-academia linkages.

The attacks by Hamas on Israel and other complex global security issues highlight the need for a strong C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance) network to serve as a backbone for real-time intelligence gathering and decision-making. Space-based assets have become indispensable instruments offering vital capabilities for safe military operations. India has taken major strides in space technology, with young private sector space operators emerging as new dynamic force eager to support the country's defense requirements.

Robots, artificial intelligence (AI), and autonomous weaponry are all anticipated in future warfare. The competition to rule space, however, is another important factor that has evolved. Combat systems on Earth can benefit from a number of features that satellites in orbit offer, including command and control, GPS guidance for soldiers and weapons, and observation of enemy movements. Their destruction or disablement may have multiple repercussions on the ground. With technology revolutionising combat and the geopolitical landscape always shifting, combining defence and space could bolster our nation's defences. Conflicts in the past and present have shown how crucial satellite imagery is in times of peace as well as in the gray area between war and peace. For the Indian Armed Forces, advanced satellite sensors, hyperspectral imaging, and satellite-based navigation are essential technologies.

India has not only become the most populous country, but also on the back of its rapidly growing economy and as the world's largest democracy it has strengthened its position in the global arena. There is a strong push for the country to strengthen its national and military security capabilities and for this the defence space is emerging as a critical domain and is likely to be a game changer. The two aspects in this domain would be defending space capabilities that will increasingly become vulnerable, and using space in situations of war.

India's space security endeavour, which is entwined with defense readiness, should be guided by a comprehensive national policy. The use of space should be fully integrated for military, diplomatic, and commercial objectives. There is a need to examine and debate the use of this niche technology for bolstering national and military security and evolving concepts, doctrines, practices and technologies. This comprehensive issue of Synergy on space, therefore, is timely and relevant. The creative viewpoints could generate constructive debates to help shape policies, doctrines, practices and innovative ideas for bolstering India's national and military security through space.

Jai Hind!

(Johnson P Mathew)
Lt Gen
CISC

Maj Gen (Dr) Ashok Kumar, VSM (Retd)
Director General CENJOWS

FROM THE DIRECTOR GENERAL'S DESK

'Synergy Journal' is a flagship journal of CENJOWS and is being published bi-annually since September 2008. The current profile of this journal has changed since June 2023 after getting accreditation as ISSN Synergy Journal of the Centre for Joint Warfare Studies. It has been a theme based journal wherein multiple aspects concerning the selected theme are deliberated by various authors from across the country coming from diverse fields.

I am happy to present the 29th Edition of the Synergy Journal to my esteemed readers. Theme of this edition of 'Synergy Journal' is 'Space: Bolstering National and Military Security'. This was an obvious choice given the changing contours of space utilisation both for civil as well as for the military purposes. Indian Defence Forces also need to prepare themselves to factor 'space' as an important dimension of the conflict both for prevention as well as for carrying further the nation's will through appropriate means wherever core national interests are challenged.

India has already become a leading nation in space whether it is related to placing the own or the satellites of other countries in space, success in landing at South Pole of Moon and now successfully test firing Agni 'V', its *Divyastra*. As we go ahead, these and other missions will enable us to explore the space for nation's good in all the domains including in the security domain.

I am happy to present this issue of 'Synergy Journal' for your professional reading while acknowledging the contribution of all authors, team at CENJOWS and the publishers for successful completion of this challenging task.

Jai Hind!

(Ashok Kumar)
Maj Gen (Retd)
Director General

1-13

SPACE: THE UBIQUITOUS DIMENSION OF MILITARY MATTERS

Lt Gen P R Shankar, PVSM, AVSM, VSM (Retd)

Abstract

Space is the fourth military dimension besides land, air, and sea. Space enables nations to project power, shape battle fields and play a decisive role in conflicts. Possessing space-based military capabilities could well be the difference between adversaries in future. Space capability dictates application of force in all other domains and is often the common, critical and binding factor for such action. Navigation, information, international communication, weather forecast, vision capability and more are all space based. All such common utility capability is being increasingly militarised. As time has passed military utility of space has gone beyond the terrestrial battle to space battles and counterspace operations. Accordingly security of space systems has also assumed importance. There is also a scramble for resources and energy in space as military needs increase. Overall, as militarisation of space has increased geopolitics has also become more complex. The ubiquity of space is now well established.

SPACE: THE FOURTH DIMENSION OF WAR

Traditionally wars were fought in three dimensions – land, air and sea. As early as the 80’s, it was felt that Space was the fourth and newest military dimension.[1] Military experts began discussing space power, its implications and impact of new technologies on battle. Space was extensively utilised by

USA during the first Gulf War in 1990-91. It provided precision capabilities to the coalition forces. It was the key to enhance the capability of traditional air, sea and land forces. The coalition forces could see far into the innards of Iraq and engage targets with pinpoint precision at will. "*Intelligence preparation of the battlefield, warning, battle space awareness, operational timing and tempo, synchronisation, manoeuvre, targeting, the integrated application of firepower, and battle damage assessment*" came into the lexicon of military discussion.[2] Ever since then, military exploitation of space enabled USA to project power, shape battle fields and play a decisive role in its conflicts. The advantage provided by space based capabilities has been the defining military difference between USA and its adversaries on any battlefield so far. That might shift now as others are following suit.

UBIQUITY OF SPACE

The first Gulf War also triggered the information revolution. In a parallel mode, communication and data networks proliferated in the battlefield. Electronic warfare gained manifold importance. This led to the concept of cyber operations. In most discussions, one finds electronic warfare, information operations or cyberspace variedly being described as the fifth dimension[3] of war.[4] The sixth dimension of war coming into focus is cognition.[5] An analysis of all these domains indicates that Space is the common, critical and binding domain for all these. Space capability enhances the time-space (distance) equations in application of force or resource in all other domains. The ubiquity of space is evident in a mob phone which empowers any and everyone who owns a reasonable handset with navigation capability, information, international communication, weather forecasts and vision capability on fingertips in one go. This capability is being increasingly militarised to empower the soldier on ground to enhance his/her lethality. To a large extent, this capability has been conferred to him/her by exploitation of the space dimension. In addition to this, technology has enabled space to be utilised as an independent platform from which operations can be launched. As time goes by, military matters will be increasingly space dependant. Space is without doubt the ubiquitous dimension of military matters from hereon.

THE TERRESTRIAL BATTLE THROUGH SPACE

Throughout history, military commanders have aspired to engage their enemies at longer ranges and with greater lethality. This has led to a proliferation of weapon systems which are reaching out farther into enemy spaces through better propulsion systems and are able to destroy their intended targets with either pinpoint accuracy or mass widespread effect. In this quest, space based technologies have come to the fore in a significant manner. To engage a target at great ranges, one needs to acquire it and analyse it to make the best fit of a weapon system. Conjointly, one needs to move men and material over large distances to put these weapon systems at a place of advantage. Acquisition of coordinates of own location and those of the enemy become a primary requirement. This is now largely done through the Global Positioning System (GPS) satellites in medium earth orbit[6] or equivalent systems. GPS remains the favourite for most forms of military navigation - lethal and non-lethal, till countries develop indigenous alternatives. Gaining intelligence of the target and its posture is largely through a network of sensor borne satellites in low earth orbit.[7] The communications[8] which stitch all these operations together and the meteorological data[9] which goes with it is normally based on satellites in the geostationary orbit. Networked joint operations in the land, sea and air domains are fully enabled through a combination of satellites in the LEO, MEO and GEO beaming ultra-high frequency, high band width, high data signals at each other. It will not be out of place to say that the terrestrial battle is space dependent in all phases of a campaign from the preparatory stage where the requirement is primarily ISR, till the terminal phases where the stress and need is battle damage assessment. It is also further mentioned that electronic aspects of warfare viz electronic support measures, electronic countermeasures, cyber warfare and its by product information warfare are heavily dependent on space based assets. In nuclear operations, space based assets in the LEO are being used to detect missile locations, launches and nuclear detonations. They also enable a response system based on an adopted doctrinal philosophy. View it from any direction, space is now a force multiplier whose utility is expanding geometrically in all forms of the terrestrial battle.

THE BATTLE IN SPACE

Strategic Defense Initiative (SDI). Till recently, space was a support medium to the battles in terrestrial dimensions. However, with advancing technologies, that is changing rapidly. The trend today is to use space as a platform from where operations are initiated and conducted. The original concept was propounded as far back as 1983 in the SDI of the USA.[10] The SDI was positioned as a defensive system that could neutralise a nuclear attack against USA well before it reached its shores. As per the original thought process, "the heart of the SDI program was a plan to develop a space-based missile defence program that could protect the country from a large-scale nuclear attack. The proposal involved many layers of technology that would enable the United States to identify and destroy automatically a large number of incoming ballistic missiles as they were launched, as they flew, and as they approached their targets. The idea was dependent on futuristic technology, including space-based laser systems that had not yet been developed. Critics of the proposal nicknamed SDI 'Star Wars' after the movie of the same name. However, the entire concept of SDI fell though on two factors. Firstly, USSR had collapsed and the threat vanished. Secondly, the SDI was deemed to be too expensive and based on unproven technologies. However, that has now changed and SDI is reincarnating in a new format.

Space-based Weapons. Till recently, it was well established that space was militarised. Hitherto fore it will be weaponised.[11] Space-based weapons intending to attack targets in space or on the ground are on the horizon. These could be space-based ballistic missiles, defence interceptors and ground-attack weapons. These weapons will have to be necessarily placed in low earth orbits. These systems can be kinetic or non-kinetic in nature and can have effects that are either permanent or temporary.[12] Space based weapons could be '*space to space*' or '*space to earth*'. The '*space to space*' category will be discussed subsequently as counterspace capability. Space to earth weapons pose certain technical challenges at present and might not manifest in the short term. However, their coming into the equation is a matter of time. The trends which will propel deployment of weapons in space include advances in miniaturisation of technology, convergence of diverse technologies into space design, new material capabilities and reduced costs of space operations due to commercialisation of space industry. One must also realise that space to earth capability to carry out ISR and monitoring is already in place including the communication linkages. A major factor which must be realised is that space-based weapons need not always target hard ground-based targets or incoming missiles. As civil and military systems become increasingly dependent on space, there will be a proliferation of ground-based systems and components to support the space-based systems. In addition, every military system has a vast array of logistic material spread over large areas. These widespread and vulnerable targets (soft/semi soft) are ideal for interference by '*space to earth*' weapon systems. Targeting these through space-based weapons will be highly effective in either military or non-military contestations- in peace or war. In many cases, the operation could be made into deniable & non attributable soft kills. The day is not far when the SDI concept of USA is a reality far beyond the original thought process. In this vein, it must also be understood satellites with laser/Directed Energy Weapon capabilities are easiest to deploy and proliferate in space.

Earth to Earth Through Space. There is another category of weapons which can be termed as the '*earth to earth through space*' systems. In its simplest form these are the ICBMs or MRBMs of the yore which necessarily go into space before making a re-entry into the atmosphere on their way to the intended targets. A later day version of these are missiles which are fitted with Multiple Independently Targeted Re-entry Vehicles (MIRVs) as warheads. A sophisticated version of these systems is the Fractional Orbit Bombardment

System (FOBS) in which a missile is launched from earth and put into a low earth orbit and then turned suddenly on to its target to achieve surprise. A FOBS can suddenly be directed onto any unsuspecting target. However, when such a system provides the launch platform for a hypersonic glide vehicle on re-entry in the atmosphere, it is a breakthrough moment.[13] That is what the Chinese hypersonic glide vehicle is all about. This is next gen space capability which fuses multiple technologies through space.

COUNTERSPACE OPERATIONS

Concept and Danger. Counterspace operations deny use of space capabilities to adversaries. They have turned from being passive to being offensive in the recent past. Nations are investing and developing counterspace capabilities at an unprecedented rate with established space faring nations at the fore front. Counterspace capabilities are being developed along five lines. These are direct ascent (also commonly known as ASAT), directed energy weapons, co-orbital satellites, EW, and cyber platforms. These systems pose a threat to an adversary's space assets from the earth to geosynchronous spaces.[14] They are both destructive and non-destructive by nature. The major issue with counter space capabilities is that in a medium like space they tend to affect military and civil systems alike without differentiation. Hence, use of counterspace systems has huge ramifications for the global economy which has increasingly become more dependent on space in day-to-day activities. The focus of counterspace operations is to achieve superiority in a particular domain at a time and area of choice. It will not be out of place to mention that the PLA aims enablement in unimpeded use of space-based information systems and in denying adversaries their space-based information gathering and communication capabilities through counter space systems. This is a critical part of their concept of modern *"informatised warfare" as they aim beyond and further at "intelligetised warfare".*

Lines of Development. Direct-ascent anti-satellite (ASAT) weapons use a missile launched from ground to strike at satellites mainly in the LEO.[15] This capability exists with USA, Russia, China and India only. The effort is taking ASAT capability into the high geosynchronous orbit. There have also been reports of the Chinese contemplating use of low yield nuclear weapons to take out an adversary's satellites in the LEO.[16] Co-orbital systems (also known as "*space stalkers*"[17]) are those which are placed in orbits close to the intended target satellites to effect a kinetic kill.[18] These have been tested out by advanced space faring nations. However, achieving a soft kill through co-orbital systems in the near future is also on the cards. Satellites can be destroyed or incapacitated using directed energy weapons like Lasers and High-Powered Microwaves. These can be fired at the target satellite either from space based or ground-based platforms. Soft kills aim to damage/destroy the electronics of the target satellite and cause irreparable damage to its circuits and processors. Incapacitating a satellite can be done through electronic interference of its up or downlink communication links through jammer systems which can be either ground or space based. Cyber operations against satellites is increasingly becoming the norm in which monitoring or interfering or falsifying or infecting data traffic from target satellites, their ground stations, communication networks or end-user equipment is being resorted to.

THE ECONOMY OF SPACE MILITARISATION

The Potential of Privatisation. As per Mckinsey[19] "*SpaceX, Blue Origin, and other private companies are launching their own rockets and deploying satellite constellations. These activities, once primarily the domain of government agencies, are now possible in the private sector because recent technological advances in manufacturing, propulsion, and launch have made it much easier and less expensive to venture into space and conduct missions. Lower costs have opened the door to new start-ups and encouraged established aerospace companies to explore new avenues that once seemed too expensive or difficult. The technological improvements have also intrigued investors, resulting in a surge of space funding over the past five years*". There is a boom in the space economy. India is also onto it. It is one of the few countries in which the space sector has been opened up. The Indian commercial space sector is on the threshold of a major privatisation drive.

ECONOMY OF MILITARISATION

As militarisation of space progresses, there will be a natural fusion of civil and military activities in space. Civilian organisations, universities, research establishments and military organisations will gravitate towards each other to augment all space related activities. In effect, the civil and military requirements will drive each other to enlarge the commercialisation of the space economy through profit generating launches, scientific endeavours, and space exploration. In 2021, the space economy was valued at $469 billion.[20] The rough estimate is that it will grow at about 10 percent annually. Presently, the bulk of the value of the space economy is in the ground sector. As the costs of launching a satellite keeps falling and expansion of space launch facilities takes place, the overall economy is only set to grow further. As space launch and maintenance costs become cheaper, these systems will become more affordable for militaries even if they are small. Resultantly, countries with an established space program will see a huge uptake in profits and income through end to end provision of space services. In sum, the economy of militarisation will increase and benefit those countries with mature space programs immensely.

SPACE AND MILITARY TECHNOLOGY

Space and military technology have an umbilical connect. Space is the toughest environment for survival. It is harsh and hostile for both manned and unmanned satellite operations. Any system or technology which survives in space will naturally survive in the battle field. I had earlier written[21] that *"any space based system contains technologies which have a natural application on the battle field. Mastering space system technologies like robotics, nuclear, new Materials, ultralight devices and high-strength materials, super conductors, Hydrogen energy systems, AI, communications, energy harnessing, and cyber-space (to name a few) will have immense payoffs in development of advanced cutting edge weapon systems".*

As modern and advances systems are inducted into the battlefield, they will need an increasing amount of energy. The current method of utilising fossil fuel for our battle requirements, especially in our high altitudes is logistically untenable in the long run from any point of view as also form an environmental perspective. Hydrogen technology which is sheet anchor of space system energy has the potential to meet most of the energy requirements in operational environments. Renewables and green energy systems will be even more important high altitudes, in inhospitable and remote areas. Battlefield stamina and mobility will improve if fuel cell technologies which are essential for space systems are used in the military.

SECURITY OF SPACE SYSTEMS

Every space based system be it for ISR, meteorology, navigation, communication or counterspace is dependent on a vast array of ground based systems which are interconnected. As militarisation and weaponisation of space expands, the vulnerability and hence the security of these systems will also increase. Their physical and non-physical security assumes greater importance on ground. Similarly, as adversaries start deploying their space assets, their ground infrastructure and networks will also expand to become vulnerable. These vulnerabilities will sooner than later be discerned and exploited. This is a military aspect which has received much less attention than it deserves. However most militaries will get around to it. Protection and denial of own ground infrastructure which support space activities and exploiting weaknesses in an adversary's infrastructure will assume importance.

THE ENERGY SCRAMBLE

As the world's reserves of fossil fuels deplete, there is a scramble in space for energy. One option is to harness energy from space based solar power. The other option is to obtain Helium-3 and Deuterium from space and fuse them to produce energy. The reason to go to moon is to mine it for water and Helium-3.[22] Water, often called the "oil of space", if obtained in sufficient quantity from Moon, it will provide the energy to travel to Mars and for mining Helium-3 from the Moon surface. The reason to go to Mars is to mine it for Deuterium. Presence of Deuterium in Mars is about five times that on Earth. The combination of Helium-3 from Moon and Deuterium from Mars enables feeding the fusion process. Though the fusion process is complicated, the lab scale model has been successfully developed in USA in Livermore.[23] The next step is to establish a fusion reactor, which could take another decade to establish. There is another indirect option. That is to mine asteroids/moon/mars surfaces for rare earths. Rare earths if obtained there in sufficient quantities will help in making superconductors which will substantially reduce energy consumption. It is in this context that the Moon and Mars program of USA, China, Russia and India make sense. Countries which harness energy from space and achieve energy dominance will be the future global powers in a depleting energy scenario.[24]

THE SPACE FORCE

As activities in space have increased manifold, there is huge competition unfolding from the earth surface all the way to the Mars. The security requirements of space based assets has increased. Hence nations are also putting together resources to create Space Forces. The USA established the U.S. Space Force on 20 December 2019 with a mission to "Secure its Nation's interests in, from, and to space".[25] As per the US thought process "space is a national security imperative" and "there is a need for a military service focused solely on pursuing superiority in the space domain". China on the other hand established the PLA Strategic Support Force (PLASSF) in late 2015. This force looks after all space related activities of the PRC along with its netcentric and information war capabilities. It integrates PLA's space, SIGINT, cyber, electro-magnetic and psychological operations capabilities under one umbrella. One of the main tasks of the PLASSF is to provide security for China's growing Chinese interests and capabilities in space.[26] Given the way these two countries are progressing, it is high time that India starts thinking of a Space Force of its own to safeguard its fourth domain of war.

GEOPOLITICS OF SPACE MILITARISATION

In the days of the yore geopolitics around space was a bipolar affair between USA and USSR. However, in the present scenario, there is multipolar dynamic in space. Major countries in the space race are USA, Russia, China and India.[27] Other countries which have been making forays into space are Japan, Canada, UK, France, EU and Israel.[28] In the realm of great power competition, space is an important domain where there is a fierce jostling for position. The position revolves around technological prowess, soft power projection and national capabilities. Major space powers are competing for influence through achievements in space and posing threats through its militarisation. At the same time there is a scramble for energy and resources into asteroids and planets beyond the GEO.[29]

CONCLUSION

There should be little doubt that Space is not only being militarised but also weaponised. Further as technologies improve, the ubiquity and importance of Space in battle is increasing. More importantly the divide and the gap between the civil and military aspects of space is almost non-existent. In this context military and space agencies must get their act together by acting in concert with each other. Militaries of tomorrow must understand space better to be able to utilise it better. If not, they will be left out of the race. The Indian government and military has to take a call in this regard.

Lt Gen P R Shankar, PVSM, AVSM, VSM (Retd) is a retired Director General of Artillery. He gave great impetus to the modernisation of Artillery through indigenisation. He has deep knowledge, understanding and experience in successful defense planning and acquisition. The General Officer is now a Professor in the Aerospace Department of Indian Institute of Technology, Madras., Chennai. He is actively involved in applied research. He writes extensively on defence and strategic affairs at www.gunnersshot.com

NOTES

1. Space: The Fourth Military Dimension. The Strategic Defense Initiative and the Implications for Land Warfare in the Twenty-First Century Defense Technological Information Center, https://apps.dtic.mil/sti/citations/ADA181427#:~:text=This%20study%20considers%20space%20as,the%20Army%20began%20around%201983. Accessed on 16 February 2024.
2. Samantha Marquart, Space Power: A Unique Military Asset, https://www.iar-gwu.org/printarchive/dsg88kx84rnur2d523e47hj7pe9ger#:~:text=Space%20power%20became%20a%20key,substantial%20advantage%20in%20the%20war. Accessed on 18 February 2024.
3. Lt Gen (Dr) R S Panwar, Cyberspace: The Fifth Dimension Of Warfare - Part II, https://futurewars.rspanwar.net/cyberspace-the-fifth-dimension-of-warfare-part-ii/. Accessed on 18 February 2024.
4. Malcom James Cook et al. (2003), "Electronic Warfare in the Fifth Dimension: Human Factors Automation Policies and Strategies for Enhanced Situational Awareness and SEAD Performance", Defence Technical Information Centre, https://apps.dtic.mil/sti/citations/ADA422254.
5. Neeraj Mahajan, Cognitive Domain: The Sixth Domain Of Warfare, Def Strat, Vol 16 Issue 6 Jan – Feb 2023, Page 42, https://www.defstrat.com/magazine_articles/cognitive-domain-the-sixth-domain-of-warfare/.
6. Satellite Navigation - GPS - How It Works, Federal Aviation Administration, USA, https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/gps/howitworks. Accessed on 19 February 20204.
7. TechTarget Contributor, low Earth Orbit (LEO) Satellite, https://www.techtarget.com/whatis/definition/low-earth-orbit-LEO-satellite#:~:text=LEO%20satellites%20are%20commonly%20used,delay%20results%20in%20less%20latency. Accessed on 16 February 2024.
8. Geostationary Satellites: Definition, Application, Limitations, Unacademy, https://unacademy.com/content/neet-ug/study-material/physics/geostationary-satellites-definition-application-limitations/. Accessed on 17 February 2024.
9. Geostationary Satellite, Science Direct, Synoptic Analysis and Forecasting, 2018, https://www.sciencedirect.com/topics/earth-and-planetary-sciences/geostationary-satellite. Accessed on 17 February 2024.
10. Strategic Defense Initiative (SDI), 1983, U.S. Department of Space, Archive, https://2001-2009.state.gov/r/pa/ho/time/rd/104253.htm. Accessed on 18 February 2024.
11. An Introduction to Space Weapons, Ensuring Space Security, https://www.ucsusa.org/sites/default/files/2019-09/intro-to-space-weapons.pdf. Accessed on 18 February 2024.
12. Fact Sheet: Space Weapons, November 15, 2023, Centre For arms Control and Non Proliferation, https://armscontrolcenter.org/fact-sheet-space-weapons/. Accessed on 17 February 2024.
13. Jeffrey Lewis, China's Orbital System is Big Bad News – But Not A Breakthrough, Prolifetation News, Carnegie Endowment For International Peace, https://carnegieendowment.org/2021/10/19/china-s-orbital-bombardment-system-is-big-bad-news-but-not-breakthrough-pub-85606. Accessed on 17 February 2024,
14. Global Counterspace Capabilities, An Open Source Assessment, https://swfound.org/media/207350/swf_global_counterspace_capabilities_2022_rev2.pdf. Accessed on 17 February 2024.

15. Stephen Fallon, The Ongoing Militarisation of Space, Parliament of Austarlia, https://www.aph.gov.au/About_Parliament/Parliamentary_departments/Parliamentary_Library/pubs/BriefingBook47p/OngoingMilitarisationSpace. Accessed on 15 February 2024.
16. Tanmay Kadam, China Uses Nuclear Anti-Satellite Weapon To Destroy Space Target In Simulation Drills; Is Elon Musk's Starlink A Target? https://www.eurasiantimes.com/china-uses-nuclear-anti-satellite-weapon-to-destroy-space-target/#:~:text=In%20simulation%20drills%2C%20Chinese%20military,China%20Morning%20Post%20(SCMP). Accessed on 16 February 2024.
17. Stefan Cako, The Challenges of Russian Militarisation of Outer Space, http://www.diva-portal.org/smash/get/diva2:1517053/FULLTEXT01.pdf. Accessed on 15 February 2024.
18. Counterspace Weapons, Aerospace, https://aerospace.csis.org/aerospace101/counterspace-weapons-101/#:~:text=Co%2DOrbital%20ASAT&text=The%20attacking%20satellite%20is%20first,the%20path%20of%20another%20satellite. Accessed on 15 February 2024.
19. Ryan, Brukardt, How Will The Space Economy Change The World? Mckinsey Quarterly, November 2022, https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/how-will-the-space-economy-change-the-world. Accessed on 15 February 2024.
20. The space economy is booming. What benefits can it bring to Earth? 19 October 2022, World Economic Forum, https://www.weforum.org/agenda/2022/10/space-economy-industry-benefits/#:~:text=The%20space%20economy%20is%20worth,according%20to%20a%20new%20report. Accessed on 17 February 2024.
21. Lt Gen P R Shankar (R), India's Energy Security Through Space, PINNACLE, The ARTRAC Journal, Vol 19, 2020, Pages 165-179, https://gunnersshot.com/2021/06/16/indias-energy-security-through-space-by-lt-gen-p-r-shankar-r/.
22. Helium-3: Lunar Gold Fever, https://www.bbvaopenmind.com/en/science/physics/helium-3-lunar-gold-fever/. Accessed on 14 February 2024.
23. A shot for the ages: Fusion ignition breakthrough hailed as 'one of the most impressive scientific feats of the 21st century', Lawrence Livermore National Laboratory, https://www.llnl.gov/article/49301/shot-ages-fusion-ignition-breakthrough-hailed-one-most-impressive-scientific-feats-21st. Accessed on 16 February 2024.
24. Lt Gen P R Shankar (R), India's Energy Security Through Space.
25. About The Space Force, United States Space Force, https://www.spaceforce.mil/About-Us/About-Space-Force/. Accessed on 20 February 2024.
26. Li Nan & Ryan Clarke, The New Strategic Support Force Of The Chinese Military and Implications For Regional Security, EAI, Background Brief No 1606, 25 August 2021, https://research.nus.edu.sg/eai/wp-content/uploads/sites/2/2022/07/EAIBB-No.-1606-PLASSF-and-Regional-Security-2.pdf.
27. Giorgio Cardile, Militarisation Of Space: Terrestrial Geopolitics Or Prevention Strategy, https://en.amistades.info/post/militarisation-space-terrestrial-geopolitics-prevention-strategy. Accessed on 19 February 2024.
28. Lt Gen P R Shankar (R), India's Energy Security Through Space.
29. Dawn L Rothe, Victoria E Collins, Planetary Geopolitics, Space Weaponization and Environmental Harms, The British Journal of Criminology, Volume 63, Issue 6, November 2023, Pages 1523–1538, https://academic.oup.com/bjc/article-abstract/63/6/1523/7066931?redirectedFrom=fulltext#.

14-30

SPACE WARFARE: THE FINAL FRONTIER OF 'WAR IN SPACE'

Gp Capt (Dr) Dinesh Kumar Pandey (Retd)

Abstract

Given the unstipulated nature of conflict in the vast expanse of outer space, space warfare remains speculative and enthusiastically debated at relevant levels. The war through Space-based assets is making conventional warfare more lethal. However, constructing a space war in outer space requires everyone's serious consideration. If there were a war in space, it would have devastating effects on every person on Earth as well as on the accomplishments of the future human exploration of Space. Nevertheless, drawing upon contemporary high-tech advances and the intricacies of military strategies, one can conjecture regarding warfare's prospective conduct in the vast outer space expanse. Due to its intricate and demanding nature, space warfare necessitates in-depth and critical analysis for the utilisation of innovative and creative technologies and techniques. The study also references the need to focus on the challenges of Space warfare and address the areas in which we need to improve. However, in order to mitigate the likelihood of any military conflict in the space domain that may paralyse the humanity, it is essential to explore and initiate the necessary measures.

INTRODUCTION

Multiple engagements with space are rapidly transforming the global economy and geopolitics. Navigation, weather forecasting, research on climate change, communication, and military operations depend on it. A growing number of countries are engaged in space missions, while many others rely on services provided in space. Private sector funding for space exploration has brought new capabilities and potentially more widely shared benefits; these interests are changing the direction of technology and the norms surrounding it. However, strict laws need to be enacted to ensure continued viability and security of the space.

Space technology is almost indispensable today, although the last century can be described as the 'golden age' of space exploration due to great scientific and technological advancements during the period between 1957 and 1975.[1] We use them daily, they are indispensable. Different satellites are used for various purposes, such as weather forecasting, television broadcasting, navigation or telecommunications. We get assistance from them when needed at any particular time. There are numerous satellites in various orbits around the Earth. Human civilisation is limited to a Low Earth orbit, a site for the International Space Station and high-resolution satellite imagery. Medium Earth orbit is essential for the Global Positioning System (GPS), so we have navigation on mobile phones or tracking sizeable commercial aircraft. In terms of weather tracking and telecommunications assistance, Geostationary, Polar and Sun-synchronous orbits may be used.[2]

A number of Global space activities are conceivable due to exploration of the 'Space'. With the advent of space technology, GPS, surveillance, and rapid communications have become crucial for contemporary military warfare. A few nations are in the process of weaponising space, aiming to establish military supremacy on all fronts of warfare. Civil and military operations are conducted using 'Space' as a 'medium only'. Space is generally mentioned as the final frontier. Satellites, therefore, have become essential components for the armed forces and non-military society.

War in space, as such, is still a 'distant' concept. How military operations in space will be conducted is to be seen. We all have seen 'Space Wars' in several movies. 'War in Space', so-called 'Space Wars' in the cinema world, is a more theoretical/hypothetical/ simulated concept. With time, the density of flying objects in space is increasing. Hence, it merits studying various considerations and other dimensions of 'War in Space'.

SIGNIFICANCE OF SPACE FOR MODERN WARFARE

The general population, including the armed forces, is becoming phenomenally more dependent on space-based technologies. Therefore, The primary objective has been to enhance their technological capabilities in space, minimise their susceptibilities, and elevate their significance as a strategic sphere. Space systems are crucial in various areas, such as navigation, communication, and remote piloting. Additionally, they are indispensable for operating GPS-guided weapons, surveillance, and information warfare.

GPS signals have become essential to our day-to-day activities for various purposes, such as banking, travel, navigation, agriculture, and communication facilities, using the internet access. Reliance on satellite navigation accounts for approximately 6 to 7 percent of Western countries' Gross Domestic Product (GDP).[3]

Communications satellites are utilised not only for direct broadcast television but also to facilitate numerous terrestrial networks. In isolated regions of the globe, they could serve as the sole method of communication. In the foreseeable future, global broadband internet access could be facilitated by communications satellites.

Satellites facilitate the acquisition of weather forecasts and enhance agricultural productivity. In addition, they assist us in strategising for disaster relief efforts, locating and extracting natural resources, monitoring environmental well-being, and various other applications.[4]

The first Gulf War, which took place in 1991, is often denoted as the first space war, although it was not fought in space. Instead, the United States and coalition forces heavily depended on GPS and other satellite technology to further their interests in that conflict.

ASATS

The proliferation of anti-satellite weapons (ASATs) is gradually becoming challenging. In 2007, China utilised a ground-based missile to obliterate an inactive communication satellite, resulting in the creation of approximately 3,000 fragments of debris that can be monitored. Similarly, the United States launched a missile to target a reconnaissance satellite during its descent from orbit in 2008. It is worth observing that Russia has also conducted various tests with ground-based missiles.

India conducted a successful ASAT test, codenamed 'Mission Shakti', on March 27, 2019. The test successfully targeted and destroyed a live satellite in the Low Earth Orbit using indigenous technology. India's space programmes have achieved substantial growth. Like other nations, India possesses space assets that must be protected and preserved. This achievement brought India to join the select group of nations, the US, Russia, and China, that possessed this capability.[5] The use of Kinetic ASAT weapons has caused significant international concern due to the resulting creation of debris, which poses a potential threat to all space systems. Debris resulting from ASAT tests has penetrated orbits at higher altitudes than initially predicted, with a portion persisting in space. Currently, the potential for global disapproval has prevented kinetic ASATs from posing a more significant risk to security.

Subsequently, space-based resources have facilitated enhanced capacity for land, naval and air forces. Given the dual use of numerous satellites, an armed conflict in space could have catastrophic effects on modern life. These satellites are a crucial element of ballistic missile defence, capable of detecting missiles immediately after launch and tracking their paths.[6]

The establishment of the United States Space Force has evoked a plethora of imaginative conjectures about the prospect of warfare within the Space realm. This created suspicion about the conduct of operations in the observers' minds.[7]

SPACE WARFARE V/S CONVENTIONAL WARFARE

In contrast to terrestrial warfare, when opposing troops strive to control a specific physical area, satellites in orbit do not occupy invariably a singular position. Satellites are commonly employed in circular orbits exhibit velocities ranging from 3km/s to 8km/s, dependent upon their respective altitudes. In contrast, an average bullet travels approximately 0.75 kilometres per second. They appear quickly and then disappear.

The volume of the section between the Low Earth Orbit as well as the geostationary orbit is almost 200 trillion cubic kilometres. The volume is 190 times greater than that of Earth. Placing a satellite in orbit requires significant time and delta-V (change in velocity) to execute phasing manoeuvres.[8]

Space operations, therefore, including moves and actions, necessitate meticulous pre-planning. Any conflict in space will exhibit a significantly reduced pace and heightened intentionality. Throughout history, warfare has invariably ventured into unexplored regions to achieve the element of surprise. It might not be possible to precisely quantify the prospective role that space could play in future conflicts. Future space conflicts will primarily revolve around satellites.

Several nations presently possess military satellites deployed within the space domain. The United States, Russia, and China are widely recognised as the prominent triumvirate in global power dynamics. However, it is noteworthy that nations such as France, India, Israel, and the United Kingdom have also made significant explorations to enter the competitive domain of military aerospace development.

However, could we anticipate the emergence of conflict solely within the dimensions of outer space? It is highly improbable that we shall witness any conflict exclusively transpiring within the celestial world in the foreseeable future. Space warfare remains predominantly theoretical today, as no tangible instance of armed conflict in outer space has transpired. Nevertheless, numerous concepts and technologies have been explored for implementation in space combat. As the existence of space technology continues to proliferate among countries, its implementation in various world conflicts is set to increase. There are two main strands through which satellites can be drawn into a war in space: "cyber-attacks" and "anti-satellite missiles."

The fundamental nature of space warfare is expected to differ significantly from the typical forms of terrestrial warfare. However, the physical limitations of space may render its use impossible. In the huge expanse that is outer-space, there is no air resistance or gravity making it an environment where weapons can be used as much as one wishes. Besides some specific weaponry tactics, what else would distinguish space combat, are:

- Space warfare would have an extraordinary swiftness and span our long distances, taking place within seconds. Space amplifies weapon platforms by increasing velocities for missile trajectories, thus, enhancing speed and accuracy.
- Getting weapons into space would create tremendous precision, making it difficult for enemy spacecraft and satellites to try to hide. It is also important to note that aerial equipment cannot be shielded in the empty void of space, making aerial assets in the air highly vulnerable to potential acts of aggression.
- Ships in the sea and satellites in space are highly vulnerable to attacks due to a lack of relative shielding. Moreover, wars in space will be strongly interconnected with ongoing events on Earth.

CONSEQUENCES OF SPACE WAR

Any space conflict would have far-reaching implications since it could disable or destroy satellites that are indispensable to our planet. Nevertheless, the function of satellites underwent a transformation to support traditional military activities, as demonstrated by the involvement of the U.S. military in the 1991 Gulf War and subsequent operations. Space assets, therefore, were recognised as not just a means of gaining operational military advantage but also as a possible vulnerability.

Space weaponisation raises numerous strategic concerns, including fostering distrust, jeopardising commercial and scientific operations, contributing to space debris, and potentially monopolising orbits.

Space is a domain where assets are enormously valuable and massively exposed to risk, and the actions of any one individual — whether intended or not — can trigger consequences that affect the interests of not just a few but everyone. Those consequences can be immediate, as well as cumulative and long-term. Indeed, one potential outcome of the physical deployment of such arms is the post-conflict political considerations as allies and adversaries consider new alignments.[9]

Incorporating space assets into land-based military operations has had significant strategic implications. In essence, the space systems that granted tactical advantages also became perceived as potential weak points that adversaries could exploit in times of conflict.

The potential outcomes of any space war would be wider and more devastating, affecting every aspect of human life. According to an expert, life would alter drastically from its current form. The following are only a few possible outcomes:

- **GPS Systems.** The vulnerability of satellites to attacks that can disrupt GPS systems needed across multiple industries such as supply chains (air, road and shipping), as well as military activities and other important spheres.
- **Banking Systems.** International banking systems may be significantly affected.
- **Power Grids.** Power supplies could be interrupted leading to extensive blackouts with hospitals, water, food supply networks being the most affected sector.
- **Emergency Call Centers.** Communication channels used by first responders might be disrupted, thus, hindering their response times for life-saving emergency services, like ambulances, fire brigades, etc.
- **Military Actions.** Satellite technology facilitates communication, intelligence gathering, and navigation for military operations worldwide. These operations may experience significant disruptions and may result in loss of lives. Specifically, distant Drone operations, Anti-Access and Area Denial (A2/AD), and Manned Unmanned Teaming (MUMT) missions will be severely impaired as satellite support is paramount in such operations.

- **Debris.** The wreckage resulting from a satellite's destruction can potentially a satellite which has the potential to cause additional harm. For example, even a minuscule fragment of wreckage from an obliterated satellite can cause significant harm to spacecraft such as the International Space Station.
- **Civilian Consequences.** The complete elimination of a space infrastructure that offers positioning, navigation, and timing services to civilians and the military could result in aviation disasters, vehicular collisions, and disruptions in the worldwide financial market.

The above-mentioned ramifications of any conflict in space are only a limited number of instances. Acknowledging that ongoing international initiatives are aimed at averting conflicts in outer space is crucial. Nevertheless, these endeavours need to catch up to the swiftly changing circumstances.

THE POTENTIAL MODUS OPERANDI OF SPACE WARFARE

The manner in which space warfare will be realised is thought to be that in a future war, only unmanned vehicles coded from the ground will do battle in space. Moving around in space might have to cope with all sorts of restrictions. Satellites have been indispensable for the military in recent years, and the U.S. is making substantial investments to maintain its military dominance in space. Other than land-based missiles, satellites can also be attacked by radio waves. Such waves can jam and confuse an opponent's satellites, forcing them to issue orders that are nothing but ugly covert messages.[10]

Among the paramount objectives within the arena of celestial conflict would undoubtedly encompass the neutralising of adversary satellites. Vital navigation, communications, and intelligence services are provided by these satellites. The act of neutralising or incapacitating adversary satellites possesses the potential to induce a state of sensory deprivation, rendering them incapable of visual, auditory, and navigational functions. This strategic manoeuvre confers a considerable upper hand upon the attacker.

In an enormous space area, the absence of an atmospheric medium renders the velocity of projectiles free from constraints, thereby endowing space-to-space combat with unprecedented pace and lethality. The utilisation of laser technology, particle beams, and kinetic projectiles presents a viable prospect for annihilating adversary spacecraft, including but not limited to satellites, spaceplanes, and space stations.

Cyber-attacks have emerged as a formidable armament in space warfare. By strategically targeting adversary communication networks, control systems, and navigation infrastructure, assailants can severely impair their opponent's capacity to engage in combat operations. Cyberattacks possess the potential to be employed to undermine adversary satellites, spacecraft, and terrestrial infrastructure.

It is imperative to comprehend the fundamental elements of space warfare to effectively mitigate the likelihood of any potential celestial confrontation, safeguard humanity's welfare, and preserve human civilisation. Various relevant components of space warfare are discussed in the following paragraphs.

POTENTIAL COMBATANTS

The domain of space warfare encompasses a diverse array of participants, encompassing not only nation-states but also non-state actors and even private enterprises. It is highly probable that nation-states possessing substantial spacefaring capacities, such as the United States, Russia, China, and India, shall assume the leading roles in any prospective conflict within the world of space. A few countries, like North Korea, Turkey, Iran, and Pakistan, may also be potential long-term or short-term players in Space. Nevertheless, it is imperative to acknowledge that entities outside the purview of governmental authority, commonly referred to as non-state actors, possess the capacity to obtain and harness space-related capabilities. This development, if realised, has the potential to generate a significant menace to vital infrastructure and communication networks. Private enterprises, particularly those engaged in satellite development and operation, may be susceptible to becoming focal points in a conflict launched in outer space.

TYPES OF WEAPONS

The weapons used in space warfare may differ greatly from those on Earth. In the great emptiness of space, there is no atmospheric pressure to resist the motion of solid particles flying out of a gun and no medium to slow down these projectiles. Conventional kinetic armaments such as projectiles and missiles would multiply their destructive potential, greatly increasing their potential. Moreover, with no atmosphere to resist their movement through space, we could use high-powered laser and particle beam technologies to neutralise or utterly destroy enemy ships.

NON-KINETIC WEAPONS

Non-kinetic weapons like cyber warfare and electromagnetic pulses (EMPs) are also being used in space warfare. EMPs have the capability to render electronic systems inoperable, leading to the possibility of substantial disorder and disruption. Cyberwarfare has the potential to intrude and interrupt adversary’s communication networks, command and control systems, satellite navigation and other systems.

STRATEGIC CONSIDERATIONS

Space warfare would necessitate a completely different set of strategic considerations than conventional land warfare. Rapid response to attacks in space would be challenging due to the immensity and severity of the environment and the speed of movements. It would be difficult to conceal spacecraft from detection because there would be no air resistance to contend with. Consequently, any space war in the future would probably be waged using long-range weaponry and emphasis on hitting enemy infrastructure instead of directly confronting enemy forces.

REGULATORY CONTROL ON SPACE

Space warfare is a delicate and intricate concept in itself, yet a space confrontation could be on the horizon sooner than most people think. But if such a thing were to happen, the global population would feel the full force of it both immediately and later, and human space exploration would take a terrible blow. Some of these principles are well established but still lack precision. Studies are underway. The concept of touching on some basic principles or using them for this purpose is essential. A research team with members from around the world has been compiling what they call the space war law handbook for several decades. Universal knowledge law requires human society to make full use of the advantages provided by space, and this requires that no one will be injured or killed unjustly for simply occupying a certain position. Human effort for celestial dominions should be directed unwaveringly towards peace. Any potential dispute should smoothly be resolved by diplomatic means. It is of paramount importance for governments to place the highest priority on ensuring the maintenance of the physical and emotional welfare of all individuals while diligently refraining from engaging in any practices that may potentially result in adverse consequences or inflict harm. Let's focus on finding solutions that promote understanding and cooperation.[11]

Only five of the numerous international treaties pertain specifically to space activity. The primary one is the 1967 Outer Space Treaty, which prohibits the deployment of weapons of mass destruction into space. However, only one of its provisions (Article IV) specifically addresses military activity. Other methods of damaging or interfering with satellites are not illegal despite the fact that their use is subject to other legal frameworks, such as the Laws of Armed Conflict. This encompasses a range of advanced technologies, including anti-satellite missiles, directed energy weapons like lasers, electronic warfare capabilities, cyber warfare tactics, and the utilisation of dual-purpose technology, such as on-orbit servicing satellites commonly referred to as 'mechanic' satellites.[12]

In December 2022, the U.N. General Assembly passed a resolution that urged governments to refrain from conducting harmful direct-ascent (DA) anti-satellite (ASAT) experiments. The resolution received affirmative votes from 155 nations, while nine nations, including China and Russia, voted in opposition. Nine other nations refrained from voting. ASAT tests can have detrimental effects on global peace and security. These tests pose a risk to the long-term viability of the outer space environment and hinder countries' ability to explore and utilise outer space peacefully. Notably, such resolutions are non-binding, and countries are not legally obligated to comply.[13]

The idea of space warfare is both disturbing and risky. Preventing such a war requires a concerted effort to create global standards and agreements governing space usage.

THE CHALLENGES OF SPACE WARFARE

The concept of space warfare is intricate and demanding, and several hurdles must be surmounted before it can be realised. Satellites are susceptible to various threats, encompassing cyber-attacks, communication disruptions, electronic warfare, tangible assaults, and maintenance issues. Cyber-attacks targeting space capabilities resemble non-space systems, as they frequently entail endeavours to input user-derived data into a system, thereby inducing software to exhibit unforeseen behaviours. The financial burden of creating and maintaining essential infrastructure and technology to counter such issues is a significant challenge.[14]

Satellites are complex structures requiring significant financial resource allocation, personnel, and effort. However, in the event of fuel exhaustion or any malfunction in any component, the satellite is abandoned. Consequently, this generates a substantial amount of debris in outer space. On-orbit satellite servicing has brought this situation to the point where it is on the approach of becoming a thing of the past. On-orbit satellite servicing refers to the technology used to repair, refurbish, and refuel satellites already launched into space.[15]

The challenges in space manufacturing, as well as maintenance, entail the requirement for specialist equipment and materials, manufacturing processes affected by microgravity, quality control, and guaranteeing the compatibility of space-manufactured items with Earth's environment.

Any conflict within the realm of space will undoubtedly have a profound impact on the intricate mechanisms governing airspace management. The complex nature of the congested space environment has rendered the concept of 'Space Traffic Management' unduly complicated.

'Space Debris' is another challenge that Space operations are facing. Anything that is man-made and no longer in use in orbit is known as 'Space Debris'. Debris in space is generated by human-made objects such as defunct satellites, discarded rocket stages, and fragments resulting from erosion, collisions, and disintegration of items in orbit. Smaller components of space debris encompass remnants of vehicles that have undergone explosions or collisions, as well as shards of insulation and paint that have originated from space vehicles. The collision occurred in 2009 between the U.S. Iridium 33 communications satellite and the decommissioned Russian military communications spacecraft Cosmos 2251.[16] In general, the quantity of debris increases as its size decreases. The excessive number of debris necessitated the establishment of military space monitoring to avoid any collision issues. Space debris adds to the cost of operating satellites because if debris destroys a satellite, it may take years and hundreds of millions of dollars to restore that satellite's service. Even tiny debris objects can damage critical sensors and spacecraft components.[17]

WAY AHEAD

Notwithstanding the challenges, the possibility of space warfare is a genuine cause for concern. The likelihood of armed conflict in space increases as countries continue investing in spacefaring capabilities. This issue needs to be addressed by the international community as soon as possible before it is too late.

To avert such a disastrous occurrence, it is paramount to prevent the weaponisation of space and promote peaceful exploration of outer space. Exploring international laws about Earth that could be relevant measures to conflicts in outer space is imperative. The subject comprehension could facilitate the practice of diplomacy and the establishment of treaties to avert such hostilities. The objective is to prevent such conflicts in the initial stages or to ascertain the most suitable and commensurate measures in reaction to any activities in outer space. A global team of experts is currently working to create an authoritative manual that delineates the legal principles governing military activities in outer space. The objective is to create a comprehensive Manual on International Law Applicable to Military Usage of Outer Space (MILAMOS) that encompasses periods of heightened tension and open conflict. The primary objective of this project, launched in May 2016, is to cultivate a universally embraced compendium elucidating the core principles governing the utilisation of celestial expanse for military purposes during periods of tranquillity, encompassing the various obstacles that may impinge upon the preservation of peace. It is stipulated that the study will facilitate the establishment of transparency and trust among nations engaged in space exploration. This measure aims to mitigate the likelihood of a conflict occurring in outer space and, if it does happen, minimise the consequences on the space infrastructure that is crucial to our daily operations.[18]

Besides legal measures, defensive, offensive, and diplomatic alternatives exist to prevent confrontations in space. Defensive measures encompass the advancement of technologies to safeguard satellites against attacks, and offensive measures involve the development of weaponry designed to hinder or annihilate adversary spacecraft. Diplomatic measures involve negotiating and establishing treaties and accords to constrain space militarisation and avert space weaponry creation.

The following measures may be considered to facilitate the execution of military operations if space assets are wholly or partially non-functional:

- **Advanced Strategies.** Given the intrinsic features of space combat, such as velocity and range, tactical manoeuvres may not be relevant.

Hence, it is imperative to integrate the constraints while formulating the initial offensive or defensive operations missions.

- **Alternative Means of Communication.** Efficient communication systems are required for interoperability and collaborative operations. One could consider utilising existing resources for other communication methods, such as LoS-based tropo and fibre optics-based communication.
- **Redundancy in the Context of A2/AD and MUMT.** A2/AD and MUMT are military strategies encompassing various capabilities across various domains, including space. Multiple strategies may be attempted to mitigate the impact of a conflict in outer space on A2/AD and MUM-T in case of failure or disruption.
- **Training and Exercises.** Acquiring knowledge empowers the workforce. Hence, skilled military personnel enhance the effectiveness of the operations. It is imperative to ensure the capacity building associated with space warfare is well in time. Regular military training and operations are necessary to acquaint the armed services with the intricacies of space warfare. Simulated and live exercises can serve as effective means to accomplish the objectives.

India's inception of appropriate steps to deal with any potential danger merits consideration in light of the Chinese space projects and the Chinese government's efforts to establish its dominance in space.

CONCLUSION

Space warfare, as a concept, still remains speculative in nature and energetically debated at relevant levels, given the unstipulated nature of conflict in the vast spread of outer space. While the concept of a war in outer space may seem like a plot from a science fiction story, it is a matter that requires everyone's serious consideration. A space war would have catastrophic consequences for all individuals on Earth and for future human space exploration.

Nevertheless, drawing upon contemporary technological breakthroughs and the intricacies of military tactics, one can conjecture regarding warfare's prospective conduct in the vast outer space expanse. The domain of space warfare necessitates the utilisation of innovative and creative technologies and techniques due to its intricate and demanding nature.

Nations capable of achieving mastery in space warfare will own a substantial edge in the future of military conflict, which may result in inhuman dividends. In view of catastrophic consequences, the international community should create and adhere to rules for its regulation to avoid the possibility of space warfare becoming a global conflict.

Gp Capt (Dr) Dinesh Kumar Pandey (Retd) was a Group Captain in IAF. He had served in the IAF for more than three decades. He has experience of more than 2500 Air combats. He was the Director Air Staff Inspections and retired as Director, Joint Control and Analysis Centre. He has written research papers for journals and websites. Presently he is a 'Senior Fellow' at 'the Centre for Air Power Studies' (CAPS).

NOTES

1. John Uri, "60 years ago, the Space Age began", NASA, October 4, 2017, https://www.nasa.gov/history/60-years-ago-the-space-age-began/. Accessed on 30 January 2024.
2. Sitki Egeli, "Space-to-Space Warfare and Proximity Operations: The Impact on Nuclear Command, Control, and Communications and Strategic Stability", Journal for Peace and Nuclear Disarmament, June 25, 2011. https://www.tandfonline.com/doi/full/10.1080/25751654.2021.1942681. Accessed on 16 December 2023.
3. "Space could become the battleground of the future", World Economic Forum, 24 November 2017, https://www.weforum.org/agenda/2017/11/the-conflicts-of-the-future-will-take-place-in-space-heres-one-way-were-preparing/. Accessed on 06 December 2023.
4. Ibid (WEF).
5. "Mission Shakti", BYJU's, 2024, https://byjus.com/free-ias-prep/mission-shakti/. Accessed on 30 January 2024.
6. Talia M. Blatt, "Anti-Satellite Weapons and the Emerging Space Arms Race", Havard International Review, 26 May 2020, https://hir.harvard.edu/anti-satellite-weapons-and-the-emerging-space-arms-race/. Accessed on 30 January 2024.

7. Eric Berger, "This is what "war in space" probably would look like in the near future", ArsTechnica, 16 October 2020, https://arstechnica.com/science/2020/10/this-is-what-war-in-space-probably-would-look-like-in-the-near-future/. Accessed on 19 December 2023.
8. Ibid.
9. Allison Goody, Ariel Shapiro, "The Growing Complexity of Space: Implications for Security and Stability", Library of Parliament, 26 July 2022, https://lop.parl.ca/sites/PublicWebsite/default/ en_CA/ResearchPublications/202210E. Accessed on 30 January 2024.
10. Ibid (Arstechnica).
11. Ibid (WEF).
12. Ibid (WEF).
13. Jeff Foust, "United Nations General Assembly approves ASAT test ban resolution", Space News, 13 December 2022, https://spacenews.com/united-nations-general-assembly-approves-asat-test-ban-resolution/. Accessed on 30 January 2024.
14. Travis J. Kneen, "Technologies and Strategies to Protect Satellites From Cyber and Electronic Warfare", DSIAC, 22 November 2019, https://dsiac.org/technical-inquiries/notable/technologies-and-strategies-to-protect-satellites-from-cyber-and-electronic-warfare/. Accessed on 19 December 2023.
15. Mahashreveta Choudhary, "What is on-orbit satellite servicing?", GW Prime, 15 October 2019, https://www.geospatialworld.net/blogs/on-orbit-satellite-servicing-process-benefits-and-challenges/#:~:text=As%20every%20technology%20comes%20with,that%20has%20to%20be%20serviced. Accessed on 30 January 2024.
16. Alison Lawlor Russel, "Strategic Anti-Access/Area Denial in Cyberspace", 7th International Conference on Cyber Conflict, 2015, https://ccdcoe.org/uploads/2018/10/Art-11-Strategic-Anti-Access-Area-Denial-in-Cyberspace.pdf. Accessed on 20 December, 2023.
17. "Space Debris And Space Traffic Management", The Aerospace, 14 November 2018, https://web.archive.org/web/20211025162828/https://aerospace.org/space-debris. Accessed on 19 December 2023.
18. "The Manual on International Law Applicable to Military Uses of Outer Space", https://www.mcgill.ca/ milamos/. Accessed on 19 December 2023.

31-41

RELEVANCE OF SPACE SITUATIONAL AWARENESS FOR INDIA'S SPACE SECURITY

Col Gaurav Soni & Dr William Selvamurthy

Abstract

This paper brings to fore the need to build Space Situational Awareness (SSA) capabilities for India. It identifies threats affecting the smooth functioning of satellites through space thus arriving at the needs of SSA. It presents a brief discussion on the elements of SSA, including Data Collection by means of Sensors, Data Processing and Production at SSA nerve centres and finally Data Sharing between international partners. It differentiates between the military and civilian needs of SSA and discusses USA's SSA architecture which gives primacy to military SSA. It also briefly throws light on developments in SSA by major spacefaring nations with the aim of understanding how SSA can be conceived in India's context.

The paper discusses India's SSA proficiencies in light of SSA programmes of space faring nations. Finally, the paper suggests steps towards moderate capabilities in the near term and also an incremental approach for reaching maturation in SSA over the long term.

INTRODUCTION

Key military operations to include navigation, deep surveillance and long distance communication are increasingly being supported through assets in outer space. These assets are also pivotal in running and sustaining vital civilian operations to include banking, weather forecast, resource monitoring etc., thus, making own governance increasingly reliant on them. While their role as enablers is well established, it must be understood that such assets are vulnerable to adversary actions thus jeopardising both civil and military operations. All events occurring in space, whether natural or by human design, need to be watched by observation equipment like radars and telescopes in order to assess vulnerabilities and undertake preventive measures. Space Situational Awareness (SSA) incorporates mechanisms to observe activities in space, collate the information centrally and suggest agencies for corrective actions in order to safeguard own assets in space. This paper focuses on understanding concepts of SSA, its emerging trends and steps that India may take towards building its SSA capabilities.

UNDERSTANDING SSA

The 1967 Outer Space Treaty lays down the general rules governing the use of Outer Space, ironically though, a clear definition of 'Outer Space' has yet not been arrived at. For common understanding however, space beyond 100 Km from the earth's surface is perceived to be Outer Space. In our immediate outer space operate the man-made satellites poised in the Low Earth Orbits (LEO), Medium Earth Orbits (MEO) and the Geostationary Earth Orbit (GEO). However, satellites are not the only objects present in this space. In it are also present Atomic Fluxes and Solar Winds which originate from the sun[1] and have the potential to impair satellite electronics. It also consists of Outer Space Objects (OSO) which include inactive or dormant satellites and Space Debris which refers to fragments ejected during the stages of satellite separation from the rocket body, paint flecks chipped off from the satellites and junks of dead or destroyed satellites. It is believed that every satellite launch may result in about 100 fragmented pieces chipping off from the satellite. Together the number of such Space Debris may well reach upto 5,00,000 in our immediate outer space.[2] These move at high velocities and even a tiny object of size one cm can damage a satellite while that of size 10 cm and above can completely disrupt a satellite's functioning on collision. Presence of these objects needs to be monitored and tracked in order to safeguard own satellites. While the number of Space Debris is high, only about 20,000 such objects may have been observed, logged and registered by major agencies worldwide. This is so since objects lesser in size than 10 cm are extremely difficult to track.

In the space are also undertaken bona fide human activities which are generally civilian in nature. Such activities undertaken by other nations need to be observed to extrapolate rocket trajectories in order to avoid accidental collisions and thus plan safe missions. Of grave concern are malicious activities which may include use of Anti Satellite (ASAT) missiles or Direct Energy Weapons (DEW), unannounced manoeuvring or launching of satellites or undertaking suspicious activities like use of robotic arms. Such activities need to be actively monitored in order to ensure continuity of own services during critical civil and military operations.

Radars and telescopes forming the basics of SSA infrastructure observe these solar winds, atomic fluxes and OSO. They also monitor human activities in outer space. Information so obtained is processed at a nerve centre where large pools of data bases help extrapolate trajectories to arrive at possibilities of collisions. Once the possibilities of collision are ascertained[3] course corrections can be undertaken for collision avoidance.

CIVIL AND MILITARY VIEWPOINTS ON SSA

The SSA programme of the European Space Agency (ESA) is expected to be oriented towards civilian objectives with an aim to monitor satellites, space debris and weather[4] in order to arrive at course corrections. A civilian perspective to SSA entails knowledge of activities in space in order to avoid accidental collisions. Avoidance of such collisions is for common good of all space users and thus nations are normally inclined to share such information with other space faring nations in order to ensure space traffic management.

On the other hand, the United States Strategic Command (USSTRATCOM) perceives SSA as a tool to enable space superiority during conflicts.[5]

USSTRATCOM lays down that SSA should be able to obtain data on use of military satellites by adversary nations, detect suspicious ascent, descent or manoeuvres, or detect offensive use of ASAT missiles by adversary. Such perspective on SSA is militarily oriented and not all of the data so obtained may be shared with other countries.

Thus, should a space faring nation seek SSA for accidental collision avoidance facilitating global Space Traffic Management, data is likely to be easily shared amongst countries. However, should it seek for advancement or progression of its own military activities or for protection of its assets which support military operations, preserve over data is likely to be maintained. Envisioning such scenarios, prominent space players are beginning to develop their own SSA capabilities.

USA'S SSA PROGRAM

- USA operates more that 375 telescopes and radars thus being a global leader in SSA.[6] Elements of USA's SSA are briefly discussed in following paragraphs.
- ***Data Collection***

  The USA is expected to host its sensors both on ground and in space aboard satellites. On the ground are Falcon Telescope Network (FTN), Ground Based Electro Optical Deep Space Surveillance (GEODSS), the 'Orbit Outlook' and the 'Space Fence'. GEODSS is a network of telescopes spread globally at Hawaii, Diego Garcia, and Socorro[7] with a likelihood of additional mobile facilities. The FTN is also a separate network of telescopes spread in countries of Chile, South Africa and Australia and is a collaborative effort between the US Air Force and educational institutes worldwide.[8] The 'Orbit Outlook' connects academic institutes and amateur observers and is expected to comprise of 29 radars.[9] USA's most premium asset the 'Space Fence' is a fence like radar which is three kilometer long and has the ability to track objects even lesser than 10 cm in size. Located at Kwajalein islands[10] the Space Fence can undertake upto 10,000 detections per day.

Based in space are USA's satellite constellations to include Space Based Space Surveillance (SBSS), Geosynchronous Space Situational Awareness Programme (GSSAP), the Space Tracking Surveillance System (STSS), and the Space Based Infra Red System (SBIRS). The GSSAP comprising of GSSAP 1, 2, 3 and 4[11] satellites can observe objects in GEO well upto 36,000 km, while the STSS and SBIRS form the essential eyes and ears of USA's Ballistic Missile Defence Systems with an ability to detect incoming missiles.

- ***Sharing of Data***

  The Joint Space Operations Centre (JSpOC) of the US Space Force functions as a nerve centre and controls most of its SSA sensors spread across the globe. Data obtained through these sensors is processed and registered in form of a Satellite Catalogue(SAT-C). This SAT-C is posted in the official website of US government called Space-Track.org. Data of space objects which have been detected and tracked is expected to be present on the website. This data is used by most space faring nations for planning the launch of their satellites and even their collision mitigation. Though the basic data is expected to be made available for all users, uninterrupted and unconditional supply of such information cannot be guaranteed. Further, advanced data having strategic implication is not posted on the website and is usually shared only on government to government basis under strategic agreements.[12] Thus, in order to seek comprehensive SSA data, countries have to develop their own SSA infrastructure. Further, such SSA infrastructure has to be spread across the globe in both northern and southern hemisphere in order to build the overall picture. Thus, arises the need to also simultaneously develop networking and strategic information sharing mechanisms with global partners. One such mechanism is the Joint Forces Component Command (JFCC) comprising of USA, Canada, UK and Australia functioning under the lead of the US Air Force. These countries jointly operate and contribute towards building common SSA picture which is then shared exclusively amongst the four nations.

SSA PROGRAM: GLOBAL TRENDS

The ESA employs Proba-2 and Proba-3 satellites for space based sensing. Based on ground are Solar and Heliospheric Observatory(SOHO), Space-Surveillance and Tracking-Data-Centre in Spain, Space Weather Centres in Belgium, Near-Earth-Object(NEO) Coordination Centre in Italy and Optical Telescopes spread worldwide. Its SSA operational centre is the European Space Operations Centre (ESOC) located in Germany.

Russia operates International Scientific Optical Network (ISON) consisting of nearly 25 observatories and about 32 telescopes[13] spread across nine different countries. In addition to its ground based sensors, Russia also operates surveillance ships which are mobile and can provide larger expanse of coverage.

Chinese space radars are likely to be located at Xuanhua, Kunming, Henan, Hainan, and Jiangxi. Its Yuangwang series of space tracking ships enhance the coverage over a much larger area. These ships have also been known to be operating in the much discussed port of Hambantota of Sri Lanka during the recent times. China's Purple Mountain Observatory is one of largest ground based telescopes in the world. China has also recently commissioned the Ngari telescope in Tibet and the Patagonia telescope in Argentina.[14] Being a prominent member of Asia Pacific Ground Based Optical Space Objects Observation System (APOSOS).[15] China also reserves its rights to base its observatories in other countries.

INTERNATIONAL COOPERATION

Private companies and business groups have built their own network of SSA. Formed in 2009 is the the Space Data Association (SDA) wherein key private players like INTELSAT, SES and INMARSAT have come together to share sensors and data. Freelance space observers and private companies also come together on a common platform called See Sat-L which is a highly active group sharing some of the most exclusive data on space. It is popularly believed that See Sat-L has been responsible for detecting nearly

200 space objects which otherwise have not been made known to common space faring nations.[16]

SUMMARY

In all thus, following aspects emerge with respect to SSA:

- Major space faring nations are alive to the growing needs of SSA and are continuing to steadily upscale their SSA programs.
- SSA strengthens space security and is much desired for any prospective space power.
- Advancements in SSA sensors need to be made to enable detection of tiny space objects. Further, such sensors need to be spread globally needing a collaborative effort at government level.
- In addition to building superior sensors, SSA needs networking of sensors and undertaking interlinkages of agencies for fluent data flow.
- SSA synthesis needs to be undertaken in form of a structured organisation and collating data from sources on ground and also from sources based in space.

INDIA'S SSA CAPABILITIES

In the recent times, India has taken remarkable steps in the domain of SSA. In 2019, ISRO commissioned the SSA control centre which is to act as nerve centre for SSA data. As regards sensors, ISRO has developed the Multi-Object Tracking Radar (MOTR), which can simultaneously track 10 objects[17] in space. India may has also developed various civilian facilities like optical telescopes, radio telescopes, Gamma Ray & Metrewave Telescopes and Solar Observatories for scientific observations.[18]

In the domain of international cooperation, India together with the USA has worked towards a joint-statement in SSA in 2014. Further, BECA agreement with the USA and the SSA agreement in 2022 are noteworthy and speak of government's resolve in the domain. In 2018, India together with France, identified SSA as a one of the key domains of cooperation.[19] As bilateral cooperations are being progressed well by India, multilateral forums like the Consultative Committee of Space Data Systems (CCSDS) are yet to register India as a member country.

While considerable steps are being taken, ISRO has remained concerned about the need to further our SSA capabilities in light of India's reliance on USA's SSA data. ISRO's former Chairman, Dr K. Sivan highlighted the need to develop indigenous systems of sensors to reduce reliance on SSA data obtained from USA.[20] This may entail having a greater number of sensors with a much larger expanse. This also entails that India may not only have to rely on ground based SSA but also on SSA obtained from space-based assets thus requiring launch of a separate constellation on the lines of USA's SBSS, GSSAP & STSS.

WAY AHEAD FOR INDIA

A comprehensive and worldwide SSA network is cost prohibitive. It is therefore that most space faring countries have adopted a measured approach in the domain. Growing security concerns in space and fluid geo-political scenarios however imply that, SSA be given its due priority. While an all-indigenous SSA mechanism is an ideal answer, its practicability is questionable. A more pragmatic approach is to make gradual and steady progress in terms of building SSA sensors and their networks while also simultaneously progressing sharing mechanism with countries worldwide. India should, in the near term, aim to build moderate capabilities and work gradually with an eye for maturation in the domain in the long term. Five major lines of effort are presented here.

Policy Orientation. For most space faring nations, as began their endeavours for space, so did also begin their efforts for its military utilisation. National security, thus, lies at the heart of their space programmes. On the contrary, security as a defining tenet, was apparently not an essential component in India's case. Recent incorporation of the same in the India's Space Policy of 2023 is a remarkable and much awaited change. India should aim to build upon this policy change by strategically aligning its SSA program while also retaining its civilian scientific character. This entails that duality may have to be built in the SSA programme to meet the needs of both Civil and Military users.

Development of Superior Sensors. India may have to develop sensors with superior capabilities to observe immediate outer space in order to detect, track and catalogue OSO of sizes upto 10 cm or even below. This is significant not only from the point of view of collision avoidance with space debris, but also in light of presence of suspicious micro satellites which may have sizes as less as 10 cm.

Expanding the Spread of Sensors. In the near term, presence of these sensors has to be built across the Indian landmass while in the long term, presence of Indian sensors may have to be built globally. Initiation of such international mechanisms need to be undertaken now for their fructification in the long term. India may also consider developing and operating ships with inbuilt space tracking facilities on the lines similar to Russia and China.

Building a Sensor Network. Once data is collected, a network is required to enable its collation and processing at the Control Centre. Further, such network not only connects sensors to control centre but also to executive agencies which can undertake corrective actions on receipt of a collision warning. While building a national level network should be a near term objective, building a global network as also patching with networks of other countries should remain in the long term vision.

Data Sharing Mechanisms. Data sharing mechanism needs to be two pronged. Firstly, data sharing with international partners and secondly, collaboration with private partners. While international partnerships are being initiated, in the long term, India should aim for their maturation with robust mechanisms built-in. Participation in multilateral institutions like CCSDS needs to be given due weightage. Mechanisms like Defence Trade and Technology Initiative (DTTI) may be identified as a joint platform for research and development in this domain. India may also need to develop a more vibrant and comprehensive ecosystem of private SSA players. Public-private ventures in the domain not only speed up the SSA capabilities, but also help them expand faster globally.

CONCLUSION

India's space assets are likely to increase and so shall its civilian and military reliance on space. Safeguarding against collisions and countering malicious adversarial actions will therefore remain a desired capability. SSA will therefore be a key facilitator for India's continued space access. As major space faring entities are incrementally enhancing their budget allocations for SSA every year, their intentions for Space Control are becoming increasingly evident. To start with, moderate and short term objectives may have to be undertaken essentially focussing on strategic orientation and building of own capabilities. In the long term, increased indigenisation, matured international data sharing arrangements, global networking and well coordinated national level SSA organisation may have to be kept in the horizon in order to arrive at comprehensive solution.

Col Gaurav Soni is presently posted as Directing Staff in the Junior Command Wing, Army War College. The officer is from Artillery and has commanded his regiment along the Indian borders. He is currently pursuing PhD Research in 'Space Security Challenges: India's Response' from Amity University, Noida.

Dr William Selvamurthy has served as a Chief Controller, Research & Development in Life Sciences and International Cooperation DRDO. He is currently President of Amity Science, Technology and Innovation Foundation and Director General for Amity Directorate of Science and Innovation.

NOTES

1. *An Overview of Space Situational Awareness* at https://www. Spaceacademy.net.au/ intell/ ssa.htm. Accessed on 30 May 2019.
2. Mark Garcia *Space Debris and Human Spacecraft* at nasa.gov/mission-pages/station/ news/orbital-debris.html. Accessed on 30 August 2019.
3. Bhavya Lal, Asha Balakrishnan, Becaja M Caldwell, Reina S Buenconsejo and Sara A Carioscia 2018 *Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)(IDA* Virginia) pp.iii-iv.
4. Tim Flohrer, Krag Holger *Space Surveillance and Tracking in ESA's SSA Programme* at https://conference.sdo.esoc.esa.int/proceedings/sdc/paper/242/SDC7-paper242.pdf. Accessed on 30 May 2019.

5. Hand J Kelly et al 2016 *Environmental Space Situation Awareness and Joint Space Effects*, (USAFA Colarado) pp.2-3.
6. Mike Gruss *US Plans $6 Billion Investment in Space Situational Awareness* at https://spacenews.com/planned-u-s-investment-in-space-awareness-is-6- billion-gao-says. Accessed on 05 November 2019.
7. *A GEODSS Sourcebook* at https://fas.org/spp/military/program/track/geodss.pdf. Accessed on 04 May 2021.
8. Chun francis et al June 01, 2021 *A New Global Array of Optical Telescopes: The Falcon Telescope Network* at www.iopscience.iop.org.
9. *Orbit Outlook (Archived)* at https://www.darpa.mil/program/orbitoutlook. Accessed on 04 May 2020.
10. Mike Gruss *More Satellite Collision Warnings to Come with Space Fence Data* at https://spacenews.com/more-satellite-collision-warnings-to-come-with-space-fence-data. Accessed on 01 June 2021.
11. Staff Writers *Two New Satellites Now Operational to Expand US Spac Situational Awareness* at www.spacedaily.com/reports. Accessed on 7 November 2021.
12. Cheryl Pellerin *Top Official Describes DARPA Real-Time Space Awareness Efforts* at www.defense.gov/news. Accessed on 12 October 2021.
13. Molotov I Etal *ISON Worldwide Scientific Optical Network* at https://conference.sdo. esoc.esa.int. Accessed on 01 June 2019.
14. Cassandra Garrison *China's Military-Run Space Station in Argentina is A 'Black Box* at https://www.reuters.com/journalists. Accessed on 30 May 2021.
15. Ajey Lele 2013, *Space Awareness: A Need for a Multilateral Mechanism, Strategic Analysis Journal*, Vol 37 Pp. 2-7.
16. *Staff Writers Meet the Amateur Astronomers Who Track Secretive Spy Satellites for Fun* at www.popsci.com/zuma-spy-satellite-amateur-stronomer#page-5. Accessed 03 November 2019.
17. *Space Situational Assessment 2021* https://www.isro.gov.in/SSA.html. Accessed on 20 March 2024.
18. Mrilani Deshpande *Space Situational Awareness : Indian Perspective* at https://swfound.org/media/india-ssa-perspective. Accessed on 31 May 2019.
19. Rose A Frank *Op-ed : Growing US-India Space Security Ties* at https://spacenews.com/op-ed-growing-u-s-india-space-security-ties. Accessed on 21 April 2022.
20. Madhumati DS *ISRO initiates Project NETRA to safeguard Indian space assets from debris and other harm*, at https://www.thehindu.com/sci-tech/science/isro-initiates-project-netra-to-safeguard-indian-space-assets-from-debris-and-other-harm/article29497795.ece. Accessed on 30 March 2022.

42-58

REQUIREMENT AND CHALLENGES OF MULTI-SENSOR DATA FUSION

Gp Capt Amitabh Mathur (Retd) & Wg Cdr Vishal Jain

Abstract

Space has evolved as the fourth domain of warfare and has proven to be a 'game changer' as demonstrated by the recent conflicts. Space-based sensors offer enormous capabilities and possibilities that grow larger every day, and their exploitation is only limited by the users' innovative thought processes. However, the current satellites host only one or at least two sensors on one platform. Each sensor has some strengths and weaknesses. There is a case for hosting more than one sensor on a single platform with a real-time fusion of these, as well as the outputs of multiple single-sensor satellites and even ground-based sensors, to make the best use of the strengths of the sensors. The fusion of sensors will provide a much more precise picture to the commander on the ground, enabling him to make a more accurate and timely decision. The concept of data fusion has existed for some time now. However, fusion of data in real-time has been accentuated by the advent of newer sensors, processing techniques that are more advanced, and better hardware that has improved the quality of processing data. Presently, data fusion systems are being utilised expansively for tracking targets, their identification in an automated fashion, and applications with limited automated reasoning. The commercial market is becoming available with software for data fusion applications. In principle, fusion of multisensory data provides significant advantages over data from a single source. This article discusses the feasibility of multi-sensor data fusion and its advantages and suggests some civil and military applications. It also brings out challenges in multi-sensor data fusion and possible solutions using the latest technologies, such as Artificial Intelligence (AI) and Machine Learning (ML), to overcome these challenges.

INTRODUCTION

The current Russia-Ukraine and Israel-Hamas conflicts have highlighted the need for nations to embark on a rapid race to develop new capabilities. In future conflicts, space-based sensors would be essential for detecting, classifying, identifying, and destroying targets deep inside enemy territory. Surveillance and reconnaissance satellites provide strategic data for intelligence assessments and play a critical role in meeting the rapid response that is the requirement today for national security. The mission of these satellites has grown beyond the strategic sphere to more time-sensitive operational and tactical levels of support, even though intelligence is still a critical component of the mission. Persistence is necessary to meet these demands for quick responses in order to recognise threats that could arise at any moment or from any place, including mobile launchers, ships, submarines, aircraft, and even space.

The remote sensing process involves the use of various imaging systems where the following elements are involved: illumination by the sun or moon; travel through the atmosphere; interactions with the target; recording of energy by the sensor; transmission, absorption, reflection, and emission data for analysis; retrieval, interpretation, and analysis of the signals; and decisions for applications. Multi-sensor data fusion has drawn a lot of interest lately for both military and non-military uses. By combining data from several sensors with relevant information from linked databases, data fusion techniques can produce outcomes with greater precision and increased accuracy than obtained with just one sensor. Multi-sensor data fusion, as a concept, is not new; animals and humans have developed the ability to use multiple senses to improve their survival. Military applications for multi-sensor data fusion include guidance for autonomous vehicles, automated target recognition for intelligent weapons, battlefield surveillance, remote sensing, and automated threat recognition systems, such as identification of friend or foe systems. Fusion of multi-sensor data may increase the accuracy by combining data from the same source and its adding statistical advantage.

A prime example of the advantages of multi-sensor data fusion that is currently in operation is the F-35 fighter aircraft. It has multiple systems with associated sensors, like the airborne interception radar, the Electro-Optical Targeting System (EOTS), the Electro-Optical Distributed Aperture System (DAS), the Electronic Warfare suite that includes sensors like Radar Warning Receiver (RWR), the Communication, Navigation and Identification (CNI) system, etc, the data generated by which is fused together. The aircraft features autonomous sensor management where it also receives data from other friendly airborne and surface-based platforms which is fused on-board the aircraft's fusion engine using advanced computing algorithms. Applying this corollary to space, deploying different sensors, say combination of SIGINT and IMINT sensors, onboard a satellite along with use of AI and edge processing would help enhance situational awareness at strategic level.

PLATFORMS

In addition to ground and airborne sensors, near-space and space sensors are finding more significant applications in sensing. There are three overarching categories that satellites can be divided into: Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Orbit, also called Geosynchronous Equatorial Orbit (GEO) satellites. The most common satellites supporting global development are GEO satellites for communications, wildfire mapping and weather monitoring. These satellites orbit the Earth's equator at the same speed from west to east as the planet, which enables them to stay over a certain spot on the planet's surface continuously to capture imagery of its surface and atmosphere. GEO satellites' spatial resolution has been on an improving trend courtesy the technological advancements. The photographs of the Earth captured by sensors on-board LEO satellites at a considerably higher spatial resolution as compared to those by GEO satellites as the former are at much lesser distance to the planet. Another prominent kind of LEO satellites are the north to south moving Polar-orbiting satellites. Sun-synchronous orbit is a particular kind of polar orbit in which when a satellite orbits, it is able to capture the Earth at approximately the same time every day. Near space has become a domain where civil and military platforms find Intelligence, Surveillance and Reconnaissance (ISR) applications at heights from 20 to 50 km. The low perturbation in the weather allows the platform to remain aloft more easily with basic propulsion systems, a better line of sight to the ground is offered, and laser communications allow connectivity, which are the advantages for ISR applications. The High-Altitude Pseudo Satellite (HAPS) drones flying in the stratosphere have provided low-cost solutions and technological advantages compared to LEO satellites, which can stay aloft for 60 to 90 days. These HAPS can provide persistent coverage over the area of choice and can be exploited to cover the gaps, especially to counter the threats from hypersonic weapons. Recently, the US launched the X-37B, and China tested the Shenlong spacecraft, which is capable of delivering and intercepting payloads in space, altering their orbits, and returning to the Earth for refuelling.

ADVANTAGES OF MULTI-SENSOR FUSION

Data fusion is amalgamation of data obtained from multiple sources in order to attain improved information. Data fusion in a multi-sensor environment, by using data from multiple dispersed sources, results in various advantages such as the few enumerated below:

- Higher probability of detection.
- Ambiguity reduction.
- Increase in detection accuracy.
- Reduction in false alarm rate.
- Reduction of heterogeneous errors.
- Lower detection error probability.

- Higher reliability.
- Increased system availability.
- Reduced communication bandwidth.
- Improved all-weather performance.

TRENDS IN MULTI-SENSOR FUSION

Software tools like the Geographic Information Systems (GIS) are crucial in military operations as they translate the database to create, manage and analyse the information spatially on the map. Command, control, communication and coordination concepts in military operations primarily depend on the availability of accurate data and enable fast decision-making. In the present digital era, ISR requirements are near real-time. While there are different sensor technologies for target detection, identification, and classification [Communication Intelligence, Electronic Intelligence, and Imagery Intelligence (COMINT, ELINT, IMINT)], we may not get near real-time actionable technical intelligence unless data from these sensors are fused. Due to technology constraints, each sensor type and platform has advantages and disadvantages. Aerial imagery offers spatial resolution of up to 1-5 cm per pixel. Compared to satellite photos, the field of view covered by an aerial photograph is substantially smaller and more mission or task-specific. Aerial photography is excellent for more localised applications that maximise spatial resolution. Aerial and satellite data share this complementary relationship making the two potent sources of valuable geospatial information. Thus, different sensors detect, identify, and classify other targets (static or moving) with varying resolutions, swaths, and revisits. Different image fusion algorithms may be needed due to the proliferation of space-borne sensors. Another challenge in fusing the real-time data from various sensors is the platform (ground, air and space-based) on which these sensors are installed. In the maritime domain, the moving targets and their data are available at different times and pose a challenge for data fusion. In the current Russia-Ukraine conflict, Palantir's software, which uses Artificial Intelligence (AI) to analyse satellite imagery, open-source data, drone footage, and reports from the ground to present commanders with military options, is "responsible for most of the targeting by the Ukrainians".[1]

The development of remote sensing images in many visual tasks has increased the demand for obtaining images with better precision in details. However, directly providing images rich in spatial, spectral, and temporal information at the same time is not feasible. Combining the information from several photos is one workable technique. Deep learning has made remarkable progress in image processing for fusing remote sensing images at the pixel level. There must be a trade-off among spatial, spectral, and temporal resolution, as these cannot be maximised simultaneously. Trade-offs between the temporal, spatial, and spectral resolutions must be made by a single remote sensor. In order to properly give the various properties of the targets, many modern satellites frequently have two or more different types of sensors. Besides optical images, radar images obtained by Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LiDAR) enhance the detected target's descriptive and expressive ability. While LiDAR measures the time and change in intensity of the laser to travel to and for the target, SAR records the intensity of the radar signal's backscatter. Deep learning is to be used. Compared to optical images, they can provide complementary contextual and structural information, widely used in visual tasks such as cloud removal and mapping.[2] Therefore, there is a need to understand the difference between syntactic understanding and semantic understanding to build a fusion hierarchy.

One feasible solution is to use image fusion technology. The fusion results can fully use complementary information and correlation of multiple images to generate a more comprehensive and accurate interpretation of the same scene than ever before.[3] The best remote sensing method depends on the classification problem's complexity, the available data set, and the goal of the analysis.[4] Multi-sensor data fusion can be carried out at following four processing levels:

- **Signal Level Fusion.** In signal-based fusion, signals from different sensors are combined to create a new signal with an improved signal-to-noise ratio than that of the original signals.[5]
- **Pixel Level Fusion.** Pixel-based fusion is performed on a pixel-by-pixel basis. It generates a fused image in which information associated with each pixel is determined from a set of pixels in source images to improve the performance of image processing tasks such as segmentation.[6]
- **Feature Level Fusion.** Feature-based fusion at the feature level requires extracting objects recognised in the various data sources. Depending on their environment, it involves extracting salient features such as pixel intensities, edges, or textures. These similar features from input images are then fused.[7]
- **Decision Level Fusion.** This consists of merging information at a higher level of abstraction and combining the results from multiple algorithms to yield a final fused decision. Input images are processed individually for information extraction. The obtained information is combined, and decision rules are applied to reinforce common interpretation.[8]

Current Trends. The present trends in multi-sensor data fusion are:

- **Deep Learning for Feature Extraction and Fusion.** Deep learning models (like convolutional neural networks) are revolutionising how features are extracted from diverse sensor data. Instead of hand-crafted features, deep learning involves the most relevant representations directly, improving fusion accuracy and adaptability.
- **Multi-Modal Fusion.** Combining data from significantly different sensor types (e.g., optical, hyperspectral, radar, LiDAR) is a significant focus. This unlocks a much richer understanding of the observed environment.
- **Generative Adversarial Networks (GANs).** GANs are used for tasks like image super-resolution and image translation. This allows the fusion process to generate enhanced data or translate between sensor modalities, improving decision-making.

- **Attention-Based Models.** Attention mechanisms (like transformer architectures) selectively focus on the most critical features from different sensor data streams. This improves the efficiency of data fusion and makes it more robust.
- **Graph-Based Fusion.** Graph Neural Networks (GNNs) characterise the dependencies and relationships between the data points from various sensors. Fusion methods that are more sophisticated are made possible by GNNs, especially for time-series or complex scenes data.
- **Uncertainty Quantification and Explainable AI.** Fusion models can be integrated with uncertainty measures so as to be able to assess the reliability of the result, a crucial requirement for critical applications. Explainable AI techniques help improve the transparency of these complex models.

NOAA'S HAZARD MAPPING SYSTEM (HMS)

The Hazard Mapping System (HMS) is a tool used by the National Oceanic and Atmospheric Administration (NOAA) to detect fires and the smoke emissions produced by them over North America that degrade the quality of air. The system utilises imagery produced by the sensors on-board seven NASA and NOAA satellites operating in geostationary and polar orbits in a singular workstation environment to generate the desired results. The data produced by the geostationary satellites, GOES-11 and GOES-12, has high temporal (15 minutes) but nominal spatial (4 km) resolution. Visible imagery that is used for detection of smoke has a resolution of 1 km. NASA's Terra and Aqua spacecraft in the polar orbits provide host the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument whereas the Advanced Very High Resolution Radiometer (AVHRR) is available on NOAA-15, NOAA-17 and NOAA-18 satellites, again, in polar orbits. This data by polar satellites has a resolution of 1 km for the 3.9μm band but lower temporal resolution. The low and mid latitudes are imaged twice a day by the polar orbiting satellites while locations at higher latitudes have a frequent temporal resolution of up to 6 times a day. The sensors employ automated fire detection algorithms. The analysts incorporate suitable algorithms and control procedures for accepting, adding, discarding and validating fire detection hotspots which is them analysed. The HMS generates forty eight hour smoke forecast aids in air quality forecasting. The HMS also allows integration of other ancillary data with the imagery data in near-real time and continuously updates as newer data keeps becoming available.[9] In this manner, data from different types of sensors with varying temporal and spatial resolutions is fused to exploit the strengths of each one of the sensors while overcoming their individual limitations.

CIVIL APPLICATIONS FOR MULTI-SENSOR FUSION

- **Precision Agriculture.** Multi-sensor fusion of hyperspectral and high-resolution optical imagery can enable precision agriculture by identifying nutrient deficiencies and diseases in crops and crop stress early on. For targeted interventions, structural information of crops can be provided by LiDAR data.
- **Disaster Monitoring and Response.** Pro-active monitoring of natural disasters is possible by amalgamating radar, optical and thermal data which builds up timely situational awareness in case of fires, floods and earthquakes. The usage of radar data enables monitoring in cloudy conditions as well. This pro-active approach would result in much improved rescue efforts and more efficient allocation of resources.
- **Urban Mapping.** LiDAR point clouds fused with optical imagery generate highly detailed 3D urban models, invaluable for urban planning, change detection, and infrastructure monitoring.
- **Environmental Monitoring.** Data fusion enables comprehensive tracking of land-use changes, deforestation, water quality, and biodiversity across multiple sensor types and periods.

MILITARY APPLICATIONS FOR MULTI-SENSOR FUSION

- **Intelligence, Surveillance and Reconnaissance (ISR).** These are the core applications. Fusing imagery and data from various sensors (optical, infrared, radar, hyperspectral, LiDAR) on satellites, drones, and aircraft provides unprecedented situational awareness. The Automatic Identification System (AIS) for maritime tracking is being installed on ISR satellites

- **Troop and Vehicle Movements.** Identifying enemy formations, concealed units, and force build-ups.
- **Infrastructure Detection.** Mapping supply routes, bases, communication facilities, and potential targets.
- **Camouflage Penetration.** Synthetic Aperture Radar (SAR) can pierce some camouflage; infrared and hyperspectral sensors can detect heat signatures or spectral anomalies indicating concealed objects.
- **Target Acquisition and Precision Strikes.** Multi-sensor fusion creates highly accurate targeting data for guided weapon systems.
- **Geolocation Accuracy.** Combining GPS, optical imagery, and terrain data (from LiDAR, for example) delivers precise coordinates for artillery, missiles, or air strikes.
- **Change Detection.** Comparing images over time highlights anomalies for targeting, like new structures or the appearance of high-value targets.
- **Battle Damage Assessment (BDA).** Post-strike analysis using high-resolution imagery and sensor data evaluates the effectiveness of attacks. This informs decisions on re-engagement or target confirmation.

THREAT DETECTION AND COUNTER MEASURES

- **Missile Defence.** Combining radar, infrared, and optical sensors offers enhanced early warning and tracking of ballistic and cruise missiles.
- **Counter-Drone Systems.** Fusing acoustic sensors, radar, and optical data helps detect, identify, and neutralise small drones that pose increasing threats.

TERRAIN MAPPING AND NAVIGATION

- **3D Terrain Models.** LiDAR and photogrammetry create accurate 3D terrain representations for mission planning, identifying choke points, and simulating attack scenarios.

- **Obstacle Avoidance.** Real-time sensor fusion on vehicles and drones enables autonomous navigation and obstacle detection in complex environments.

MULTI-SENSOR FUSION METHODOLOGY

Data collection is the first step. The accuracy of target coordinates' data will assist in integrating the targeting weapon system. Artificial Intelligence (AI) and Machine Learning (ML) require data to train the system. There must be a trade-off among spatial, spectral, and temporal resolution, as they cannot be maximised simultaneously. Deep learning is to be used. For example, hyperspectral imaging is the best way to handle camouflage. The data set for strategic targets like a silo of Intercontinental Ballistic Missiles (ICBMs) is not readily available for ML. Therefore, there should be mechanisms to generate synthetic data. To build a fusion hierarchy, there is a need to differentiate between syntactic and semantic understanding. Fusion algorithms like high pass filtering, Intensity-Hue-Saturation (IHS), multi-resolution analysis-based methods, Principal Component Analysis (PCA), different arithmetic combinations (e.g., Brovey transform) and artificial neural networks are some of the algorithms used for remote sensing. Each fusion method offers its own advantages and suffers from its limitations. Clouds offer benefits in speed, scale, and flexibility. They also help with "data fusion"—combining different pieces of information to reveal things one source cannot capture, including things no human would think of looking for.[10] Resilience helps systems to remain adaptable and flexible to ad hoc changes and resistant to failures without loss of performance.

Some of the examples of sensor fusion are:

- **Hyperspectral + SAR**. Hyperspectral imagery reveals objects' 'chemical fingerprints', identifying materials used in camouflage or weapons manufacture. By seeing through clouds and some foliage, SAR confirms the locations of these potential targets.
- **Optical + Infrared + Radar**. Optical imagery provides high-resolution visual detail. Infrared detects heat signatures from vehicles and activity.

Radar can see through adverse weather conditions or even provide ground penetration capabilities. Fusing these delivers a clearer picture, by day or night, in rain or sunshine.

- **Signals Intelligence (SIGINT) + Geospatial Data**. Geotagged SIGINT data (like intercepted communications) fused with satellite or drone imagery can reveal the disposition of enemy forces or the origin of hostile transmissions.

CHALLENGES IN MULTI-SENSOR DATA FUSION

Data fusion based on multiple sensors hosted on ground and aerial platforms is a reality today. However, space-based platforms still host mostly single sensors [Electro-Optical (EO), SAR, COMINT, ELINT, etc.], and data fusion in near real-time from different sensors is a challenge due to the non-availability of varying sensor data simultaneously. By repeatedly returning to the same region of the Earth, satellites are able to give great temporal resolution over vast regions of the surface. A satellite can constantly collect data for the length of its lifespan (for decades), thereby, making the imagery valuable and cost-effective for use cases like detecting changes and monitoring on a large scale. Considering the advantages of space-based sensors, most advanced armed forces have deployed multiple single-sensor satellites in different orbits and inclinations to achieve near real-time ISR capabilities in their area of interest at considerable cost. The concept of 'Tip and Cue' has evolved to achieve near real-time ISR with single-sensor systems. At the same time, SIGINT satellites provide the tip for subsequent cues by the high-resolution EO/SAR sensors for detection, identification, and classification.

Deploying multiple sensors on identical spacecraft is the need of the hour for near real-time persistent ISR. A consortium of private companies, including GalaxEye, Ananth Technologies, and XDLINX Labs, has initiated a SAR and optical payload project on-board a single satellite, which will likely be launched in 2024.[11] Apart from hosting the various sensors on the spacecraft, there is also a need to develop high-speed on-board processing capabilities and data fusion algorithms and establish Earth stations spread across the globe connected on high-speed data downlinks for near real-time ISR capabilities. Communication satellites placed in geosynchronous orbit are increasingly broadcasting high-power digital signals. They can be used for passive bistatic geosynchronous radar applications by adding an appropriate receiver to another satellite. Such a receiver will sense the scattered signals of the transmitter, and if in sync, will form SAR images of the target. Ground-based bistatic receivers can also help track targets using space transmissions and ground and air assets of commercial and military broadcasts. While the need for correlating and collating the data and information received from the various types of sensors described earlier is indisputably justified, the task is more complex and uphill than appears at first glance.[12] The challenges in integrating the information are also of several types and originate from various contexts. Some of these are enumerated below:

- Data quality and calibration. Misalignment, noise, and resolution differences between sensors remain key challenges. Preprocessing and sensor calibration are essential. The five Vs of data are volume, velocity, veracity, variability, and variety. They are derived from big data systems but often, sensors produce large volumes of data sent at high speed through network links, the veracity of which must be checked, which might vary over time and contain a wide variety of data types from various sub-systems. The task of optimising satellite communications can be done by using AI.[13]
- Integrity as a property ensures accuracy and comprehensiveness of the system where multiple nodes are operating in each system. Resilience helps systems to remain adaptable and flexible to ad hoc changes and resistant to failures without loss of performance.
- Scalability to big data. Large-scale fusion demands efficient algorithms that can handle the increasing volume and variety of remote sensing data sources. Modularity is a property where smaller components are combined to form large systems. These modular components should be

such that they can be removed or replaced without any disturbance to the system's operation.

- Data accessibility. Promoting open data policies and cloud-based solutions will democratise multi-sensor fusion research and applications.
- Non-standard data formats are used by different Original Equipment Manufacturers (OEMs). Sensor data conflicts arise from different accuracies and reliabilities of the deployed sensors.
- Non-homogenous data increases false alarms. For example, one aircraft detected by different radars might be presented as multiple aircraft on an integrated screen.
- Requirement of high level of customisation because of a wide variety of sensors.
- A more significant challenge for customising space-based sensors as compared to terrestrial sensors.
- Challenges of integrating near-real-time data. The capability of a system to perform computation in real-time when an external process occurs so that those results can be made use of to control, monitor, and respond to, the process.
- Copyrighted algorithms used by OEMs in sensor handling.
- Non-maturity of indigenous data fusion and integration algorithms.
- Use of AI applications to interpret and fuse a large volume of images / videos at a centralised data processing facility.

MILITARY APPLICATION CHALLENGES

- **Formulation of Joint Space Doctrine.** There is a need to evolve the procedure for the formulation of a Military Space Doctrine and place it in the open domain for use by the civil-military industrial complex. It will pave the way for those involved in research, development, innovation, safe operations, and maintenance of systems. After the doctrine is released, it will be a precursor for the Military Space Strategy to provide the right direction to the stakeholders. Following the existing international treaties, the strategy will bring solutions to enforce net-centric ISR.

- **Defense against Non-Kinetic Weapons.** The Outer Space Treaty of 1967 bans territorial claims on celestial bodies and the stationing of nuclear weapons in space, but it is silent on conventional weapons. Other threats include ground-based "directed energy" weapons: lasers, high-power microwaves, and radio-frequency jammers.
- **Data handling and processing speed.** Massive amounts of raw sensor data pose challenges. On-board pre-processing and robust computing infrastructure are needed for real-time analysis.
- **Artificial intelligence.** Employing AI and ML for automated object recognition, threat analysis, and optimised sensor deployment will be essential. That is, while AI and ML are exploited to analyse the information and deliver solutions, they also need be used for automated threat detection, mitigation and response against cyber-attacks for protection of critical information, systems and infrastructure. Developing ML algorithms for cyber security of own networks and systems would make them more robust by enabling them to work in real-time.
- **Sensor miniaturisation.** Smaller, more powerful sensors enable deployment on a broader array of platforms, especially small drones, for tactical battlefield awareness.
- **Defense against Cyberattacks.** Data security and resilience fusion systems must be robust against cyberattacks, jamming, and deception, as adversaries will also employ advanced counter measures.

CONCLUSION

Space, the fourth domain of warfare, is the new frontier which has emerged as a "game changer" in war. Space control has become as important as land, sea, and air dominance and is increasingly congested, contested, and competitive. Space technology makes military forces in all other domains more powerful. ISR satellites offer nations a "persistent stare capability" that makes battlespace transparency possible through practical ISR. The SIGINT (ELINT and COMINT) satellites help monitor the enemy's radar transmissions and communications. The electro-optical, synthetic aperture radar and infrared capabilities help accurately locate the targets in real-time. Military forces use GIS in various ways, including cartography, terrain analysis, intelligence, battlefield management, remote sensing, and military installation management. There is a need to have satellites carrying multiple payloads of ISR. A start-up in India has recently taken one such step. In addition, the fusion of data monitored by various sensors mounted on numerous platforms must be undertaken to ensure accurate data is correlated. Developing software and AI tools will enable a better appreciation of the situation. The promulgation of the Space Doctrine and Strategy will pave the way for the optimal utilisation of civil-military assets.

Gp Capt Amitabh Mathur (Retd) was commissioned in the Aeronautical Engineering (Electronics) branch in the IAF. He has served in various systems like surface-to-air guided missiles, Electronic Warfare, specialist aerial weapons fitted on a frontline fleet and CBRN. He is an alumnus of Defence Services Staff College, Wellington and College of Defence Management, Hyderabad.

Wg Cdr Vishal Jain is a Senior Fellow with Centre for Joint Warfare Studies (CENJOWS), New Delhi.

NOTES

1. Vear Bergengruen, "How Tech Giants Turned Ukraine into AI War Lab", Time, 08 February 2024. https://time.com/6691662/ai-ukraine-war-palantir.
2. Zhaobin Wang, Yikun Ma and Yaonan Zhang, "Review of Pixel-Level Remote Sensing Image Fusion Based on Deep Learning", *Information Fusion*, Volume 90 (February 2023), pp 36-58. https://doi.org/10.1016/j.inffus.2022.09.008.
3. Ibid.
4. *Image Processing for Remote Sensing*. (n.d.). Google Books. https://books.google.co.in/books?hl=en&lr=&id=gG25PB-NY7MC&oi=fnd&pg=PA249&dq=multisensor+data+fusion%2Bremote+sensing&ots.
5. Magdi S. Mahmoud and Yuanqing Xia, Networked Filtering and Fusion in Wireless Sensor Networks (Boca Raton: Taylor & Francis, 2015) 260-261. https://vdoc.pub/documents/networked-filtering-and-fusion-in-wireless-sensor-networks-2sft4mp8djpg.
6. Ibid.
7. Ibid.
8. Ibid.

9. Ruminski, Mark & Simko, John & Kibler, Jamie & Kondragunta, Shobha & Draxler, Roland & Davidson, Paula & Li, Po. (2008). Use of multiple satellite sensors in NOAA's operational near real-time fire and smoke detection and characterization program. 7089. DOI:10.1117/12.807507. https://www.researchgate.net/publication/252456636_Use_of_multiple_satellite_sensors_in_NOAA's_operational_near_real-time_fire_and_smoke_detection_and_characterization_program.
10. "Where to Process Data, and How to Add Them Up", *The Economist*, 29 January 2022. https://www-economist-com.ezproxy01.rhul.ac.uk/technology-quarterly/2022/01/29/where-to-process-data-and-how-to-add-them-up.
11. "GalaxEye, Ananth Technologies, XDLINX Labs, Antaris Join Forces to Build Satellite with Optical Payloads", *Outlook*, 16 September 2022. https://startup.outlookindia.com/sector/saas/galaxeye-ananth-technologies-xdlinx-labs-antaris-join-forces-to-build-satellite-with-optical-payloads-news-6389?utm_source=article_sharing.
12. David L. Hall and Alan Steinberg, "Dirty Secrets in Multisensory Data Fusion", https://apps.dtic.mil/sti/tr/pdf/ADA392879.pdf.
13. Janette Beckman, "Navigating the Future: AI and Satellite Communication at the Heart of TS2 Space's Reliability", Zaman Österreich, 16 March 2024. https://zaman.co.at/bez-kategorii/navigating-the-future-ai-and-satellite-communication-at-the-heart-of-ts2-spaces-reliability/870146/.

59-70

LEVERAGING 'NEW SPACE' DOMAIN-AN INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE PERSPECTIVE

Gp Capt Arvind Pandey (Retd)

Abstract

In present times Space has become ultimate high ground for warfare. In past two decades space exploration has seen global outreach and will to conquer. Intelligence is a prerequisite to win a war and ISR plays a crucial role in ensuring precise and timely intelligence. Globally, space faring nations have concluded that without public private partnership timely inclusion of evolving technology is difficult to achieve in this domain. News pace has thus born to commercialise the space and take the applications to new heights. Earth orbit altitudes give an insight into the capabilities of ISR sensors onboard these satellites. LEO has been most sought after orbit as it gives several advantages for earth observation and capability to responsive launch. Evolving technologies i.e. AI, edge computing and sensor fusion along with novel methods of ISR generation i.e. RF cueing and IR/SAR/Hyper spectral imaging gives a cutting edge in present era. Indian space ecosystem has got a boost in recent times with government policies and require public private partnership for success.

INTRODUCTION

Space has made substantial contributions to our civilisation. The moon was used to build the earliest calendars, the sun allowed humans to measure the number of hours in a day, and stars assisted explorers in navigating the world. In recent years, space has continued to drive human creativity, with scientific discoveries in space helping us to understand more about our own planet. Space has increasingly become a battlefield during the previous few decades. Since the start of warfare, obtaining intelligence on adversaries has been essential to military strategy. Being aware of your rivals' strategies, tactics, and goals might spell the difference between victory and failure.

There is a need for strategy oriented approach to evolve ISR mechanisms thereby ensuring meeting the commanders need on ground and expectations in a complex operating environment. ISR strategy is to start by examining and framing of the problem, identifying mission expectations and objectives in a way that fulfills the requirement. The capacity to observe what the opponent is doing, by any means of collection of intelligence on ground or from the air/space, is crucial to knowing about the enemy in advance which ultimately leads to conquest. With the evolving space-based imaging, intelligence analysts were able to gaze deeply and consistently into rivals' territories, frequently offering initial signals and indications of military activities in successive wars in recent past.

The space sector is undergoing significant changes, known as 'New Space'. This outlines the process of liberalizing space operations and reorienting the space sector for commercial objectives. New Space is related with the rise of new players from private entrepreneurship who wants to exploit space technology and create new market possibilities, lowering barriers to entrance into the industry. Convergence with the technological revolution is a critical component of the space sector's ongoing evolution. Global technological behemoths spent substantially in space in the early 2000s, developing their space systems with government assistance.

Intelligence, Surveillance and Reconnaissance (ISR)

The goal of ISR, a military activity, is to assist "decision makers in anticipating change, mitigating risk, and shaping outcomes." The definition of ISR is "an integrated operations and intelligence activity that plan and coordinate the use of assets, processing, exploitation, and dissemination systems, as well as sensors, in direct support of ongoing and future operations." The result of surveillance and reconnaissance activities, intelligence is produced at the nexus of military strategy, operations, and assessment.[1]

Intelligence. The outcome of gathering, integrating, evaluating, analysing, and interpreting the information that is now accessible about other countries, hostile or possibly hostile troops or components, or regions of current or future operations is intelligence.

Surveillance. Aerospace, cyberspace, places, people, or objects that are systematically observed using visual, auditory, electronic, photographic, or other methods is known as Surveillance.

Reconnaissance. It is intended to gather information on an enemy's or adversary's activities and resources by visual observation or other detecting means, or to secure data on the meteorological, hydrographic, or geographic aspects of a certain area.

Recent ISR satellites are technologically advanced and potent, but they are also incredibly costly. Because of the short period between design and manufacturing, it is impossible to include all technological improvements that have occurred in the meanwhile. An ISR satellite's life expectancy is typically five to 10 years, as constructed or computed. At lower altitudes, satellites suffer more from Earth's atmospheric drag and need more fuel to keep their orbit altitude. The principal cost driver, the size limits of the observation equipment, is influenced by the selected altitude. Reducing the satellite's orbital altitude results in a shorter lifespan because of the fuel's weight for operation of the satellite.

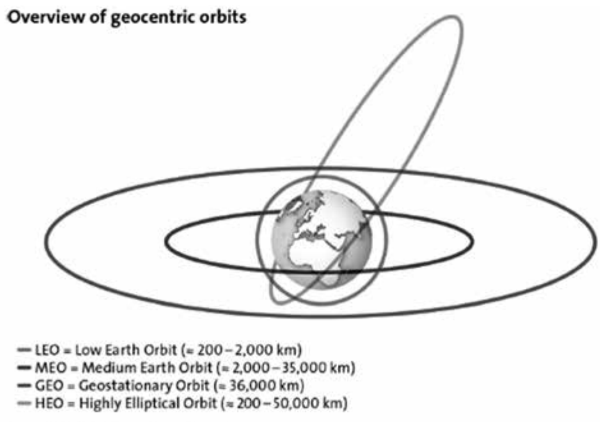
On the other hand, lowering the orbit height enables a decrease in the overall optical system's size and weight or an increase in the maximum ground resolution. Reducing the satellite's total launch mass will also decrease its anticipated lifetime and thus launch costs. Satellites operate in a hazardous atmosphere wherein it is important that the exposed components are radiation hardened and ensuring redundancy of involved sub-systems will help them attain their intended lifespan while drastically increasing production costs. Shorter-lived, smaller satellites are less expensive, and until they are deployed, provider countries may continue to upgrade them with cutting-edge technology.

There are technologies available now that allow for resilience and reconstitution, and they may be developed and demonstrated using tiny satellites. These technologies will address customers' most difficult challenges, significantly shorten the design-to-launch timescale, fly in formation to provide huge synthetic apertures for improved resolution, and quickly alter on-orbit configurations in response to changing mission sensing needs. In the years running up to 2035, such technologies will continue to progress, creating off-ramps to fresh, perhaps superior capabilities.

Congested, contested, and competitive are the three tendencies that will shape the strategic environment of the future. In terms of the trend of congestion, as more countries enter the space industry, their satellites and space debris are contributing to physical congestion. The radio frequency spectrum for space applications is also becoming more crowded. As more nations attempt to launch their systems into space, the trend of space as a disputed region will only intensify. The United States will face ongoing challenges in space as nations like China and Russia vie for supremacy. The third trend of competitiveness has also increased with commercial imagery providers like MAXAR, ICEYE and countries such as the Japan, Germany, Canada and India.[2]

Nowadays, the fifth operational area in combat is space. It consists of the space-based satellites, the terrestrial infrastructure they support, and the information layer that links the two. Our Armed Forces can now compete in the Information Age thanks to all of this. In order to deal with ongoing competition in the future, we need to establish a standard for space behaviors that will improve the predictability, security, and transparency of all space systems and allow us to operate—and compete, if needed—in and via space. Enabling our Armed Forces to respond to upcoming global problems will need a thorough awareness of activities in the space domain and the capacity to guard, defend, and integrate, just as we have done for the other domains.

Current Space-Based ISR Architecture. Presently, the space-based ISR architecture consists of satellites in Low Earth Orbit (LEO), 200–2,000 km; Medium Earth Orbit (MEO), 2000–35,000 km; Highly Elliptical Orbit (HEO), 200–500 km above the earth at the closest point, and 50,000 km above it at the farthest point, as well as Geostationary Orbit (GEO), which is roughly 36,000 km above the earth.



For space-based ISR applications, each form of orbit offers pros and cons. A system in LEO provides superior resolution and a greater return rate over earthly points of interest because of its close proximity to the planet, but it also needs more satellites for global or regional coverage and is more vulnerable to attacks. Due to its orbit, a system in MEO can cover a larger area continuously and with fewer satellites than a system in LEO. It also offers faster response times in the event of launched threats. However, achieving the same resolution as LEO systems requires a larger sensor, and launching and positioning into a final MEO orbit requires more power.

The benefit of hours of continuous coverage over a region of interest is available to a system deployed into a High Earth Orbit (HEO). Since a GEO system is further from Earth than the other three, it would be harder for an enemy to threaten it; nevertheless, its resolution is lower and its launch needs more power to this orbit.[3]

SENSORS ONBOARD COMMERCIAL SATELLITES

- **Electro Optical (EO) Spectrum Sensors.** The aim of satellite constellation of Planet is to be able to capture a daily image of the whole world. The WorldView Legion constellation, which Maxar is developing, is expected to visit similar spots on Earth by viewing them several times every day for better battle transparency. A fleet of high-resolution satellites teamed with high revisit rate on daily basis for intelligence gathering is operated by BlackSky. Indian start up KaleidEO is developing EO satellite with onboard edge computing for faster data delivery.[4]
- **Synthetic Aperture Radar (SAR) Sensors.** Commercially owned SAR satellites, such as those being developed/operated by Capella, ICEYE and Umbra Lab, are able to capture images of the Earth under a variety of atmospheric conditions both during the day and at night. In addition to supporting several other uses, the NASA-ISRO jointly developed SAR (NISAR) Mission will assess Earth's dynamic surfaces, ice masses, and changing ecosystems. This data will be useful in determining groundwater levels, biomass, natural hazards, and sea level rise. NISAR will be the first radarof its kind in space with two different radar frequencies which will observe Earth's surfaces globally with regular intervals.[5]
- **Infrared (IR) and Hyperspectral (HSI) Sensors.** Commercial satellite operators are also developing systems with evolving technology in Infrared region and Hyperspectral imaging that can potentially determine chemical and material composition of the surface monitored. This ability of the satellite helps to identify the agricultural pick and subsequently finalising what crops to put in which fields while simultaneously detecting different camouflage materials aiding in concealing a weapon system. Teledyne, HySpecIQ, Orbital Sidekick, Albedo, and Hypersat are among

the global commercial suppliers. Indian start up Pixxel is establishing a constellation of HSI satellites after initial technology demonstrator.[6]

- **Multi Sensor Fusion Data.** Maxar is working with numerous commercial service providers to integrate its GEOINT capabilities with various sensor types for sensor fused data. Ursa is working on a software program that would allow users to leverage SAR from several sources. Image aggregators are able to identify the need of the user and provide the best solution for the military requirement. Indian start up GalaxEye is developing SAR+EO sensor on a single satellite platform to boost the requirements.[7]
- **Space-based SIGINT Sensors.** The satellite-based radio frequency (RF) collecting tools from Hawkeye 360 and Aurora Insight are available. This has a number of uses, including search and rescue and cargo tracking, by identifying and geolocating a variety of radio frequency emitters. Hawkeye 360 started tracking GPS interference with this technique in late 2021 and successfully discovered jamming of GPS signals by Russian forces around Chernobyl before they entered Ukraine. The Space Systems Command of the USSF is creating instruments to identify, track, and eventually reduce GPS and radio frequency interference. Commercial RF developers Spire, an American company, and its international partner Kleos are constructing constellations to detect and pinpoint the location of radiofrequency signals for military uses.

INDIA'S PERSPECTIVE FOR ISR

India has a lengthy coastline (about 7,516 km) and a border (length 15,106 km).[8] As a result, space-based reconnaissance capabilities for continuous area monitoring of the key regions become essential for national security. ISR space based systems gather and analyse signals and imagery for a variety of purposes to enhance efficacy of combatants: preserving order of battle and situational awareness; keeping an eye on enemy movements and weaponry; creating extremely precise targeting data; issuing alerts and warnings; and evaluating battle damage. Comprehending the adversary's counter-space capabilities and devising strategies to neutralise them or devise alternative approaches is also crucial. ISR should include any constraints or influences on assets that are in orbit rather than relying just on satellites. For example, adversaries with effective counter-Space capabilities or jamming devices may interfere with the utilisation of images to facilitate targeting assessment. It should be taken into account that the earliest generation of satellites lacks self-defense or anti-jamming hardware. In addition, ISR enhances space situational awareness and must to be protected against any encroachment or assault on military satellites.[9]

The term "New Space" describes the recent opening of the Indian space industry to private enterprises following the enactment of the national geospatial policy (2022), the Indian space policy (2023), and the Indian space FDI policy (2024). The fast growth of the downstream space segment—that is, space-related commercial applications and services—is linked to the liberalisation of space operations, which takes place at the same time that the economy is becoming more digital. To increase battlespace awareness and target beyond line-of-sight, commercial satellite images must be utilised. India's national security must take advantage of all available public and commercial space-based ISR capabilities. The mix of available resources implies that combined capabilities can be genuinely spectacular, even while no particular entity can offer the fully persistent view of all the ISR requirements of any specific defence requirement. New solutions to help make it achievable will come from industry innovation in the present times. ISR has a crucial role in disaster mitigation and management. It is prudent to have advanced information about disaster from modeling and simulations. Stake holders involved must be capable of handling the disaster as and when it strikes.

Maxar, a commercial imagery supplier, has made a significant worldwide advancement by providing mobile pads that provide real-time, direct access to their imaging satellites, therefore altering the Indian perspective, drawing on its experience in Ukraine. As a tactical operational tool, this might allow military forces in the field to download electro-optical (EO) pictures from

Maxar's satellites. Tactical timelines have shortened from days or hours to minutes or seconds as the battlefield requirements have shifted from isolated regions to several simultaneous locations at the same time. This has shortened the sensor-to-shooter latency and therefore the OODA loop.

In order to avoid relocation costs and relaying activities, LEO satellites cover all the areas that aircrafts were previously used to cover between regular satellite operations. The ISR niche may then be further narrowed to include UAVs. UAVs may be designed to deploy localised "Cubesats" at heights of 60,000 feet, pop up and loop to remain in one place for twenty-four hours a day, and provide commanders access to satellite-based communication and relay capabilities.

RESPONSIVE LAUNCH OF ISR SATELLITES

High-tech ISR satellites are and will continue to be an essential component of decision-making. They are best positioned in polar orbits to provide persistent global ISR gathering. ISR satellites would probably be the first to be targeted in a confrontation when adversaries having kinetic or non kinetic counter-space capabilities would engage in the temporary/permanent disablement of certain satellites. The development and multiplication of counter-space assets will make this even more crucial in the future. Small and quickly ready-to-launch satellites will be increasingly crucial to launch new assets in specially-designed orbits and to repair or reconstruct a degraded capacity. Definitely it is a strategy that by using satellites in an optimal orbit, nations may cover a specific area of operations.

This makes it possible for the operational planning procedure to incorporate the particular orbit design. "Operational responsive launch" is the name of this methodology. Particular orbital characteristics that are computed for a given mission define operational responsive launches. Although highly developed satellites will never be completely replaced by small, quickly launched ISR satellites, they can step in to bridge coverage gaps left by counter-space activities or technical breakdowns. The satellites that countries need to do this are modular, pre-made, or completely built.

Nationwide space stakeholders may leverage this demonstrated capacity for prompt launches, as demonstrated by India's ASAT test on March 27, 2019. In the test the Prithvi Delivery Vehicle acting as ASAT destroyed a disfunctional satellite named Microsat-R.[10]

THWARTING CHINESE CAPABILITIES

China's military satellite constellation, known as Yaogan-30, serves as the backbone for the country's implementation of Anti Access/Area Denial (A2/D2) across the South China Sea (SCS). It supports the DF-21&DF-26 class missiles launched from the land and the YJ-21 Anti-Ship Ballistic Missile launched from ships. This strengthens China's Anti-Ship Ballistic Missile systems and enhances its ability to deny access and control areas. It is anticipated that in order to challenge the American Carrier Strike Group, China would eventually deploy eighteen triplets of these satellites. The satellite could cover certain areas of the northern Indian Ocean in addition to continuously monitoring the Pacific and SCS.

The constellation of Yaogan-30 satellites offers a half-hour revisit period over a SCS region of interest, which improves China's MDA (Maritime Domain Awareness). China hopes to have three ELINT satellites in orbit that can cover an area of at least 3000 kilometers to enable space-based ELINT capabilities that include the whole planet. India needs these type of satellites constellations to improve its MDA in the vast IOR, which is bolstered by ground assets capabilities, in order to give effective ISR and long-range kill capabilities at sea.

STRATEGY FOR INDIA'S ISR GOVERNANCE

India's ISR need primarily emanates out of two neighbors Pakistan and China. China has fully developed space based ISR programme in place with ever evolving technologies while Pakistan keeps on struggling with its space programme. The threat perception of China is totally different and far bigger from Pakistan. China poses a bigger threat in land as well as in maritime domain however Pakistan's ability to exert itself limits in many ways apart from its nuclear propaganda. Indo Pacific Region and Indian Ocean Region pose a lurking Chinese threat in global relations of India. India is prepared to launch 50 Spy satellites in next five years as stated by ISRO chairman in December 2023.[11]

India established the Indian Ocean Region Information Fusion Center (IFC-IOR) in 2018 with the goal of becoming a regional leader in maritime domain awareness (MDA). The center offers regional MDA by "creating a common coherent maritime situation picture and acting as a maritime information hub for the region." The IFC-IOR is an operational entity designed to materialise the Indian navy's goal of providing net security; rather than seeing the Indian Ocean through subregions, it aims to provide an interoperable picture of the whole ocean. The IFC-IOR offers and facilitates information exchange across IOR countries to create an interoperable MDA image in real time, using Indigenous software. Information sharing on a range of topics, including as maritime terrorism, illicit drug trade, human trafficking, environmental risks, and natural catastrophes, is coordinated and facilitated by the center with partner nations and stakeholders. Anywhere in the IOR, illegitimate vessels can be identified because to the extensive database of commercial and nautical boats.

CONCLUSION

A space-based "Integrated Aerospace ISR Grid" must be established for shared aerospace awareness throughout the area and beyond, as evidenced by the success of IFC-IOR. Intelligent space borne intelligence, surveillance, and reconnaissance technologies enable automated data analysis. Instead of spending their time and skills on data analysis, this enables operators to concentrate on making critical decisions. Automated sensing systems can supply intelligence to assist combat team members in achieving high-level mission objectives. When AI and edge computing are fully exploited, the chances of any ISR operation success increases manifold. The information is sent on the first attempt, providing decision-makers and military leaders with further assurance that nothing is being overlooked and they have full intelligence to act.

Gp Capt Arvind Pandey (Retd) is a geospatial intelligence professional. Presently he is employed as senior fellow at Centre for Air Power Studies, New Delhi and is researching on creation of geospatial ecosystem in the Indian context. Linked In- https://in.linkedin.com/in/arvind-pandey-ab096aa6, Twitter- https://twitter.com/ScoutPandey

NOTES

1. Jake Harrington and Riley McCabe, August 6, 2021,Modernizing Intelligence, Surveillance, and Reconnaissance to 'Find' in the Era of Security Competition (csis.org). Accessed on 06 March 2024.
2. Department of Public Information, News and Media Division, New York, General Assembly GA/DIS/3487, 25 October 2013,Outer Space Increasingly 'Congested, Contested and Competitive', First Committee Told, as Speakers Urge Legally Binding Document to Prevent Its Militarization | Meetings Coverage and Press Releases (un.org). Accessed on 06 March 2024.
3. NASA Earth Observatory. "Catalog of Earth Satellite Orbits," n.d. https://earthobservatory.nasa.gov/features/OrbitsCatalog.
4. KaleidEO. "Home - KaleidEO," 16 January 2024, https://kaleideo.co/.
5. NASA-ISRO SAR Mission (NISAR). "Home – NASA-ISRO SAR Mission (NISAR)," n.d. https://nisar.jpl.nasa.gov/.
6. "Pixxel | Hyperspectral Imagery and Space Data Company," n.d. https://www.pixxel.space/.
7. "GalaxEye Space," n.d. https://www.galaxeye.space/.
8. Border Management II Division, "Annexure V", Ministry of Home Affairs, Government of India, https://www.mha.gov.in/sites/default/files/2022-08/BM_II_Mandate_18062019%5B1%5D.pdf. Accessed on 2 April 2024.
9. Group Captain Arvind Pandey (Retd), May 21, 2023,Cyberattack On European Spacecraft! How 'Hackers' Took Control Of Satellite's Imaging Sensors & Jeopardized Its Data (eurasiantimes.com). Accessed on 09 March 2024.
10. Group Captain Arvind Pandey (Retd), 17 October 2022. As US, Russia, China Increasingly Conduct Anti-Satellite Tests, Has The Time For Responsive Satellite Launch Arrived? (eurasiantimes.com). Accessed on 09 March 2024.
11. 29 December 2023, ISRO's Big Defence Boost For India - 50 Spy Satellites In 5 Years. Details Here (ndtv.com). Accessed on 10 March 2024.

71-95

CYBER ATTACK AGAINST SATELLITES

Capt (Dr) Nitin Agarwala, Indian Navy

Abstract

The importance of space sector to life on Earth is difficult to quantify. Everyday services like communication, air transportation, maritime trade, weather monitoring and forecasting, remote sensing, financial services, television, and even defence rely heavily on space infrastructure. As this dependency increases, risk of cyber threats to this infrastructure increases for both the provider and the policymaker. The fact that critical security gaps exist in construction of both old and new generation satellites make the problem even more complex. While old satellites were designed and built with little knowledge about cyber security, new ones are being manufactured to be cheap thereby forcing investment in cyber security to be disregarded.

The resulting cyber vulnerability poses risks to both space-based and ground-based assets. If these vulnerabilities are not addressed, they could impact financial growth and security at the global level. A cyber-attack on a satellite used for communication would result in interruption to communication that could cause panic, and even endanger security of that nation. With countries and private actors acquiring and employing numerous counter-space capabilities, the threat is no longer hypothetical.

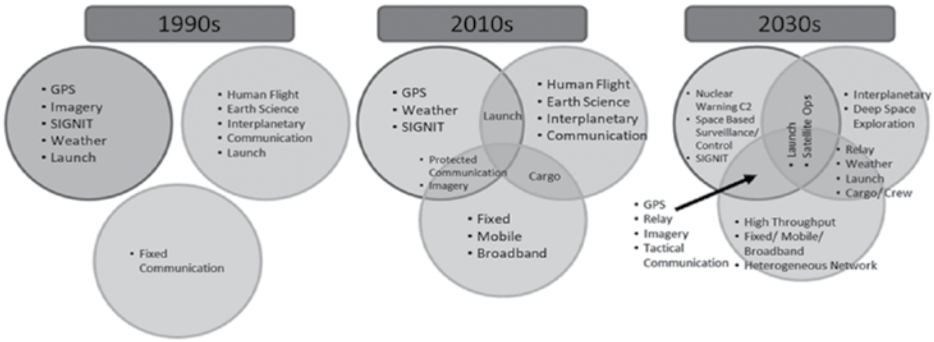
It is with this understanding that this paper aims to look at increasing cyber threat scenarios in the space sector, space infrastructure that requires hardening to address these cyber threats, and challenges and opportunities cyber threat poses to public policy.

INTRODUCTION

Human activities in space increased after the first artificial satellite was launched in 1957. In the last 66 years, 15,946 objects (that include satellites, probes, landers, space station elements, and crewed space-crafts) have been sent into space. Of these 11,330 satellites currently orbit the Earth while others have either fallen back, destroyed in space or orbiting other celestial bodies. Of the orbiting satellites, 6,718 are operational while 3,266 are useless chunks of metals that continue to move around in space. These satellites belong to various countries and have multiple purposes. These include 4,823 for communications, 1,167 for observation of the Earth, 414 for technology development and demonstration, 155 for navigation and positioning, 109 for science and observation of space, 25 for studies of Earth science and 25 for miscellaneous purposes.[1] These satellites may orbit in four main Earth orbits; LEO (Low Earth Orbit – 500 to 2,000 km), MEO (Medium Earth Orbit – 2,000 to just below 35,786 km), HEO (Highly Elliptical Orbit – above 35,786 km) or GEO (Geosynchronous Earth Orbit – exactly at 35,786 km). Small satellites dominate LEO as they are easier to reach while large ones dominate GEO. Due to the distance involved, radio signals travel lesser to reach LEO than GEO and hence satellites in LEO can deliver high-quality internet services and better communication with IoT devices.[2] Accordingly, 84 percent of satellites are found in LEO, 3 percent in MEO and the remaining in GEO.[3] Of the satellites that are operational, 57 percent are used for communication (37 percent for business, 11 percent for civil and 9 percent for military), 9 percent for military and surveillance, 8 percent for navigation, 9 percent for remote sensing and 4 percent for meteorological purposes.

With the number of satellites increasing rapidly, dependence of human life on these space systems has impacted our lives in important and fundamental ways. These activities include trade and commerce; financial transactions; communication; agriculture; transportation; weather assessment and prediction; entertainment; health care to name a few. The convergence of information gathered has been so phenomenal that sectors, products and services are fast amalgamating as seen in **Fig. 1**. Dependence on space has increased so much that if this infrastructure were not available, most of these services would experience a serious degradation or a complete shutdown.

Figure 1: Growing convergence of Sectors, Products and Services (Source: Author, Adapted from NAP, 2016)[4]



Like any other digitised infrastructure, satellites too are vulnerable to cyberattacks. The resulting cyber vulnerability poses risks both to space-based and ground-based assets. If not addressed, the threat could impact global economic development and international security. A cyber-attack on a satellite used for communication would result in interruption to communication that could cause panic, and even endanger security of the nation. With countries and private actors acquiring and employing numerous counter-space capabilities, the threat is no longer hypothetical. As risk of cyber threats to this infrastructure increases, it creates challenges for both the provider and the policymaker.

It is with this understanding that this paper aims to look at the increasing cyber threat scenarios in space sector, space infrastructure that requires hardening to address these cyber threats, and challenges and opportunities cyber threat poses to public policy.

UNDERSTANDING SPACE SYSTEMS AND THEIR VULNERABILITIES

When discussing cyber threat to satellites, it is important to evaluate cyber threat for the entire space system as the satellite is incomplete without the ground and the link segment. Hence, the space system is understood to be made up of three segments. The *space segment* that is made up of the satellite and its launch vehicle, the *link segment* provides a communication channel between two or more satellites and the satellite and ground station, while the *ground segment* is made up of ground elements that provide command and control of the satellite, and management and distribution of data received from the satellite. Since all three segments are digitised, they are susceptible to a range of cyber threats.[5]

A major security gap exists for the *space segment* in satellites of the current and the past generations. While earlier satellites were constructed with little awareness of cyber security, newer ones focus on fast and cheap production and hence funding for cyber security is kept to a minimum. These attacks can be executed through weaknesses in either the ground stations or network components or receivers receiving data from satellites. Expected cyberattacks on the space systems is by giving bad instructions to either destroy or manipulate controls (called command intrusions), by controlling payload (using malicious control such as Denial of Service), through malware (thereby infecting space systems and ground systems) or through spoofing communications to trust the source, or interrupt/delay communication. The consequences of these attacks can be amplified due to growing use of Internet of Things (IoT) devices that are connected to these satellites.

The most common threat to the *link segment* is manipulation of radio signal between the satellite and ground station. Since GPS system is the most important radio signal transmitted by a satellite to the ground station it is susceptible to attack by *jamming* or *spoofing* by disrupting or tampering with the frequency signal. Between these, spooking is more difficult than jamming to achieve but when executed correctly, it can cause greater damage as the victim is unaware of the attack. Yet, another type of attack is to *alter the legitimate signals* so that the satellite can be used for some other purpose. Such an attack is called as broadcast signal intrusion. In this, broadcast signals are hijacked by using signals of higher strength but same frequency. This hijacking can also be achieved by directly breaking into the transmitter to replace the signal.[6] Such a hijack is possible only with unencrypted signal traffic that can be intercepted, eavesdropped and modified conveniently.

The *ground segment* is responsible for collecting data from satellites and hence is exposed to cyber espionage through downloading of malwares and Trojans. These malwares and Trojans when downloaded allow attackers to access and control the satellite.[7] These threats are summarised in **Table 1**.

Table 1: Threats Experienced by the Space System

Segment	Nature of Attack	Means of attack
Space Segment	Physical attacks	By physically capturing another satellite using robotic arm in space
	Hijacking	Alter legitimate signals to use satellite for another purpose
	Monitor and track military activities	
	Exploit software and hardware vulnerabilities	• Via command intrusions - use bad commands to destroy or manipulate control of satellite • Via malicious code to control payload – Use denial of service (DoS) to overwhelm the system • Via malware
	Lock out	• Take control of asset in unauthorized manner and lock out legitimate owners - considered dangerous • Slow-moving satellite a threat similar to an anti-satellite missile
	• Attack satellites using Space Situational Awareness (SSA) • Use counterspace weapons	• Deny strategic capabilities to the satellite by identifying its presence and location • Cause jamming or spoofing using electromagnetic pulse actuators
Link Segment	• Degrade space communication • Difficult to attribute and distinguish from unintentional interference	• Via jamming - prevent intended signals to be received • Via spoofing - introduce a fake and erroneous signal
	• Eavesdropping on satellite communications	When traffic is unencrypted
Ground Segment	Physical attacks	
	Cyberattacks and intrusions	• Unauthorised access by exploiting misconfigurations and software vulnerabilities • Injection of malware • Phishing to obtain sensitive credentials
	Web page attacks	• Inject malicious code in executable script (cross-site scripting) • Force end user to execute unwanted action on web application (Cross-site request forgery) • Use script to download and install an unwanted programme (Drive-by hacking)
	Air Gap Attack	• Deploying an infection through a portable media into a secure system • Attack uncontrolled as attacker has no direct access to the secure system

Source: Author from various resources

It is important to mention that an unethical attacker is usually looking for financial gains when attacking a civilian satellite. However, when attacking a military satellite, the gains may be direct 'strategic' control or financial gains by 'selling' control to a third party. Of these, the military satellite space system while susceptible to cyberattacks, is better equipped to handle such threats through hardened procedures and hardware, we will limit our discussion to civilian satellites. For such satellites, the most productive attack for an attacker would be on services that relate to financial systems or services for which someone would be ready to pay a ransom. Since the space systems are associated with a variety of services, they are a lucrative target especially since they have the ability to impact a number of systems from a single point. Say, a gas distribution company that relies on satellites for communication for health monitoring of their pipelines if compromised can result in pipe explosion merely by inhibiting maintenance calls. Effectively, the attacker by inhibiting maintenance will be able to impact supply distribution, profits and working of the gas company.

The problem gets complicated due to technology advancement, reducing cost of satellite development due to use of open-source software,[8] use of commercial-off-the-shelf (COTS) products and lack of international or industry security standards governing space systems that does not necessitate high level of cyber security standards and hence makes attack simpler and undetected at times. Furthermore, since no clearly defined procedure exists to discover, analyse risk, mitigate or for remedy of cyberthreats during the lifespan of space systems, detection of a malware may never happen till it causes interruption of services. The situation is exacerbated due to lack of clearly defined responsibility for cybersecurity and management of space systems. With commercial agencies transforming space based capabilities, the need for regulating cybersecurity in this sector cannot be but over-emphasised.

HOW CAN ATTACKS BE CARRIED OUT?

From the discussion in the preceding section one notices that ground segment is possibly the weakest link in the entire space system. This is primarily because ground segment is susceptible to physical attacks and is also approachable. Furthermore, once someone has access to the ground segment, controlling the space segment becomes easy. However, for services such as the Amazon Web Services Ground Station and Microsoft Azure Orbital that connect to satellites from anywhere to provide instant access, attack on ground segment becomes irrelevant. For others, some of the earth segment vulnerabilities are as seen in **Table 2**.

Table 2: Earth Segment Vulnerabilities

Segment	Working	Attack	Gain to attacker
Earth station network	Uses secure shell (SSH) and IP security (IPsec) for secure communication	An incorrect protocol message can cause buffer overflows or denial of service (DoS) in the firewalls and virtual private networks (VPNs)	Provides the attacker access to the protected Earth station network
Network access points (NAP)	Connects Service Switching Point (SSPs) and user terminals to Earth station network through wireless network adapters (WNAs) or fiber connections	• NAP must determine its location and send its IP address to a connecting user terminal. • Makes NAP and rest of the network vulnerable to attack.	Rouge access point can be established using this information
During normal operations	WNAs receive data packets. Indicates that new networks are present		Data packets can be manipulated Error condition can be triggered to run programs and access files on targeted user terminal
Network Operations Centre (NOC)	Web-based user interface for connecting to the Internet backbone	Connecting NOC with Internet using a fiber connection has physical vulnerabilities of breakage and damage	
NOC connection to fiber network	Provides access to Internet or to private Intranets	Connection susceptible to vulnerabilities associated with Intranet and Internet	
NOC access router	Enables the NOC manager to allow or deny users access to satellite services	Flaws in router can permit attacker to stop traffic to enter or exit the NOC and to interrupt services.	Can reroute traffic using Border Gateway Protocol (BGP)

Source: Author; from[9]

KNOWN CYBERATTACKS

It is clear that a space system is susceptible to a range of attacks. However, space systems lack international and industry standards that require assets to protect the system from cyberattacks. Hence, involvement and knowledge of users regarding cyberattacks is limited. This ignorance disallows a mechanism for reporting any attacks on such space systems. To add to this, since space systems have a connection with government activities, little information regarding their being compromised is hard to find. It is interesting to note that with wide proliferation of social media, even videos of how to hack satellites are available for a prize (Hacking Digital Satellite Systems available for $29.95 plus $3.50 for shipping) and advertised regularly in print media.[10]

Research conducted by Ruben Santamarta in 2014 on ten leading SATCOM terminals used by the military and the mercantile marine shows that these systems use weak default passwords. The backdoor used by programmers for data units (for communication control) and control units (for control access) were easily accessible and in default mode and protocols used to communicate between control unit and user interface had a weak authentication mechanism.[47] Another study by the Department of Commerce in August 2014 in the US on security weakness of the ground system of the Joint Polar Satellite System (JPSS) showed them to be 14,000 in 2012 which increased to 23,000 in 2014. This was attributed to complacency in compliance by internal auditors and unwillingness to deviate from scheduled updates.[48] In the following November, the NOAA satellite system was attacked by attackers believed to be from China.[49] These episodes showed that poor cyber practices need to be addressed to avoid a security breach. Notwithstanding ignorance, since space systems are a critical system for economic health and security of a nation, cybersecurity agencies continue to monitor cyberattacks. While many go undetected and hence unreported, there are many others which have been reported albeit many years after attack have occurred. For these, the exact details may be confidential but some such attacks are discussed here to provide importance and relevance of such attacks on space systems. To appreciate the magnitude of these attacks, such events have been arranged chronologically and seen in **Table 3**.

The cases mentioned here provide an idea of how satellites are susceptible to cyberattacks. These cases do not discuss other cyberattacks as they are considered to be beyond the scope of this article. These events are however not considered to be a complete list of such events. A more extensive list for the duration 2006 – 2023 can be found in a publication of the Center for Strategic and International Studies (CSIS).[50]

Table 3: Known Cyberattack Event on Satellites

Year	Affected	Impact	Remarks
Earliest intrusion	Digital video broadcasts	• Information transmitted without encryption. • Can be seen by anyone who can intercept the signals	• Tutorials to intercept signals freely available online[11 12] • Common since 1970s[13]
June 2002	Intercepting signals to view NATO flights over the Balkans	• Internet connection of satellite can be intercepted as signals are unencrypted. • First indication that interceptions could impact military too.[14]	• Attacker can steal IP addresses as shown by Turla attacks. • Can be carried out by Advanced Persistent Threat (APT) groups (HackingTeam, Xumuxu group and Rocket Kitten) • Not widespread. • If spreads, will be a serious problem for security agencies.[15]
1997 - 2013	Cyber espionage against NASA networks was reported 12 times	Chinese nationals including Bo Jiang arrested with technology related information not supposed to be with them.[16]	

1998	ROSAT satellite	Sustained physical damage	• Satellite made to face the Sun by executing a command • Possibly by Russia - as a cyberattack.[17]
2002	SinoSat satellite hacked	Interrupt transmission of China Central TV (CCTV) and China Education TV.[18]	By Falun Gong, a controversial religious group of China
2004	AsiaSat hacked	Disruption of signals for nearly four hours.[19]	
2003 - 2006	DoD, NASA, aerospace contractors & research institutions working on space propulsion, solar panels & fuel systems infiltrated	Coordinated attacks from China under an infiltration campaign named "Titan Rain".[20]	• For APT-One (a cyber-espionage unit of PLA) as reported by Mandiant Technology.[21] • Aerospace industry is second most targeted industry • Satellite industry is fourth most targeted
2006	Libyan nationals	Jammed mobile satellite communications for nearly six months	To control smuggling of contraband from Chad and Nigeria.[22]
2006	Israel-Lebanon war	Al-Manar satellite channel was a target for unsuccessful jamming by Israel.[23]	• To stop Hezbollah leader to reach his followers • Commercial satellites could be potential target during conflict.
2007	Goddard Space Flight Centre was cyber attacked		For data regarding earth observation systems.
2008	NASA satellite Landsat-7 was cyberattacked	Interference for 12 minutes	

2008	NASA satellite, the Terra-EOS AM-1	Interference and loss of control • June - 2 minutes • October - 9 minutes	• Attackers could not command satellite as they did not understand actual commands for satellite manoeuvre.[24] • Some experts believe that this was interference/ jamming radio signals and not cyberattack
April 2007	Hacking of Euro Star 1 and INTELSAT-12	Illegally broadcast radio and TV signals using empty transponder on-board INTELSAT-12.[25]	The Liberation Tigers of Tamil Eelam (LTTE) of Sri Lanka accused of transmitting propaganda
2007	At least two environment monitoring satellites of the US	Cyber attacked from a ground station in Norway	• Hack traced to China • Was possible by using Internet to connect to ground station. • Hackers achieved full control of satellites - no equipment or data were compromised.[26]
2008	The International Space Station (ISS) computers	• Hackers infiltrated mission control computer network of Johnson Space Centre &uploaded a malicious Trojan • Disrupted on-board communications • Did not endanger crew or space flight.[27]	Was possible as computers not receiving software updates

2009	Iraq able to download unencrypted live video stream from American Predator drones	• Used an inexpensive, off-the-shelf software – SkyGrabber • Originally developed to • Receive unprotected satellite TV feed • Gain access to the Internet in areas of Russia	• Hacking allowed insurgents to take evasive action against the planned drone attacks.[28] • Possible because of lack of security in link system between satellite and drone. • Flaw known to designers • Requisite encryption protocols not used - as it made communication ineffective due to reduced speed. • Activity of insurgents categorised as interception hacking. • Data extraction could have been prevented if encryption was used.[29]
2009	BBC broadcast of elections in Iran was jammed	Jamming was accompanied by a cyberattack on the email service of the BBC.[30]	Most probably by Iranian government
Sept 2011	American RQ-170 Sentinel drone	Made it to land in Iran instead of Afghanistan.[31]	GPS signal reconfigured by Iran
October 2011	US Creech Air Force Base (AFB) faced a malware attack on the Predator and Reaper drones	• Attack from infected ground control stations • Earlier compromised using keystroke logger • Attack believed conducted by intelligence services of Russia or China.	• Attack on ground control system that was air gapped • Attack a classic example of air gapping method

March 2012	The BBC	• Disrupt Persian Language Services • Jam two BBC satellite feeds to Iran	
March 2013	Aerospace and defence companies and contractors of the US operating in the South China Sea	Chinese hackers found to be attacking maritime operations and maritime satellite systems, for nearly one year	
February and May 2013	BGP hijacking	Show live evolution of 21 events of Belarus[32]	Broader Gateway Protocol (BGP) hijacking (maliciously intercepting or rerouting internet traffic)
July - August 2013	BGP hijacking.	Show live evolution of 17 events of Iceland[33]	
2014	Crimean Conflict	Ukrainian authorities reported jamming of incoming GPS signals for entire area by the Russian Federation	Jamming caused chaos for navigation system of phones and several aircrafts.[34]
2014	Western companies associated with manufacturing or researching satellites	PLA Unit 61398 was undertaking space surveillance for targeting.[35]	CrowdStrike reported the event
2014		China Telecom repeatedly sent cyber traffic inside Russia from their servers	Not clear if this incident was malicious or accidental routing leak.[36]
2015	Max Headroom Broadcast Signal Intrusion[37]	Powerful microwave signals attackers hijacked satellite signals.	• No one claimed responsibility • Showed that regular TV signals could be hijacked at ground station using microwaves.

2017	GPS system of at least 20 ships spoofed	Shifted destination port 32 km inland making Gelendzhik Airport in the Black Sea as final destination	GPS spoofing was part of new electronic warfare technique being experimented with by Russia.[38]
April – June 2018	Satellite operators, defence contractors, and telecoms companies in the US and Southeast Asia	Infiltrated by Chinese hackers.[39]	Attacks undertaken with an aim of espionage and possible disruption.[40]
November 2018	Trident Juncture exercise of NATO	GPS signals were disrupted and Russia was suspected for doing so.[41]	
2018	US domestic Internet communication	Routed through servers of China Telecom	Possible by manipulating border gateway protocol (BGP) tables from 2015 to 2017
2019	Internet traffic destined for mobile providers in Europe	Rerouted to servers of China Telecom for two hours.[42]	Another incident of BGP manipulation
initial six months of 2020	BGP hijacking	Over 1,430 incidents worldwide, averaging 14 hijackings a day	Mostly involving big financial or telecom companies.[43]
March 2022	Cripple Viasat KA-SAT satellite communication network of Ukraine	Cyberattacks by Russia on the eve of its attack	Attack undertaken using a malware named 'AcidRain viper' that wiped out targeted modems to cripple them.[44]
June 2023	Telecommunication service provider satellite of the Russian FSB and military units	By Ukraine protest group associated with Wagner, a private military corporation.[45]	

August 2023	Starlink with a malware	By GRU of Russia to get Ukrainian troop movement	• Found by State Security Service (SBU) of Ukraine • Verified when SBU found malware on tablets recovered from Russians but originally belonging to Ukrainian soldiers.[46]

Source: Author's compilation

DISCUSSION

While cyberattacks as discussed in the previous section continue to occur the world over on satellites, there is a mixed acceptance about these events being hacking events. One school of thought is that as long as encryption does not exist, reconfiguration would not happen. This means that if functions originally facilitated by the administrator have not been altered, hacking is not deemed to have occurred. The other school of thought is that a hack is a quick fix that provides access to features that were otherwise inaccessible. It is the second school of thought that is usually employed to refer to nefarious activities that are categorised with cybercrime. Similarly, when talking about interception of digital video feeds since these signal are freely available and need only decoding as done by programs such as SkyGrabber, these acts while against the law cannot be considered as a cyberattack.

Before a unanimous decision is arrived at regarding this issue, such security interceptions of satellite signals are important to realise vulnerabilities that exist in this critical infrastructure. It also acts as an eye opener for policy makers and security agencies to ensure that these vulnerabilities are addressed. However, like any other information technology industry, such security controls are never put in place till a serious breach occurs and results into a serious loss. Unfortunately, this has been the operating principle for the industry for years and is considered an acceptable methodology that does not require a change. It is hence not surprising when researchers identify several vulnerabilities in software of GPS receivers belonging to both government and commercial grade or in computers of ground stations that control the satellites.

To date, the focus on providing security against cyberthreats has been to leverage cryptographic protection for data both in transit and at rest using strong encryption algorithms. While this was sufficient till now, capabilities of attackers is rapidly evolving. It is essential that this security gap be closed in future systems, and mitigating procedures adopted for platforms in orbit wherever possible.

Today, Black Hat activities are centred in a few countries and hence major cyberattacks are attributed to them. However, this may not be always true. The fact on ground remains that such activities are mostly undertaken by independent groups and usually not state sponsored. What remains as an area of concern is that as the number of satellites in space increase, their vulnerability is likely to increase since best practices of the IT industry are not implemented in these systems which could have a large and catastrophic impact on our individual lives. As the number of satellites increase, there is a likelihood that the number of players undertaking such attacks would only increase.[51]

It is thus important that information on such attacks is shared within the industry for greater learning and remediation actions and strategies that could possibly prevent another organisation to experience the same fate. In addition, emerging threats need the industry and policymakers to focus on ways and means of hardening the space architecture so that space systems can be protected from cyberattacks. However, use of implementing such technology should be done with due attentiveness to potential challenges and associated costs as the initial investment required for such hardening can be significant. This thus requires a look at the challenges and opportunities that such attacks create for public policy and how this critical infrastructure can be made secure.

CHALLENGES AND OPPORTUNITIES TO PUBLIC POLICY

Policy makers are usually driven by the magnitude of the problem and the acceptable risk that can be permitted to be associated with a given problem. In case of the space industry, since acceptance of given threats is not explicitly defined or very well understood, policy makers tend to distance themselves from the problem at hand. However, as discussed, the need for international and industry standards for cybersecurity of space systems is essential and cannot be delayed. This need is only going to increase with the sector being thrown open to the private sector. It essentially means that if adequate and timely steps in establishing policies for the space sector are not employed, the magnitude of problem may increase many a fold and become cost prohibitive to handle or even difficult to contain.

Hence, policy makers need to look at hardening the three segments of space infrastructure against cyberattack. These include the *space segment* that is considered vulnerable to attacks through command intrusions, payload control or denial of service, the *link segment* that are under threat from interference, and the *ground segment* that are susceptible to physical and virtual attacks alike. This, thus, requires them to look at not only ground stations but also at standards to be followed by satellite manufacturers to provide required hardening of space system infrastructure. The feature of hardening can be incorporated in the space architecture by adopting procedures such as 'Quantum resistance'[52] which is a key theme to achieve hardening for the US which it aims to achieve by 2035.[53] Additionally, military grade encryption such as the gold standard AES (Advanced Encryption Standard) 256 bit and dual tunnel encryption can be used. While Quantum resistance uses immutable laws of quantum mechanics for cryptography, the AES 256 bit encryption makes it difficult for a hacker as they would require 2256 combinations to break the 256 bit encryption. The dual tunnel encryption on the other hand allows data to be encrypted in memory as it moves in an encrypted form to discourage the hacker from stealing information.

Since most of the ground stations are in vicinity of commonly accessibly spaces they are susceptible to malicious intent due to easy access. At times, this intent may be deliberate or accidental. With these ground stations considered as the weakest link in the space system, they need to be made more robust by providing conditioned and generated power, centralised backup facility that is undertaken at varied geographical locations, and implementing standard IT industry norms and functions such as disaster recovery mechanisms and equipping them to withstand electromagnetic pulse and radiological fallout. There is also a need to ensure that human resource engaged in ground stations is adequately trained to understand existing vulnerabilities and impact of downloading unverified information. In addition, physical security of such installations is considered important which could be provided by perimeter fencing, closed circuit security, access control and multiple layer redundancy.

To address interference in the link segment, various types of shielding, filters, training and awareness is considered essential in addition to sharing of root cause analysis of incidents reported to ensure that effective security patches can be developed and disseminated. Furthermore, need to use data encryption including quantum encryption, error protection coding, and use of directional antennas are some other methods that can be effective in reducing interference. To add to these, some features currently being used only by military satellites can be made an industry standard. Methods such as narrowband excision scheme, burst transmission and frequency hopping, antenna side lobe reduction, and nulling antenna systems which observe interference can help address interference and hence cyberattacks on space systems. Though these may increase cost, a balance between cost and security is something that would need to be considered sooner than later. The sector would also benefit if laser based communication, intrusion detection and prevention systems are developed.

It is important to realise that with use of open-source architecture for the satellite industry, this industry is slowly moving towards the traditional IT industry and hence vulnerabilities and solution for such issues employed in the IT industry can be directly employed in the space sector. Since cybersecurity standards, processes, procedures, and methods are already available, there may not be a need for creating new ones. However, their application in the design phase needs to be included to ensure that IT industry standards are effective for which policy making is critical.[54] This additionally requires that hardware used is procured from reliable sources.

With current encryption procedures being challenged, robot encryption for every data transferred to and from any satellite using a VPN solution is a possible way ahead. In addition, to overcome challenges to encryption procedures, network segregation to restrict traffic between segments may be experimented with. A need to monitor networks for suspicious activities using intrusion detection and prevention systems is also considered essential. In addition, an incident response plan to identify, contain, eradicate and recover from any cyberattack is required to be implemented. Additionally, self-healing cyber-physical systems using machine learning can be used. Such system would automatically initiate a reboot if they sense that they are not functioning optimally thereby ensuring that the cyberattack is made ineffective.[55]

TAKE AWAY FOR INDIA

India released its Space Policy in 2023 which aims to enhance space capabilities of the nation by encouraging involvement of the private sector. The policy was released with an aim to increase contribution of the Indian space economy from an existing 2 percent by harnessing the full potential of India's space sector. While the policy has been released, it needs to be followed by legislations and regulations regarding conduct of business. As policy formulation in the space industry is at a nascent stage while cyber threats are well known and looming large, it would be prudent for India to show 'due diligence' towards cybersecurity to become a front runner in this aspect. In this regard work on advanced technological procedures like robot encryption using VPN solution, quantum resistance hardening, and network segregation and monitoring needs to be considered.

It is important to mention that India as a nation is a major contributor to Information Technology Enabled Services (ITeS) industry and hence has requisite knowhow and understanding of needs of cybersecurity for the IT industry. Drawing from this existing knowledge and knowing that the industry standard of future space industry is open-source; India can very well prepare required standards of cybersecurity for the space industry. In the interim, India should work towards establishing 'resilient space best practices' for space companies to develop their cyber protection approaches. These best practices would eventually provide valuable inputs for developing the desired space standards.

Even though naysayers may argue to say that such a step may push the country to costlier systems and hence drive away business in the space sector, this aspect cannot be overlooked. It is an inescapable requirement that should be considered to ensure that the space industry of tomorrow in India is more resilient to cyberattacks and hence is more secure and avoids unintended cost of addressing cybersecurity after launch which would eventually be higher in the long run. As a minimum, this requires that the strategic and technical approach for space systems to combat cyberattacks is incorporated in both old and new satellite space systems. These standards should apply not only to lifecycle stage but also to the development phase including the testing phase and include periodic cybersecurity assessments during development, and before and after launch.

Since the current international space laws (that are underpinned by five international treaties namely, The Outer Space Treaty, The Rescue Agreement, The Moon Agreement, The Liability Convention and The Registration Convention)[56] do not adequately address cybersecurity, there is a need to develop this regime. In doing so, India can engage with the existing intergovernmental organisations but before that it would need to create its own comprehensive domestic systems of cybersecurity for space systems.

This due consideration to cybersecurity is especially important for a nation like India that has limited number of satellites with limited options for meeting requirements through another satellite. Such identifiable satellites can be precision targeted by an attacker if not adequately protected leading to loss of services dependent on these satellites.

CONCLUSION

Space infrastructure is critical to global economic development and international security. However the security of this system has largely been ignored so far due to involvement of governmental agencies in this sector. With increasing dependence on this sector for numerous activities both in the military and the civilian domain, this sector has been subjected to cyberattacks. The problem takes greater importance with an increasing interest of the private sector in space after it was deregulated for them. Accordingly, the paper has discussed cyberattacks, their potential impact on various facets of our daily activities, available opportunities and challenges and takeaway for India.

One realises that as the space sector becomes more commercial, a shift to commercial-off-the-shelf (COTS) items is natural driven by commercial interests. This thus exposes the sector to greater security threats due to cyberattacks usually associated with digitalisation of technology. However, since the sector is critical for economic development and security considerations, it cannot be disregarded and a focused approach to addressing cybersecurity for space systems is essential. Accordingly, hardening using 'Quantum resistance', and using AES 256 bit and dual tunnel encryption are some possible solutions that are being developed. In these efforts, the role of nations such as India who are gaining strength in the global space sector cannot be overlooked.

While India has released its Space Policy in 2023, it needs to work on legislations and regulations. Since cyber threats are here to stay, India can aim to become a front runner in cybersecurity if work on advanced technological procedures like robot encryption using VPN solution, quantum resistance hardening, and network segregation and monitoring are progressed. On the same lines, using its experience and expertise of the Information Technology Enable Services (ITeS) sector India could look at developing 'resilient space best practices' to assist develop desired space standards.

Creating instituting mechanisms and policies to address these cyber threats may be an uphill task as it flouts economics. Since overcoming these cyber threats is an essentiality that cannot be disregarded, it will need to be addressed in future if not now.

Capt (Dr) Nitin Agarwala is a serving naval officer who has authored over 80 articles, papers, book chapters and two books. He was a Research Fellow at the National Maritime Foundation from 2017-2019 and currently a Senior Fellow at the Centre for Joint Warfare Studies. Email: nitindu@yahoo.com; ORCID: https://orcid.org/0000-0003-0916-3044

NOTES

1. Andy, "How many satellites are orbiting the Earth in 2023?" (05 July 2023). https://www.pixalytics.com/satellites-orbiting-earth-2023/. Accessed on 18 March 2024.
2. Z. Qu, G. Zhang, H. Cao and J. Xie, "LEO Satellite Constellation for Internet of Things," in *IEEE Access* 5, (2017): 18391-18401, doi: 10.1109/ACCESS.2017.2735988.
3. NanoAvionics, "How Many Satellites are in Space?," Kongsberg, (04 May 2023), https://nanoavionics.com/blog/how-many-satellites-are-in-space/#:~:text=As%20of%20May%20the%204th,satellites%20in%20various%20Earth%20orbits. Accessed on 18 March 2024.
4. National Academies of Sciences, Engineering, and Medicine, "National Security Space Defense and Protection: Public Report." Washington, DC: The National Academies Press, (2016): 21 https://doi.org/10.17226/23594.
5. Varadharajan, V., and Suri, N., "Security challenges when space merges with cyberspace," Space Policy, (2023), https://doi.org/10.1016/j.spacepol.2023.101600.
6. J. Fritz, "Satellite hacking: a guide for the perplexed," Bulletin of the Centre for East-West Cultural and Economic Studies 10 no 1, (2013): 21–50. [Online], Available: http://www.international-relations.com/CM2012/Satellite-Hacking.pdf. Accessed on 18 March 2024.
7. Sincavage, SM, Carter, N., et al., "Space Based Platforms and Critical Infrastructure Vulnerability (Mccreight)," In Book 7 Nichols (Ed). *Space Systems: Emerging Technologies and Operations.* (KSU – NPP, Los Angeles, CA, 2022).
8. NASA uses cFS as the open source software for its small satellites which is available for free download on GitHub. *See*, Wilmot, J. and Kane, L., "Core Flight System," (2021), [online] cfs.gsfc.nasa.gov. Available at: https://cfs.gsfc.nasa.gov/Introduction.html. Accessed on 18 March 2024.
9. Jessica A. Steinberger, "A Survey Of Satellite Communications System Vulnerabilities," Thesis, (Air Force Institute Of Technology, Ohio, 2008). https://core.ac.uk/download/pdf/288295156.pdf.
10. Scrambling News, "Hacking Digital Satellite Systems Video 2002," Amateur Radio Today, (February 2002): 20. https://www.arimi.it/wp-content/73/02_February_2002.pdf.
11. Adam Laurie, "Satellite hacking for fun and profit," BlackHat, (16 February 2009), https://www.blackhat.com/presentations/bh-dc-09/Laurie/BlackHat-DC-09-Laurie-Satellite-Hacking.pdf.

12. Leonardo Nve Egea, "Playing in a Satellite environment 1.2," Kaspersky, (2015), https://media.kasperskycontenthub.com/wp-content/uploads/sites/43/2015/09/20081827/BlackHat-DC-2010-Nve-Playing-with-SAT-1.2-wp.pdf.
13. Judith S. Weinstein, "International Satellite Piracy: The Unauthorized Interception and Retransmission of United States Program-Carrying Satellite Signals in the Caribbean, and Legal Protection for United States Program Owners," Georgia Journal Of International And Comparative Law 15 no. 1, (1985), https://digitalcommons.law.uga.edu/cgi/viewcontent.cgi?article=1774&context=gjicl. Accessed on 18 March 2024.
14. Mark Urban, "Enthusiast watches NATO spy pictures," The BBC News, (13 June 2002), http://news.bbc.co.uk/2/hi/programmes/newsnight/2041754.stm. Accessed on 18 March 2024.
15. Stefan Tanase, "Satellite Turla: APT Command and Control in the Sky," Kaspersky, (09 September 2015), https://securelist.com/satellite-turla-apt-command-and-control-in-the-sky/72081/. Accessed on 18 March 2024.
16. J. Fritz, op. cit. p. 33.
17. J. Fritz, op. cit. p. 33.
18. Associated Press, "Falun Gong Hijacks Chinese TV," Wired, (24 September 2002), http://www.wired.com/politics/law/news/2002/09/55350?currentPage=all. Accessed on 18 March 2024.
19. Daly, John C. K., LTTE: Technologically innovative rebels, Wordpress, (18 June 2007), https://lrrp.wordpress.com/2007/06/18/ltte-technologically-innovative-rebels/. Accessed on 18 March 2024.
20. J. Fritz, op. cit. 32.
21. Mandiant, "APT1: Exposing One of China's Cyber Espionage Units," (18 February 2013), p. 24, https://www.mandiant.com/resources/reports/apt1-exposing-one-chinas-cyber-espionage-units. Accessed on 18 March 2024.
22. Space News, "Libya Pinpointed as Source of Months-Long Jamming in 2006," (17 April 2007), https://spacenews.com/libya-pinpointed-source-months-long-jamming-2006/. Accessed on 18 March 2024.
23. Space News, "Inability To Jam Hezbollah Satellite TV Signal Spurs Israeli Research," Space News, (29 August 2006), https://spacenews.com/inability-jam-hezbollah-satellite-tv-signal-spurs-israeli-research/. Accessed on 18 March 2024.
24. J. Fritz, op. cit. 33.
25. Daly, John C. K., op. cit.
26. Charles Arthur, "Chinese hackers suspected of interfering with US satellites," The Guardian, (27 October 2011), https://www.theguardian.com/technology/2011/oct/27/chinese-hacking-us-satellites-suspected. Accessed on 18 March 2024.
27. J. Fritz, op. cit. 33.
28. Mike Mount and Elaine Quijano, "Iraqi insurgents hacked Predator drone feeds, U.S. official indicates," CNN, (18 December 2009), http://edition.cnn.com/2009/US/12/17/drone.video.hacked/index.html. Accessed on 18 March 2024.
29. Ewen MacAskill, "US drones hijacked by Iraqi insurgents," The Guardian, (17 December 2009), https://www.theguardian.com/world/2009/dec/17/skygrabber-american-drones-hacked. Accessed on 18 March 2024.
30. J. Halliday, "BBC fears Iranian cyber-attack over its Persian TV service," The Guardian, (14 March 2012), https://www.theguardian.com/media/2012/mar/14/bbc-fears-iran-cyber-attack-persian. Accessed on 18 March 2024.

31. S. Peterson, “Iran hijacked US drone, says Iranian engineer,” Christ Science Monitor. (2011). https://www.csmonitor.com/World/Middle-East/2011/1215/Exclusive-Iran-hijacked-US-drone-says-Iranian-engineer. Accessed on 18 March 2024.
32. Stefan Tanase, “Satellite Turla: APT Command and Control in the Sky,” Kaspersky, (08 September 2015), https://securelist.com/satellite-turla-apt-command-and-control-in-the-sky/72081/. Accessed on 18 March 2024.
33. Ibid.
34. T. Harrison, K. Johnson, and T. Roberts, “Space threat assessment 2018,” US Center for Strategic and International Studies, (2018). https://csiswebsite-prod.s3.amazonaws.com/s3fs-public/publication/180823_Harrison_SpaceThreatAssessment_FULL_WEB.pdf.
35. Lily Hay Newman, “Report: Another Chinese Military Unit Has Been Hacking U.S. Systems—This Time Satellite Networks,” Slate, (10 June 2014), https://slate.com/technology/2014/06/putter-panda-crowdstrike-reports-chinese-military-hackers-have-been-infiltrating-satellite-networks.html. Accessed on 18 March 2024.
36. Dan Goodin, “Citing BGP hijacks and hack attacks, feds want China Telecom out of the US,” Technica, (04 October 2020), https://arstechnica.com/tech-policy/2020/04/citing-bgp-hijacks-and-hack-attacks-feds-want-china-telecom-out-of-the-us/. Accessed on 18 March 2024.
37. Katie Serena, “The Story Of The Max Headroom Incident, America’s Creepiest Unsolved TV Hack,” (15 March 2022), https://allthatsinteresting.com/max-headroom-incident. Accessed on 18 March 2024.
38. Chris Lo, “GPS spoofing: what’s the risk for ship navigation?,” Ship Technology, (15 April 2019), https://www.ship-technology.com/features/ship-navigation-risks/?cf-view. Accessed on 18 March 2024.
39. Dan Goodin, “China-based hackers burrow inside satellite, defense, and telecoms firms,” Technica, (21 June 2018), https://arstechnica.com/information-technology/2018/06/china-based-hackers-burrow-inside-satellite-defense-and-telecoms-firms/. Accessed on 18 March 2024.
40. Threat Hunter Team, “Thrip: Espionage Group Hits Satellite, Telecoms, and Defense Companies,” Symantec, (19 June 2018), https://symantec-enterprise-blogs.security.com/blogs/threat-intelligence/thrip-hits-satellite-telecoms-defense-targets?API1=100&API2=100017430&SID=100098X1555750Xa111007bba56c9e65774ebf19afaefe9&cjevent=901b335499a011ee82ffc9610a18b8f9&cjid=100017430. Accessed on 18 March 2024.
41. Gerard O’Dwyer, “Finland, Norway press Russia on suspected GPS jamming during NATO drill,” Defence News, (16 November 2018), https://www.defensenews.com/global/europe/2018/11/16/finland-norway-press-russia-on-suspected-gps-jamming-during-nato-drill/. Accessed on 18 March 2024.
42. Dan Goodin, 2020 op. cit.
43. Olivier Moli, “Border Gateway Protocol Hijacking - Examples and Solutions,” Anapaya, (10 November 2020), https://www.anapaya.net/blog/border-gateway-protocol-hijacking-examples-and-solutions. Accessed on 18 March 2024.
44. Christian Vasquez and Elias Groll, “Satellite hack on eve of Ukraine war was a coordinated, multi-pronged assault,” Cyberscoop, (23 August 2023), https://cyberscoop.com/viasat-ka-sat-hack-black-hat/. Accessed on 18 March 2024.
45. AJ Vicen and Christian Vasquez, “Hackers attack Russian satellite telecom provider, claim affiliation with Wagner Group,” Cyberscoop, (29 June 2023), https://cyberscoop.com/russian-satellite-hack-wagner-group/. Accessed on 18 March 2024.

46. Gareth Corfield, “Russian spy agencies targeting Starlink with custom malware, Ukraine warns,” The Telegraph, (12 August 2023), https://www.telegraph.co.uk/business/2023/08/12/russian-spy-agencies-targeting-elon-musk-starlink-malware/. Accessed on 18 March 2024.
47. Ruben Santamarta, “SATCOM Terminals: Hacking by Air, Sea, and Land,” IOActive Security Services, (2014), https://www.blackhat.com/docs/us-14/materials/us-14-Santamarta-SATCOM-Terminals-Hacking-By-Air-Sea-And-Land-WP.pdf.
48. Department of Commerce, “OIG-14-027M: Expedited Efforts Needed to Remediate High-Risk Vulnerabilities in the Joint Polar Satellite System’s Ground System.” Office of the Inspector General’s Report (Washington DC, 21 September 2014): 2-5.
49. Mary Pat Flaherty, Lisa Rein and Jason Samenow, “Chinese Hack U.S. Weather Systems, Satellite Network,” Washington Post, (12 November 2014), http://www.washingtonpost.com/local/chinese-hack-us-weather-systems-satellite-network/2014/11/12/bef1206a-68e9-11e4-b053-65cea7903f2e_story.html. Accessed on 18 March 2024.
50. CSIS, “Significant Cyber Incidents Since 2006,” (2023), https://www.csis.org/programs/strategic-technologies-program/significant-cyber-incidents. Accessed on 18 March 2024.
51. Meg King & Sophie Goguichvili, “Cybersecurity Threats in Space: A Roadmap for Future Policy,” Wilson Centre, (08 October 2020), https://www.wilsoncenter.org/blog-post/cybersecurity-threats-space-roadmap-future-policy. Accessed on 18 March 2024.
52. Also called as “quantum-safe” and “post-quantum” (PQ) cryptography. Used to describe cryptographic algorithms that can be run on computers to provide resistant against cryptanalytic attacks from both classical and quantum computers.
53. NSA, “The Commercial National Security Algorithm Suite 2.0 and Quantum Computing FAQ,” https://media.defense.gov/2022/Sep/07/2003071836/-1/-1/0/CSI_CNSA_2.0_FAQ_.PDF. Accessed on 18 March 2024.
54. Jeffrey Bardin, “Chapter 89 - Satellite Cyber Attack Search and Destroy,” Editor(s): John R. Vacca, Computer and Information Security Handbook (Third Edition), (Morgan Kaufmann, 2013): 1173-1181, https://doi.org/10.1016/B978-0-12-803843-7.00089-2.
55. Johnphill, Obinna, Ali Safaa Sadiq, Feras Al-Obeidat, Haider Al-Khateeb, Mohammed Adam Taheir, Omprakash Kaiwartya, and Mohammed Ali., “Self-Healing in Cyber–Physical Systems Using Machine Learning: A Critical Analysis of Theories and Tools,” *Future Internet* 15, no. 7 (2023): 244. https://doi.org/10.3390/fi15070244.
56. UNOOSA, “International Space Law: United Nations Instruments,” United Nations Office at Vienna, (2017), https://www.unoosa.org/res/oosadoc/data/documents/2017/stspace/stspace61rev_2_0_html/V1605998-ENGLISH.pdf. Accessed on 18 March 2024.

96-113

POSTURING IN OUTER SPACE & CONTOURS OF AN INDIAN INTEGRATED SPACE DEVELOPMENT PROGRAM

Lt Gen (Dr) Anil Kapoor, AVSM, VSM (Retd)

Capabilities take Time to Develop, Intentions can Change Anytime !
Whatever can be precisely defined, can be accurately designed and developed !
Geospatial data is the new oil, geospatial technologies are the new oil refineries !

Abstract

Indian Space Policy 2023 is iconic with a strong emphasis on international collaboration and technological advancements aiming for joint missions, knowledge sharing, capability and capacity building in satellite launches, scientific missions, space exploration, and technology transfers with an intent of the growth of the commercial space industry. The Policy aims to retain flexibility in addressing its national security concerns while maintaining strategic autonomy in outer space affairs and highlights India's achievements and future goals in the development of nano satellites, advanced launch vehicles, hypersonic glide vehicles, ASATs and ambitions for human spaceflight through public-private partnerships to stimulate economic growth, technological innovation, and job creation within the space sector. But the ambition is bereft with challenges. This calls for an Indian Integrated Defence Space Development Program, on the lines of IGMDP, to gain technology sovereignty in state of the art satellites and SLVs, Resilient PNT, and military assets - offensive, defence, hard kill, soft

kill based on, into and from, outer space platforms and Defence Space Technologies.

INTRODUCTION - EXPLORING OUTER SPACE AS A NATIONAL ASSET

India has been on the forefront in exploring outer space as a national asset encompasses multiple dimensions comprising scientific, technological, strategic, economic, and diplomatic facets. The space sector is a growing industry with opportunities in satellite communications, earth observation, remote sensing, space exploration and space based scientific and technological research. Engaging in space exploration has positioned India as one of the leaders in strategic and defence applications, hi-tech industries, enhancing its competitiveness on the global stage. Space capabilities are critical for national defence, including satellite-based navigation (GPS), communication, and surveillance. Satellites provide critical data for weather forecasting, climate monitoring, and disaster management, contributing to global safety and resilience. That said, space exploration initiatives contribute to the development of technologies that can enhance a country's security. Collaboration in space exploration can serve as a tool for diplomatic engagement, fostering partnerships and cooperation between countries. Joint missions and projects can build trust and reduce geopolitical tensions and foster international cooperation.

NavIC and Indian Space Policy 2023 are major milestone and have created reverberations among space agencies, institutions and industry alike to harness the opportunities in defence and dual use technologies. The policy is expected to institutionalise private sector participation in the space sector, with ISRO focusing on R&D of advanced space technologies and is likely to increase India's share in the global space economy substantially from 2 percent to 10 percent in the foreseeable future. It is envisaged that the boost in satellite manufacturing and launch capabilities will yield USD 3.2 billion by the year 2025 against USD 2.1 billion in 2020.

Navigation with Indian Constellation (NavIC)[1] is an autonomous Indian Regional Navigation Satellite System (IRNSS) that provides accurate real-time positioning, navigation and timing services. NavIC is designed with a constellation of seven satellites initially and a network of ground stations. The NavIC receivers in the ground based systems are proliferating the employment of NavIC based systems. The coverage of the satellite system currently is effective in the equatorial belt, in India and regions extending approximately 1500 km with plans for further extension.

THE FUTURE OF SPACE WARFARE - TRYST WITH TECHNOLOGY

The future of space as a domain for warfare encompasses a range of potential developments shaped by technological advancements, geopolitical dynamics, military strategy and international regulations. Nations are likely to develop both offensive and defensive space capabilities. Defensive measures could include satellite hardening, manoeuvrability to avoid attacks, and the development of systems to track and neutralise threats. The international community's response to these developments, through regulations and agreements, will be crucial in shaping the nature and extent of militarisation in space. The Outer Space Treaty of 1967, which outlines that space shall be used for peaceful purposes, faces new challenges with the militarisation of space. Future conflicts may test the limits of current international law, leading to potential revisions or new treaties to address the realities of space warfare. Salient aspects in outer space based applications, speculative overview based on current trends and technological advancements: for consideration are given below:

- **Satellite Technology**. Satellites are critical strategic assets and play a crucial role in communication, navigation, surveillance and reconnaissance. With advanced materials, nanomaterials and nano energisers, there is a paradigm shift from the traditional large single satellites to multiple small constellations. Small, nano satellites and launch on demand satellites with a variety of payloads would be imperative for real time situational awareness. A number of dual use satellites '*RADARSAT*', '*CARTOSAT*' and other military satellites can be easy targets by an adversary and hence, multiple smaller satellites are a preferred choice. There is requirement to have a fortified approach to protect our space based assets. In addition, drone based pseudo satellites with a variety of payloads, solar panels for higher endurance are popular for bridging surveillance gaps and launch on demand. In an overall analysis, there is immense technology upgrade to configure a *'zero trust secure architecture'* by infusing emerging critical technologies to include software on chips, software on platforms, quantum materials, quantum compute and quantum encryption, big data analytics, multi platform, multi sensor data fusion, to name a few big tickets, with an intent to enhance security of satellite communication data from space assets.

- **Satellite Communication Payloads**. Communication payloads are designed based on the specific needs of the service they are intended to provide, such as television broadcasting, internet services, mobile communications and military applications. The advancements in payload technology, such as higher frequency bands and digital signal processing, continue to improve the capacity, flexibility, and efficiency of satellite communications.[2] These payloads can include transponders, antennas, and other equipment that facilitate the transmission and reception of signals. The key elements and their functions are given below:
  - **Antennas, Amplifiers and Transponders.** Antennas on satellites are designed for specific frequency bands, C-band, S-band, Ku-band, Ka-band, critical for sending and receiving signals. These may be highly directional to focus on particular areas of the Earth or more omnidirectional for broader coverage. The transponders are the heart of the satellite's communication payload. A transponder receives signals from an Earth station, amplifies them, changes the frequency, and re-transmits them back to another Earth station. This process allows for efficient, long-distance communication across the globe. Amplifiers boost the strength of the incoming and outgoing signals.
  - **Beams Technology.** Modern communication satellites use beam technology to focus their signal on specific geographical areas. This can enhance signal strength and efficiency. Spot-beams, a more focused

version of beams, allow for even greater precision and positioning and are particularly useful in providing high-speed internet services. Laser communication beams are being used for data transfer with minimum latency.

- o **On-board Processors**. Advanced communication payloads include on-board processing capabilities, allowing the satellite to perform geospatial data analytics, data manipulation, routing, and error correction, which can significantly improve the efficiency and quality of the communication service.

- **Satellite Surveillance Payloads**. Satellite based space situational awareness mission payloads are specialised equipment carried by satellites to perform surveillance from space. Each payload is tailored to its specific mission, which can range from environmental monitoring, disaster response, intelligence gathering and military functions.[3] The design and deployment of such payloads are highly sophisticated, involving cutting-edge technology to ensure reliability, accuracy, and efficiency in data collection and analysis.
  - o **Electro Optical Imaging.** High-resolution cameras capture detailed images of the Earth's surface. These can be used for military reconnaissance, environmental monitoring, and mapping.
  - o **Radar Surveillance.** Synthetic Aperture Radar (SAR) can penetrate cloud cover and work in all weather conditions, day or night. SAR is used for military surveillance, maritime monitoring, and to observe changes in the Earth's surface.
  - o **Thermal Imaging.** Sensors that detect heat, including the heat emitted by vehicles, industrial activities, or geological phenomena. Useful in both military and environmental applications.
  - o **LiDAR (Light Detection and Ranging)**. Uses pulsed laser light to measure variable distances to the Earth. This technology is used for mapping and analysing the Earth's surface, vegetation, and buildings.
  - o **Signals Intelligence (SIGINT).** Equipment to intercept communications, electronic signals, and other types of information

transmission. This is primarily used for national security and intelligence purposes.

- **Space-Based Weapons Platforms.**[4] An ever increasing pursuit in the space domain has led to the design and development of new weapon platforms and systems. Space weapons may be characterised by earth to space, space to space and space to earth both kinetic and non-kinetic. Earth to space weapons have been of immense interest to include anti satellite (ASAT) weapons, directed-energy weapons and jammers. The US, Russia, China and India have all tested ASATs. Space to space based combat systems are satellites and similar assets which are deployed in the outer space to attack, destroy and disrupt other satellites through direct hit, use of directed energy and EM waves. Space to Earth weapons are now on the anvil of R&D and include satellite based kinetic or non-kinetic weapons for soft and hard kills to disrupt/destroy terrestrial targets.. Ballistic Missiles Defence (BMD) is yet another space controlled land based guided missiles weapon platform system. Further, the idea of intercepting missiles while they are in space or shortly after launch is not new, but advancements in sensor technology, interceptors, and directed energy weapons could make space-based missile defence systems more viable and effective in the future. The capability to conduct soft kill and hard kill based on the emerging technology landscape may result in reinterpretation of Outer Space 1967 Treaty and could change the legal landscape.
- **Cyber Warfare in Space.** As satellites and other space assets rely heavily on digital technologies, they are vulnerable to cyberattacks. Future space warfare could see a rise in cyber operations aimed at disrupting, hijacking, or disabling space-based systems. Hacking or jamming satellite communications could disrupt enemy operations without physical destruction.
- **Space Debris and Its Implications.** The destruction of satellites, either through anti-satellite weapons or other means, can generate significant space debris, posing risks to other satellites and space activities. This

issue might lead to an international push for more regulated conflict management in space to prevent unsustainable levels of debris.

- **Technological Innovations.** Emerging technologies, such as autonomous drones capable of operating in space, laser-based communication and weapon systems, and advanced propulsion technologies, could significantly alter the dynamics of space warfare, making it more sophisticated and potentially more destructive. Space drones and unmanned autonomous vehicles deployment in space for surveillance, repair, or even attack missions could become more common. These could range from small CubeSats[5] for espionage to larger drones capable of performing a variety of missions autonomously. That said, with the increasing presence of commercial and civil entities in space, the distinction between military and non-military targets could become blurred in conflicts, raising ethical and legal concerns.
- **On-Orbit Servicing and Space Manufacturing.** Technologies enabling on-orbit servicing, repairing, refuelling satellites and manufacturing[6] could significantly extend the lifespan and capabilities of space assets. This would also allow for the construction of advanced spacecraft and structures directly in space, potentially including weapons systems.

THE DEFENCE SPACE PROGRAM DELIVERABLES

General. Satellites offer huge intelligence, information, surveillance and communication advantages. Military and other application based satellite systems have the potential of being the centre of gravity of military operations planning and execution. In fact the Tri Services requirements of 24x7 real time situational awareness and common operating picture can be realised by invoking satellite systems for military perspective planning. Further, as the need for monitoring EEZ and maritime domain awareness expands, weaknesses in Indian space security eco system need to be addressed by building up the present small number of military satellites. There are major opportunities in Defence Space Technologies to carry out realistic scenario building in this fourth dimension for invisible cyber space based warfare. Salient deliverables are given in the succeeding paras.

IGMDP – The Flagship R&D Program. The Indian Integrated Guided Missiles Development Program (IGMDP), envisioned development of five Guided Missiles, Prithvi as SSM, ATGM Nag, Akash and Trishul as SAMs and Agni as technology demonstrator. The Program is a case study in technology sovereignty. Motivated by the overwhelming accomplishments of ISRO in satellite launch vehicles (SLV) project, despite dependencies on imports of key space technologies, IGMDP was planned to gain self reliance in the Guided Missile Technologies. The challenges compounded in 1987 when Missile Technology Control Regime (MTCR) was slapped to restrict proliferation of missiles components, sub systems and systems. India demonstrated a robust political resolve and organised a concerted whole of Nation approach to with academia for basic TRL 1-6 research, developed PSUs, and private Indian industry and R&D agencies. The key payoffs accrued include advance materials for airframes, gyros – accelerometers – servo systems for guidance control systems hardware and software, inertial measurement units, launch pad & onboard computers, solid and liquid propellants, liquid propulsion engines, precision technologies in hydraulics and pneumatic actuators, to name a few big tickets. The momentum has continued into large number of variants of Agni with multiple warheads, Brahmos, MRSAM and many more. Given the present Government impetus and whole of Nation approach with Aatmanirbhar Bharat, Make in India, Startup and Skill India Missions, India is well poised to be a global leader in the Defence – Space Technology Program.

Integrated Defence Space Development Program (IDSDP). There is a dire need to launch a major *Indian Integrated Defence Space Development Program (IDSDP) akin to IGMDP*. Policy, structure and strategy are three quintessential macros for launch of a successful IDSDP. The three structures comprise space sector PSU New Space India Limited (NSIL) for oversight on strategic and operational activities in the Space Sector, Indian Space Research Organisation (ISRO) with focus on developing new technologies and new systems, Indian National Space Promotion and Authorisation Centre (IN-SPACe) as an interface between ISRO and private entities. There is a dire need to create and develop an overarching structure comprising subject matter experts (SMEs) for providing long term strategy and management oversight through an Integrated Defence Space Development Program akin to Integrated Guided Missiles Development Program to prepare a cogent strategy, plan, direct, coordinate and monitor, short, medium and long term deliverables to ensure that the policy's efforts are carried forward as a joint effort with academia and industry stakeholders. This would provide velocity to a well orchestrated hub and spoke wheel to the Indian National Space Development Program. The success of IGMDP to a great measure is attributed to the Technology Wizard and Charismatic Leader, late Dr APJ Abdul Kalam, ably supported by hand picked project directors, system directors and SME veterans as advisors. In a similar endeavour, IDSDP calls for a cogent Program Structure suitably led by a Space Technology SME as a Program Director. Salient pre-requisites for this are given below and would need deliberation to create a thesis and a baseline document for the next 23 years to Viksit Bharat:

- **Project Structure.** Configure at least ten Project Verticals in the Program comprising Project LEO, Project MEO, Project Nano Satellites, Project Pseudo Satellites, Project ASAT, Project Hypersonic Glide Vehicle, Project Surveillance Payloads, Project Communication Payloads, Project Satellite Launch on Demand Systems, Project Ground Control Platform System, led by a Project Director each. Obviously each project would have their roadmaps and milestones clearly defined.
- **Technology/Systems Verticals.** At least eleven systems verticals led by a Technology Director each comprising Advance Materials, Smart manufacturing, SAR, Laser, Semiconductor, advanced electronics manufacturing with software on chips and platforms, robot refuelling and in orbit repair, hypersonic systems, guidance and control systems, propulsion systems and emerging & critical technologies big data analytics, AI and Info Decision Support Systems etc.

- **User Advisory Interface.** It would be imperative that the Tri Services Space Command be suitably integrated with SMEs as technology managers to value add the program with user inputs.
- **Public Private Partnership (PPP).** This calls for a cogent *'whole of nation approach'* with collaboration for developing niche technologies by DRDO, ISRO and other R&D Organisations, DPSUs, private players and startups and a synergy with academia, technology innovation hubs and centres of excellence.IDSDP will integrate & synergise efforts of this PPP Defence Space Ecosystem. At present the system is working in silos and needs to be vectored for a well directed outcome and impact.
- **Defence and Space Industrial Corridors.** The scope of Defence Industrial corridors could be enhanced with inbuilt space development clusters of startups, MSMEs and OEMs duly supported by International Collaborations through Strategic Partnerships and Joint Ventures under the aegis of the IDSDP. This would give the necessary filip to the short, mid and long term strategies of the program.
- **Strategic Oversight Committee.** A Program of this magnitude requires a strategic structure under the Office of The Honorable Prime Minister. The proposed structure may comprise Union Ministers of MoD, Department of Space, Department of Science, Chairman ISRO, Chiefs of Staff Committee and special invitees for a quarterly update. The Strategic Oversight Committee could assess the needs of Integration of Civil Space and Military programs, International cooperation for technology development, budget requirements including FDIs and review of Space and Geospatial Policies in National interest. The success of the space missions and security of space assets depends on building a resilient Defence Space Technology and a skilled Workforce which could be organised under the IDSDP and given a strategic oversight.

Integrated Space Domain & Situational Awareness Capabilities.[7] Space is a congested, contested, and competitive domain with a highly dynamic and rapidly evolving environment. More than 10000 satellites have been placed into Earth orbit and the number is expected to increase in advanced small satellites, LEO, MEO, pseudo satellites and myriad of satellite launch capabilities. That said, Space Situational Awareness (SSA) and Space Domain Awareness (SDA) become a vital space capability. SDA is the capability to detect, identify, track and characterise space objects including space debris and the space environment with an intent to support safe sustainable space activities. Consistent with SDA, Space Situational Awareness (SSA) is fundamental to the deportment of all space-based operations based on important ingredients of space domain capabilities and capacities. SSA comprises technologies to detect and track objects in space so as to establishing their orbits, comprehend the environment they are operating in, and predicting their future positions and threats to their operations. In fact, SDA and SSA are two sides of the same coin for military, civilian and dual use. Space surveillance and tracking systems detect space objects and classify them as friendly, hostile or debris and predict their orbits. On the other hand, space intelligence plays a fundamental role to coordinate, command and control space ISR based ground data in support of military commanders, thereby ensuring that space services driven right info is available at the right place and right time.

Designing a Satellite Constellation for Space Situational Awareness (SSA). SSA and Intelligence, Surveillance, and Reconnaissance (ISR) with a focus on terrain info mapping with rapid revisit times, involves a complex interplay of technological, orbital, and mission-specific factors. To achieve a significant reduction in revisit time for terrain mapping to at least 4 hours, as a revisit time, and to incorporate advanced capabilities like Hyperspectral Imaging (HSI), Synthetic Aperture Radar (SAR) including bistatic configurations, and Multi-Spectral Imaging (MSI), requires salient strategic considerations as given below:

- **Types of Satellites**. Nano and Small Satellites are preferred for creating a cost-effective, responsive constellation. Nano-satellites typically weigh 1-10 kg, while small satellites may weigh up to 500 kg. Theses are discussed in details ahead. Micro, Nano & Software Defined Satellites,[8] comprise the nextgen satellites based on advanced materials, nano materials and energisers. These miniaturised satellites have resulted in proliferation of LEO and MEO satellites and launch on demand satellites given the ease of their launch with smaller launchers and cheaper launch vehicles. Software defined satellites are the next disruption. A large number of surveillance devices are deployed, but given the porosity and the sheer length of the borders and areas of interest and influences, for round the clock surveillance, India must develop capability to launch nano - tech enabled LEO satellites, drone based pseudo satellites and a number of ground stations enabled by big data analytics with a GIS platform duly integrated for real time situational awareness.

- **Hybrid Constellation.** Incorporating a mix of satellites with different sensing capabilities (ELINT, SAR, MSI, HSI, Optical) ensures comprehensive surveillance and intelligence gathering. Alternatively, satellite systems may be designed with multiple payload features.
- **Advanced Payloads.** As discussed above, an array of communication and surveillance payloads may be deployed singly or as a hybrid constellation with SAR, Optical, Laser, Electro-optical, ELINT, and others, for effective Image Intelligence. The following spectrum of payloads would be important:
    - o **Hyperspectral Imaging (HSI)** would be essential for detailed information across a wide range of wavelengths for precise identification of materials and objects.
    - o **Bi-Static and Tandem SAR** facilitates dem-data for objects of military importance, 3D mapping and enhanced imaging regardless of weather or lighting conditions.
    - o **Multi-Spectral Imaging (MSI)** for a wide range of applications to include military applications, agriculture to combatting climate change.
- **Multi Platform, Multi Sensor Data Fusion (MPMSDF).** It is imperative to configure a ground command and control platform for giving decision makers and stakeholders real time situational awareness and a common

operating picture. Given the myriad of surveillance platform and sensors, space satellite based, Medium Earth Satellites MEO, Low Earth satellites LEO, psuedo satellites, AWACs and aerial platforms, ground based sensors, there is a dire need to get the true picture through *meshed intelligence*. This involves the integration of data from various sources (satellites, drones, ground stations) to create a comprehensive intelligence picture. It necessitates advanced data processing and communication capabilities and a MPMSDF integrated unified platform.

- **Revisit Time & Quantification of Satellites.** The primary goal of achieving a revisit time of 4 hours or less requires a carefully designed constellation. This involves calculating the optimal number of satellites and their orbital parameters to ensure global coverage with the desired temporal resolution. The exact number of satellites required would depend upon depends on several factors, including orbital altitude and inclination in that Lower Earth Orbit (LEO) satellites which have shorter orbital periods would necessitate more satellites for continuous coverage; sensing capabilities based on different types of sensors (SAR vs optical) having varying swath widths and resolutions, affecting how many satellites would need to be deployed and constellation design which may be Walker Delta or Star constellations for global coverage, with the specific design impacting satellite numbers.
- **Estimation of Number of Satellites.** Based on the above and assuming a mix of SAR and optical satellites in LEO (altitude around 500-600 km), achieving 4-hour revisit times globally might require a constellation of over a hundred satellites, as a part of limited coverage of India's areas of interest and influence, considering the need for different payloads and redundancy. This assessment provides a broad overview, and detailed constellation design would necessitate more precise calculations and considerations tailored to the specific mission requirements and technological capabilities.
- In an overall analysis, incorporating advanced technologies like AI for data analysis and autonomous satellite management systems can also

enhance the efficiency and responsiveness of the constellation, potentially reducing the required number of satellites.

Space Based Surveillance Network Systems.[9] There is a dire need to configure a network of varied space surveillance systems space radar systems, phased array and synthetic aperture radars, thermal infrared spectrometers, multi spectral imagers, glimmers, rolling mirror space telescopes with varying resolution on ground and in space. This shall generate info for space situational awareness and debris status and ground based geospatial data for military applications and National Missions/ SDGs of India.

Secure Space Communication Systems. Space Communication systems is a two way communication in uplink and down link which need to be secured to convey signals and geospatial data in real time. Satcom Association of India is an Agency which is tasked to identify areas of research, design and development in seamless secure satellite communication systems. There is a need to proliferate NavIC based satellite receivers for mobile handsets, drones and myriad of applications.

Research Centre of Big Data for Nation Mission & Defence.[10] A unified secure cloud (Space Data Centres) for storing big data that will get generated would need to be created. This Research Centre would be the most important repository of the humongous amount of data for defence and National Missions /SDGs and would be a strategic asset of National Importance. This Data Platform would aim to integrate Big Earth Data, data from multiple Tri Services platforms and other agencies for collation, synthesis & monitoring data to create business analytics., augmented intelligence and predictive analytics. Big Data Platforms, Multi Platform Multi Sensor Data Fusion and AI platforms would need to be created for generating an *Integrated Information, Actionable Intelligence and Decision Support System*.

Global Navigation Satellite System (GNSS) -NavIC. A system of GEO and Medium Earth Orbit (MEO) and LEO satellites would need to launched to configure a robust NavIC as a reliable global positioning system (GPS).

This would need to be hardened for a robust global positioning, navigation and timing.

Resilient Positioning Navigation and Timing (PNT) Systems. PNT is the critical mass of all space based systems. In the digital world, it is a National level problem but can affect Armed Forces at the time of crisis and war. The Indian Satellite Based Systems are dependent on Global Navigation Satellite Systems to include US based Global Positioning System (GPS). The ability of USA or an inimical Nation degrading GPS and affecting PNT will have serious implications on e-Governance and decision support systems and can be disastrous in war. There is need to design, develop and deploy three layers of systems for assured PNT:

- **A terrestrial system for PNT.** This shall help in getting geospatial data from in premise infrastructure so important in management of information, resources and autonomous systems
- This terrestrial grid must be layered with low earth orbit (LEO) satellite-based systems which are ready to launch on demand for real-time situational awareness.
- **Tethered/solar based drones as quasi satellite as eye in the sky,** on demand for localised PNT support up to 30 Km above the mean sea level.

Launching of Satellite Systems on Demand. There is a void in real time satellite imagery. The present system of terrain mapping in the areas of interest and influence need to be reduced to at least four hours. This calls for a concerted effort to launch more defence payload satellites. These may be nano and small LEO satellites on demand. There is also a need to develop software defined satellites for muti payloads. As a fallout, resilient PNT can also be achieved by developing launch on demand satellites.

Weaponising Space Systems.[11] Hypersonic glide vehicles, hypersonic missiles, Anti Satellite Systems based on Ground based launchers for hard kill and soft kill systems in the space is in the realms of technology demonstration and a void. There is a need to design, develop and deploy anti satellite missile systems. Also, space based hard kill guided missile systems, jamming, directed energy weapons and electromagnetic pulse systems need to be developed for use from space to earth. There is a need to create soft and hard kill systems including jammers and directed energy weapons (DEWs) for Outer Space Warfare. The scope of such capabilities include ground to space warfare, space to space warfare (satellites destroying hostile satellites, space to ground warfare. These technologies include EM spectrum, laser based DEWs and hard kill missile ASAT systems.

Space Force Development. Several countries have already established or are in the process of establishing dedicated military branches for space, recognizing the strategic importance of space dominance. These space forces would comprise manned unmanned technology based teams which, in future, may drive the development of doctrines, technologies, and strategies for space warfare. While this overview is speculative, the rapid pace of technological advancement and the increasing strategic importance of space suggest that the future of space warfare will be shaped by a combination of innovation, international policy, and the evolving nature of conflict.[12] The challenge will be in balancing the aggressive capabilities for space warfare with the need for cooperation and peaceful use of outer space, as it remains a global commons crucial for the entire benefit of humanity.

Value Addition Space Based Projects. That said, there are two key drivers of Defence Space Program – Technology and Data. Technology comprises space technologies and supporting emerging technologies AI, AR, VR, nano materials and energisers, quantum technologies, communication tech, cyber and electronics warfare tech, directed energy tech[13] to name a few big tickets. Data comprises geospatial data and all forms of unstructured data from various sensors and devices tied into big data analytics. There is a need to create enabling technologies and space based projects for 24/7 situation awareness:

- AI platform for satellite and other imagery interpretation and identification of military objects and combat groupings of interest.
- Integrated Battlefield Management System (IBMS) for Blue and Red Force Tracking, intelligence collection in real time including tracking key

enemy military targets of interest for int preparation of the battlefield (IPB) and effective IFF to ensure RTSA and COP, so important for integrated Tri Services theatre operations.
- All weather surveillance and satellite communication.
- Tri Service Platform for Electronic Warfare – electronics surveillance, electronics counter /counter-counter measures.
- Cyber defensive and offensive systems.
- Weather and met data for artillery and long range vectors though autonomous space based met data software systems.
- Effective disaster management, precision agriculture and defence through MPMSDF based proactive forecasting and follow up actions.

CONCLUSION

C7I2S2R DSS.[14] The paradigm of future warfare is invisible warfare and cyber warfare is a good example. The same would be true for information and Space Based Warfare. Given the emerging technology landscape and the primacy of space warfare with time, there is a need to develop a major Integrated Space & Aerial Systems Development Program to create a Command, Control, Communications, Computers, Cyber, Cognition (C6) Intelligence, Info, Surveillance, Security, Reconnaissance Big Data Decision Support System for National Missions/SDGs and add Combat (C7) systems for defence. This should be the ultimate intent for exploitation of Space Mission in National Strategic interest. In an ultimate analysis the IDSDP would create the platforms for C7I2S2R DSS and foster development of weapons to "degrade, disrupt, destroy or deceive an adversary's space capabilities". Opportunities beckon!

Lt Gen (Dr) Anil Kapoor, AVSM, VSM (Retd) superannuated as Director General Electronics and Mechanical Engineers on 31 December 2020. He was also the Director General Info Systems.

NOTES

1. Press Information Bureau, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1962180, India's NavIC will now be supported by 'Made in India' chipsets, 29 September 2023.
2. Guglielmo S. Aglietti*, Current Challenges and Opportunities for Space Technologies, Paper by Department of Mechanical Engineering, The University of Auckland, Auckland, New Zealand.
3. Peng Mun Siew, · Daniel Jang, Thomas G. Roberts, Richard Linares, SpaceBased Sensor Tasking Using Deep Reinforcement Learning, 26 October 2022, MIT, Journal of Astronomical Science.
4. Fact Sheet: Space Weapons - Center for Arms Control and Non-Proliferation, https://armscontrolcenter.org/fact-sheet-space-weapons/.
5. https://www.esa.int › Talking_technology › CubeSats, Roger Walker, CubeSats: from educational tools to autonomous space drones.
6. Boyu Ma, Zainan Jiang, Yang Liu, Zongwu Xie Advances in Space Robots for On-Orbit Servicing: A Comprehensive Review.
7. Malgorzata Polkowska, Integrated Space Situational Awareness Systems: SDA and SSA--Advantages and Limitations. June 2021.
8. Lt Gen Anil Kapoor (Retired), Posturing in Defence Space, Geo ASTRA, May 2023.
9. Lt Gen Anil Kapoor (Retired), Posturing in Defence Space, Geo ASTRA, May 2023.
10. Ibid.
11. https://armscontrolcenter.org/fact-sheet-space-weapons/.
12. newsletters@breakingdefense.com, In Focus-Military Space USA – The Way Forward, December 2023.
13. Lt. Gen. Matthew Glavy, 'Space can be the most resilient capability': LEO sats vital for next war, Space.Com.
14. Lt Genn Anil Kapoor Retied, Posturing for Defence Space, Geo Artha.

114-131

VERY LOW EARTH ORBIT (VLEO): THE EMERGING BAND OF INTEREST IN SPACE

Gp Capt Puneet Bhalla (Retd)

INTRODUCTION

The domain of Outer Space has seen growing interest in recent years. This has been enabled by technological advancements and innovations and increasing space enabled applications across various civil, defence as well as commercial sectors. The most important developments have been the increasing demand for remote sensing data and the Low Earth Orbit (LEO) enabled communications. This has caused greater participation, leading to overcrowding of this belt of space. In this evolving landscape, Very Low Earth Orbit (VLEO) is emerging as an alternative orbital band of interest. The first use of this belt was by the U.S.' Corona reconnaissance satellites in the 1960s and early 1970s that operated at around 150 kilometres altitude and interestingly jettisoned their camera films back to Earth, which were then captured mid-air by aircraft, to be processed by intelligence analysts.

As with the lower boundary of space, there is no consensus on the exact band that constitutes the VLEO. This is because there is no clear demarcation in terms of physicality of the atmosphere/space that could delineate these bands. Except for the Corona programme, satellites in the LEO region were deployed above 500 kilometres to obviate multiple physical challenges experienced below this altitude. Therefore, VLEO is taken as the orbital area below approximately 450 kilometres altitude, with 100 kilometres above the Earth's surface broadly accepted as the lower boundary of space.

Spacecraft operating in the VLEO band could potentially provide significant benefits over those operating in LEO and manned and unmanned aircraft operating in near space regions. It could also help unlock new possibilities for military intelligence and communication operations. VLEO operations could potentially offer cheaper alternatives to the growing number of private initiatives in the domain, seeking commercial gains. There are attempts to overcome the unique physical and operational challenges that it presents through technological advances in miniaturisation, digitisation, materials and propulsion. In recent years, the European Union, U.S., Japan and China have all expressed their interest in VLEO, testing and demonstrating utilisation concepts.

ADVANTAGES OF VLEO

VLEO offers great advantages for both remote sensing and telecommunications missions, influencing technological features as well as functional characteristics.

- **Higher Resolution Imagery.** Physically, a reduction in orbital altitude improves the spatial resolution for a given electro-optical (EO) equipment. Alternatively, simpler instruments could achieve equivalent results, thereby enabling reduction in mass and size of the payload.[1]
- **Active Sensing.** Active sensing includes Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LIDAR). For these, being closer to the target reduces the power requirements and improves the signal-to-noise ratio. Consequently, at lower altitudes, for a given power, the same spatial resolution can be achieved over larger swath widths, reducing the requirement of the number of satellites in a constellation for a desired coverage.[2]
- **Communication Efficiency.** Lesser distance between the satellite and terrestrial stations reduces the power requirements for communication.

This can be used to either lower the power demands or achieve higher data transfer rate at the same power, or a combination of both.[3]

- **Temporal Resolution.** A lower altitude results in smaller orbits and hence a better temporal resolution, (time between satellite reappearing over a given point). Hence, similar coverage can be achieved with lesser number of satellites. [4]
- **Lower-Latency Data Transfer.** Latency is the time taken between transmission of data from the source to reception at the destination. Lower latency has become an important requirement of modern satellite enabled communications (SATCOM). This has caused the recent race for LEO based SATCOM constellations that offer a latency of around 32 milliseconds, as compared to the close to 600 milliseconds provided by GEO based satellites. Even lower latency could be achieved by further lowering the orbital altitude of satellites to VLEO.[5]

Various studies have highlighted these advantages. One such study paper, sponsored by Thales Alenia Space in 2016 for its proposed Skimsats VLEO satellites explained, "The decrease of altitude, with respect to a 650 kilometres orbit, by a factor of four (around 160 kilometres) leads to a 64x reduction in radar RF power, 16x reduction in communications RF power and 4x reduction in optical aperture diameter to achieve the same performance. It also helps reduce the weight and cost of optical payloads by 50 percent while providing the same resolution."[6] The study also highlighted that at an operating altitude of 160 kilometres, the Skimsat platform can provide SAR and optical imagery at 1 m Ground Sample Distance (GSD) with a launch mass of less than 75 kilogram.[7]

Additional benefits that would impact space operations, applications and employability include:

- **Spacecraft Design and Manufacture.** Reduction in power requirements for sensing and communications also cuts into the requirements for large solar panels, positively influencing the spacecraft design and manufacture.

- **Access to Orbit.** Presently, satellites headed for VLEO are carried to LEO from where they manoeuvre to their planned orbits. As VLEO operations become more regular, dedicated launchers would deploy satellites at their designated orbits, enabling saving on precious onboard propellant. Involving shorter flight times and having lesser gravity losses to be overcome would allow usage of smaller launch vehicles or permit more satellites to be delivered per launch to orbit,[8] enhancing the commercial viability.
- **Self-Cleaning Orbits.** Growing participation in space has contributed to orbital crowding in the LEO. At the same time, low cost, mass production of satellites coupled with cheaper launch alternatives, has eliminated the requirement of longevity of deployment. Space overcrowding and orbital debris have been identified as major challenges to safety and sustainment of space operations by all major space faring nations. The Inter-Agency Space Debris Coordination Committee's (IADC) "Space Debris Mitigation Guidelines" is an international regulatory document on space debris mitigation, based on consensus among the IADC members (space agencies of all major space faring nations, including ISRO). These include the capability for end-of-life manoeuvres for de-orbit or towards graveyard orbits to ensure efficacy and safety of future missions. VLEO not only provides an alternate orbital space, but also the advantageous characteristic of auto-cleaning. All spacecraft placed in VLEO orbits and the orbital debris created as part of their deployment and operations are exposed to relatively higher degree of gravitational pull and atmospheric drag. They will more easily undergo orbital decay at the end of their operational life, with eventual burn up on re-entry, keeping the orbit clean for future missions. The self-cleaning characteristic of the orbit also obviates the requirement of carrying additional propellent for end-of-life de-orbit manoeuvres, with associated cost savings in terms of propellent weight and launch costs.
- **Radiation.** Satellites operating at these altitudes face a more benign radiation environment, reducing the requirement of satellite hardening

and allowing the use of commercial off the shelf (COTS) components.[9] This would lower the complexity of production and reduce the costs and developmental timelines.

- **Advantage over Near Space Operations.** VLEO based constellations score over UAVs and airships operating in Near Earth Space, as they can overfly all regions of the Earth without any regulatory restrictions, covering significantly larger areas with more persistence. They are less vulnerable to terrestrial weapons and offer redundancy due to numbers.[10]
- **Satellite Enabled Communications (SATCOM).** LEO enabled satellite communication is already seeing much interest owing to the benefits it offers in terms of lower latency, reduced electromagnetic propagation losses, lesser power requirements and lower production and launch costs, when compared to GEO enabled telecommunications. These advantages have made SATCOM being considered as an important component of 5G-Advanced and 6G networks of the global communications ecosystem that envisages integrating terrestrial and non-terrestrial networks to achieve economies of scale, wider global utilisation and cost-effective services.11 Commercially, these communications would be critical for emerging use cases such as autonomous vehicles, smart cities, smart homes, human-computer interaction, smart manufacturing and industrial Internet of Things.12 Militaries are especially showing interest in these for providing reliable connectivity and broadband services in remote and dispersed deployments and while on the move and for pursuing futuristic concepts like Internet of Military Things (IoMT) that would require incessant, ubiquitous, low-latency, automatic real-time information sharing. Reducing altitudes further to VLEO would add onto the contributory advantages, even as technologies developed for LEO based constellations, such as high-quality pointing subsystems, could be effectively utilised for VLEO constellations with some upgradations/ modifications.
- **Better Turnaround.** Presently, satellites once deployed cannot be serviced or upgraded. This has become an operating challenge in an environment

where technology is upgrading faster and becoming obsolete sooner. Shorter orbital lives would allow replacement by satellites with latest hardware and software, improving upon the performance and services.

Challenges. Operations from VLEO have not yet achieved maturity owing to several challenges that need to be overcome towards reliability, safety and profitability.

- **Constellation Numbers.** A lower altitude comes with a penalty of decreased instrument swath width for EO instruments and lesser ground coverage for communication satellites, necessitating more satellites in a constellation to achieve the desired regional or global coverage.
- **Platform Stability.** Operating in residual atmosphere could cause aerodynamic perturbations reducing platform stability and adversely affecting missions that require stable attitudes for precise pointing of instruments.
- **Ground Stations.** Shorter orbital periods at lower altitudes would reduce the communication window available over a ground station, impacting data transfer and tracking. A VLEO constellation would thus require more globally widespread ground station network to support its operations.
- **Propulsion Systems.** Unlike satellites deployed to LEO and GEO that require little or no propulsion to maintain orbit, satellites in VLEO would require onboard propulsion, with sufficient propellent for providing continuous or periodic thrust, to overcome atmospheric drag and higher gravitational forces to achieve a practicable operational lifespan. Fuel consumption would also increase exponentially as orbits get closer to the Earth. In the VLEO belt itself, an increase in altitude of the International Space Station (ISS) from 350 kilometres to 400 kilometres in 2011 reduced the average fuel consumption from 8,600 kilogram per year to 3,600 kilogram per year.[13]
- **Satellite Design.** Conventional satellite designs of a large square object with huge solar panels would generate significant drag in VLEO, making it unsuitable for operations.

- **Knowledge of Lower Thermosphere.** The atmospheric drag in the lower thermosphere belt varies diurnally and is affected by solar radiation.[14] This makes it difficult to predict operating conditions and programming satellite handling accurately.
- **Atomic Oxygen.** Satellites in VLEO are exposed to very high levels of elemental oxygen, also known as atomic oxygen (AO), a highly reactive form of oxygen that corrodes most substances quickly. It is estimated that at some VLEO bands, up to 96 percent of the atmosphere is AO.[15] This has remained one of the main limiting considerations for utilising these altitudes.
- **Regulations.** The very nature of VLEO may require adaptation and even modification of launch and operating licensing procedures to account for its inherent features and their impacts on space activities.[16]

Evidently, making operations in this band viable would require constant efforts to balance the advantages and challenges, for achieving meaningful orbital lifetimes whilst minimising spacecraft size, mass and complexity. Designers and engineers would require calculation of optimal altitudes that best balance the savings in terms of payload and reduced number of spacecrafts in a constellation for achieving the mission goals and the increased mass related to addition of the propulsion and electrical systems. Success would depend upon the developments in enabling technologies and applications that would allow development of satellites and systems optimised for operation VLEO.[17]

ENABLERS

- **Spacecraft Design.** Novel aerodynamic designs that combine smaller size and more streamlined shapes for drag reduction are being explored. Aerospace Corporation, a U.S. based company, is testing DiskSat, a satellite shaped like a plate with onboard thrusters to keep it upright.[18] Stingray, another satellite being developed in the U.S., envisages a 'space shuttle' styled bus, with solar panels on the wing structures.[19] The residual atmosphere has also allowed designers to envisage control surfaces for aerodynamic attitude and orbit control methods. These would enable better spacecraft control and limited manoeuvrability for drag reduction in a variable atmosphere and for end-of-life de-orbit manoeuvre.[20]

- **Propulsion.** Operations in VLEO are being envisioned through the development of smaller, lightweight and efficient engines utilising different concepts for propulsion.
    - **Solar Electric Propulsion (EP).** These systems utilise electrical energy to accelerate charged particles through controlled nozzles to generate thrust. Being pursued for decades, some of the methods have now achieved maturity and are gaining traction as the propulsion of choice for commercial satellites being deployed in LEO, including the Starlink constellation.[21] These systems have a higher propellant efficiency (more thrust per unit of propellant), thereby reducing the requirement of fuel to be carried at launch.[22] Although presently limited in the amount of thrust that they can generate, they can provide it more consistently and precisely over extended periods, making them suitable for smaller spacecraft operating in regions requiring persistent thrust. They do however present challenges in terms of complexity of design, testing, reliability and scalability. A major shortcoming of EP for VLEO operations is the high electric power requirements, necessitating larger solar arrays, with the associated drag penalty. New propellants, such as water or air, are also being pursued to reduce cost and environmental impact.
    - **Atmosphere-Breathing Electric Propulsion (ABEP).** In addition, the residual atmosphere in VLEO band offers opportunities to develop and utilise novel atmosphere-breathing electric propulsion (ABEP) systems, thrusters that absorb the surrounding air and generate plasma from it to be used as the propellent. Using just air and solar power for this process would greatly reduce the mass and volume of fuel to be carried at launch. However, the power consumption of such engines is likely to be high for per unit of thrust,[23] requiring greater

solar power generation and storage capacity. Improvements in solar power generation and storage capability are helping overcome challenges related to these propulsion systems.

- **Materials.** Advanced lightweight and durable materials and coatings that could help reduce drag and protect from AO corrosion are being developed and tested. Success in these would provide a further impetus to regular use of VLEO belt.
- **Commercial Exploitation.** Lowered cost of access to space is democratising the domain and has resulted in more private initiatives seeking novel spaces and technologies for commercial gains. This has spurred growth in the sector through investments in technology development, innovative applications, increased use cases and establishment of supportive ecosystems. Investments seeking cheaper alternatives would help generate ideas to bring down the launch costs and the complexities related to this band.

GLOBAL EFFORTS

Recent years have seen a growing global interest in VLEO, both by governments and private enterprises for scientific, military and commercial applications.

EUROPE

The interest in VLEO was first demonstrated in 2009, with the launch of European Space Agency's (ESA) Gravity Field and Steady-State Ocean Circulation Explore (GOCE), a scientific satellite designed to take accurate measurements of the Earth's gravitational field.[24] It demonstrated a sustained orbit between 250 and 300 kilometres for three years from 2009 to 2013, with the help of xenon-fuelled electric thrusters. [25]

The European Union has devoted 5.7 million Euros ($6.7 million) to Discoverer, a Horizon 2020 research program aimed at a "radical redesign" of Earth observation satellites for low-altitude operations.[26] University of Manchester's Rarefied Orbital Aerodynamics Research is being used to test materials for drag reduction. In-orbit tests were carried out on its Satellite for Orbital Aerodynamics Research (SOAR), a CubeSat deployed from the ISS on 14th June 2021 into a naturally decaying orbit, finally deorbiting on 14th March 2022. Using a set of steerable fins that allowed attitude changes, it tested aerodynamic performance of different materials at VLEO altitudes.[27] It also made measurements of atmospheric properties at these altitudes.[28]

In July 2022, the ESA awarded the Skimsat program, which aims to reduce the cost of Earth observations by operating in VLEO, to Thales Alenia Space and Redwire Space. Funded under ESA's Discovery Preparation and Technology Development (DPTD) activities, Thales Alenia Space, along with QinetiQ Space team in Belgium, carried out an exhaustive study for VLEO operations.[29]

In October 2023, the ESA launched a 'Call for Ideas' towards exploring and exploitation of VLEO – seeking new and innovative solutions to take advantage of the unique characteristics of VLEO and to mitigate the challenges. These include technology development activities specific to VLEO, such as atmospheric-breathing propulsion, protective materials and coatings, navigation and control. Ideas related to re-entry and possible re-use of space assets have also been included.[30]

JAPAN

Japan Aerospace Exploration Agency (JAXA) operated its Super Low Altitude Test Satellite (SLATS) from 2017 to 2019. The satellite, powered by xenon-fuelled electric thrusters, operated at seven different altitudes, decreasing from an initial altitude of 630 kilometres to 167.4 kilometres, for testing purpose.

UNITED STATES

In the U.S., the efforts are being led by private enterprises, supported by the government. In 2016, U.S.' private company Skeyeon, filed the first VLEO satellite patent on a propulsion system using a self-sustaining ion engine. The company, which seeks to provide high-resolution daily Earth imagery from VLEO, now has seven U.S. patents across satellite designs, materials, satellite communications and air breathing propulsion.[31] The company claims to have identified promising sample materials in a dedicated AO test facility and these are now being tested on an exterior ISS platform.[32]

Albedo, a U.S. based start-up, is developing a VLEO constellation with an aim to collect 10-centimetre optical imagery and 2-metre thermal infrared imagery. The technology is eliciting interest and the company has been able to garner a total funding of $97 million.[33]

Earth Observant (EOI) is developing a VLEO Earth-imaging satellite with a contract from U.S. Air Force that seeks a capability of collecting 15-centimetre-resolution imagery and transferring data "directly to the warfighter" in minutes.[34] The first satellite in the 'Stingray' constellation is planned for launch in 2024, with an aim to deploy six satellites to VLEO by the end of the year. This is expected to upscale to a 60-satellite constellation with multispectral (MS), near-infrared (NIR) imagers, for both government and commercial use. Operating at an altitude of 250 kilometres utilising electric propulsion, the constellation is expected to have a 10-to-15-minute revisit period.[35] They will also make use of on-board computing (edge computing) to improve latency.[36]

CHINA

As with much of its space program, China has defined the roadmap for developing its capability in the VLEO space, with commensurate investments. Its 14th Five Year Plan (2021-2025) has proposed building a remote sensing space infrastructure system with global coverage and efficient operation, and VLEO is an important component of this infrastructure.[37] It has already gained some experience of this band of space, through its space stations. (Its Tiangong-1 and Tiangong-2 space stations orbited at an average altitude of 355 kilometres and its main space station Tiangong operates between 350 and 450 kilometres). As with its other developments in the domain, it is supporting and encouraging its commercial space sector to develop technologies and enabling sustainable supply chains and ecosystems.

An experimental Chinese satellite Tianxing-1 was launched in June 2022, which maintained an orbit of around 300 kilometres before its orbit continually decayed over a month. Analysts have speculated that one of the tasks for the satellite could have been technical verification tests for VLEO.[38] Its Shiyan 25 (SY-25) launched in June 2023 has now sustained operations at an altitude of around 275 kilometres since early Sept 2023.[39] CSPACE, a private Chinese company, is developing Qiankun (QK) series satellites for operating in VLEO for remote sensing and telecommunication. Its first experimental satellite, QK-1 was launched onboard China's commercial launch company, Galactic Energy's Ceres-1 solid fuel rocket in July 2023.[40] It has continued its slow descent and was last reported operating at around 350 kilometres.[41]

Senior officials of its Second Academy of the China Aerospace Science and Industry Corp (CASIC), a state-owned space contractor, made statements in diverse forums in March[42] and July[43] 2023 about its interest in VLEO. As per CASIC, its first prototype VLEO satellite had already emerged from the design and production phase in July 2023.[44] Although the launch planned for December 2023 has been delayed, once in orbit, the satellite is planned to study the VLEO environment and demonstrate and verify VLEO orbital flight and key technologies, including high-resolution ground imaging technology, onboard intelligent processing and direct data transmission to user terminals.[45] Subsequently, the company plans to have a nine-satellite constellation for service verification and demonstration in orbit by end 2024. The operational constellation is expected to have a network of 192 satellites in orbit by 2027, further upscaling to 300 satellites by 2030, for both communication and remote-sensing services.[46] According to Zhang Nan, chief designer of the constellation, the constellation will achieve 0.5-metre spatial resolution and transmit spatial information to users within 15 minutes.[47]

Chinese VLEO efforts are going to benefit from the advances made in electric propulsion. Premier government institutes that have developed electric propulsion systems are Shanghai Spaceflight Power Machinery Institute, the Centre for Space Science and Applied Research (CSSAR) under the Chinese Academy of Sciences and the Lanzhou Institute of Physics.[48]

The most significant development has been the scaled-up ion thrusters being used on its Tiangong space station, which has allowed substantial mass saving on fuel when compared to the ISS which uses conventional propulsion. Kongtian Dongli, a Chinese company established in March 2022, is developing Hall thrusters and microwave electric propulsion systems to power future spacecraft.[49]

SPAIN

A Spanish company, Kreios Space, is developing an ABEP system for VLEO satellites.[50] In December 2023, it signed an agreement with Elecnor Deimos, a space engineering company, to jointly develop and commercialise the world's first commercial satellite designed to operate indefinitely in VLEO.[51]

INDIA

India also needs to add VLEO into its list of future initiatives to exploit its benefits and contribute to the overall capability and capacity building in the domain. Technology pursuance and advancement by Indian Space Research Organisation (ISRO) in recent years is encouraging. For example, it first demonstrated an EPS system onboard its GSAT-9 launched in the year 2017[52] and is now gearing up to demonstrate the use of an indigenously built EPS (developed by its Liquid Propulsion Systems Centre) on board a Technology Demonstration Satellite (TDS-01), expected to be launched in the second half of 2024.[53] Recent policy enablers have energised Indian private sector participation in the domain, but most new players are looking at commercial gains by exploiting contemporary capabilities. Operationalising this belt would require focussed efforts in novel technologies, design and materials and this would be best served through collaborative research and development involving ISRO, academia and 'new space' industrial communities. However, emphasis should be on standardisation and interoperability for seamless integration into the information and communication networks.[54]

For the armed forces, operations in this band have the potential to significantly contribute to improving the quality and quantity of imagery and speeding up the information flow for C4ISR and other applications, thereby contributing to the shortening of the OODA loop. Dedicated or dual-use VLEO operations could initially supplement the existing and more mature LEO-based and Near Space capability, utilising an optimum combination of platforms and altitudes (including UAVs, near space platforms and aircraft) to achieve the best end products or communication extent.[55]

China's Civil Military Fusion strategy would support exploitation of the dual-use potential of the capability developed and have implications for its military operations in far-flung, remote and dispersed areas, including those of its Western Theatre Command. Chinese developments in this belt of space need to be continuously monitored for formulating a comprehensive capability picture and response options.

CONCLUSION

VLEO is emerging as a promising space mission regime to supplement imaging and communication services and to contribute to the sustainability of outer space operations by mitigating the threats related to overcrowding and space debris. Most capabilities that are required for overcoming technical and economic challenges of this belt are still in their nascent stages and would take a few years to fructify and operationalise. Technology development would need constant study and addressing of issues specific to understanding of the lower thermosphere and its variable aerodynamic drag and AO corrosion. The armed forces need to study how VLEO missions could contribute to their capability enhancement, offer novel applications, and shape the dynamics of space defence strategies. Efforts would benefit from a defined plan, such as that laid out by China, for achievement of timebound goals. In pursuance of VLEO operations, it is pertinent to highlight that the success of applications like reusable rockets and LEO enabled communication constellations had faced much scepticism from established space farers in the past. With SpaceX now reaping the first comer advantage, the same organisations are now striving hard to catch up.

Gp Capt Puneet Bhalla (Retd) is a former helicopter pilot and has been a Senior Fellow at Centre for Land Warfare Studies (CLAWS) and Centre for Joint Warfare Studies (CENJOWS). He has authored a book "Space Security: Emerging Technologies and Trends" and has contributed multiple articles on technology and national security to reputed think tanks and publications.

NOTES

1. Zhao Lei, "CASIC plans new satellite network by 2030." China Daily, 2023, https://global.chinadaily.com.cn/a/202307/13/WS64af9523a31035260b8163bb.html.
2. Ciara McGrath et al., "Investigation of Very Low Earth Orbits (VLEOs) for Global Spaceborne Lidar." CEAS Space Journal, Springer, 2022, https://link.springer.com/article/10.1007/s12567-022-00427-2.
3. Hejia Luo et al., "Very-Low-Earth-Orbit Satellite Networks for 6G." Huawei, 2022, https://www.huawei.com/en/huaweitech/future-technologies/very-low-earth-orbit-satellite-networks-6g.
4. Ciara McGrath et al., "Investigation of Very Low Earth Orbits (VLEOs) for Global Spaceborne Lidar." CEAS Space Journal, Springer, 2022, https://link.springer.com/article/10.1007/s12567-022-00427-2.
5. Anna Sánchez-Juárez, "A new space economy: the emerging business in low orbit satellites." Universitat Oberta de Catalunya (UOC), 2022, https://www.uoc.edu/portal/en/news/actualitat/2022/237-economy-new-space.html.
6. Bacon, A., Olivier, B. (2017). Skimsats: bringing down the cost of Earth Observation. Hatton, S. (eds) Proceedings of the 12th Reinventing Space Conference. Springer, 2017, https://doi.org/10.1007/978-3-319-34024-1_1.
7. Bacon, A., Olivier, B. (2017). Skimsats: bringing down the cost of Earth Observation. Hatton, S. (eds) Proceedings of the 12th Reinventing Space Conference. Springer, Cham. https://doi.org/10.1007/978-3-319-34024-1_1.
8. N.H. Crisp et al, "The Benefits of Very Low Earth Orbit for Earth Observation Missions," Progress in Aerospace Sciences, Volume 117, August 2020, https://www.sciencedirect.com/science/article/abs/pii/S0376042120300312.
9. Chan Yuk Chi et al., "How Low Can You Go: Advocating Very Low Earth Orbit as the Next Frontier for Satellite Operations." Proc. 8th European Conference on Space Debris (virtual), Darmstadt, Germany, 20–23 April 2021, published by the ESA Space Debris Office, 2021, https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/109.
10. Ciara McGrath et al., "Investigation of Very Low Earth Orbits (VLEOs) for Global Spaceborne Lidar." CEAS Space Journal, Springer, 2022, https://link.springer.com/article/10.1007/s12567-022-00427-2.

11. Hejia Luo et al., "Very-Low-Earth-Orbit Satellite Networks for 6G." Huawei, 2022, https://www.huawei.com/en/huaweitech/future-technologies/very-low-earth-orbit-satellite-networks-6g.
12. Longfei Yin et al., "Integrated Sensing and Communications Enabled Low Earth Orbit Satellite Systems" IEEE Network, 28 February 2024, https://ieeexplore.ieee.org/document/10453227.
13. "Higher Altitude Improves Station's Fuel Economy." NASA, 2011, https://www.nasa.gov/mission_pages/station/expeditions/expedition26/iss_altitude.html.
14. Longfei Yin et al., "Integrated Sensing and Communications Enabled Low Earth Orbit Satellite Systems" IEEE Network, 28 February 2024, https://ieeexplore.ieee.org/document/10453227.
15. Lucas Laursen, "Civilian Satellites Descend into Very Low Earth Orbit: Climate monitoring and telecom stand to benefit from 100 kilometres orbits", IEEESpectrum, https://spectrum.ieee.org/vleo. Accessed on 14 December 2023.
16. Chan Yuk Chi et al., "How Low Can You Go: Advocating Very Low Earth Orbit as the Next Frontier for Satellite Operations." Proc. 8th European Conference on Space Debris (virtual), Darmstadt, Germany, 20–23 April 2021, published by the ESA Space Debris Office, 2021, https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/109.
17. Bacon, A., Olivier, B. (2017). Skimsats: bringing down the cost of Earth Observation. Hatton, S. (eds) Proceedings of the 12th Reinventing Space Conference. Springer, 2017, https://doi.org/10.1007/978-3-319-34024-1_1.
18. "DiskSat: A New Form Factor for Small Satellites." Aerospace, 2022, https://aerospace.org/fact-sheet/disksat-new-form-factor-small-satellites-fact-sheet.
19. "Stingray VLEO Constellation." Eoportal, 2023, https://www.eoportal.org/satellite-missions/stingray#mission-capabilities.
20. N.H. Crisp et al, "The Benefits of Very Low Earth Orbit for Earth Observation Missions," Progress in Aerospace Sciences, Volume 117, August 2020, https://www.sciencedirect.com/science/article/abs/pii/S0376042120300312.
21. John R. Brophy, "Perspectives on the success of electric propulsion", Journal of Electric Propulsion, Springer, 2022, https://link.springer.com/article/10.1007/s44205-022-00011-0.
22. John R. Brophy, "Perspectives on the success of electric propulsion", Journal of Electric Propulsion, Springer, 2022, https://link.springer.com/article/10.1007/s44205-022-00011-0.
23. Chan Yuk Chi et al., "How Low Can You Go: Advocating Very Low Earth Orbit as the Next Frontier for Satellite Operations." Proc. 8th European Conference on Space Debris (virtual), Darmstadt, Germany, 20–23 April 2021, published by the ESA Space Debris Office, 2021, https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/109.
24. Debra Werner, "How Low Can Satellites Go? VLEO Entrepreneurs Plan to Find Out." SpaceNews, 2021, https://spacenews.com/how-low-can-satellites-go-vleo-entrepreneurs-plan-to-find-out/.
25. Debra Werner, "How Low Can Satellites Go? VLEO Entrepreneurs Plan to Find Out." SpaceNews, 2021, https://spacenews.com/how-low-can-satellites-go-vleo-entrepreneurs-plan-to-find-out/.
26. Debra Werner, "How Low Can Satellites Go? VLEO Entrepreneurs Plan to Find Out." SpaceNews, 2021, https://spacenews.com/how-low-can-satellites-go-vleo-entrepreneurs-plan-to-find-out/.

27. "University launches new materials to the International Space Station." The University of Manchester, 2019, https://www.manchester.ac.uk/discover/news/university-launches-new-materials-to-the-international-space-station/.
28. Crisp, Nicholas H.; Macario Rojas, Alejandro; Roberts, Peter et al./Experimental Results from the Satellite for Orbital Aerodynamics Research (SOAR) Mission. 73rd International Astronautical Congress, 2022, https://research.manchester.ac.uk/en/publications/experimental-results-from-the-satellite-for-orbital-aerodynamics-.
29. Rachel Jewett, "Thales and QinetiQ to Study VLEO Skimsats Under ESA Contract", Satellite Today, 19 July, 2022, https://www.satellitetoday.com/imagery-and-sensing/2022/07/19/thales-and-qinetiq-to-study-vleo-skimsats-under-esa-contract/.
30. "ESA seeks space applications ideas in Very Low Earth Orbit", European Space Agency, 18 October 2023, https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/ESA_seeks_space_applications_ideas_in_Very_Low_Earth_Orbit.
31. Clarence Oxford, "Skeyeon unveils novel patent for Enhanced VLEO satellite communication", Space Daily, 11 January 2024, https://www.spacedaily.com/reports/Skeyeon_unveils_novel_patent_for_Enhanced_VLEO_satellite_communication_999.html.
32. Clarence Oxford, "Skeyeon unveils novel patent for Enhanced VLEO satellite communication", Space Daily, 11 January 2024, https://www.spacedaily.com/reports/Skeyeon_unveils_novel_patent_for_Enhanced_VLEO_satellite_communication_999.html.
33. "Booz Allen Invests in Albedo to Develop Very Low Earth Orbit (VLEO) Satellite Constellation", Financial Times, 23 January 2024, https://markets.ft.com/data/announce/detail?dockey=600-202401230800BIZWIRE_USPRX____20240123_BW915853-1.
34. EOI Space. "EOI Space | 15 Cm-resolution Satellite Imagery | Earth Intelligence," February 28, 2024. https://eoi.space/.
35. EOI Space. "EOI Space | 15 Cm-resolution Satellite Imagery | Earth Intelligence," February 28, 2024. https://eoi.space/.
36. "Earth Observant Inc. Successfully Tests Next-generation Propulsion Technology to Support Future Very Low Earth Orbit Missions." EOI Space, 2021, https://eoi.space/propulsion/.
37. Andrew Jones, "Chinese defense contractor to begin launching VLEO satellites." SpaceNews, 2023, https://spacenews.com/chinese-defense-contractor-to-begin-launching-vleo-satellites/.
38. Andrew Jones, "Chinese defense contractor to begin launching VLEO satellites." SpaceNews, 2023, https://spacenews.com/chinese-defense-contractor-to-begin-launching-vleo-satellites/.
39. "Track Shiyan 25 (SY-25)", N2YO.com, 08 March 2023, https://www.n2yo.com/satellite/?s=57047.
40. Zhao Chenchen, "China's private rocket launches 1st VLEO satellite and 1st satellite for digital life service." CGTN, 2023, https://news.cgtn.com/news/2023-07-22/Private-Chinese-rocket-company-sends-two-satellites-to-space-1lDYSWjh7Jm/index.html.
41. "Track Object B", N2YO.com, 08 March 2023,https://www.n2yo.com/satellite/?s=57422.
42. Zhao Lei, "CASIC plans new satellite network by 2030." China Daily, 2023, https://global.chinadaily.com.cn/a/202307/13/WS64af9523a31035260b8163bb.html.

43. "China to build constellation of very-low Earth orbit satellites." Global Times, 2023, https://www.globaltimes.cn/page/202303/1286489.shtml.
44. Deng Xiaoci, "State-owned aerospace giant to build 300-satellite constellation at Very Low Earth Orbit by 2030 for better, more economic remote sensing services", Global Times, 12 July, 2023, https://premium.globalsecurity.org/space/library/news/2023/space-230712-globaltimes02.htm.
45. "China to build constellation of very-low Earth orbit satellites." Global Times, 2023, https://www.globaltimes.cn/page/202303/1286489.shtml.
46. Joshua Faleti, "China Begins Construction of VLEO Satellite Constellation." Space Watch Global, 2023, https://spacewatch.global/2023/07/china-begins-construction-of-vleo-satellite-constellation/.
47. Deng Xiaoci, "State-owned aerospace giant to build 300-satellite constellation at Very Low Earth Orbit by 2030 for better, more economic remote sensing services." Global Times, 2023, https://www.globaltimes.cn/page/202307/1294211.shtml.
48. Victor Tangermann, "China's New Space Station Is Powered by Ion Thrusters." Futurism, 2021, https://futurism.com/chinas-new-space-station-powered-ion-thrusters.
49. Andrew Jones, "Chinese Satellite Propulsion Startup Secures Funding as Country's Constellation Projects Grow." SpaceNews, 2022, https://spacenews.com/chinese-satellite-propulsion-startup-secures-funding-as-countrys-constellation-projects-grow/.
50. Kreios Space. "Kreios Space," n.d. https://www.kreiosspace.com/.
51. Elecnor Deimos and Kreios Space Sign an Agreement To Develop a Satellite for Very Low Earth Orbits. 07 December 2023, https://www.spacequip.eu/2023/12/07/elecnor-deimos-and-kreios-space-sign-an-agreement-to-develop-the-worlds-first-satellite-for-very-low-earth-orbits/.
52. "Electric Propulsion System", Press Information Bureau, 01 August 2018, https://pib.gov.in/Pressreleaseshare.aspx?PRID=1541000.
53. Tiki Rajwi, "ISRO to demonstrate indigenously developed electric propulsion system on satellite", The Hindu, 07 March, 2024, https://www.thehindu.com/news/national/kerala/isro-to-demonstrate-indigenously-developed-electric-propulsion-system-on-satellite/article67921892.ece.
54. Hejia Luo et al., "Very-Low-Earth-Orbit Satellite Networks for 6G." Huawei, 2022, https://www.huawei.com/en/huaweitech/future-technologies/very-low-earth-orbit-satellite-networks-6g.
55. Bacon, A., Olivier, B. (2017). Skimsats: bringing down the cost of Earth Observation. In: Hatton, S. (eds) Proceedings of the 12th Reinventing Space Conference. Springer, Cham. https://doi.org/10.1007/978-3-319-34024-1_1.

132-149

SPACE-BASED SOLAR POWER (SBSP) GEOPOLITICAL CONNOTATIONS AND IMPLICATIONS FOR INDIA

Col Kaushik Ray & Dr William Selvamurthy

Abstract

The global search for clean, renewable energy resources has led to the concept of producing solar power in the Earth's orbit and relaying it to the Earth. SBSP, other than its environmental and economic advantages, may also accrue certain military advantages including providing electricity at remote locations for the military in ships and isolated bases, wireless sensor networks, satellite-to-satellite power transmission, offensive space capabilities, and beaming electricity to power drones to virtually unlimited flight endurance. SBSP has tremendous potential. However, the technology is not ripe yet and faces obstacles such as high cost of production and technological challenges which are yet to be resolved. However, various studies suggest that costs will come down in future due to better and cheaper technology and greater scale. Amongst the leading space powers, China and the US have made significant progress in this domain. Japan has also been researching SBSP since the 1980s, aiming for commercial space-to-solar power by 2025. India is collaborating with the US as part of the joint Kalam-NSS Indian-American Energy Initiative However, this collaborative effort has seen little progress.

China is fast emerging as a potential global SBSP provider. This will provide the Chinese with windfall financial gains, and also provide diplomatic leverage and geopolitical dominance. Moreover, China's proclivities towards exploiting the military capabilities of SBSP to achieve dominance in space, particularly in the region of Geosynchronous Earth Orbit (GEO), raise concerns about India's national security in the domain of space. India needs to focus on SBSP technology development, collaborate internationally, and address security concerns in the evolving space landscape.

INTRODUCTION

A recent report titled International Energy Outlook 2023 published by the U.S. Energy Information Administration of the US Govt suggests that the global consumption of primary energy would increase from the current 640 quadrillion B.T.U. to around 850 quadrillion B.T.U. This increase in demand and consumption of energy will primarily be met by nuclear and renewable energy resources. Solar and other renewable energy consumption would cumulatively increase from the current 86 quadrillion B.T.U. to around 206 quadrillion B.T.U. Such a growing demand for clean energy resources has spurred global research on newer, more efficient means to tap solar energy, of which Space-Based Solar Power (SBSP) has found the most traction. Conceptually, it envisages placing an array of solar panels in the earth's orbit, converting the incident solar energy into microwave and transmitting it securely to earth. At the Earth receiving stations, this microwave would be converted into electricity and further integrated into a nation's power grid.

GENESIS

The idea of a solar power plant orbiting the Earth was first proposed by Peter Glaser in a 1968 paper titled "Power from the Sun: Its Future". [1] [2] The broad concept is to launch satellites housing massive solar arrays into space that would receive continuous intense solar energy uninterrupted by the terrestrial cycles of day and night and the lowering of solar intensity due to weather and atmospheric conditions etc. The light energy thus absorbed by the photovoltaic cells of the solar panel would be converted into microwave by the satellite in space and then radiated back to receiving earth stations. The receiving stations would then convert it to electricity. In July 1971, Glaser applied for patenting "Method and Apparatus for Converting Solar Radiation to Electrical Power" and obtained the patent in 1973.[3] Major spacefaring nations have been conducting extensive research on developing these capabilities for several decades.

BASIC WORKING OF SBSP

A standard SBSP system consists of a group of large satellites that orbit the Earth in the GEO. These satellites have lightweight solar panels and mirrors that focus the sunlight on to the panels, each producing approximately 3.4 GW of energy. The electrical energy thus produced is then converted into microwave radiation. The microwave frequency used is generally 2.45 GHz, which can pierce through moisture and the atmosphere. Finally, a net power of 2.9 GW is transmitted to a fixed point on the ground using a receiving antenna. To ensure the accuracy of the transmission, a guiding beam is transmitted by the earth-based stations to the satellite to enable the microwave beam to lock onto the correct point. The rectifying antenna at the earth-station, also known as 'rectenna', is a net structure that contains small dipoles designed to capture radio wave energy. This energy is then converted into electricity amounting to approximately 2 GW and transferred to the power grid. Due to the relative of motion of the SBSP spacecraft with respect to the Sun and the Earth, the mirrors of the solar panels have to be constantly facing the sun and the microwave transmitter has to be facing the fixed ground station on earth. This allows the system to provide full power levels day and night, in all weather conditions and throughout the year. The microwave is transmitted at an intensity level of around 240 Watts/metre^2, which is only about 25 percent of the intensity of mid-day sunlight. As a result, this system is not harmful to life on Earth.[4] This intensity can however be altered in case the beam needs to be repurposed for damaging an adversary's space-based/ ground-based critical infrastructure.

Laser beam power transmission is being explored as an alternative to microwave power transmission technology. The incident solar radiation is intensified into a monochromatic laser beam which is then directed at the designated ground receiving station. The photovoltaic receiver at the receiving station then converts the incident laser beam into electricity."[5]

BENEFITS OF SBSP

Environmental and Economic Advantages

- SBSP will provide a virtually endless source of clean energy and contribute to our energy security, lowering dependence on fossil fuels and reducing our carbon footprint. As a part of a bouquet of emerging clean energy solutions, it offers a technologically and commercially viable option for our efforts towards net zero.
- The main advantage of SBSP over earth-based solar power and wind, tidal or geothermal power is the ability to produce energy day and night without interruption, all year long irrespective of the weather. The intensity of the solar light beams are 40 percent stronger in space than on the Earth's surface.[6] In space solar beams do not face interruptions due to clouds, atmosphere, and night downtime due to the earth's rotation. So solar arrays in space would provide a steady flow of current at a higher efficiency.
- With the source of the power generated being steady, there is the least likelihood of a surge, fluctuations, or even interruptions. It is therefore safe for integrating seamlessly into the nation's power grid. Several such plants can be deployed in space to meet the increasing power requirements in a grid. SBSP not only contributes towards a nation's energy security but it can also be exported for commercial purposes and also as humanitarian or diplomatic endeavours.

- Since solar power is not vulnerable to geographic and geopolitical upheavals, the cost of the power generated will remain stable, unlike fossil fuels.
- SBSP systems placed in a suitable orbit could even provide power to future lunar bases etc. or spacecraft for cislunar travel.

Military Advantages

- SBSP will enhance the movement capability and deployment of military forces by providing energy automatically at Forward Operating Bases, Ships and other large sea-borne platforms etc.
- Wireless Distributed Sensor Networks (WDSN) that are deployed in remote locations and used to perform a variety of surveillance functions can be provided power through SBSP obviating the requirement of using time-limited battery power.
- SBSP can provide satellite-to-satellite power transmission.
- SBSP can provide power to UAVs for extended flight endurance.
- In case conventional power plants are degraded due to enemy action, SBSP could act as a reserve source of power feeding the power grid.
- The solar arrays might also be used as Directed Energy Weapons for space targeting.
- SBSP could also supply power to existing dual-use RPO satellites for executing kinetic attacks in space or to DEW satellites for EM attacks in space, enhancing their endurance capability for space-based offensive.
- Wireless Power Transmission (WPT), a crucial component of SBSP could also have terrestrial uses, such as beaming power from space to UAVs to enhance their endurance, beaming power from ship to landing troops

MAJOR CHALLENGES

- **Cost of SBSP.** The cost of production appears prohibitive at this stage, though with economies of scale and future advancements, it is fair to assume that SBSP will become financially viable. Recently European Space Agency commissioned two studies in 2022 to ascertain the commercial viability of SBSP as a source of clean energy on Earth.[7] One of these studies conducted by Frazer-Nash Consultancy Limited was ordered by the UK for the European Space Agency. The study report, published in September 2021, based on the CASSIOPeiA (Constant Aperture, Solid-State, Integrated, Orbital Phased Array) concept, estimated the Liberalised Cost Of Electricity (LCOE), including the end-to-end production, launch, assembly, operational service life, and decommissioning costs to be around £50 per megawatt hour with an investment hurdle rate of 20 percent and assuming this system is commissioned in 2040. In comparison, LCOE for large-scale solar power is estimated to be around £33 per megawatt hour and wind power to the tune of £40-£45 per megawatt hour while nuclear power and dedicated biomass would cost around £96-£98 per megawatt hour.[8] Another similar study by Roland Berger in Germany on behalf of European Space Energy concluded *"The competitiveness of SBSP vs. other clean energy sources was measured using the Value-Adjusted Levelised Cost of Electricity (VALCoE) introduced by the International Energy Agency (IEA). Based on the cost assumption of SBSP, the projected VALCoE could even reach 69 EUR/MWh for the first system. Applying a learning curve metric already shows cost reduction potential in the setup of the first 10 SPS station deployments, leading to an estimated VALCoE of 49 EUR/MWh. This means that SBSP has the potential to even become a cost-competitive renewable technology while also providing baseload generation capacity. Depending on the pace of climate target implementations and the state of energy supply, future electricity prices can range between 25 and 300 EUR/MWh."*[9] International collaboration in developing the technology could resolve the problems related to development funding/long ROI of the SBSP.

- **Technology Development.** There are significant technological and infrastructural issues that need to be overcome before the solar power generated can be made financially viable. The three major technological challenges that need to be addressed in the development of a massive electricity generator and the transmission of power generated from space include transporting the heavy electricity generator to geosynchronous orbit using a carrier rocket; completing the automatic assembly of the SBSP satellite in space; and, transmitting power from space to the earth. The energy losses incurred due to the conversion of solar energy into microwave and further into electricity and also due to transmission losses of the microwave need to be factored. Also, large areas to be occupied by the receiving stations for housing the rectennas and other terrestrial infrastructure might have environmental impacts.

COMPARISON OF STRATEGIC, SOCIETAL & ENVIRONMENTAL DIMENSIONS

Besides the economic dimensions that were considered in the previous paragraph, it is also necessary to compare various other cost dimensions of SBSP technology.

- **Strategic Dimensions.** Nuclear energy has high potential but is limited by technology and uneven distribution of resources. Floating bases for offshore wind turbines could be a game-changer for the nations with access to the sea. Solar PV and onshore wind are less efficient due to resource-intensive construction, location-dependent efficiency, and limited potential for further improvements. None of these however affect the SBSP construct.
- **Societal Dimensions.** Nuclear power plant construction, historically the biggest job generator, has lost public acceptance since the Fukushima disaster, due to opposition from green NGOs and political parties. Though renewable energy is popular, onshore wind farms face local community resistance due to visual pollution. SBSP space-based infrastructure is located too far away, in the GEO, for similar perturbations, while the ground-based receivers would hardly occupy enough physical or mind space for any viable societal impact.
- **Environmental Dimensions.** Nuclear power plants require less material input and have a limited impact on the environment, but safe disposal of nuclear waste remains a concern. Renewable power plants require more material input and have a high-energy, carbon-intensive manufacturing

process. While most materials used in wind turbines can be reused or recycled, the blades cannot be recycled. Solar PV recycling is more feasible than wind turbines, but currently only in general-purpose facilities with high recovery yield.

CHINA'S FORAY INTO SBSP

In February 2009, China's National Bureau of Statistics published a report which predicted a strategic shortfall in China's energy sector by the year 2050 and advocated for a rapid switch to renewable energy.[10] The Chinese government has planned to mitigate this energy gap and turn it into a strategic advantage through SBSP. In 2010, the China Academy for Space Technology (CAST) published a roadmap for developing SBSP in China. By 2010, the CAST planned to complete the entire Research & Design. The prototype of the SBSP was planned to be developed by 2019. By 2025, a space-based plant will be placed in the LEO which would produce 100kW electricity. By 2050, it is envisaged the GEO-based solar power plants would generate electricity for commercial purposes.[11] In 2019, China established the world's first SBSP manufacturing unit in the Bishan district of Chongqing. The Chongqing Collaborative Innovation Research Institute for Civil-Military Integration (CCIRICMI) is overseeing the construction of this manufacturing facility in collaboration with scientists from CAST, Chongqing University, and Xidian University. The SBSP plant has been testing various technologies, including WPT and the construction of SBSP satellites located in the GEO using automated assembly.[12]

The development program seems to be on track and may be launched in 2028, two years earlier than scheduled. An article in the refereed Chinese journal Chinese Space Science and Technology published in June 2022 states: *"a satellite will be launched to test WPT technology from an altitude of 400km (250 miles). The researchers explained that the satellite will transform solar energy into microwaves or lasers and direct the energy beams to various targets, including fixed locations on Earth and moving satellites. The generated power will be 10 kilowatts, which is enough to meet the needs of a few households. However, the technology can* *be scaled up significantly and become an effective contributor [to achieving] China's carbon neutrality goals."*[13]

Again in June 2022, Xidian University in Xi'an, North China released a statement declaring a successful test of a fully linked and integrated SBSP prototype. The work at this facility, designed to test and verify technology for the OMEGA system, was led by Academician Duan Baoyan, a leading Chinese expert in SBSP.[14] Researchers associated with the China Academy of Science and Technology (CAST) are hopeful that after a test satellite "*Space High Voltage Transfer and Wireless Power Transmission Experiment*" launch in LEO in 2028, a 10-megawatt power plant located in GEO will start sending energy to certain military and civilian users by 2035. By 2050, the station's power output is expected to rise to 2 gigawatts, and the cost reduced to commercially affordable levels.[15]

US EFFORTS AT DEVELOPING SBSP CAPABILITY

Northrop Grumman in collaboration with the Air Force Research Laboratory is leading the US efforts towards SBSP funded by a $180 million federal program. The primary purpose of the research, as stated in the AFRL's official website, is to provide power to the military from space during operations, thus obviating the threat to the long convoys and supply lines that are the usual methods to provide power.[16] The aim is "*to develop and demonstrate technology including lightweight sandwich solar panel PV/ RF modules, and lightweight extendable mirrors, under the SSPIDR (Space Solar Power Incremental Development And Research Project)*"[17] Six critical technologies that require further research and development will be validated in critical technology demonstrations:

- Space Power InfraRed Regulation and Analysis of Lifetime (SPIRRAL) experiment to test the thermal management technology will be conducted in the International Space Station this year.[18]
- The keystone flight experiment in the SSPIDR project, Arachne, will demonstrate the sandwich tile and its ability to collect solar energy, convert it to RF, and beam it to a rectifying antenna on the ground from

low earth orbit. A panel of nine sandwich tiles, under development by Northrop Grumman, will be flying on Arachne.[19] It will carry the Space Solar Power Radio Frequency Integrated Transmission Experiment (SSPRITE) payload, also being developed by Northrop Grumman, to collect and convert solar energy. Arachne will be based on the Helios bus manufactured by Northrop Grumman Space Systems. It is planned for launch in early 2025, followed by months of on-orbit demonstrations.[20]

Concurrently, a similar project by the California Institute of Technology (Caltech) named the Space Solar Power Project (SSPP) and funded by the philanthropist Donald Bren has worked on another prototype. In January 2023, in an article titled Beaming Power From Space: Caltech's Prototype Achieves Wireless Energy Transmission published by the California Institue of Technology in the journal Scitech, stated "A space solar power prototype, SSPD-1, has achieved wireless power transfer in space and transmitted power to Earth. The prototype, including MAPLE, a flexible lightweight microwave transmitter, validates the feasibility of space solar power, which can provide abundant and reliable power globally without ground-based transmission infrastructure." The other two main experiments as per the report are the "DOLCE (Deployable on-Orbit ultraLight Composite Experiment), a 6 feet by 6 feet structure that demonstrates the architecture, packaging scheme, and deployment mechanisms of the modular spacecraft; and ALBA, a collection of 32 different types of photovoltaic cells to enable an assessment of the types of cells that are the most effective in the punishing environment of space. The ALBA tests of solar cells are ongoing, and the SSPP has not yet attempted to deploy DOLCE."[21]

JAPAN'S ENDEAVOUR TOWARDS DEVELOPING SBSP

Research on SBSP has been happening in Japan since the 1980s. Japan has identified SBSP as a key focus area for its space program. According to a May 2023 article published by Igor Bonifacic in the journal 'Engadget', in 2015 "JAXA successfully beamed 1.8 kilowatts of power more than 50 meters to a wireless receiver. A Japanese public-private partnership will attempt to beam solar energy from space as early as 2025. The project, led by Naoki Shinohara, a Kyoto University professor who has been working on SBSP since 2009, will attempt to deploy a series of small satellites in orbit. Those will then try to beam the solar energy the arrays collect to ground-based receiving stations hundreds of miles away."[22] [23]

INDIA'S STATUS

The 'Kalam-NSS Indian-American Energy Initiative' – a joint US-Indian effort aimed at developing SBSP satellites was announced on 04 November 2010.[24] However, the project has not progressed further. The Indian Express reported on 08 July 2018, that, while "*delivering the 11th Air Chief Marshal LM Katre Memorial Lecture organised by the Air Force Association at the HAL Convention Centre on Saturday, [the then ISRO Chairman] Dr K Sivan made a strong pitch for creating a solar power satellite. Sivan said, "We need to have a solar panel on the spacecraft. It should be 30 kilometres in length and 10 kilometres in width. This spacecraft needs to be put into space and it will convert solar energy into electrical energy and then into microwave energy*".

GEOPOLITICAL CONNOTATIONS

The U.S. and China have made significant progress towards developing SBSP, through different technology routes, both focussing on the reliability and cost-effectiveness of the project. Various studies conducted on cost-effectiveness indicate that the project will be commercially viable in the longer term. The environmental dividend of the project and its military applications further bolster the viability of SBSP. SBSP will likely expand the current geopolitical competition to new astral heights. At this point, Chinese efforts towards SBSP make it the leading player in the domain, being closely followed by the U.S. The geopolitical rivalry of the terrestrial powers has already spilt over into space. It is possible that the realisation of SBSP could give Beijing a clear, unassailable lead in this race.

With a leadership position in SBSP technology, Beijing will dominate the global energy market and become the global provider of energy, especially to smaller or poorer countries that may not be able to afford the high development costs. SBSP and its allied space-based and terrestrial infrastructure will enhance Chinese hegemony. This is because China will be able to offer the cheapest and safest space launches, and hence most nations will contract China for their satellite launches. Also, the export of SBSP and profits thereof will give China an unassailable leading position in the financial world. SBSP will feed the global narrative of China as a benevolent superpower. Diplomatically they would control an easily redirected energy source that can be provided to anyone or taken away at will.

While denying a "global commons" approach, China aims to take ownership of space resources, asserting that space has a tangible geography and territory that can be claimed. Beijing's hegemonistic aspirations towards space are poorly disguised. In 2017, Ye Peijian, the head of China's lunar program said, "*The universe is an ocean, the Moon is the Diaoyu Islands, Mars is Huangyan Island*", referring to Mandarin names of the disputed Senkaku island in East China and the Pantang Shoal in the South China Sea, and equating these celestial bodies with disputed islands whose ownership China has been aggressively claiming.[25] Beijing's SBSP ambitions are articulated in the statement of Lt Gen Zhang Yulin, who as a member of the Central Military Commission of PLA said in 2016 - "*China will manage to exploit the space between Earth and the Moon for solar power and other resources after it builds a space station in 2020… The Earth-Moon space will be strategically important for the great rejuvenation of the Chinese nation*."[26]

The need for securing national economic interests in space, and the terrestrial geopolitical and military contestations have led to the increased militarisation of space. In China's case, this is more evident since China's space program is led by the PLA. In its 2015 defence white paper, *China's Military Strategy*, China designated outer space as a "critical military domain" and so, the Chinese military should be prepared for "*a wide variety of emergencies and military threats*" and "*prepare for military struggle in all directions and domains*."[27] Therefore, the military must "safeguard China's security and interests in new domains" and that "*threats from such new security domains as outer space* *and cyberspace will be dealt with to maintain the common security of the world community.*"[28] Therefore, "*China will keep abreast of the dynamics of outer space, deal with security threats and challenges in that domain, and secure its space assets to serve its national economic and social development, and maintain outer space security*."[29] Chinese authors believe that future wars might begin in the outer space. Due to the increased pace of militarisation of space, "*competition has become increasingly intense, and the curtain of space confrontations has been drawn open. The several local wars that have recently occurred before our eyes have shown that whoever is strong in military spaceflight will rule the battlefield, that he in whose hands lies space superiority will master the initiative in warfare, and that with the support of 'space,' it is possible to win victory, but without the support of 'space' this is impossible*."[30] Chinese geopolitical thoughts on space, therefore, evince its military intent to optimally exploit the offensive space capabilities offered by the SBSP.

China's untrammelled expansion into space including its efforts at establishing SBSP in the GEO are not merely to satisfy scientific curiosity or for economic considerations alone. It aspires for global domination by:

- Gaining unprecedented economic advantage and geopolitical leverage by dominating the global energy markets through SBSP.
- Developing offensive space capabilities in space, particularly in the GEO.
- Having a ready source of energy in GEO for powering the spacecraft en route to the moon and deep space destinations.

INDIA'S PERSPECTIVE

- **Technology Development.** Considering the critical strategic importance of SBSP, India's efforts towards developing its own SBSP technology will, in all probability, receive a boost in the next few years. As is New Delhi's wont, a graduated approach to developing the component technologies for SBSP is likely. The financial viability of the project is of paramount importance and initiation costs are expected to be high. However, the various studies ordered by reputed international agencies have concluded that the project is viable in the longer term. However, considering the forte of our scientists, especially the Indian Space Research Organisation (ISRO) in developing low-cost solutions for high-end technologies, an independent study group at the national level to assess the cost of a similar project needs to be appointed. This study group, though led by ISRO also needs to incorporate experts from the DRDO and academic institutions in the areas of photovoltaic cell technology, renewable energy domain and experts in power grid integration among others. Initial technology components with terrestrial/ dual-use that could be identified for prioritised development are:

  - o **Investment in WPT Technology.** WPT, which is a critical component of SBSP technology, also has several earth-based applications like beaming power to UAVs to enhance their endurance. Prioritising research and development of the WPT technology would avoid risks and provide immediate benefits to Earth.
  - o **Investment in Reusable Launch Technology.** Considering the massive tonnages required to be delivered in the GEO, the cost of launch will need to be reduced significantly. Ongoing research and development of reusable launch vehicles will lower the cost of launch, which in turn would help lower the costs for SBSP.

- **Funding the SBSP Program.** Research grants to develop component technologies awarded to reputed universities besides concerted projects by ISRO & DRDO would kickstart this effort. Since the initial development cost of the SBSP technology will be very high and the financial returns from the project will start only after several years, the government will need to fund the initial research efforts. Once the component technologies are adequately mature, these may be handed over to the private sector for further investment to refine the component technologies for achieving commercial viability.
- **International Collaboration.** The U.S. and India have a long history of space cooperation, which was further strengthened by the signing of the Artemis Accords. Already a signatory of the 'Kalam-NSS Indian-American Energy Initiative', U.S. endeavours towards SBSP would

therefore be beneficial for India. A similar collaboration could also be planned with Japan or the European Space Agency. Considering the enormity of the scale of SBSP, a multi-national coalition of like-minded space powers might take shape, akin to the Artemis Accords.

- **The China Angle.** However the same is not the case with the Chinese SBSP program. Considering the geostrategic competition between the two countries, and China's proclivities towards weaponisation of space, India needs to closely monitor the Chinese program and adapt to the new capabilities that China would acquire as a result. Of particular concern are the offensive space capabilities that could pose a threat to India's national security interests in space.

CONCLUSION

SBSP may in future resolve the global energy crisis by providing us with a virtually unlimited source of clean energy, which would be the ultimate solution to terrestrial energy problems. It could further facilitate deep space exploration and also supply electricity to future lunar bases. After overcoming the technological hurdles and the cost-related issues, the project will have to surmount other hurdles like the efficiency of WPT, the damage that the space debris might cause to the thin, lightweight solar arrays, and the long-term effect high-intensity microwave beams on the earth's atmosphere and on the people etc. Leading space powers like the U.S. and China have already taken a significant lead in this area. With the first movers advantage, China will dominate the global energy market. With windfall financial gains, it will be able to monopolise the world financial markets. SBSP capability will also enable China to militarily dominate space, particularly the region of the GEO. As a consequence, there would be increased militarisation of space to secure the expanded national security interests in space.

India needs to use the momentum gained by its successful lunar missions and upend its astrostrategic game to keep pace, in cooperation with other like-minded spacefaring nations. In the currently effervescent, if not volatile geopolitical scenario, the need to adopt a "global commons" approach to space and its resources is the way ahead. However, at present, Realism in space policy appears to be the driving force. Prudence demands that India maintains its strategic focus and prioritisation towards these contestations in space. New Delhi is seised of these growing challenges and opportunities in space. Measured steps are being taken towards fortifying India's national security interests in space.

Col Kaushik Ray is an alumnus of the National Defence Academy, Pune, and Indian Military Academy, Dehradun. Col Kaushik Ray has commanded a Field Artillery Regiment at High Altitude along the Northern Borders and has also commanded a Surveillance and Target Acquisition unit along the Western Borders. Col Kaushik Ray is presently pursuing a PhD on 'Weaponisation of Space and its Implications on India' from Amity Institute of Defence and Strategic Studies.

Dr William Selvamurthy has served as a Chief Controller, Research & Development in Life Sciences and International Cooperation DRDO. He is currently President of Amity Science, Technology and Innovation Foundation and Director General for Amity Directorate of Science and Innovation.

NOTES

1. Zhao Lei, Scientists envision solar power station in space, China Daily, 27 February 2019, https://www.chinadaily.com.cn/a/201902/27/WS5c75c8b3a3106c65c34eb8e3.html. Accessed on 17 November 2023.
2. Peter Glaser, Power from the Sun: Its future, New Series, Vol. 162, No. 3856 (22 November 1968), pp. 857-861, Published By: American Association for the Advancement of Science1968, https://www.jstor.org/stable/1725510. Accessed on 22 December 2023.
3. Leonard David, Peter Glaser Father of Solar-Power Satellite Idea Dies at 90, Space.com, https://www.space.com/26175-peter-glaser-solar-power-satellite-obituary.html#:~:text=Glaser%20envisioned%20harvesting%20solar%20radiation,obtained%20the%20patent%20in%201973. Accessed on 22 December 2023.
4. Space Based Solar Power, Space Energy Initiative, https://spaceenergyinitiative.org.uk/space-based-solar-power/. Accessed on 31 January 2024.
5. Venugopal R, Manjunath H. R, Raghu A. V. Overview of Space Based Solar Power. Mat. Sci. Res. India;19(2), https://www.materialsciencejournal.org/vol19no2/overview-of-space-based-solar-power/. Accessed on 31 January 2024.

6. Research on the Space Solar Power Systems (SSPS), JAXA Research and Development Directorate, https://www.kenkai.jaxa.jp/eng/research/ssps/ssps-index.html. Accessed on 22 December 2023.
7. Costs vs. Benefit Studies, European Space Agency, 2022, https://www.esa.int/Enabling_Support/Space_Engineering_Technology/SOLARIS/Cost_vs._benefits_studies. Accessed on 22 December 2022.
8. Space-Based Solar Power: De-risking the Pathway to Net Zero, Frazer-Nash Consultancy Limited, 2021, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1020631/space-based-solar-power-derisking-pathway-to-net-zero.pdf. Accessed on 22 December 2023.
9. Manfred Hader, Martin Hoyer, Helping Decarbonise Europe and Make it More Energy Resilient Thanks to Electricity Generated in Space, Roland Berger, 2022, https://www.rolandberger.com/en/Insights/Publications/Space-based-Solar-Power.html. Accessed on 22 December 2023.
10. Gao, Ji; Hou, Xinbin; and Wang, Li "Solar Power Satellites Research in China," *Online Journal of Space Communication*: Vol. 9: Issue 16, Article 6, 2021 https://ohioopen.library.ohio.edu/spacejournal/vol9/iss16/6/. Accessed on 17 November 2023.
11. Gao, Ji; Hou, Xinbin; and Wang, Li "Solar Power Satellites Research in China," *Online Journal of Space Communication*: Vol. 9: Issue 16, Article 6, 2021, https://ohioopen.library.ohio.edu/spacejournal/vol9/iss16/6/. Accessed on 17 November 2023.
12. Pan Zhaoyi, China Starts to Build World's First Space-Based Solar Power Plant, CGTN dated 18 February 2019, https://news.cgtn.com/news/3d3d514f34597a4e32457a6333566d54/index.html. Accessed on 02 November 2023.
13. Stephen Chen, China Plans to Start Building First-Ever Solar Power Plant in Space by 2028, South China Morning Post, 07 June 2022, accessed from https://www.scmp.com/news/china/science/article/3180627/china-brings-forward-plans-space-solar-power-plant?module=perpetual_scroll_0&pgtype=article&campaign=3180627. Accessed on 18 November 2023.
14. Guan Hongcai, The Full-Link, Full-System Space Solar Power Station Ground Verification System developed by Academician Duan Baoyan's Team Passed Acceptance, Xidian News Network, Xidian University, 14 June 2022 accessed from https://news.xidian.edu.cn/info/2106/220926.htm. Accessed on 17 November 2023.
15. Stephen Chen, China plans to start building first-ever solar power plant in space by 2028, South China Morning Post, dated 07 June 1922, https://www.scmp.com/news/china/science/article/3180627/china-brings-forward-plans-space-solar-power-plant. Accessed on 31 October 2023.
16. Space Power Beaming, The Air Force Research Laboratory, https://afresearchlab.com/technology/space-power-beaming/. Accessed on 19 December 2023.
17. Space Based Solar Power: De-risking the Pathway to Net Zero, Frazer Nash Consultancy, https://www.fnc.co.uk/media/e15ing0q/frazer-nash-sbsp-executive-summary-final.pdf. Accessed on 19 December 2023.
18. Space Power Beaming, AFRL, https://www.afrl.af.mil/Portals/90/Documents/RV/AFRL_SSPIDR_FS_0922.pdf?ver=VAE9L00LRfAtQkWmG9uDkQ%3D%3D. Accessed on 19 December 2023.
19. Ibid.
20. Theresa Hitchens, Next Step for AFRL's Space-Based Solar Power Quest: Energy Beaming, Breaking Defense, 26 May 2022, https://breakingdefense.com/2022/05/next-step-for-afrls-space-based-solar-power-quest-energy-beaming/. Accessed on 19 December 2023.

21. Robert Perkins, In a First, Caltech's Space Solar Power Demonstrator Wirelessly Transmits Power in Space, The Caltech Weekly, 01 June 2023, https://www.caltech.edu/about/news/in-a-first-caltechs-space-solar-power-demonstrator-wirelessly-transmits-power-in-space. Accessed on 19 December 2023.
22. Igor Bonifacic, Japan will try to beam solar power from space by 2025, Engadget, 19 May 2023, https://www.engadget.com/japan-will-try-to-beam-solar-power-from-space-by-2025-214338244.html?fbclid=IwAR1aapGj4WvaD_2R5XkksYd88P4wo62tOW4ZqLvd1K5RDhglKqCLArgg0ak&guccounter=1. Accessed on 19 December 2023.
23. Satoshi Kawahara, Japan to Try Beaming Solar Power from Space in Mid-Decade, Nikkei Asia, dated 27 May 2023, https://asia.nikkei.com/Business/Science/Japan-to-try-beaming-solar-power-from-space-in-mid-decade. Accessed on 19 December 2023.
24. Ajey Lele, Kalam-NSS Indian-American Energy Initiative, IDSA Comment, Manohar Parrikar Institute of Defence and Strategic Analysis, 09 November 2010, accessed from https://idsa.in/idsacomments/KalamNSSIndianAmericanEnergyInitiative_alele_091110. Accessed on 19 December 2023.
25. Gordon G.Chang, We're in a New Cold War in Space: China Plans to Take Over the Moon, Newsweek, 09 January 2023, https://www.newsweek.com/were-new-cold-war-space-china-plans-take-over-Moon-opinion-1772306#:~:text=%22The%20universe%20is%20an%20ocean,to%20which%20Beijing%20claims%20sovereignty. Accessed on 17 November 2023.
26. Exploiting Earth-Moon Space: China's Ambition After Space Station, Xinhua, chinadaily.com.cn dated 08 March 2016, https://www.chinadaily.com.cn/china/2016-03/08/content_23775949.htm. Accessed on 29 October 2023.
27. The Information Office of the State Council of PRC, *China's Military Strategy*, 2015, https://english.www.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm. Accessed on 03 November 2023.
28. Ibid.
29. Ibid.
30. Jiang Lianju, "An Outline of Space Operations" Lectures on the Science of Space Operations, Military Science Press, January 2013, sourced from "In Their Own Words: China Aerospace Studies Institute", P 16, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Translations/2022-08-12%20Lectures%20on%20the%20Science%20of%20Space%20Operations.pdf. Accessed on 03 November 3, 2023.

150-161

A STRONG CASE FOR A BHARATIYA ‘TERTIA OPTIO’ CISLUNAR STRATEGY

Prof Chaitanya Giri

Abstract

Activities in the Earth-Moon (cislunar) space were solely under the purview of civilian space agencies, and its commercialisation began some 15 years ago. The US-led Artemis Program and the China-led International Lunar Research Station are commercial cislunar megaprojects. Laying out of commercial assets may not lead to cislunar ‘weaponisation’ or ‘militarisation’ but to ‘cislunar securitisation’ where both US- and China-led astropolitical blocs block-chain their respective public and private cislunar assets, isolate these assets into un-interoperable systems with different sets of space standards, and raise independent cislunar C4ISR systems that help maintain a code of conduct as desired by them with the existing international space treaty system becomes subservient or ineffective. This article aims to illustrate a position for New Delhi, where it operates in cislunar space with its strategic autonomy and exercises a ‘tertia optio’ when space diplomacy between the two contesting blocs fails and cislunar conflicts remain inadvisable.

INTRODUCTION

The Western economy, which leads the Bretton Woods system, is currently at the outermost extremity of a ‘super bubble’.[1] The term is synonymous with the peaking of the profit-to-earning ratio, an outcome of a long-duration bull run at the market, and with only one eventuality, a big stock market crash. Such bear and bull runs happen cyclically, and the pursuit of establishing a human and robotic presence in the Earth-Moon (cislunar) space will span many such cycles. This means the long-duration economic stability of nations, stability of their innovation ecosystems, domestic politics, cultural integrity, and secured progress of strategically crucial public and private entities are of the utmost consequence to any nation's sustained excellence in space capabilities.[2] But excellence is not an end goal; it is a means to achieve accountable leadership or unaccountable hegemony. The accountability-driven leadership aims to lead the cislunar activities through consensus and upholding global order.

There are advantages of being both accountable and unaccountable. Accountable space leadership will drive consensus on the code of conduct in outer space, forge natural business partnerships, have strategic economic interests secured through international cooperation, and have a sway over the narrative that human space activities are the world's heritage.

The unaccountable space leadership will lead through force; it would be the sole progenitor of novel space capabilities, including those that permit it to carry out covert space operations; it would be a rule-setter and a rule-breaker simultaneously, setting rules for other players and breaking the rules when it deems fit.

This has been the endgame of superpowers in space - full-spectrum dominance, ability to singularly set rules through control over intergovernmental organisations, and bending of codes while actively achieving short-term goals at regular intervals. Seven decades is a long enough period to analyse that all superpowers since the 1940s, be it the United States, the Soviet Union, or the People's Republic of China, followed this same modus operandi. However, there are limits to the sporadic growth that these superpowers have seen. The redundancies in the economic and political system set the limits. However, these limits can be triumphed. For

India to do so, it will have to come up with a strategy unique to its own and one that is not stuck in the Orient-Occident, Conservatism-Liberalism, Dove-Hawk, or Capitalism-Communism dichotomies.

OPENING A NEW AND PERPLEXING FRONT

At the 15th BRICS Summit, held in Johannesburg, South Africa, the Indian Prime Minister Narendra Modi made a startling bid. In his formal address, he said, "We are already working on the BRICS satellite constellation, but to move a step further, we should think about establishing a BRICS space exploration consortium."[3] The announcement was startling because India did not hesitate even a bit, as it was just two months prior to the summit that it had signed the US-led Artemis Accords, becoming the 27th country to do so.[4]

India signed the Artemis Accords but is not part of the US Artemis program that aims to go. India proposes the BRICS space exploration consortium but is not part of the China-Russia-led International Lunar Research Station. This atypical position of strength gives India access to deliberations on both the contesting projects, yet it is neither a participant. There are multiple reasons to these:

- India does not want to be a junior partner on projects that it has not conceived or are not its initiative.
- India wants to refrain from committing its national lunar and planetary exploration program or its commercial space ecosystem to either of the two projects exclusively.
- India intends to engage in deliberations on the principles of space activities and determine the codes of conduct with mature space-faring nations. Still, it necessarily needs to abide by the diktats they laid out.
- India intends to plug its space-sector non-governmental private entities across all space ecosystems, and these liaisons will be based on business potential.
- India does not believe in an over-arching space umbrella (akin to a nuclear umbrella), where a leading mature space-faring nation is the aggregator

of financial, technical and human resources instrumental in carrying out space activities.

In April 2023, India and Russia discussed the technology transfer of RD-191 semi-cryogenic rocket engines. Any rocket that will use the RD-191 would be likely to serve the Indian commercial cislunar market.[5] Likewise, with the success of Chandrayaan-3 and India hosting the G20 Summit in September 2023, the US extended an overture by discussing the 'modalities, capacity building, and training for mounting a joint effort to the International Space Station in 2024.'[6] During the Strategic Space Dialogue between India and France in 2023, both countries identified space situational awareness and human spaceflight as two of the few major areas of bilateral space collaboration.[7]

Apart from India, UAE and France have begun to engage both the Artemis and ILRS proponents. In October 2023, UAE's University of Sharjah signed a cooperation agreement with China's Deep Space Exploration Laboratory to work on ILRS projects.[8] The university is likely to develop small exploration platforms that could be piggy-backed on the scheduled Russia- and China-led ILRS missions. A Russia-France partnership may not be vivid at present, but the countries have certainly not closed their doors to each other. France's investment, before the beginning of the Russia-Ukraine conflict, has been five times the other way, standing at USD 15 billion. The relationship has seen a downward spiral, but Russian LNG supplies to France grew 41 percent year-on-year between January and September 2023 despite the conflict.[9] France may currently be unable to cross the NATO line, but it does prefer its strategic autonomy. During the China-France Strategic Dialogue held in Paris in February 2024, both countries reiterated the significance of European autonomy, which France espouses strongly. Also, they discussed the importance of preventing bloc confrontation and major power rivalry. Cislunar activities could become the detenté for France with Russia, as their relationship has not been strained as much as the US-Russia or US-China relations. In 2021, French and other European space experts from Italy, Netherlands, Germany, and the European Space Agency were present in a closed-door workshop on ILRS organised by China National Space Administration and Roscosmos.[10] In a turn of events in Europe, this Franco-Russian space cooperation could be revived.

Where UAE, France and many other nations are in a strife between the US-led and the China-led astrodiplomatic options for their respective geo-economic reasons, India definitely is the harbinger of a third option, one that can be geopolitically and geoeconomically attractive, competitive yet non-confrontational, and alleviating the existing hegemonic aspirations. India's strong economic forecast for at least the next 2-3 decades is not going to close the window of opportunity anytime soon. Only a country that is part of both the blocs and has an unshakeable strategic autonomy would be the progenitor of the cislunar 'Tertia Optio.'

LUNASPATIAL INTELLIGENCE (LUNINT) OF PAX SINICA AND PAX AMERICANA

The cislunar system is not a domain only of scientific exploration and commercial exploitation; where both these meet, securitisation comes into play. For the foreseeable future, there are no wars to be fought in cislunar space, and diplomacy between the two major astropolitical blocs is not happening. To that end, the securitisation of cislunar activities, cislunar assets, and the creation of a cislunar command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) seems imminent.

The US space innovation ecosystem is currently working towards developing lunaspatial intelligence (LUNINT) to monitor human activities in cislunar pathways and on the lunar surface. A 3D lunaspatial situational awareness dashboard is currently being made by the US private space contractors for the Department of Defense to ensure sustained operations of the US Space Force and US Air Force during this decade, the 2020s, and beyond and ensure US dominance in space.[11] The US Air Force calls an element of its LUNINT architecture the Cislunar Highway Patrol System,[12] which aims to place a long-range-narrow-field and a short-range wide-field scanning satellite that would monitor any spacecraft or object coming in close proximity to the Moon. By having a patrol system, the US intends to have a military unit that regularly monitors the civilian space. However, it still needs to be determined if the patrol system is to identify those who break the code of conduct in outer space. If yes, which are these codes, and under which treaty system do they persist? Is there a global consensus on this patrol system, if space indeed is the common heritage of humankind, irrespective of the geopolitical differences? And if none of this is true, the patrol is merely to ensure dominance over an unregulated and frontier outer space. The article in the later section discusses the concept of frontierism.

China's DSEL, during the International Astronautical Congress 2023 in Baku, Azerbaijan, presented the Queqiao cislunar navigation, communication and remote sensing satellite constellation placed in circumlunar orbits and at the Earth-Moon Lagrange point.[13] The first-generation Queqiao satellites have already been demonstrated. They helped the Chinese space program with the lunar far-side operations of the Chang'e-4 spacecraft, and two more Queqiao satellites will be up in mid-2024 to support the Chang'e 6, 7 and 8 missions. When the second generation of Queqiao comes up, it will be ready to provide coverage of the whole Moon, and the third generation will be part of the Earth-Moon-Mars and Earth-Moon-Venus communication and navigation system.

The US and Chinese LUNINT systems are not exclusive from the Artemis program and the ILRS; in fact, it is the critical infrastructure necessary to carry out a plethora of activities varying in their economic, military and scientific criticality. Both countries are interested in leading a pack of loyal junior partners that would partake in the lesser critical operations and perform under the watchful eye of the LUNINT C4ISR that the two bloc leaders raise.

The LUNINT C4ISR has no apparent application for securing the territorial integrity of nations. It is not a tool of geopolitics that plays out in the seas, on mountains, and plateaus. The US LUNINT is for the Americans to take their *Pax Americana* and for the Chinese to take their *Pax Sinica* into cislunar realms. The ILRS is nothing but, as the Chinese would think, part of the *Cèfēng t□zhì*, or the Chinese tributary system, where the ILRS partners engage in trade, military relations, and diplomacy, but by prostrating to the *Tianzi*, the Son of Heaven, the Chinese Emperor, and his *Tianchao*, Celestial Empire.

For the West, led by the US, dominance over the cislunar space is a version of 'Manifest Destiny', where the settlers, read as Artemis Program partners, are the settlers destined to expand to the Moon and in a way, it is a given. The way, the goddess Columbia is the personification of the US's 17th century Manifest Destiny; in the 21st century, the goddess Artemis, after whom the Artemis Accords and the Artemis Program are named, has become the allegory of the cislunar Manifest Destiny.

How many of us have read articles, essays, and books where outer space has been called the 'last' or 'next' frontier to achieve? Any individual, expert or novice, writing on outer space, once in their lives, uses these terms. Many Indians, especially English-language writers, use these words without comprehending that the word 'frontier' emerges from the European colonisation of the New Worlds (new words for them), which comprised the Americas. Frontierism is the phenomenon of winning the wilderness,[14] which unfortunately also included the Native Americans and their cultures. By the 1890s, the US did not remain a frontier for Europe once the Europeans substantially saturated its expanses with its populations and established towns that were named after European towns, regions and cities. What next? It was US President John F. Kennedy, a Democrat, who revived the word ' New Frontier' when he determined to take the first Americans to the Moon.[15] So when we, Indians, use the words 'new frontier' or 'last frontier,' we ignorantly invoke the Western construct of frontierism for the cislunar space.

LUNINT, which neither the Indian civilian space agency, ISRO, nor its Defence Space Agency is preparing for, is the first step towards the US and

China creating exclusive logistics and supply chain pathways to the Moon, and these pathways are agnostic. They could be used for lunar commerce, military activities, or natural scientific research. Exclusivity is a hallmark of dominance, and both these superpowers want to offer that pathway to their bloc members at a geopolitical and geoeconomic premium, which they mutually accept. The establishment of exclusive LUNINT by the US and China is not going to foster any constructive diplomacy between the two; it would rather create divisions that would get stronger by the year. Such an acrimonious impasse is detrimental and would only lead to the build-up of a larger conflict. In such circumstances, the impasse needs to be broken by creating a third option.

CONCLUSION: INDIA HAS A TERTIA OPTIO ROLE IN CISLUNAR SPACE

On 27th February 2024, the Indian government publicly announced the first batch of Indian astronaut-designates, all from the Indian Air Force, and now preparing to fly on two missions, a flight to the International Space Station, and on the Gaganyaan capsule before the end of the 2030s. By 2035, India would have its modular space station, Bharatiya Antariksha Station, and during the Amrit Kaal, by 2047, India would have landed its astronauts on the surface of the Moon.[16] These are the milestones that New Delhi has identified, and irrespective of the fact that these are spectacular milestones, there is a need for evolving comprehension of a Bharatiya Cislunar Strategy. This paper makes the following two suggestions for stake holders to take an early decision:

- **The Chandrayaan Series must now evolve into a Bharatiya Cislunar Program.** India now has strong lunar credentials among the second-generation space-faring nations. It will emerge as the third largest economy on the planet, giving it the never-before ability to make substantial investments to progress from the Chandrayaan series of missions. For India to have its astronauts on the Moon by 2047, it must now create a Bharatiya Cislunar Program.

The first arm of the Bharatiya Cislunar Program after the split proposed here should be of Chandrayaan. Chandrayaan should continue to be the 'brand' for surface exploration and non-exploration activities. The Chandrayaan series of missions should be commercialised with contributions coming in from Indian robotics, precision instrumentations, traditional medicine and pharmaceuticals, biotechnology, automotive, materials, defence, and allied industries and innovation labs. By bringing in commercial enterprises in the Chandrayaan fold, the next missions after the currently contemplated Indo-Japanese Lunar Polar Exploration (LUPEX) could be expedited and yield a quicker return on investment.

The second arm would be to develop the cislunar human spaceflight and long-duration lunar presence technologies. These missions would encompass crew-rated cislunar transportation, heavy-tonnage logis tics and replenishments through the Next Generation Launch Vehicle, crew-rated lunar habitats and life-support systems, and lunar surface transportation technologies. As an outcome of the space reforms, ISRO has been unburdened from numerous tasks, which are now delegated to newer institutions of the Department of Space, particularly IN-SPACe and NSIL. ISRO can now be in charge of developing these technologies with industry partners.

The third arm should be a series of cislunar C4ISR projects tasked with the Defence Space Agency. These C4ISR installations could be placed along the cislunar pathways at the Earth-Moon Lagrangian Point and in circumlunar orbits, offering positioning, navigating, cislunar situational awareness, and communication capabilities. Just like the Hindu Lunar God is called *Dikpala*, the 'guardian of the directions', this C4ISR would be crucial for setting the next-generation Chandrayaan-driven surface infrastructure on the Moon, long-duration operations of robotic spacecraft on the lunar surface and ensuring incessant connectivity (deep space communication) and security for astronauts and logistics missions, taking into account all contingencies. It goes without saying that the Indian private space ecosystem would play a major role in constructing the C4ISR spacecraft, components, subsystems and systems as per DSA's specifications.

- **India must have a Bharatiya Comprehensive Cislunar Strategy.** It is evident from the actions of the US and China that both these countries are following a comprehensive cislunar stratagem, taking into tow all the arms of their governments. Similarly, and in a non-reactive manner, India must contemplate that for its growing global stature. This well-structured all-of-a-nation cislunar strategy must be in tune with India's global geoeconomic and geopolitical goals.

The remarkable attribute of this strategy is that it does not fall for the systemic ideologies that the US and China espouse. This strategy would not arm-twist countries to join the Bharatiya cislunar plans on exclusivity. The leverage for joining would be equitable stakes, maintaining a code of conduct, and ensuring equal accountability and respect for the true global order, one that is based on respect for the natural well-being of the planet and the cislunar space.

India's cislunar ambitions are developing in an era where the global geopolitical order established in the middle of the 20th century is in flux; the global economic institutions are reshaping to accommodate global multipolarity. The treaties for outer space established in the 20th century are appearing increasingly outdated. To that end, India, true to its potential and growing heft, must develop its cislunar strategy in this grey zone. The grey zone may not necessarily be a challenge but an opportunity to establish an order that has a strong Bharatiya imprint. India will only lose if it falters in not executing a cislunar strategy in this small window of time, which coincides with our Amrit Kaal.

India will remain a strong economy; it will remain an enormous and young population and a country that has woken up after a long period of geopolitical disorientation. These are reasons enough for India to carve out its identity as a non-hegemon and a junior partner to none. India will soon be not only the third largest economy on the planet but also the Tertia Optio, which comes into play when diplomacy fails and when war between two impasse-ridden superpowers is difficult. That is why the Prime Minister says, "This is not the Era for War."

Prof Chaitanya Giri is a Member of the Advisory Board, Satcom Industry Association-India, New Delhi. He is also an Associate Professor, FLAME University, Pune and Space Policy Consultant at the Research and Information System for Developing Countries, New Delhi.

NOTES

1. Ron Surz, 'The Bursting of a Stock Market Superbubble', Nasdaq, 12 October 2022, https://www.nasdaq.com/articles/the-bursting-of-a-stock-market-superbubble.
2. Patrick Besha, 'Economic Growth and National Competitiveness Impacts of the Artemis Program,' Office of Technology, Policy & Strategy, National Aeronautics and Space Administration, May 2022, https://www.nasa.gov/wp-content/uploads/2022/10/artemis_economic_competitiveness_impacts_5-18-2022_tagged.pdf?emrc=fe4bfc.
3. 'English translation of Prime Minister's remarks at the 15th BRICS Summit', Prime Minister's Office, Press Information Bureau, 23 August 2023, https://pib.gov.in/PressReleasePage.aspx?PRID=1951403#:~:text=Taking%20it%20a%20step%20further,education%2C%20skill%20development%20and%20technology.
4. Claire A. O'Shea, 'NASA welcomes India as the 27th Artemis Accords Signatory', NASA, 23 June 2023, https://www.nasa.gov/news-release/nasa-welcomes-india-as-27th-artemis-accords-signatory/.
5. Siddharth M.P, 'Exclusive: India-Russia discuss tech-transfer, making of 'RD-191' semi-cryo rocket engine', WION, 13 April 2023, https://www.wionews.com/india-news/exclusive-india-russia-discuss-tech-transfer-making-of-rd-191-semi-cryo-rocket-engines-581784.
6. Surendra Singh, 'US ready to send an Indian to International Space Station next year, says NASA chief', Times of India, 29 November 2023, https://timesofindia.indiatimes.com/city/delhi/us-send-indian-astronaut-international-space-station-2024/articleshow/105576807.cms#:~:text=place%20next%20year.-,The%20US%20will%20help%20train%20and%20send%20an%20Indian%20astronaut,activities%20of%20astronauts%20in%20space.
7. 'Inaugural India-France Strategic Space Dialogue', Ministry of External Affairs – Press Release, 27 June 2023, https://mea.gov.in/press-releases.htm?dtl/36738/Inaugural+IndiaFrance+Strategic+Space+Dialogue.
8. Ling Xin, 'UAE university joins China's moon project after Arab nation's initial bid killed by US sanctions', South China Morning Post, 28 November 2023, https://www.scmp.com/news/china/science/article/3242545/uae-university-joins-chinas-moon-project-after-initial-bid-arab-nation-killed-us-sanctions.
9. Lidia Kelly, 'Russia LNG sales to France up 41% y/y in Jan-Sep 2023 – RIA news agency', Nasdaq, 10 February 2024, https://www.nasdaq.com/articles/russia-lng-sales-to-france-up-41-y-y-in-jan-sep-2023-ria-news-agency.
10. 'Russian-Chinese Joint Seminar on Cooperation in International Lunar Research Station', China National Space Administration, 28 September 2021, https://www.cnsa.gov.cn/english/n6465652/n6465653/c6812568/content.html.
11. 'LUNINT: Lunaspatial Intelligence', Award Information – SBIR-STTR – America's Seed Fund, https://www.sbir.gov/sbirsearch/detail/1941917.

12. Joanne Perkins, 'AFRL's Cislunar Highway Patrol System seeks industry collaboration', US Air Force Research Laboratory, 21 March 2022, https://www.afrl.af.mil/News/Article/2972971/afrls-cislunar-highway-patrol-system-seeks-industry-collaboration/.
13. Andrew Jones, 'China wants a lunar satellite constellation to support deep space missions', Space News, 05 October 2023, https://spacenews.com/china-wants-a-lunar-satellite-constellation-to-support-deep-space-missions/.
14. Ansel Adams, 'The closing of the American Wilderness', PBS – American Experience, https://www.pbs.org/wgbh/americanexperience/features/ansel-closing-american-wilderness/.
15. 'John F. Kennedy, 35th President of the United States: 1961-1963; Address Accepting the Democratic Nomination for President at the Memorial Coliseum in Los Angeles, California', The American Presidency Project – UC Santa Barbara, 15 July 1960, https://www.presidency.ucsb.edu/documents/address-accepting-the-democratic-nomination-for-president-the-memorial-coliseum-los.
16. 'PM visits Vikram Sarabhai Space Center (VSSC) in Thiruvananthapuram, Kerala: Reviews progress of Gaganyaan and bestows 'astronaut wings' to astronaut-designates', Prime Minister's Office – Press Information Bureau, 27 February 2024, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2009320#:~:text=Shri%20Modi%20also%20reviewed%20the,and%20Wing%20Commander%20Shubhanshu%20Shukla.

162-175

SPACE BASED ELINT - A CHINESE CASE STUDY: MEASURES TO DEVELOP CAPABILITIES IN INDIAN CONTEXT

Air Vice Mshl Sanjay Bhatnagar, VM, VSM (Retd)

"The doctrinal imperative to gain the higher ground for tactical advantage, in the military domain, has manifested in us seeking capabilities in air and now in space, and utilisation of space-based assets has revolutionised warfare by enhancing our capacities in intelligence gathering, surveillance and reconnaissance, communications, early warning, weather forecasting and navigation."

Chief of the Air Staff
Air Chief Marshal VR Chaudhari
June 14, 2022

Abstract

Significance of ELINT in modern multi domain operations (MDOs) cannot be overemphasised. Surveillance of Electromagnetic Spectrum (EMS) is vital to gain advantage in symmetric, asymmetric and hybrid conflicts. It is accorded highest priority during peacetime operations. Knowledge of adversaries of EMS is vital for Indian armed forces. ELINT systems provide the armed forces with effective means to intercept, classify and localise any type of air and surface RF emitters. Indian armed forces have a robust ELINT collection mechanism from ground-based sensors and a few airborne platforms; however, the intervening ground/ obstructions and limited line of sight issues constitutes a great drawback. Space based ELINT gathering

by virtue of its elevated character overcomes these limitations. This article explores the way ahead for development of Space based ELINT system for Indian armed forces using a real world case study of the Yaogan satellite constellation of the Chinese People's Liberation Army Strategic Support Force (PLA SSF).

INTRODUCTION

China has been steadily ascending as a global space power, it is now a full-fledged space power in all respects and is ready to compete with any nation across the spectrum of space capabilities. Space power seems to be critical component of its aspiration to emerge as a global power at the regional and global level.

China has been leaping forward in enhancing its space capabilities. Last year alone it undertook 67 orbital launches, including 17 by its private entities, thereby putting more than 200 satellites in various orbits. Prior to that, it has undertaken 64 launches in 2022, 54 in 2021 and 45 in 2020, despite the Covid pandemic. At the global level, space activities have increased, there are more than 5200 active satellites today, owned by 80 countries, in 2023 itself, some 675 satellites were launched.

Chinese President Xi Jinping in his 20th Party Congress address in October 2022 emphasised the need to enhance the space infrastructure as a critical component to Chinese Communist Party's legitimacy to power.[1] Enhancing situational awareness about adversary's disposition of assets, especially mobile assets, constitutes a significant component of this capability. Having a set of reliable ISR, EO and SAR constellation of satellites is one of the most reliable asset in providing near real time situational awareness about the adversary.

Of the launches by China in 2023, 9 launches specifically augmented China's reconnaissance and strike capabilities, these included, Yaogan 37 on January 13; Yaogan 41 (YG 41)[2] a geostationary SIGINT satellite on December 15 and a set of seven triads between July and October last year.

This paper characterises the development of Space based ELINT system for Indian armed forces using a real world case study of the Yaogan satellite constellation of the Chinese PLA SSF (People's Liberation Army Strategic Support Force).

ELINT: AN IMPORTANT ARM OF WAR FIGHTING

Electronic Warfare (EW) has tremendous importance in modern multi domain operations (MDOs). In all the phases of a multi domain operations, EW encompasses military actions involving the use of electromagnetic (EM) energy to determine, exploit, reduce or prevent hostile use of EM spectrum and the actions, which retain friendly use of the EM spectrum.

ELINT gathering is of prime importance for all competing forces. Surveillance of Electromagnetic Spectrum (EMS) is vital to gain advantage in symmetric, asymmetric and hybrid conflicts. It is accorded highest priority during peacetime operations.

ELINT relies on the passive detection of emissions from radar systems (RF Emitters) and can be used to classify as well as geolocate radar systems operated by an adversary. ELINT is responsible for supplying intelligence and threat recognition.

The objective of ELINT, is to achieve high sensitivity & direction finding (DF) accuracy with accurate RF emitter parameters with an ultimate aim to create EW threat databases that are used to update the Electronic Order of Battle (EOB) which is concerned with location updates, movements and the readiness status of adversary emitters.

ELINT provides radar operating parameters, waveform details, geo-location and other pertinent information. ELINT involves in-depth signal analysis of RF emitters, accurate characterisation, analysis and tracking by employing sophisticated software tools for RF pulse and most importantly the intra pulse detailed analyses. An efficient ELINT system is required to have a capability to detect and measure the angle of arrival (AOA) of any RF emitter. Systems employ obtain geo-location of emitters by triangulation algorithms.

ELINT undertakes accurate measurement and analysis of parameters of RF emitters and powerful correlation with known-emitters reference database.

Database storage is a repository of all detected waveforms and elaborated information, accurately time stamped. Integration and assessment of the acquired data to generate the Electronic Order of Battle (EOB) of friendly and hostile radar emitters is another significant facet of ELINT.

During peacetime, the quest for knowing enemy's EOB is high on priority so that during hostilities, own forces are able to decipher the electronic signatures and exploit the EMS to the best advantage.

ELINT Requirements for Indian Armed Forces

Knowledge of adversary's of EMS is vital for Indian armed forces to gain advantage in a symmetric, asymmetric or hybrid conflicts. ESM and ELINT systems provide the armed forces with effective means to intercept, classify and localise any type of air and surface RF emitters. Normally, frequency coverage is 0.5 to 18 GHz, where most of radars work is considered essential, with an additional option of keeping tab on extremely high frequency radars, like the air defence tracking radars of up to 40 GHz.

ELINT Collection Mechanism

Indian armed forces have a robust ELINT collection mechanism from ground based sensors. Besides, all three armed forces are also employing certain drones and airborne platforms to acquire ELINT through an elevated observation concept.

Ground Based ELINT System (GBES) are required for fulfilling strategic EW requirements. GBES comprises of a Control Station and a triad of three Receiving Stations integrated to search, detection, monitor, record and process the hostile emissions as well as to find the location of the emitter.

Ground based ELINT systems work on the principle of line of sight wherein the intervening ground/ obstructions constitutes a great drawback. Such systems do not meet the operationally essential requirement of covering larger areas and perseverance over time. India faces threat on western and northern front, at the same time modern day threat environment is fast evolving with most of the RF emitters becoming highly mobile and versatile in modifying its RF parameters as part of its ECM features. The EM spectrum too is getting highly contested. In such an operational scenario, a ground based ELINT system suffers from the drawback of lack of persistent coverage, limited to a small area. Space based ELINT gathering by virtue of its elevated character overcomes these limitations.

ELINT gathering process within the armed forces is essentially being carried by Electronic Warfare (EW) units/sub-units and Wireless Experimental Units (WEU) of the three services. The effort is supplemented by agencies under the Cabinet Secretariat such as National Technical Research Organisation (NTRO) and Aviation Research Cell (ARC).[3] Integral UAV/ drones and airborne platforms further supplement these efforts. While the overall ELINT gathering and dissemination can be made more efficient by synergising efforts of all these organisations at the national level, the limitations of line of sight, ground obstructions, persistence coverage and limited area can be overcome by employing space based mechanisms.

ELINT THROUGH SPACE: TECHNICAL FEASIBILITY

In view of evolving EM spectrum threat of modern days, Indian armed forces need to upgrade to ELINT gathering from space to be able to exploit the knowledge of EOBs in a dynamic tactical and strategic battle ground for its armed forces. Space based ELINT offers unique advantages and is a great game changer.

Space based ELINT gathering has its own sets of challenges like housing the antennas in the space craft, especially wide frequency band needs different types of antennas of varying shapes and sizes. Other issues like fast moving spacecrafts, of approximately 7 to 9 kms per second, gathering RF emissions from LEO (typically from approximately 400 to 600 kms) comes with its own sets of challenges of gathering enormous amount of data in each millisecond, of multiple radar characteristics, RF sensors requiring highly sensitive antennas, limited field of view available for signal gathering due typical beam patterns of RF emitters and reduced radar horizon for gathering emissions. Added to all this is the challenge of expeditiously analysing data and passing the information to ground station.

Newer problems and challenging operational environment demand technologically sound solutions. Indian space sector is evolving, new private space companies are emerging. Consequent to space sector reforms in 2020, the whole of the Indian space ecosystem is highly catalysed. The challenge of gathering ELINT from space can be technically addressed. The same is discussed later in the paper.

PLA'S SPACE BASED ELINT CAPABILITIES: A CASE STUDY

China has been launching its electronic surveillance satellite under the Yaogan series- a combined military surveillance constellation of electro-optical (EO), imagery intelligence (IMINT), synthetic aperture radar (SAR) and electromagnetic intelligence (ELINT) satellites.

Yaogan constellation is essentially intended to enhance China's anti-access and anti-denial (A2AD) capabilities. Today, China is involved in conflicts with a number of nations, including Taiwan, Philippines, India and most importantly, with the US in the South China Sea (SCS). China feels that it needs to keep its vast neighbourhood under continuous surveillance, to be able to locate, identify and reliably track the US Aircraft Carrier Groups in the Western Pacific, before it comes consequently close to be able to threaten its own freedom of operation in its area of interest.[4]

Electronic Intelligence (ELINT) satellites pick up the electronic emissions from the RF Emitters from ground or Aircraft Carrier Group in the Ocean with a relatively coarser spatial resolution; thereafter, Synthetic Aperture Radar (SAR) satellites are cued by the ELINT satellites inputs once an object of interest has been spotted; and Electro Optical (EO) satellites that are cued to identify and locate the RF Emitter to accurately identify, locate and track an RF emitter on the ground or an Aircraft Carrier Group (ACG) on the high seas.[5]

Yaogan-class satellites are used for military intelligence purposes and are controlled by the Strategic Support Force of the Chinese People's Liberation Army (PLA SSF), which is responsible for space, cyberspace, and electronic warfare. PLA SSF came into being on 31 December 2015.

To keep the entire area of interest (for China, its concern would be the western Pacific Ocean) under surveillance the constellation will need three kinds of satellites: Electronic Intelligence (ELINT) satellites that pick up the electronic emissions from the Aircraft Carrier Group and locate it in the Ocean with a relatively coarser spatial resolution; Synthetic Aperture Radar carrying satellites that are cued by the ELINT satellites or by other satellites in the constellation that have located the object of interest; and Electro-optical satellites that are cued by the ELINT satellites or by other satellites in the constellation that had located the aircraft carrier earlier.[6]

China operated 136 reconnaissance satellites in 2022, as compared to 66 in 2019. According to the Military Balance report published by the London based International Institute for Strategic Studies, China has significantly increased its reconnaissance satellite capabilities. Additionally, China is expanding its fleet of electronic intelligence (ELINT) and signals intelligence (SIGINT) satellites, which are capable of intercepting electronic information.[7]

China embarked upon its Yaogan project with the launch of its first military EO satellite (Yaogan-1 from Taiyuan Satellite Launch Centre) on April 26, 2006 in a sun synchronous orbit with 97° inclination. Yaogan means "remote sensing" in Chinese. With the launch of Yaogan-9, an ELINT triad, on March 05, 2010 from Jiuquan Satellite launch Centre (JSLC),[8] the constellation became fully operational in 2010. Yaogan-9 had all three satellites 120° apart, in the same plane of 63° inclination to the equator. China further kept adding a few more EO and SAR satellite under the Yaogan-series name.

A detailed study of the architecture of ELINT, EO and SAR satellites deployed by the PLA forces over the past 17 years brings out certain significant aspects, important for Indian space agencies to draw lessons and craft our own ELINT satellite deployment plans.[9]

Yaogan constellation scan a large area over land and sea by acquiring electromagnetic signatures of various RF emitters, leading to optical acquisition by EO or SAR satellites, thereby ascertaining their precise location. This methodology or template is termed as tipping and cueing model, simply put, tipping about the presence of an RF emitter is made available by space based ELINT and the same is ascertained to a high degree of geo-location accuracy through an EO/SAR satellite. Thereafter, if required the RF emitter and its associated assets can be targeted through a proper targeting cycle at a time and weapon of its choosing.

Yaogan constellation scan a large area over land and sea by acquiring electromagnetic signatures of various RF emitters, followed by optical imaging by EO or radar imaging by SAR satellites, thereby ascertaining the precise location of source of RF emitter. This methodology or template is termed as tipping and cueing model, simply put, tipping about the presence of an RF emitter is made available by space based ELINT and the same is ascertained to a high degree of geo-location accuracy through an EO/SAR satellite. Thereafter, if required the RF emitter and its associated assets can be targeted through a proper targeting cycle at a time and weapon of choosing.

In order to shorten the OODA loop, China has strengthened the Yaogan constellation by adding more ELINT triad satellites, coupled with a combination of EO and SAR satellite at various equatorial crossing times so as to keep the AoI under near continuous surveillance by ELINT and EO/SAR satellites. The People's Liberation Army (PLA) today has a network of the ELINT, SAR and EO satellites in orbit, enabling the integrated system of tip-and-cue to sweep vast target area once in less than 30 to 40 minutes, thereby enabling rapid target identification with precision.[10]

The concept has been evolving over the last two decades, based on the experience gained by Chinese forces in operating these satellites, new technological advances and operational thinking based upon tactical scenarios that armed forces are likely to encounter.

As far as the EO/SAR satellites are concerned, all of them have continued to be in sun synchronous orbits with inclination of 97° to 100°. Initially, the resolution expected was of the order of 3-10 metres, over a period of time the accuracy has improved to sub-metric levels. Also improved satellite bar (CAST-100 and CAST-2000[11]) has made the satellite stabilise in an earlier time frame and has made the system of transmission of data more efficient and robust, thereby reducing the time gap between acquiring the data and dissemination to the ground station. At the same time the number of these satellites has kept on increasing.

Interestingly, it is the employment and exploitation of data from ELINT satellites that has witnessed the maximum evolution, essentially with the understanding of keeping the Taiwan and SCS region under better surveillance and the whole concept has further evolved especially after the formation of PLA SSF.[12]

The ELINT triads in early 2010s were all in 63.4° inclined, approximately 1200 km altitude orbit, with all three satellites displaced 120° in the same plane.

On December 31, 2015, against the backdrop of broader structural reforms, the PLA took a major institutional step to integrate its previously disaggregated space, communication network, and electronic warfare elements by creating the Strategic Support Force as a fifth service of PLA, named as PLA SSF. This clearly signifies Chinese military leaders' belief that "achieving information dominance and denying adversaries the use of the EMS is necessary to seize and maintain the strategic initiative in any conflict."[13]

Coincidentally, from September 2017 onwards (with Yaogan-30 A,B,C), China started launching ELINT triad of Yaogan satellites in a new configuration. Unlike the earlier triads their altitude was brought down to 600 Km with inclination of 35° and saw satellites being maneuvered to fly in a six spot configuration in the same orbital plane, thereby increasing the number of ELINT satellites to 18 in this 35° orbital plane. The relative angles were observed to be 260°, 140°, 20°, indicating that these triads were themselves displaced by 120°.

Reducing of inclination to 35° and having six set of satellites in each orbit was possibly to bring the areas of Taiwan and SCS under enhanced surveillance. This pattern has continued to be observed in subsequent ELINT satellite launches as well.

A well stabilised constellation of Yaogan has given China a revisit time of approximately 30 minutes over a vast area of Indian territory and Indian Ocean area, thereby providing its armed forces a close watch over Indian strategic assets. This imposes a great limitation on conduct of operations to the Indian armed forces, in equal measure for its Army, Navy and the Air Force, as it denies them a great deal of flexibility of operations, thereby impeding the momentum of operations, considered so very essential for success of any military campaign.

Space-based ELINT has the potential to provide timely and accurate intelligence on potential threats from adversaries, a critical aspect of national security for formulating defence strategies for India. Thus, India need to accord highest priority amongst all the space capabilities.

SPACE BASED ELINT FOR INDIA

EMISAT, the lone ELINT Satellite

EMISAT is an ELINT satellite developed jointly by DRDO and ISRO, under Project Kautalya, Defence Electronics Research Laboratory (DLRL) Hyderabad, under DRDO is the lead developing agency for payload development. EMISAT is a satellite built around ISRO's Mini Satellite-2 bus weighing about 436 kg, with solar panels providing 800 watts of power to the satellite.

It was launched on April 01, 2019 onboard India's PSLV-C45 launcher from Satish Dhawan Space Center (SDSC), Sriharikota and successfully injected EMISAT and 28 international satellites from four countries- Lithuania, Spain, Switzerland and the US, into their designated orbits. It placed EMISAT in a sun-synchronous orbit, with 98.4° inclination and an apogee of 749 km. This is expected to give the satellite enough dwell time for picking up RF emissions from a specific area on the ground and recording them. The height of 749 km provides the EMISAT with a sufficiently large footprint and a 6 to 8 revisit per day, translating into a capability to be over the same point every second day.[14]

ELINT being a highly secretive and sensitive subject, not much information is available about the forthcoming projects in the open domain. Just having a single space based ELINT platform is not sufficient as it does not meet the most essential requirement of triangulation. It also has a limitation of very high revisit time that does not enhance the overall surveillance capability.

The fact remains that requirement to have a constellation on the same technical capability that the PLA SSF possess is the need of the hour for Indian armed forces. No nation is known to share niche intelligence gathering technology to any other nation, India would have to depend space based ELINT gathering capability by harnessing indigenous technology. Indian armed forces and ISRO are to do much more to design and develop space based ELINT capability, which may involve investing in research and development to design and develop satellite based RF sensors and other related capabilities.

Drivers for Indian Space Based ELINT: Path Ahead

Developing and operationalising Space based ELINT capability requires mastering certain high end technologies and developing efficient software based solution. Major building block technologies or components required for the same are covered in subsequent paragraphs.

In order to triangulate the location of RF emitter, a triad based satellite constellation would be required in the space also. To offer increased dwelling time over the area of interest (AoI), the complete constellation would have to be in inclined orbit. The exact angle of inclination would depend upon our AoI.

Considering the sensitivity of antennas onboard the satellite and strength of RF signals available and other peculiarities of EM emissions, a triad in LEO orbits would be able to provide an ideal solution. Also, placing more number of triad satellites in each planar orbit would help increase the number of observations in each orbit, thereby improving the accuracy of observation. A well knit constellation would also demand that each satellite communicates with the other members of the constellation, requiring inter satellite links (ISL), imposing more power and system management challenges.

Amount of data getting accumulated at a fast-moving satellite (approx 7 km per second in LEO) would demand more dwell time for undertaking a focused search on intra pulse parameters. This could only be achieved by edge computing by employing latest AI and ML models and related processing technologies of software on chip (SoC) or Field Programmable Gate Array (FPGA) in which Integrated Circuits (ICs) can be programmed to perform a customised operation for a specific application related to ELINT processing, lets say specific to a particular geographic area, for a certain intra-pulse characteristic, as the case may be.

Inclined orbit has their own peculiar challenge of limited solar charging time availability. At the same time heavy computing and processing demands and ISL-link requirements would be placed on the satellite bus, thereby, imposing high power requirements. There is thus a need to consider designing a light weight agile satellite that is small, light and power efficient system. These systems need to be SWaP optimised with highly efficient algorithms to extract accurate radar parameters. Designing of such a system is a persistent challenge due to the limited availability of space graded components and associated tools.[15]

Also, space radiation effects on electronic devices are an important system design consideration. They can cause problems ranging from operational malfunctions to severe physical damage to the devices and possibly a catastrophic mission failure. Integrated Circuits (ICs) are susceptible to two types of space radiation effects viz. caused by electrons and protons trapped in the terrestrial magnetic field.[16] The system needs to be hardened to meet these standards.

RECOMMENDATIONS

Space-based ELINT capabilities have significant implications for national security, as they provide insights into adversary's activities, intentions and capabilities. Since 2020, the Indian space sector has been opened up to private sector participation, amongst the various space based capabilities that are being sought by the Indian armed forces, these need to be prioritised and space based ELINT capability needs to be accorded highest priority. Maximum amount of investment in terms of resources and effort needs to be invested in this domain on an urgent basis. Gaps in the space based ELINT capability can be addressed by purchasing data from foreign friendly countries and simultaneously developing indigenous capability to gather RF emissions from ELINT satellites.

The issue may be taken up at the highest level to steer space based ELINT design and development on a mission mode by ISRO or by Indian private space companies or both together as a joint project. This capability building presently is being steered under iDEX challenges by the armed forces as well as under the aegis of ISRO as a further to EMISAT, Project Kautilya. This two-prong approach should continue to expeditiously strengthen national security posture. Acquiring such a versatile capability should be a national security endeavour, hence, a whole of nation approach and more resources needs to be accorded towards acquiring space based ELINT capability.

Air Vice Mshl Sanjay Bhatnagar, VM, VSM (Retd) is a former Consultant with CENJOWS. Commissioned in the IAF in the fighter stream in December 1983, he superannuated in August 2020. He has held various command and staff appointments. He is a Presidential award winner (VM Gallantry) during the Kargil operations in 1999. In his last rank, the author has served as Air Defence Commander at HQ EAC, Shillong, Assistant Chief of Air Staff (Ops Offensive) at Air HQ and Assistant Chief of Integrated Defence Staff (Tech Int) at HQ IDS, holding appointments related to air defence,offensive air operations, space and ISR matters.

NOTES

1. Fumiko Sa saki (2023), "China's Rising Space Power and the CCP's Survival in the Indo-Pacific Era ", [Online web], https://muse.jhu.edu/article/881959/pdf. Accessed on 23 February 2024.
2. Krebs, Gunter D. “Yaogan 41 (YG 41)”. Gunter's Space Page, https://space.skyrocket.de/doc_sdat/yaogan-41.htm. Accessed on 26 February 2024.

3. CLAWS (June 2019) Brig Akhelesh Bhargava "EMISAT: A Force Multiplier " [Online web], https://www.claws.in/static/IB184_EMISAT-A-Force-Multiplier.pdf. Accessed on 22 February 2024.
4. S. Chandrashekar and Soma Perumal (2016), "China's Constellation of Yaogan Satellites & the Anti-Ship Ballistic Missile: May 2016 Update", [Online web], https://cms.nias.res.in/publications/chinas-constellation-of-yaogan-satellites-the-asbm-may-2016-update. Accessed on 17 February 2024.
5. Ibid.
6. Ibid.
7. Tech360.tv (2024), China and India Take the Lead in Expanding Spy Satellite Networks in Asia", [Online web], https://www.tech360.tv/china-india-lead-expanding-spy-satellite-networks-asia. Accessed on 23 February 2024.
8. Krebs, Gunter D. & ldquo; Yaogan 9, 16, 17, 20, 25, 31 (JB-8 1, 2, 3, 4, 5, 6) & rdquo;. Gunter's Space Page, https://space.skyrocket.de/doc_sdat/yaogan-9.htm. Accessed on 26 February 2024.
9. Krebs, Gunter D. & ldquo; Yaogan 30-01, ..., 30-10 (CX 5) & rdquo;. Gunter's Space Page, https://space.skyrocket.de/doc_sdat/yaogan-30-01.htm. Accessed on 26 February 2024.
10. S. Chandrashekar and Soma Perumal (2016), "China's Constellation of Yaogan Satellites & the Anti-Ship Ballistic Missile: May 2016 Update", https://cms.nias.res.in/publications/chinas-constellation-of-yaogan-satellites-the-asbm-may-2016-update. Accessed on 17 February 2024.
11. "CAST Satellite Platform by China Great Wall Industry Corporation", https://www.cgwic.com/RemoteSensingSatellite/index.html. Accessed on 25 February 2024.
12. S. Chandrashekar and Soma Perumal (2013 & 2016), "China's Constellation of Yaogan Satellites & the Anti-Ship Ballistic Missile: May 2016 Update", https://cms.nias.res.in/publications/chinas-constellation-of-yaogan-satellites-the-asbm-may-2016-update. Accessed on 17 February 2024,
13. Marcus Clay (2021), "To Rule in The Invisible Battlefield: The Electromagnetic Spectrum and Chinese Military Power", https://warontherocks.com/2021/01/to-rule-the-invisible-battlefield-the-electromagnetic-spectrum-and-chinese-military-power/. Accessed on 24 February 2024.
14. CLAWS (June 2019) Brig Akhelesh Bhargava "EMISAT: A Force Multiplier " https://www.claws.in/static/IB184_EMISAT-A-Force-Multiplier.pdf. Accessed on 22 February 2024.
15. Niranjan, R., Singh, A., & Rao, C. B. (2020). "SWaP Optimised Parameter Extraction of Radar Signals for Space Electronic Intelligence Application. *Defence Science Journal*, *70*(6), 642-649", https://doi.org/10.14429/dsj.70.15619. Accessed on 24 February 2023.
16. Josh Broline & Nick van Vonno, Renesas Electronics America (1999), "Mission Critical Space Flight Systems Stay Rad Hard", https://www.eetimes.com/mission-critical-space-flight-systems-stay-rad-hard/. Accessed on 23 February 2024.

176-191

INDIA'S ROLE IN LEVERAGING SPACE IT PARKS TO PROMOTE SPACE BASED CSR

Ms Anamitra Banerjee

Abstract

The commercial space industry has the potential to have a substantial influence, notably the creation of a groundbreaking hyperspectral satellite array which can collect information at multiple wavelengths per every pixel, resulting in extremely precise images that help with the recognition of items and substances. Considering the planned second spaceport, India's intention of outsourcing space missions is likely to result in additional launcher agreements for ISRO and five times rise in worldwide space revenue. This piece delves to investigate whether the choice made by the government to let commercial firms access the Indian space environment is likely to stimulate space launching activity. Further it will also study the concept of space parks and the reforms brought by the Indian govt which can facilitate the Indian entrepreneurs to capitalise on the aerospace sector with new technology.

INTRODUCTION

A handful of nations interested in space exploration have the financial capacity or ideological determination to support a national space programme, so governments must use what they do have: the capacity to offer financial incentives, the influence to bring together major players within negotiations, and the foresight to integrate intellect and assets to beneficial impact.[1] The European Space Agency, for instance, pools intellectual property and study facilities from throughout EU and promotes renowned, specialised enterprises and universities to form satellite clusters—collaborations on satellite-related research and development efforts.[2] The emergence of private businesses is going to assist the sector grow more profitable. Low-cost space launchers, along with large-scale manufacturing, are expected to drive global demand.

The "Make in India" and "Aatmanirbhar Bharat" projects envision a transformation predominantly within the government-led space system.[3] To achieve the current objective of boosting India's representation of the international space sector, commercial engagement and support for the nation's space venture capitalist sector remain critical. Given a strong legal structure, additional initiatives aimed at fostering the simplified process of operating for spacetech enterprises, and avenues for foreign investment, India's space sector has a chance to become a pathfinder in the international space industry.

According to the Indian Space Association (ISpA) idea document, the establishment of Space Technology Parks (STP) in the country would propel the industry to greater high places, much as the creation of IT park achieved for Indian commercial business.[4] The key ISpA idea document, "Space Technology Parks to Energise Aatmanirbhar Bharat in Space Domain," issued around the sidelines of Aero India 2023, addresses the changes and facilitators required to build an environment for STPs and to assist businesses in developing fresh aerospace technologies.[5] The demand for the creation of STPs is motivated by the desire to provide an encouraging atmosphere for the expansion of the aerospace manufacturing sector, according to the report. This move follows after the Indian government implemented a spate of space changes commencing from 2020.[6] India's Prime Minister announced a three-pronged drive to strengthen its space industry.[7] INSPACe was established to oversee and regulate space regulations, including national and unique regulations for imagery collection, exchanges, tracking satellites, human space flight, foreign direct investment, and modern technology transfer.[8]

At present, India has more than one hundred space-tech firms. 2021 marked a historic time-period for space-tech businesses, with funding totalling US$68 million, representing a 196 percent rise year over year.[9] In 2021, the country saw the launch of 47 unique space-tech businesses. The primary factors for investing within the Indian space market include:[10]

- Government's ambition to include commercial actors in the space section.
- Reduce satellite development and launch expenditures.
- Assurance of a large profit from capital.
- Increasing business interest for geospatial information.
- Advances in technology in the space business.

CONCEPT OF SPACE INDUSTRIAL PARKS

Space industrial parks are specialised locations where both public sector agencies and businesses can operate in space research, satellite production, along with other aerospace-related sectors. Space parks frequently include buildings, amenities, and aid operations to encourage joint ventures and creative thinking in the space industry. They are critical for a nation's advancement towards space exploration and expansion of the aerospace sector.[11] Further a Space Park can assist in modifying and revolutionising certain fields like communications, managing of assets, debris tracking, as well as HADR operations by creating robust satellite systems and facilitating space related geospatial intelligence. Although, globally, the notion of "Space IT Parks" is not frequently understood and still an evolving niche sector; the marriage between fusing critical IT systems with space-related functions is a continuous development. Infact with the help of technology, global space organisations and businesses have been leveraging operations like satellite transmission, image processing, and missions planning.

So why is there a growing impetus for Space Industrial Parks within the Indian subcontinent? India operates a robust space programme, which has been aided through the methodical realisation of indigenisation, infrastructure, frameworks, and programme deployment.[12] By privatising the space sector, Indian economy plans to overcome the technological gap, ushering unconventional space-based solutions, and propel Delhi to be emerge as the champion in space-tech competition.[13]

Key aspects and potential features of space industrial parks include:[14]

- Manufacturing and Assembly: Space industrial parks could house facilities for the manufacturing and assembly of spacecraft, satellites, and other space-related components. Such necessitates dedication between corporate and public sector space exploration organisations.
- Research and Development: These parks might provide spaces for research and development activities related to space technologies. This could involve collaborations between different entities to advance space-related innovations.
- Launch Facilities: Proximity to launch sites or the development of dedicated launch facilities within or near the space industrial park could be an essential component. This will help in efficient transportation of spacecraft and associated component.
- Testing Facilities: Testing facilities for space technologies are essential for ensuring the reliability and safety.
- Education and Training: Incorporating Educational and training facilities can impart training to the skilled workforce. Universities and vocational institutions could also collaborate.
- Commercial Ventures: Private companies should be given incentive in the fields of space tourism, asteroid mining and related commercial activities. These parks could provide a centralised location.
- Infrastructure & Services: Supporting infrastructure, such as transportation links, utilities, and other essential services, would be crucial for the success of a space industrial park.
- International Collaboration: Space industrial parks could encourage international collaboration, bringing together companies and organisations from different countries to work on common goals in space exploration and development.

HOW THE GLOBAL SPACE PARKS HAVE TAKEN A SHAPE?

Space parks are famous in many nations throughout the globe.

- In China, these took the shape of National High-Tech Industrial Development Zones (NHTIDZs), which displayed unique geographic and temporal traits throughout the last three decades. NHTIDZs, being exclusive places, exemplify the strong link among state power and urbanisation, and they have evolved into an organisational structure for growth in space.[15] The evolving disparity across time and space exhibits a pair of key traits: a quick and unpredictable centralising tendency and a very unequal geographical spread. Any spatial organisation structure of urbanisation that is regulated through the authority of government. Due to their fast geographical growth and significant economic advantages, national-level space organisations have evolved into goals for administrations across all tiers.[16] The nation's goal is to encourage urbanisation by establishing advanced technology areas across the country; as a result, urbanisation within China has evolved into a spatial method of manufacture. China's satellite industry has a diverse range of subjects, from huge state-owned enterprises to tiny, privately held startups. Some organisations, including CASC, CASIC, and its subsidiaries, participate in economic activities such as purchasing and selling items. Some commercial organisations, like CAS institutions, are not commercial firms.[17] The majority of commercial space enterprises in China are concentrated in a few cities and provinces. Beijing has the highest concentration of businesses with firm locations. Other important locations include Shenzhen, Wuhan, Shanghai, and Changsha. While firm offices are often located in a few cities, we discovered that many have offices and affiliates in other locations. Xi'an, Nanjing, Guangzhou, Chengdu, and Changchun are other major industry hubs with many production or research sites. Access to providers, factories, talent, clients (including government agencies), and discounted or free real estate in city-sponsored aviation or high-tech manufacturing areas.

- In the US, NASA is using its assets to help accelerate the space IT parks.[18] Its corporate personnel project, which promotes space goals at the Boeing Company, Space X, and Sierra Nevada Corp., is particularly successful. In anticipation seeking the following stage, named Commercial Crew Transportation Capability, the aerospace agency published an early demand for bids over every summers.[19] Striking capabilities among private players like the NewSpace Age's Henry Ford's sought to create an inexpensive spacecraft, Bigelow Aerospace intends to construct a flexible, commercially controlled and run space facility. Lightweight inflatable objects work past rockets' restricted cargo capacity by fitting a large habitat into a small container. NASA considered the concept for years. In reality, Bigelow's voluminous condos are based on the aerospace agency's trademarked TransHab, a robust, inflatable housing designed for use on Mars or the moon's surface.
- The Russian space and satellite industry is mostly state oriented, although this is likely to shift in coming years. Beginning with modest satellites to an elaborate lunar community, the Russian commercial space IT park has ambitious desires that may be cost advantageous under Putin's leadership. Moscow's transition to a free-market system in 1992 had little impact regarding the Russian aerospace field because the majority of entities were part of government run initiatives. However, entrepreneurial spirit did emerge when a couple of players formed enterprises to take on tiny contracts from government space corporation. Private businesses are currently constructing mini and cube satellites, lightweight rockets, and potentially Lunar homes with unparalleled backing offered by the Russian nodal space agency, Roscosmos, on space R&D, infra and tech.[20]

SPACE SECTOR REFORMS

The global space economy as per one estimate is currently valued at about USD 360 billion.[21] Despite being one among a few space-faring nations in the world, India accounts for only about 2 percent of the global space economy. In addition to establishing itself as a pioneer in external launch solutions, India is well-known for developing low-cost satellites and launch vehicles. With the documentation, made available to gather feedback from organisations and others, one of the key goals under PM Modi's leadership was to establish an industry-driven group that represents the sector's voice. This resulted to the founding of Indian Space Association (ISpA).[22] The changes provided a rich foundation for the emergence of several space start-ups, yet it failed to resolve their financial requirements. Although FDI policies hold a chance to alleviate this issue, it is inadequate on their own. India's contribution to the international space market is $8 billion, with government officials aiming for a five times growth by 2040.[23] To do this, the authorities will need to make greater investments. The new companies are split between both upstream and downstream activity. Upstream operations involve creating and maintaining different space-related assets.[24] These involve launchers, satellites, spacecrafts, and spaceports. These actions take some time and carry a possibility of disaster. They necessitate significant and persistent financial commitments.

Throughout the last twenty years, private industry has grown in importance across other space-faring nations as part of the international space market. Organisations such as SpaceX, Blue Origin, Virgin Galactic, and Arianespace have transformed the aerospace sector using breakthroughs and improved technology, lowering prices, and speeding up turnarounds. In India however, players within the private space industry have been limited to being vendors or suppliers to the government's space program. Thus, there was a need to provide opportunities for private industry for enhanced participation in Indian space programme and playing key roles to boost India's market share in global space economy.

Government of India took a major reform in June 2020 with announcement of opening of space sector to Non-Government Entities (NGEs). All parties involved have positively embraced these alterations, and India's space industry participants continues to thrive. Numerous Indian commercial enterprises and start-ups are exhibiting an intense fascination in space-related solutions and services. Thus, to provide a level playing field and favourable regulatory environment for players within the Indian private sector and to allow them to become independent actors in the space sector instead of being solely vendors or suppliers to the government program, Indian National Space Promotion and Authorisation Centre (IN-SPACe) has been created as the single window agency for promoting the NGEs in the recently carried out space sector reforms.

IN-SPACe role includes promoting, enabling, authorizing, and supervising the NGEs' various space activities, such as developing launch vehicles and satellites and offering space-based services, sharing existing space infrastructure and facilities under Department of Space (DoS)/ ISRO control, and enabling establishment of new space infrastructure and facilities.[25] The revision also intends to render the national space systems established over time accessible to be exploited by the commercial sector via a business-friendly framework. A framework had been developed in which enterprises can contact IN-SPACe to use ISRO resources. Space sector regulations would optimise the utilisation of space facilities including satellites and launch capability by establishing transparency among diverse players. Creation of new assets will be made contingent on confirmation of demand from user agencies.[26] In line of the proposed modifications, New Space India Limited (NSIL) would henceforth function as an authorised government-owned integrator for both the need and the production of commercial space-related resources and amenities like as image processing, connectivity, communications, transponder chips, launching solutions, and so on. Using its capacity as a market platform, NSIL will buy satellites, launch services, and additional assets created by ISRO or the business community. NSIL recently finished an exclusive commercial flight requiring controlled capacity to place 36 One Web satellites in LEO utilising the LMV3 rocket. IMS-1, an end-to-end satellite transportation system for generating 100 kilogramme class spacecraft is now accessible for adoption by NSIL. NSIL just revealed the planned launch of GSAT-20, a High Throughput Ka Band Satellite, aboard Star Link's recyclable Falcon-9 rocket in the second quarter of 2024. The choice was made in response to the tremendous demand for high-speed internet in distant locations, as well as marine and onboard transmission. One of the major breakthroughs in commercialisation is, PSLV productionisation through industry. HAL and L&T is part of the consortium to produce 5 numbers of PSLVs. To capture the small satellite launching market ISRO has developed Small Satellite Launch Vehicle (SSLV) with a view to transfer the technology to the industry, which was successfully tested recently.[27] Private space firms are coming up and striving to make India a hub for small satellite launches. The launch segment is becoming a key area for start-ups and Small and Medium Enterprises (SMEs) as they have developed a significant amount of competence in orbit management for LEO, MEO, and GEO satellite launches. The major private players in this industry are Skyroot Aerospace, Agnikul Cosmos, etc.[28]

ISRO has traditionally been catering to the growing demand for small satellites launches, but with opening of space sector, would offer great opportunity to private sector. Furthermore, the space parks will provide benefits to SMEs including start-ups by utilising common assets and amenities. Dhruva Space, Pixxel Space India Pvt Ltd, Bellatrix Aerospace, Manastu Space, and others are among the developing private sector firms. To foster the commercial usage of space tech, the "Space Remote Sensing Policy - 2020" seeks to encourage multiple stakeholders for actively engaging in satellite-based sensing activities. Accessible data and intel using space-based sensors will enable the development of knowledge-driven approaches to the country's multi-faceted approach in strategy and surveillance requirements. The norms of the policy are as follows:

- An Indian space asset for remote sensing data collection.
- An Indian base facility for tracking and controlling satellites.
- Uses space assets to disseminate remote sensing information throughout India.
- Remote sensing data/services for Indian territory using satellite assets.
- Use space-based remote sensing technologies for social, calculated, and study and production purposes.
- Ensure prompt and flexible regulatory environments.

The Space Communication Policy - 2020 aims to meet the country's growing need for space-based telecommunications while also developing appropriate tools for self-sufficiency in the domains of commercial, security, and social communications. The strategy promotes Indian firms as partners in accomplishing these aims.[29]

- Supervise and authorise the utilisation of space capabilities for transmission to and from Indian territory.
- Protect current space facilities and integrate new ones within operational supervision to enhance national space-based telecommunication capabilities.
- Increase industrial Indian market engagement in space-based interactions, both domestically and internationally.
- To develop and operate space-based communication equipment, the Indian corporate sector requires a rapid and adaptable legal structure.
- Expand space-based transmission solutions to address demands that Indian private enterprises cannot satisfy owing to national defence or financial constraints.

CHALLENGES FOR THE SPACE STARTUPS

The industrial sector's development presents technical problems and possible dangers to the outer space ecosystem. Massive clusters of orbiting satellites operate in an organised system and may have identical circular arrangements to competitors. MicroSats and CubeSats are increasingly being launched without propellers or successful monitoring capacities. Emerging uses, such as space assets improvement, on-orbit service, and corporate satellite terminals, may potentially fall under established legal systems. The space market is seeing an increase of freshly founded industrial and public organisations. New funding and talent supplied by the other businesses may challenge old procedures and practices. Requirement for preserving ecological priorities, including space junk removal and radio frequency cooperation. While some firms may engage in ethical business practices, their operations lack a consistent industry-wide pledge to uphold standards. To cope with the problems of shifting industries, legislation and market autonomy are necessary. Sustainability has become widespread in non-space businesses and certain space enterprises, potentially supporting sovereign efforts.

APPLICATIONS OF CSR IN THE SPACE PARKS

Overall, the space sector has proved lagging to incorporate Sustainability. The SatCom Industry Association (SIA) advises caution while encouraging responsible space operations, emphasising the importance of considering commercial and technological constraints.[30] A few the variables which have influenced the development of sustainability in other sectors are less widespread in the aerospace/space industry. Businesses focused on selling to customers are more inclined to incorporate corporate social responsibility into the way they operate than those focused on business-to-enterprise or business-to-government transactions, such as the space market. Further iteration of CSR in case of Space Parks can be demonstrated through SWOT Analysis as shown below:

Figure 1: SWOT Analysis of CSR in Space Parks

Strengths	Weaknesses
• Long term planning perspective that complements space industry timelines • In a traditionally risk adverse industry, CSR may enhance a risk mitigation approach • Increased public facing transparency	• Relationship to supply chain is clear but links to operations challenges is not • Short-term resource drain/diversion with potentially unclear operational impacts • Disconnect between large corporate CSR policies and space unit practices/ issues
Opportunities	**Threats**
• In some geographic regions, CSR can be a vehicle for attracting and sustaining talent • Sets the stage for dialogue on new regulatory issues • Links between CSR, Sustainable Development Goals and the benefit of space development to society • Relatively small size of space industry may ease widespread adoption of CSR	• Culturally, structural and maturity differences in space companies complicate industry wide adaptation of CSR principles • Limited competition means brand differentiation is not as impactful • The space environment is not [yet] linked to environmental sustainability, challenging the connection to CSR

Source: Secure World Foundation, & Well[31]

Implementing CSR-based initiatives at headquarters fosters an organisational culture that drives partnerships to address sustainability issues. It promotes collaboration among opponents to overcome mutual difficulties. Yet, corporate social responsibility fails to function as a commercial or tactical necessity for establishing industry-wide ethical standards. Implementation of CSR techniques is mainly driven on company objectives and effect at the organisation stage. Developing standards that correspond across sustainability can promote acquisition by ensuring alignment with company values and performance.

The ISpA recommends the following factors when developing Space Parks with CSR elements:[32]

- Fresh efforts ought to coincide with current SSA procedures and technology. They additionally ought to minimise cost obligations on satellite users.
- Future programmes ought to foster standards regarding the orbital protection instead of enforcing particular rules.
- Advocates for the integration of corporate objectives with innovation, as well as fostering a spirit of cooperation at the company scale through CSR techniques. The tenets of CSR will present an operational setting to encourage ethical conduct.

WAY FORWARD

Space-based connectivity is a key tool for bridging India's digital gap. Satellites' long range and speedy connection make them ideal for remote places where conventional connectivity is limited. As early July 2022, the nation's overall tele-density was 85.1 percent, with remote tele-density close to 58 percent. Using satellite connection in combination with a ground connection may dramatically increase connectivity. Excellent internet access is crucial for economic development and welfare worldwide, including in India. The use of satellites promotes digital inclusiveness by providing access to the internet. The Prime Minister's Office is developing a comprehensive strategy for satellite-based navigation systems in order to meet the growing demand for position, speed, and timestamp solutions for different fields. Establishing space parks around the nation is expected to benefit industries in the aerospace sector, particularly industry. This would attract international companies in the rocket industry and foster Indian space-tech enterprises. Currently, establishing upstream/downstream missions in space requires administrative permission from multiple departments, including DoS, DoT, and MoIB. Organisations may have a variety of objectives. Implementing an integrated clearance procedure via an umbrella organisation dedicated to the space economy will simplify the procedure of obtaining necessary permissions, making it easier to do commerce. TRAI recommends that authorities disclose an inventory of licenced foreign satellites whereby purchasers may acquire bandwidth. This will assist speed up the licencing procedure.

Space parks will offer a perfect environment for SMBs and entrepreneurs focusing on rocket components and sub-components. Space parks may greatly enhance constellation makers' unit profitability through pooled assets and amenities. Space parks can attract enterprises interested in satellite uses, in addition to satellite production. This will aid in developing fresh company cases for the downstream section and identifying possibilities for profit. The choice made by the government to let commercial firms access the Indian space environment is likely to stimulate space launching activity. The emergence of private businesses is going to assist the sector grow more profitable. Low-cost space launchers, along with large-scale manufacturing, are expected to drive global demand. Indian entrepreneurs want to capitalise on the aerospace sector with new technology.

To conclude, till recently ISRO was catering to both the R&D requirements for indigenous capability in space technologies, as well as space-based services requirements for both strategic and commercial users with its meagre resources. As a result, there was a huge gap in meeting aspirations of both strategic and commercial users in space-based services, and small contribution in India's economic growth. Like the IT sector which has grown leaps and bounds in last few decades, space sector reforms will unlock the potential of space in India's economic growth to become a developed country by 2050 as envisioned by our Honourable Prime Minister.

Ms Anamitra Banerjee is a Research Assistant with Centre for Joint Warfare Studies. Her specialisation entails West Asia and Arctic. She has contributed to multiple thinktanks and her publications have been featured under several journals and magazines.

NOTES

1. Ians. "Space Technology Parks Will Ensure 'Lift off' for the Indian Space Sector: ISpA." Defence Monitor, 15 February 2023. https://defencemonitor.in/space-technology-parks-will-ensure-lift-off-for-the-indian-space-sector-ispa/.
2. The Hindu Bureau. "ISpA Releases Concept Paper Outlining Plans for Space Technology Parks." The Hindu, 16 February 2023. https://www.thehindu.com/news/cities/bangalore/ispa-releases-concept-paper-outlining-plans-for-space-technology-parks/article66511954.ece.
3. "Atmanirbharata - Department of Space," n.d. https://www.isro.gov.in/Atmanirbhar/.
4. ET Bureau. "Indian Space Association Pitches for Incubation Centres in Space Technology Parks, Flags Challenges Faced." *The Economic Times*, 15 February 2023. https://economictimes.indiatimes.com/tech/startups/indian-space-association-pitches-for-incubation-centres-in-space-technology-parks-flags-challenges-faced-by-startups/articleshow/97953502.cms?from=mdr.
5. "Setting up of Space Technology Park and Museums," n.d. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1558441.
6. Dutta, Prabhash K. "India'S Nasa: Why Privatisation of Isro Is the Right Call." *India Today*, 25 June 2020. https://www.indiatoday.in/news-analysis/story/india-s-nasa-why-privatisation-of-isro-is-the-right-call-1692576-2020-06-25.
7. Correspondent, Special. "IN-SPACe to Be New Space Industry Regulator, Says ISRO Chief Sivan." The Hindu, June 25, 2020. https://www.thehindu.com/sci-tech/science/new-space-industry-body-inspace-to-be-in-place-in-3-6-months-ksivan/article31911841.ece.
8. Special Correspondent, "IN-SPACe to Be New Space Industry Regulator, Says ISRO Chief Sivan," The Hindu, 25 June 2020, https://www.thehindu.com/sci-tech/science/new-space-industry-body-inspace-to-be-in-place-in-3-6-months-ksivan/article31911841.ece.
9. Raju, Narasimha. "ISpA EY Report Highlights." CXOToday.com, 18 November, 2022. https://cxotoday.com/press-release/ispa-ey-report-highlights/.
10. AIPPI. "Exploring the Opportunities in Indian Space Sector," n.d. https://www.aippi.org/news/ascending-skies-exploring-the-opportunities-in-indian-space-sector/#:~:text=This%20rapid%20propulsion%20in%20investment,satellite%20components%2C%20launch%20facilitation%20services%2C.
11. Vishal Kumar Singh, "Why The Indian Space Agency Needs Privatization? Part-1," *Medium*, 15 December 2021, https://medium.com/@vishal.ks.iitg/why-the-indian-space-agency-needs-privatization-part-1-dc3b3a3bb9ca.

12. Rajagopalan, Rajeswari Pillai, Observer Research Foundation, and K Kasturirangan. *Space India 2.0*. Edited by Narayan Prasad, 2017. https://www.orfonline.org/wp-content/uploads/2017/02/ORF_Space-India-2.0_NEW-21Nov.pdf.
13. India Brand Equity Foundation. "Opening up New Opportunities in the Indian Space Sector | IBEF," n.d. https://www.ibef.org/blogs/opening-up-new-opportunities-in-the-indian-space-sector.
14. India, Hans, and Hans India. "The Hans India." *The Hans India*, 15 February 2023. https://www.thehansindia.com/technology/tech-news/space-technology-parks-will-ensure-lift-off-for-the-indian-space-sector-ispa-783080.
15. Singer, Jeffrey Lin and P.W. "China's Private Space Industry Prepares to Compete With Spacex and Blue Origin." Popular Science, 07 October 2016. https://www.popsci.com/chinas-private-space-industry-booms-prepares-to-compete-with-spacex-and-blue-origin/.
16. Asean, China Report. "Commercial Aerospace: The Next Launchpad for the Chinese Economy." *PR Newswire*, 06 March 2024. https://www.prnewswire.com/apac/news-releases/commercial-aerospace-the-next-launchpad-for-the-chinese-economy-302081190.html.
17. CGTN. "China's Private Space Companies: A Race for the Universe," 24 December 2021. https://news.cgtn.com/news/2021-12-24/China-s-private-space-companies-A-race-for-the-universe-16fCBj4ss9y/index.html.
18 Johnson, Kaitlyn. "The Private Sector's Assessment of U.S. Space Policy and Law - Aerospace Security." Aerospace Security, 13 December 2022. https://aerospace.csis.org/the-private-sectors-assessment-of-u-s-space-policy-and-law/.
19. Tran, Lina. "These 3 Companies Are the Future of Space Tourism - AFAR." AFAR Media, 11 October 2022. https://www.afar.com/magazine/these-companies-are-the-future-of-space-tourism.
20. Room the Space Journal of Asgardia. "Russian Business: A Long Road to the Stars for Private Space Initiative - Room: The Space Journal," n.d. https://room.eu.com/article/Russian_business_a_long_road_to_the_stars_for_private_space_initiative.
21. Singhal, Prashant. "The Dawn of the Space Economy in India," 04 November 2022. https://www.ey.com/en_in/aerospace-defense/the-dawn-of-the-space-economy-in-india#:~:text=Setting%2Dup%20space%20parks%20across,incubate%20spacetech%20companies%20in%20India.
22. *Indian Space Association (ISpA): India on the Move in Space Domain*. (21 December 2021). Centre for Land Warfare Studies. https://indianstrategicknowledgeonline.com/web/IB-319_Indian-Space-Association-ISpA.pdf
23. Mukul, P., & Aryan, A. (2021, October 13). Explained: Public-private partnership breaches space frontier. *The Indian Express*. https://indianexpress.com/article/explained/indian-space-association-narendra-modi-7565248/
24. *India in space Domain - Pathbreaking developments*. (n.d.). Vivekananda International Foundation. https://www.vifindia.org/brief/2021/october/29/India-in-Space-Domain-Pathbreaking-Developments
25. Prime Minister. (2022). *Commitment towards a reformed space sector on the path to Atmanirbhar Bharat* [Report]. https://www.isro.gov.in/media_isro/pdf/Publications/Vispdf/Pdf2017/space_reform_booklet_E.pdf
26. *Roles and responsibilities*. (n.d.). https://www.isro.gov.in/Responsibilities.html
27. *IN-SPACE - Indian National Space Promotion and Authorisation Centre - IN-SPACE*. (n.d.). https://www.inspace.gov.in/inspace

28. Prime Minister. (2022). *Commitment towards a reformed space sector on the path to Atmanirbhar Bharat* [Report]. https://www.isro.gov.in/media_isro/pdf/Publications/Vispdf/Pdf2017/space_reform_booklet_E.pdf
29. Government of India. (2020). Draft Spacecom Policy - 2020. In *Department of Space*. https://dipa.co.in/contentpdf/Department%20of%20Telecommunications/Spacecom%20Policy%202020%20and%20Spacecom%20NGP%202020-15-10-2020.pdf
30. *Reports & Publications - SatCom Industry Association (SIA-India)*. (n.d.). https://www.sia-india.com/category/reports-publications/
31. Christensen, I. A., Secure World Foundation, & Wells, R. (2016). *Applying corporate social responsibility principles in the space sector* (By Reinventing Space Conference & BIS-RS-2016-45). https://swfound.org/media/205652/rispace_applying_csr_principles_in_the_space_sector.pdf
32. *Mission DefSpace | ISPA Events*. (n.d.). ISpA Events. https://www.ispaevents.space/mission-defspace

192-205

MOSAIC WARFARE: SPACE AS ENABLER IN THE INDIAN CONTEXT

Lt Gen Karanbir Brar, AVSM

Abstract

Technological advancements in war fighting enables autonomous systems, Artificial Intelligence (AI); Machine Learning (ML) systems, real time ISR operational picture, precision strikes, etc to function across Multi Domain Operations (MDO). This is enabled due to net centricity or Net Cetric Warfare (NCW) which is a pre-requisite to operationally and functionally link all these technologically enabled systems. Shortfalls in NCW and are recommending a modification to NCW terming it as Mosaic Warfare. NCW works on a Kill Chain concept, where this kill chain can easily be disrupted with the cyber warfare; electronic warfare (EW) capabilities as also with targeted precision strikes. Hence, instead of a Kill Chain based OODA loop, Mosaic Warfare works on a Kill Web based OODA loop. Since it is 'Web', it enhances survivability.

Space being the common frontier over land, sea and air can act as an enabler and facilitator for implementing Mosaic concept. Thus, Indian Armed Forces can directly adopt tenets of Mosaic Warfare instead of first adopting NCW and then transforming to Mosaic Warfare. In previous wars, the units at tactical level operations alone sufficed for victory. However, in any future conflict especially on Northern borders, conflicts will be more in the non-contact domain and will reduce effectiveness of tactical level operations. Hence, it is imperative that our armed forces transform and adopt these

technological advances (AI, ML, autonomous systems, precision systems, etc) networking them in a Mosaic Concept – for which Space is an effective enabler.

INTRODUCTION

War fighting is being impacted due to the rapid technological advancements and is undergoing transformations, as evident from Russia-Ukraine and Israel-Hamas conflicts. This technological revolution enables autonomous systems, Artificial Intelligence (AI) & Machine Learning (ML) systems, real time ISR operational picture, precision strikes, etc to function across Multi Domain Operations (MDO). However, this is enabled due to **net centricity or *Net Cetric Warfare (NCW)*** which is a *pre-requisite to operationally and functionally link all these technologically enabled systems*. The Think Tanks of warfighting in USA have noticed some shortfalls in **NCW** and are *recommending a modification to NCW* terming it as Mosaic Warfare[1] - an ***improvement to*** **NCW**.

Mosaic Warfare is the latest buzzword in war fighting and is being discussed intensely in the concept and doctrine formulation in the USA.[2] Mosaic is basically a **command-and-control function**, an innovative approach to military command and control that employs a networked, distributed architecture to enhance flexibility, resilience and decision-making speed.

Applicability of Mosaic Warfare is across all domains i.e., Space, Cyber, Land, Sea and Air. Since, ***Space has the advantage of being the common frontier over land, sea & air; thus, it can act as an enabler and facilitator for implementing Mosaic concept which is now a war fighting imperative to link all technological systems. Thus, Indian Armed Forces can directly adopt tenets of Mosaic Warfare*** instead of first adopting NCW and then transforming to Mosaic Warfare. Mosaic Warfare is also referred as the *5th Generation Warfare* or *Kill Web strategy.*

Space is the next frontier and its immense potential is still untapped. To discern and define the future military concepts with respect to space, it is imperative that visualisation of how the space is going to manifest & transform is done correctly. As a reference to an analogy, "air power in WW I", was largely only a source for observation/surveillance, (akin to what space is/was some years ago) & air power since then has transformed manifolds. However, transformations in space would be more significant and disruptive owing to enhanced rapid technological advancements taking place. Therefore, *to capitalise on the intent to use Space as an enabler for Mosaic Warfare, decisions and affirmative actions have to be taken in time.*

TECHNOLOGY DRIVERS

In the commercial space as well as in the military domain, the technological advancements are becoming a big facilitator in enhancing efficiency all across human functional sphere. In the military space also, these technological drivers are facilitating better connectivity amongst various weapon systems and the sensors, so that the sensor to shooter link referred as the Observe-Orient-Decide-Act (OODA) loop is speeded up. The major technology drivers which will impact warfare in current and future scenarios are listed below, ***their usage needs to be defined in our concepts and doctrines***:

- Unmanned Systems – Aerial, Ground, Sea and Sub-surface.
- Artificial Intelligence (AI) & Machine Learning (ML) driving software applications and military equipment.
- Communications and connectivity.
- Space based systems – control of space.
- Cyber Warfare.
- Electromagnetic Spectrum – control & usage, Electronic Warfare (EW).

NETWORK CENTRIC WARFARE (NCW)

It is collaborative information sharing for optimum utilisation of available resources to enhance combat efficiency. Its implementation/execution is best with US Armed Forces, wherein they have common and integrated Tactics, Techniques, Procedures (TTPs) across their armed forces and they are networked. This technological advantage initially was seen in the Gulf

War in 1991, gave them an edge and has been a subject of much study by rival militaries especially China.

Net centricity would be sine qua non for current and future technology enabled environment.[3] In simplistic terms, net centricity can be considered analogous to internet, wherein it is the internet which has harnessed power of computing (computers) and has revolutionised every aspect of human development - global economy, business, transportation, banking, science, etc. In a standalone mode, computers have limited abilities. *Likewise inducting the force multipliers, unmanned systems, AI enabled system, etc into the armed forces would not achieve the desired outcomes if they are not networked & become a part of Net Centric Operations (NCO).* ***NCO is not about technology alone*** but more so pertains to methods and means to harness & synergise all information and resources for greater combat effectiveness. Technology acts as an enabler and assists in achieving this by ensuring communications, generating common operational picture and faster computation thus enabling Effect Based Operations (EBO).

In NCW, the decision-making is structured, control is centralised & command is hierarchical. *US think tanks and their foremost think tank on warfighting strategies & technology – Defence Advanced Research Projects Agency (DARPA) have recently wargamed*[4] *that in current or future war, based on their major adversary's counter capabilities (i.e., China and Russia), NCW architecture with a centralised control would be targeted by soft or kinetic kill and render them ineffective*. NCW works on a **Kill Chain** concept, where in all decisions, command, control, collation, and analysis is largely centralised at one point/ location. Thus, this *kill chain* can easily be disrupted with the cyber warfare & electronic warfare (EW) capabilities as also with targeted precision strikes. This will render their whole war fighting machinery ineffective and isolate their combat forces for piece meal destruction, even when having the best of the equipment. Herein comes the *Mosaic warfare concept which in actuality is a modification of the net centric warfare concept. And in the Indian context, in an adversity we will also face similar challenges; thus, it is an imperative to adopt the concept of Mosaic Warfare.*

Despite the recent misgivings of NCW, even in its existing form it still remains a work in progress in most militaries *including ours*. NCW is a necessity for effective combat efficiency, by ensuring connectivity, collaborating & sharing information (ISR), and shortening the OODA Loop.

MOSAIC WARFARE

Mosaic warfare is the latest concept over current net centric approach. Hence, instead of a *Kill Chain based OODA loop, Mosaic Warfare works on a Kill Web based OODA loop.* Since it is 'Web', it enhances survivability.

Mosaic Warfare is described as an innovative approach to military command and control that employs the network distributed architecture to enhance flexibility, resilience and decision-making speed. Key characteristics are as follows:

- Distributed architecture: decentralises decision making across multiple nodes, reducing vulnerability and enhancing operational resilience.
- Adaptability: rapidly adjust to changing operational environments and threats, enabling forces to respond with agility.
- Resilience: minimises single points of failure through redundancy, ensuring continuous operation even after attack.

Under the mosaic approach, air, cyber, land, sea and space domains will focus on operating in a more integrated framework. Advances in microelectronics and communications are making possible a degree of networked coordination and collaboration between different systems almost unimaginable just a few years ago. This, in turn, is enabling distributed system–of–systems architectures that will be more resilient to attack, less costly to develop and faster to upgrade when compared to today's *centralised expensive monolithic system*.

MULTI DOMAIN OPERATIONS (MDO)

MDO is not just conducting operations in all these domains separately, an actual MDO is when all domains collaborate and create effects as desired.

"Using dominance in one domain or many, blending a few capabilities or many, to produce multiple dilemmas for our adversaries in a way that will overwhelm them."

Thus, **Mosaic Warfare facilitates MDO**, wherein cross domain operations are possible. An example of ***distributed and linked cross domain operation*** for *a common operational/tactical action* where all domains are collaborating will be as follows:

- **Space**.
  - o Overhead ISR and data relay (Common Operational Picture).
  - o Navigation and timing.
  - o Beyond-line-of-sight communications.
- **Air**.
  - o Airborne ISR – aircraft and drones (High Altitude Long Endurance HALE, Medium Altitude Long Endurance MALE).
  - o Long Range Strikes – aircraft and autonomous systems.
- **Cyber and Electronic Warfare (EW)**.
  - o Integrated air defence system network monitoring.
  - o Cyber Attacks on enemy air defence/other systems.
  - o Jamming and spoofing – systems, drones etc.
  - o Deception - Insert false targets.
- **Land and Sea**.
  - o ISR – tactical battle area.
  - o Combat actions – domination, destruction and capture.
  - o Autonomous systems – swarm drones, drones, manned unmanned teaming MUM-T, etc.
  - o Long-range fires (ship/land based).

MOSAIC WARFARE FOCUS: LETHALITY & SURVIVABILITY

The various domains (largely Land, Sea, Air) work *in independent silos* spend too much time, money and effort in trying to ensure its weapons systems are more advanced than adversaries. However, the high cost and sometimes decades–long development timelines of new systems is unable to compete with the technological advancements, which can make new military systems obsolete before they are even delivered.

Mosaic Warfare propagates to focus on **lethality and survivability** with the ability to win *regardless of whose individual weapons system is the best*:

- **A fundamental way to achieve this survivability** is by distributing and disaggregating the sensors and weapons that today are tightly bound together and may not survive in an EW/Cyber environment. Disaggregation can take place by having multiple systems, incorporating autonomous systems like swarm drones (cheaper systems), cross domain operations (synergy of all domains), by deception, operational/tactical acumen, etc.
- **Lethality is achieved through aggregation of the disaggregated systems** through decision support systems which connects all weapons and sensors enabled through AI & ML to perform an Effects Based Operation (EBO).
- **Artificial Intelligence (AI) & Machine Learning (ML)**. *It is no good if machines think but humans do not.* With numerous sensors and weapons, if they are disaggregated, manually collating information and taking decision will not be feasible. AI and ML comes in to speed up this process and also automate many functions. The enabling role of Artificial Intelligence and Machine Learning is as follows:
  - o AI facilitates hardware/machines undertake intelligent functions. For e.g. in a swarm drone, the drones will interact with each other using AI and perform the tasks as given in an automated fashion *as one entity.*
  - o ML is a subfield of AI that concerns machines performing tasks without first receiving explicit instructions. Instead, the machine learns to perform the task from training data or through interactions with a simulation environment, like a machine trained to identify an adversary's tank from a data library will assist a drone in identifying the same practically in field.

BUILDING A MOSAIC C2 FRAMEWORK THROUGH SPACE

ISRO has produced remarkable results with indigenous efforts at extremely low costs. ISRO[5] has many cutting-edge technologies and expertise which can facilitate building the mosaic framework.

Compared to US, China our number of satellites for Space control (Space Situational Awareness-SSA and Space Domain Awareness-SDA) are less. Therefore, apart from the ISRO and governmental efforts, *the private sector has to step in for building a Mosaic C2 framework.*

Space Systems - Private Sector. The Indian private sector, *especially the startups have the requisite wherewithal to ensure space becomes an enabler*. This has happened due to reduced hardware costs, densification of electronic components, adoption of COTS components, etc. But *more importantly the HR talent exists within the country.* There are many in the private sector who have the capability but need the right support, financial surety and guidance (including from ISRO). Building this ecosystem is imperative in National interest.

Technology Enablers. Following technology enablers would be essential, which are well within the indigenous capability/industry realm provided the right eco system is created:

- **Ground Infrastructure**. We need ground infrastructure, which is both fixed and mobile. In fact, as part of mosaic framework, we need mmobile satellite data receiving antenna for deployment at the level of operational & tactical level for real time communication/data exchange.
- **Satellites**. For ease of proliferation, requirement is of smaller cheaper satellites ***with varying payloads as per operational requirement***, which may not have a long life. This is perfectly in order, as the technologies are changing rapidly, so we do not need large/complex and costly satellites which become outdated very fast. Lower–cost, less complex systems are easier to link in a vast number of ways to create desired, interwoven effects tailored to any scenario. In addition:

- o Another concept, which is gaining ground is of 'Software Defined Satellites' in which the software can be upgraded so that the satellite remains in tune with technology.
- o Deployment on Demand - Deploy on Demand concept envisages the availability in orbit of several small satellites suitably encased to be deployed on requirement for functions as desired.

- **Rockets**. The requirement would be to have launch on demand rockets with very short notice so that multiple launches can be undertaken in a shorter time frame.
- **Communication Links**. Intersatellite optical links, or laser crosslinks,[6] are poised to transform space communication by improving data transmissions speed and reliability. While widespread use of laser crosslinks direct data transmission between satellites could reduce reliance on ground stations. Ground network architectures will change, not go away.

In addition, optical communications are expected to play a critical role in supporting new Earth-observation technologies like 'Synthetic Aperture Radar (SAR)', a technology that enables organisations to send raw data to terrestrial applications in a highly secure manner.

- **Software and Applications**. Software and applications to be put on this space technology infrastructure is the most important aspect. These can be categorised into following major types:
  - o Functional Applications - Part of the hardware & functioning of the system viz, communications, positioning system, etc. Largely a product of the developer.
  - o Operational Applications - Applications required for conduct of military functioning i.e. ISR, generating common operational picture, data relays, etc. The User will be required to provide the 'use case' and define the 'problem statement' and also engage in the development process along with the developer.
  - o Mosaic C2 Applications – These would be complex applications using AI & ML viz. decision support systems, predictive analysis, etc.

User will have to be a proficient specialist to define the concept and then be part of or even lead the development process along with the developer.

As is evident the overall concept and use cases have to be driven by the military user and requires that kind of competency. *Private players are also capable of providing end-to-end solutions even in India similar to* 'Star Link' for communications, Mazar & Planet providing imagery/intelligence etc.

- **Security**. Security should be in design and not as an afterthought. Protection against cyber warfare, hardening against an electro-magnetic pulse and if feasible physical security should be built into every satellite from the ground up.

SPACE AS ENABLER FOR MOSAIC C2 IN INDIAN CONTEXT[7]

The Indian Armed Forces have acquitted themselves in a sterling manner warding off all security challenges both internal & external from the time of independence till date. All three services (Army, Navy & Air Force) have developed capabilities and have effective response mechanisms. However, the transition to net centricity/NCW, integration and jointness (theaterisation), cyber and space capabilities have not been at the desired pace. However, developing space capabilities with the right conceptual framework can help us leapfrog directly to Mosaic Warfare concept of warfare which can mitigate & tide over earlier anomalies. *Major aspects in this regard are highlighted below.*

- **Theaterisation**. Space as a frontier can overlap the various coordination functions (communications, ISR, etc) of the three services assist in greater jointness and integration lending to theaterisation functionality. Undertaking the same through terrestrial means is more cumbersome.
- **Communications**. Communications required in our terrain configurations from super high altitude to deserts has challenges. Space can serve as an alternate means for connectivity and provide redundancy.
- **Space also lends itself to execute cross domain operations**. Fundamentally, C2 modernisation efforts should be anchored in a clearly

defined strategy. The basis of the efforts should be the military's ability to effectively conduct synchronised MDO. The goal is enabling the warfighting effort to employ capabilities from different domains to meet a military objective.

- **MOSAIC C2**. Space also offers an opportunity wherein space/satellites can serve as a major area for dis-aggregation i.e., Mosaic C2. Managing space control, information in a Mosaic C2 environment enabled by effective ground infrastructure is highly feasible.
- **Kill Webs**. Mosaic C2 requires *decentralised functioning*. Smaller 'kill webs' based on space infrastructure in synch with ground elements can be conceptualised and then designed & produced based on terrain, operational requirements and the adversary. *It does not require the whole war fighting machinery to be networked to execute an operational action as in NCW*. A 'kill web' can have varying functionalities to assist the operational actions or decision-making process like surveillance over an area, tracking inimical elements (pirates/rebels in Arabian Sea), communication over inhospitable terrain, etc. Thus, especially in our context based on our terrain and other operational peculiarities designing kill webs for required tasks would be a force multiplier and game changer. Following systems inducted/planned to be inducted ideally describe the decentralised functioning of Mosaic Warfare C2:
  - **Swarm Drones**. A distributed area is surveyed by multiple unmanned aerial vehicles that should randomly search the space, collect information on unwanted objects classifying them as targets, and organise collective reaction on the emerging threats. They invigorate the local OODA loop without reference to the long hierarchical chain, as they have the ISR payloads, decision making and even means to destroy (no requirement of attack helicopter or air support). The Space can provide redundancy by providing it guidance link and communication and transmitting the operational action for info direct to the decision-making authority.

- o **High-Altitude Platform Station (HAPS)**. HAPS, a high-altitude platform station (HAPS,[8] which can also mean high-altitude pseudo-satellite or high-altitude platform systems) also known as atmospheric satellite is a long endurance, high altitude aircraft able to offer observation or communication services similarly to satellites. Mostly, unmanned aerial vehicles (UAVs), they remain aloft through atmospheric lift, either aerodynamic like airplanes or aerostatic like airships or balloons. Such systems will be re-usable, cheaper and difficult to locate and hence would greatly assist in the Mosaic concept for disaggregation.
- **OODA Loop**. The fastest means for information relay is turning out to be space. We live in a digital age in which commercial capabilities promise to dramatically shorten the OODA loop by collecting, processing, storing, and mining data and rapidly recommending actions based on those data. Given the increased complexity of MDO planning and the greater data requirements, space is an asset for this exploitation.

CONCLUSION

In the Indian Armed Forces, ***the units (which are the cutting edge) largely ensured victory*** in all our wars (1947-48, 1965, 1971 and even Kargil). Our lack of technology i.e., AI & ML, ISR collation, decision support systems, etc did not impact the results; *as our adversaries were in similar state* and *battles fought at tactical level sufficed*. However, now with our adversaries in collusion incorporating these technological advancements and networking them, conflicts will be more in the non-contact domain and will make tactical level operations less important. Hence, to ensure that our armed forces transform and adopt these technological advances (AI & ML, autonomous systems, precision systems, etc) networking them in a Mosaic Concept is imperative. Space will be an enabler in ensuring this.

Fruition of making a technologically enabled armed forces can take place only with the right eco system, where in there is a central decision-making body, with authority and resources which can synergise various agencies/ stakeholders involved in space, both governmental and private.

Efforts like Indian Space Congress-2023 & DEFSAT-2024 organised by SIA-India and other stakeholders will go a long way is assisting formulation of the right ecosystem by providing platform for discussion, raising awareness and collaborating efforts of all stakeholders including policy and decision-making authorities.

However, the greatest effort would be required in orientation, attitudinal change and training of the combat forces and the military leadership in such strategic & tectonic shift(s) in war fighting strategy. The task will become simpler if the higher echelons drive the change. It goes without saying that a current & future war requires the military leadership to be highly proficient in tech skills. The various training institutes need to orient their curriculum to address these challenges. The Russia-Ukraine and Israel-HAMAS conflicts and also recent challenges faced by us are a stark reminder for the urgency of the situation for need to adapt and transform.

Lt Gen Karanbir Brar, AVSM is currently GOC DBA. Technically and IT qualified, he has executed Light Tank,Swarm Drones and many niche technology projects. He is mentoring startups, other tech projects with regards to defence capability building in association with Academia, IITs, ISRO, DRDO, DPSUs and private industry.

NOTES

1. US Govt Accountability Office, Space Command and Control: Comprehensive Planning and Oversight Could Help DOD Acquire Critical Capabilities and Address Challenges, October 2019, Space Command and Control: Comprehensive Planning and Oversight Could Help DOD Acquire Critical Capabilities and Address Challenges | U.S. GAO
2. DARPA, Tiles Together a Vision of Mosaic Warfare, https://www.darpa.mil/work-with-us/darpa-tiles-together-a-vision-of-mosiac-warfare
3. Lt Gen KS Brar, (2023), "Transformations Required In Military Domain For Current & Future Conflicts", South Asia Defence & Strategic Review, 32-34
4. Talk/Panel discussion on Mosaic Warfare & Multi Domain Battle by Tim Grayson Director DARPA , mA, Strategic Technology Office, [Online: web], URL: https://youtu.be/33VAnIEjDgk?t=7

5. Lt Gen KS Brar explores collaborative opportunities at Vikram Sarabhai Space Centre, Pratham Gurung, March 2024, SSB Crack, https://www.ssbcrack.com/2024/03/lt-gen-ks-brar-explores-collaborative-opportunities-at-vikram-sarabhai-space-centre.html.
6. Carrasco-Casado, Alberto, and Ramon Mata-Calvo. 2020. "Free-space Optical Links for Space Communication Networks." In Springer Handbook of Optical Networks, by Springer, 1057–1103. https://arxiv.org/pdf/2012.13166.pdf.
7. Panel Discussion: Chair – Lt Gen PJS Pannu, Panel Speaker - Lt Gen KS Brar, Managing space control, information and Mosaic C2 enabled by effective ground infrastructure, Seminar & Exposition DEFSAT-2024, Manekshaw Centre 07-09 February 2024.
8. International Telecommunication Union (2022), "HAPS – High-altitude platform systems", HAPS – High-altitude platform systems. Accessed on 01 April 2024.

206-220

PROLIFERATION OF SATELLITES AND NEED FOR SPACE DOCTRINE

Brig Akhelesh Bhargava (Retd)

Abstract

The space technology is considered essential and an integral part of nation building. Nations are using space technology for military purposes besides peaceful ones. In recent years the focus of spacefaring nations has shifted to Low Earth Orbit where government-controlled space agencies and private players are deploying satellite mega-constellations. This aspect brings the owners at cross purpose as there is no legal framework to control or oppose rogue actions except a few treaties. So far total satellites in space are less than 10000 but within a decade the number may increase ten folds. This will lead to collision and consequent debris creation accidentally or when national interest is at stake, a satellite may be targeted using anti-satellite missile. The international legal framework needs to be strengthened to ensure that measures be put in place to minimise chances of debris creation, booking slots in space and ensuring a safe end of life termination of satellites. Therefore, there is a need to have an all-encompassing space doctrine in place. The space technology is considered essential and an integral part of nation building. Satellites are being used in many fields: communication, earth observation, navigation, space study, remote sensing, etc., all these are in domain of peaceful coexistence of humankind. However, nations are using space technology for military purpose to support functions like, reconnaissance, communication and navigation. This aspect brings them

at cross purpose as there is no legal framework to control or oppose these except a few treaties.

UNIQUENESS OF LOW EARTH ORBIT (LEO)[1]

Satellites are launched at different altitudes above the Earth. In last one decade, the focus for satellite launches has homed on to the LEO. The LEO altitude is below 2000 kilometres above the earth surface. Within LEO, lower the altitude, shorter is the life span of the satellite for a specific weight category. For a satellite to have a longer life, a good footprint (coverage) as well as have a reasonable low orbital period (90 to 120 minutes), the altitude is normally kept between 400 – 800 kilometres. There are presently thousands of operational satellites orbiting the Earth in LEO.

These satellites have to co-exist with millions of pieces of space debris. Space debris originates from defunct satellites, fragments of anti-satellites test, fragments of space objects, etc. These debris pieces are travelling at more than 7500 metre per second. As LEO becomes a congested space, the risk of collisions between and among objects increases exponentially, as well as the likelihood of an uncontrolled chain reaction of debris-generating events. A centimetre sized tiny fragment can cause tremendous damage to an operational satellite leading to critical disruption in provision of essential services.

For any satellite, with passage of time, the orbit tends to become shorter. In order to keep the satellite in their intended orbit over its life time, thrusters are used either to raise orbit or to maintain course. Thus, to ensure redundancy and a good coverage over complete earth, having a satellites constellation is the way out. This is because so many ‘defence related functions’ and ‘weapon systems control’ are dependent on inputs from satellites as in guided missiles, drones, surveillance, navigation, communication, etc.

PROLIFERATION OF SATELLITES IN LOW EARTH ORBIT (LEO)

A new trend has started of having satellite mega-constellation[2] in LEO. It is simply a set of satellites (hundreds or even thousands) which are linked to each other and capable of carrying out coordinated activity. At present there are a few thousand satellites but in coming years, this number is likely to grow exponentially. Virtually all countries in this business are not adhering to the international protocols on space usage as due to entry of private players – no one is able to regulate their activities.

Normally, Satellites and satellites related activities have been a domain of government-controlled space agencies. The whole dynamics of satellites industry has changed. The number of satellites planned for launch is enormous, driven primarily by private company's motivation to earn profits. The major players are SpaceX, G60 Starlink, One Web, and others.

Elon Musk, privately owned and controlled American aerospace company **SpaceX**[3] is operating **Starlink** – a satellite internet constellation. The SpaceX has satellite research, development, manufacturing and orbit control facilities. SpaceX started launching Starlink satellites in 2019. The number of functional satellites in LEO has more than doubled since then, due to the advent of mega-constellations. As of early January 2024, Starlink consists of over 5,289 mass-produced small satellites, operating in LEO. It is providing internet services to over 70 countries and has started providing global mobile broadband too. SpaceX plans to deploy nearly 12,000 satellites and over a period extend to an astronomical 42,000 satellites. At behest of United States Department of Defence, Starlink has played a crucial role in the Russian-Ukraine war by providing internet data services for surveillance, communication and real-time intelligence sharing. Starshield, a military version of Starlink, is designed for United States government use.

Unlike SpaceX, China's started the **G60 Starlink**[4] project in 2016, with the backing of Shanghai municipal government. The LEO based satellite mega-constellation is planned as a competition to SpaceX Starlink. The first satellite was produced by Gesi Aerospace Technology, Shanghai a state-owned company (established in 2022) towards end December 2023. The constellation will provide broadband internet services with an ultimate aim to explore potential in space technology. By end 2024, it plans to launch and operate 108 satellites and provide commercial services. The capacity will be increased to 300 satellites annually for a target of 1300 satellites in phase 1.

China has increased its efforts to foster the commercial satellite market to counter United States. Along with the G60 Starlink 12000 satellites project, a second Guo Wang national network of 13000 satellites project is under construction. The G60 mega-constellation is a vital link in the aerospace information industry. It includes an industrial chain related to satellites, data application services, artificial intelligence and deep learning. The captured data will be applied to transport, energy, communications and the military after being analysed by ground-based big data analytics.

In Indian context, Bharti Airtel has bought a stake in **Eutelsat One Web.**[5] Eutelsat One Web launched its first 6 satellites in February 2019 but soon entered bankruptcy in March 2020 due to lack of capital. The company reorganised in November 2020 with a new ownership group. As of 2021, Indian multinational company Bharti Global (21.2 percent), France-based Eutelsat (13.6 percent) and the Government of the United Kingdom (10.9 percent) were the company's largest shareholders, while Japan's SoftBank retained an equity holding of 10.9 percent. One Web constellation plans to have 648 satellites of which 544 have been launched by January 2023. This constellation was placed at an altitude of 1200 km with satellites having longer life and fuel being earmarked separately for terminal phase. On 28 September 2023, Eutelsat and One Web were formerly merged.

Other companies such as Amazon and Planet are also planning their own satellite mega-constellations. Post the Indian government decision to permit satellite manufacture and launches by private companies to enlarge base, some companies[6] have entered into satellite related businesses. These include:

- **Dhruva Space.**[7] Founded in 2012, Dhruva are satellite experts to include satellite platforms, launch solutions, and orbital deployment, as well as providers of ground services.
- **Bellatrix Aerospace.**[8] The company founded in 2015, focusses on satellite and rocket propulsion and orbital manoeuvring. It also experimented

its Hall effect thruster – an engine using an electric field for propulsion, required for anti-collision manoeuvre. It is presently concentrating on orbital transfer vehicle (OTV).

- **Agnikul Cosmos.**[9] Agnikul was founded in 2016 for manufacturing rockets that can fly payloads from 25 to 100 kg, powered by four to seven engines. The company is also planning to have mobile launch pads. Its Agnite engines, will be completely 3D-printed. Agnikul has an MoU with DOS, for access to ISRO infrastructure.
- **Skyroot Aerospace.**[10] Established in 2018, Skyroot became the first company to partner with ISRO when the agency allowed access to its facilities and expertise towards the development and testing of subsystems and systems of satellite launch vehicles (SLV). It specialises in launch vehicles (LV) and cost-efficient, non-reusable rockets to launch small satellites. It launched Vikram-S, the first privately manufactured Indian rocket in November 2022.
- **Pixxel.**[11] Founded in 2018, Pixxel specialises in small, 15-kgs satellites capture images in hyperspectral frequencies, allowing analysis 'in 100s of wavelengths rather than 10s of wavelengths as done normally.' This makes it capable of identifying vegetation patterns, emissions, and ore deposits in up to five-meter resolution. After launch of few satellites, Pixxel's plans to have larger constellations of around 24 satellites.

RISK MITIGATION DUE TO SATELLITE DEBRIS

LEO crowding is changing the nature of the space environment. There's growing attention to the potential downsides, including an increased risk of collisions that could end up littering LEO with dangerous debris and rendering it unusable. To ensure that the LEO is kept 'clean' of decaying satellite debris, two methods may be used. Either push the satellite into a lower orbit where it burns out due to Earth's atmosphere or pushed out above LEO into a graveyard orbit. In both cases, certain reserve of fuel has to be maintained.

As the number of satellites in LEO keeps increasing, the chances of collision will also become greater. Monitoring [12] of space objects is an essential component for continual assessment of the space situation and devising appropriate mitigation strategies for space asset protection. To prevent satellite collision, autonomous and accurate tracking has to be ensured. Each satellite has to be designed to have thrusters as an anti-collision measure, to maneuver the satellite away from the path of the colliding satellite. Precision control of satellite will be required. Every satellite mega-constellation needs to be designed beforehand ensuring vertical spacing with other constellation, is adequate, such that no collision takes place. Artificial Intelligence (AI) may be used to ensure altitude differentiation for collision avoidance.

So far there are no rules for how to avoid collisions in orbit, disposal of dead satellites, reduction of space debris and the like. International body has to lay down global policy and guidelines and enforce them strictly. The liability clause, when one satellite collides with another has to be defined without ambiguity.

EXPANDING THE SCOPE IN SPACE BY INDIA

Since the beginning of 2017, Indian Space and Research Organisation (ISRO) has been a newsmaker with series of upgraded and more powerful launch vehicles and more capable multi-purpose satellites. On 15 February 2017, it launched 104 satellites in a single mission, on 05 June 2017, it launched most powerful launch rocket, on 14 November 2018, India launched the heaviest satellite (GSAT 29) and later built the heaviest in December 2018 (GSAT 11). India launched Chandrayan 3 on 14 July 2023, and is slated to launch Mangalyaan 2 in 2024. India's Bharati Airtel is going in a big way of adopting One-Web satellite service on lines of Elon Musk Star-link services, and same commenced with effect from November 2023.

NEED FOR SPACE DOCTRINE

There is a high possibility of nations, either directly or indirectly, interfering in the strategic needs of the other countries resulting in their 'National

Interest' being compromised. A space-faring nation like India therefore, would like to secure its interests. So far as per international guidelines, it is first come first served basis in respect of use of orbital slots and radio frequencies. As the number of satellites being launched is increasing by the day, a fight for 'my right' is likely to commence in near future. With mega-constellation being deployed by, possibility of same increases manifolds. The space utilisation in LEO, by Russia, China and India, has great overlaps. Each one may hurt other's interest sooner than later. The other two had their Anti Satellite (ASAT) Missile in place. To protect India's interest, in times to come, an ASAT missile became the need of the hour. The ASAT Missile test '**Mission Shakti**',[13] **codenamed 'Project XSV-1',** was conducted on March 27, 2019 at around 1130 AM IST. Post 'Shakti', India too is in the same league as Russia and China (as also USA which has presently the largest number of satellites).

It is time that India spells out its Space Policy. How should the policy take shape and what should be its ingredients? It should be all encompassing, involving all agencies, from 'makers (policy, hardware, software) to users' and be available in open domain in parts/full for obvious reasons.

Space for Peace. India has maintained that space should be a frontier for peace and should not be militarised. The following has been clarified in no uncertain terms:

- India's space program is rapidly growing which has further accelerated rather rapidly in the last decade. India has presently about 108 active satellites consisting of communication, earth observation, navigation, experimental, apart from satellites meant for scientific research and exploration. New satellites are planned to be launched at a faster pace. India's space program is a critical backbone of India's security, economic and social infrastructure.
- India has no intention of entering into an arms race in outer space. It has always maintained that space must be used only for peaceful purposes. It is against the weaponisation of Outer Space and supports international efforts to reinforce the safety and security of space-based assets.

- India believes that Outer space is the common heritage of humankind and it is the responsibility of all space-faring nations to preserve and promote the benefits flowing from advances made in space technology and its applications for all.
- India is a party to all the major international treaties relating to Outer Space.
- The ASAT missile test was not directed against any country. India's space capabilities neither threaten any country nor are they directed against anyone.
- Simultaneously, the government is committed to ensuring the country's national security interests and is alert to threats from emerging technologies. The capability achieved through the Anti-Satellite missile test provides credible deterrence against threats to our growing space-based assets from long range missiles, and proliferation in the types and numbers of missiles.

FORMULATION OF SPACE POLICY

The agencies involved in making of each component (of satellite, missile, radar, etc) are many and each needs to be taken on board. The answer to, 'Who all will be involved in preparing doctrine' will fall out of, 'who all made the Anti-Satellite mission successful' and who the 'end user' will be in future. Is there a need for a separate Space Command or the Strategic Forces Command (SFC) will suffice and be made responsible. Since, a large number of International Treaties, to which India is a signatory, are involved and have to be taken care of from time to time, who all from the civil domain (read Department of Space including a legal team) should also be made part of it.

INDIAN SPACE POLICY 2023[14]

The Indian Space Policy was formulated and disseminated in 2023. Basically, it defines the way Government of India (GoI) post 2020, has embarked upon allowing Non-Governmental Entities (NGEs),[15] to participate in space domain and the overall role of Indian Space Research Organisation (ISRO)[16] and Department of Space (DoS).[17] It has defined the creation of Indian National Space Promotion and Authorisation Centre (IN-SPACe)[18] as an autonomous Governmental organisation and its role in laying down the rules and guidelines for various entities working in space sector. However, few aspects should be clarified as private participation increases:

- Audit of activities carried out by NGEs on quarterly/half yearly/yearly basis.
- Rules and guidelines for NGEs when dealing directly with other nation space related agencies on subjects which may be detrimental to own 'National Interests.'
- At no point, NGEs activities should be objectionable to armed forces.
- Sharing of sub-meter resolution images be termed as restricted and sub 30 centimeter be termed as confidential (or as decided).
- Earmark clearly no coverage zone or 'black out' areas over areas of national interest.
- It does not cater of anti-satellite missile and offensive action that needs be initiated in case of clash of interest.

Therefore, there is a requirement of groups/bodies which need to align with both the satellites for peaceful mission and the offensive actions. The following committee/groups are recommended as given in succeeding paragraphs.

THE CORE COMMITTEE (OR APEX BODY)

This should include Prime Minister, Cabinet Committee on Security, National Security Advisor (NSA), three Chiefs, Commander Strategic Forces Command (SFC), Commander, Strategic/Defence Space Command,[19] and the heads of DOS, ISRO and Defence Research and Design Organisation (DRDO). The body should lay down the broad framework for the Space related issues to include:

- Define India's national interest in space.

- State the strategic relationship in space domain with neighbors and in international forums.
- Lay both offensive and defensive guidelines for India's stance on various space related issues in international forums.
- Lay aim and guidelines and ratify space related research and development in fields of launch vehicles, satellite capability, ASAT capability, electronic warfare, cyber warfare, etc.
- Ratify and revisit the treaties which India is signatory to.
- Decide the budgetary support for the smooth growth of space-based applications.
- Lay guidelines for space related education and promotion of research and capability development.
- Since the private sector have been given a green signal to launch satellites, therefore lay guidelines for joint public-private collaboration or pure private participation in the field of satellites and space.

THE PLANNING GROUP

This Group should comprise the heads of DOS, ISRO, DRDO and Commander, SFC/Space Command. Besides, a legal team dealing with the international treaties and United Nation resolutions on space. The body should be responsible for Space related issues to include:

- Propose and/or define minimum and credible deterrence in space domain.
- Propose and suggests changes and/or modifications in the existing policies to Core Committee.
- Propose space cooperation among friendly nations and support United Nations backed development in space domain for benefit of human kind.
- Coordinate the activities of the various stakeholders viz ISRO, DRDO, Manufacturers, SFC/Space Command, etc.
- Monitor the progress of various agencies of the Space Commission in respective fields.
- Lay guidelines for establishing a Space Technology and Research University with core being provided by ISRO and DRDO. It should include

verticals such as satellite, launch vehicles, radar and radar systems, missile and missile systems, laser weapons, metallurgy, electronic warfare, cyber warfare, artificial intelligence, international space legal laws, etc.

- Lay guidelines for military training including space intelligence and surveillance.
- Lay guidelines for indigenous development and for involvement of private industry in the space program and selective or complete outsourcing for components/sub-systems/systems manufacture.

THE WORKING GROUPS

A number of working groups need to be established. Each should have a well-defined role. Within each working group, each member's role should also be defined. The dual responsibility for a specific issue should be avoided to eliminate confusion. The following working groups should be formed:

- **Working Group 1 – Satellite Operations.** This should include representatives of DOS, ISRO, DRDO, DPSUs, NGEs and Space policy related legal experts. The group should be responsible for the following:
  - o **Planning and proposing launches.** This focuses on launching of all types of satellites including:
    - **Communication**: INSAT and GSAT.
    - **Earth Observation Satellite**: RESOURCESAT, CARTOSAT, RISAT, OCEANSAT, SARAL and SCATSAT, INSAT, etc.
    - **Space Science and Exploration**: Astrosat, Mangalyan, Chandrayan.
    - **Navigation Satellite**: IRNSS, GAGAN (GPS Aided GEO Augmented Navigation).
    - **Experimental Satellites**: Remote Sensing, Atmospheric Studies, Payload Development, Orbit Controls, recovery technology etc.
    - **Small Satellites**: Indian Mini Satellites.
    - University/Academic Institute Satellites.
  - o **Debris.** Ensure debris management from the 'dead' satellites.

- o **Commercial.** Identification of data for commercial purpose including marketing to friendly foreign countries through Antrix Corporation.
- o **Legal**. Understanding all United Nations General Assembly (UNGA) resolutions, their implications and understanding space related treaties. The legal team should be well versed with following:
  - **UN Resolutions** such as Committee on the Peaceful Uses of Outer Space (COPUOS) of 1959, and 'No First Placement of Weapons on Outer Space' vide UNGA resolution 69/32 dated 02 December 2014.
  - **Treaties** such as Prevention of Arms Race in Outer Space (PAROS), Outer Space Treaty, Inter Agency Space Debris Coordination (IADC), etc.
  - **Space Use** Legal issues related to space such as first use of a specified orbit, radio frequency/s, etc.

- **Working Group 2 – Missile and Radar Manufacture and Operations.** This should include representatives of various DRDO establishments, SFC/Space Command, the Defence Forces, DPSUs and NGEs. It would continuously assess 'National Interest' based on directives as given by the core committee. The group should be responsible for the following:
  - o Planning and monitoring of various missile and radar manufacture.
  - o Upgrade and integrate various technologies and remain abreast with latest development in respective fields.
  - o Electronic and cyber warfare inclusion and adaptation of electronic and cyber warfare in all equipment.
  - o Co-opting of DPSUs and Private Industry would include Bharat Electronics Limited (BEL), Bharat Dynamics Limited (BDL), Electronic Research and Design Establishment (LRDE), Tata Power, Bharat Forge, Skyroot Aerospace, Dhruva Space, etc.
  - o Establishment of a Space Command Post (SCP) and a 24x7 surveillance of critical Space over India and selective space on as required basis.
  - o Manning of ASAT missile stations as well as other strategic missile for a K-kill of hostile ground stations.

  - o Ground Protection of Assets lay down standard operating procedures (SOPs) for protection of space related establishment including training of quick reaction teams (QRTs) against terrorist threat and security force for first layer ground defence.
- **Training.** This should include reps of all stake holders and heads of faculty of various departments of Space University. The group should be responsible for the following:
  - o Involvement of all DRDO laboratories and DPSUs in aiding training with a long-term perspective.
  - o Deciding on syllabus and courses keeping in mind the future requirement. Involving selected private universities/colleges to run courses based on prescribed syllabus.
  - o Establishment of a library including a repository of past history on space research and historic data.
  - o Be responsible for the effective functioning of the space university.

SPACE FOR MILITARY

The dual use nature of space technology enables its utilisation for security purposes too. In the last few decades, military campaigns have demonstrated the significance of space technology for military purposes. The use of outer space for military support functions like reconnaissance, communication and navigation have received global acceptability since such usage does not directly violate any existing international legal regime. The ASAT missile brings to fore, the assertion of nation state will, to allow/disallow the use of Space over its geographical boundary. The free use of space for navigation, reconnaissance, intelligence (spying), so far has been relentless and at freewill. Now it may not be so. The owner countries of satellites, in LEO, will have to inform (and may have to seek permission) to fly over-head, least it be declared as hostile action and shot down. Possibilities in form of carrying out electronic and cyber warfare against such satellites also exist. With advent and advancement of direct energy weapons (DEW) and laser guns, a day is not far when these too will form part of nation inventory in ASAT role. Thus, from the geostrategic view, space may form part of foreign policy tool.

CONCLUSION

The lack of coordinated and effective global policy, regulation and oversight among spacefaring nations and space actors has led to the prospect of hundreds of thousands of satellites planned for launch in the coming decade. It is imperative for all responsible space faring nation and private players to limit the creation of space debris by conforming to space debris mitigation guidelines. Towards this goal, space object observation capabilities need to be enhanced through the establishment of necessary infrastructure.

A space-faring country like India needs to ensure that its interests in respect of orbital slots, radio frequency spectrum, etc., are protected. The rapidly changing global space order could also give rise to newer challenges. Given all this, it is important that India formulates an effective policy to secure its interests in space.

Brig Akhelesh Bhargava (Retd) was commissioned in Army Air Defence in 1983. He commanded his Unit in Western Sector and Brigade in Eastern Sector. He has been President of a Services Selection Board (SSB). His articles have been published in Centre for Land Warfare Studies (CLAWS) on varied subjects to include Satellites, Anti-Satellite Missile, Electronic Warfare, 5G, Nano Technology, etc. He has contributed to books published by CLAWS. He also provides training for SSB.

NOTES

1. Low earth orbit: Definition, theory and facts by Andrew May, 31 May 2022, https://www.space.com/low-earth-orbit
2. The Future of Communication: Satellite Mega-Constellations published in Cyfirma, 29 December 2023. URL: https://www.cyfirma.com/blogs/the-future-of-communication-satellite-mega-constellations/
3. Tech Target: Starlink by Kinza Yaser, https://www.techtarget.com/whatis/definition/Starlink. Assessed on 22 March 2024.

4. China ups the ante in bid to rival SpaceX's Starlink as G60 mega-constellationsatellite rolls off the production line in Shanghai by Mia Nulimaimaiti dated Dec 28, 2023, https://www.scmp.com/economy/china-economy/article/3246544/china-ups-ante-bid-rival-spacexs-starlink-g60-megaconstellation-satellite-rolls-production-line. Assessed on 20 March 2024.
5. OneWeb satellite company launches into new era by Jonathan Amos dated 18 December 2020, https://www.bbc.com/news/science-environment-55365434. Assessed on 20 March 2024.
6. Top Private Space Companies in India & Industry Landscape by Julia Seibert, 12 July 2023, https://spaceimpulse.com/2023/07/12/private-space-companies-in-india/. Assessed on 20 March 2024.
7. Ibid.
8. Ibid.
9. Ibid.
10. Ibid.
11. Ibid.
12. The Satellite Boom that Threatens to Clog the Skies by Wada Roush dated 07 April 2020 in MIT Technology Review, https://www.technologyreview.com/2020/04/07/998555/podcast-the-satellite-boom-that-threatens-to-clog-the-skies/. Assessed on 19 March 2024.
13. India Joins Big League: 'Shakti' Pradarshan by Brig Akhelesh Bhargava, 27 March 2020 in CLAWS Issue Brief, https://www.claws.in/india-joins-big-league-shakti-pradarshan/
14. India Space Policy 2023, https://www.isro.gov.in/media_isro/pdf/IndianSpacePolicy2023.pdf. Assessed on 30 March 2024.
15. Ibid.
16. Ibid.
17. Ibid.
18. Ibid.
19. Agencies take shape for Special Operations, Space, Cyber War by Rajat Pande in Times of India dated 16 May 2019, https://timesofindia.indiatimes.com/india/india-begins-setting-up-new-tri-service-agencies-to-handle-special-operations-space-and-cyberspace/articleshow/69346012.cms. Assessed on 30 March 2024.

221-238

EXPLORING INDIA'S SPACE DIPLOMACY: AN ANALYSIS

Dr Ulupi Borah

Abstract
The paper purports to critically examine how space diplomacy has become a significant tool of India's foreign policy and how it can open new vistas to maximise its interests globally. In its recent successful landing on the moon, India has gained the leverage to hold a significant position in the global space community. ISRO's collaboration with the space agencies of the space faring nations such as US, Japan, Russia, France etc. enables India to have access to cutting edge technology and sharing of information. However, there are a few areas where India needs to take significant initiatives to expand its space diplomacy. This paper has delved into those gaps and challenges, and made an effort to discuss how innovation in technology in this domain would enable India to create a niche position in the world.

INTRODUCTION

A country's national interest could be maximised by initiating foreign policies which involve its strategic decision. To secure these interests, there are few aspects such as advancement in science and technology, especially in terms of space, shipbuilding and communications, which play a crucial role. Since independence, India has been looking to enhance its socio-economic growth which eventually led to the establishment of an organisation like the Indian Space Research Organisation (ISRO). ISRO has been successful in enhancing India's self-reliance in technology, including its economic and international stature.

At this point, it is also important to observe how space diplomacy can play a crucial role in enhancing space technology, especially to commence international diplomatic ties. The integration of knowledge, invention and regulation among nations for improved space application and coexistence is known as space diplomacy. India's space diplomacy is not a recent development. It enabled India to boost its bargaining capacity, as seen when India managed to launch its first satellite by Russia in return for port access. Today, space is viewed as a domain which has the ability to deal with various global issues. At 'DEFSAT', a conference on space held in New Delhi on February 2024, the Chief of Defence Staff of India, General Anil Chauhan, mentioned that space today has become the final frontier. It is huge, vast and remains unexplored. This domain has the ability to open new vistas of economy and could be linked to the future of mankind. Space diplomacy encourages international cooperation to utilise space resources for the Earth's expanding population amidst constraints on space exploration.

India's space diplomacy has developed throughout time. It has been capable of establishing a commercial route for the private space industry in addition to working with other foreign partners. Even though several legislative reforms are still needed to boost private sector engagement, India has become one of the most durable international actors in the space domain.

INDIA-US SPACE COLLABORATION

Apart from getting closer and sharing common interests in the Indo-Pacific, India and the U.S. have enhanced their friendship to include more activities in space. On June 2023, India became the 27th nation to join the Artemis Accord, an initiative led by the US to commence space exploration and cooperation. The accord aims to establish certain norms and principles for peaceful exploration of the Moon, Mars and beyond. However, these principles are non-binding in nature. Apart from the conventional partners of the US like Australia, Japan and Europe, the accord has been able to attract other signatories such as Saudi Arabia, UAE, Nigeria and now India. During PM Modi's visit to the US, the leaders of both the democracies announced a framework in human spaceflight together in cooperation between NASA and ISRO.[1]

In addition, Washington has also acknowledged the significance of maintaining a continuous and consistent space diplomacy with Artemis signatories. The State Department unveiled its 'Strategic Framework for Space Policy', a strategy to broaden and synchronise diplomatic endeavours with space policy objectives. Among the suggestions are to form two working groups centred on deconfliction and developing partners, and to utilise the accords "as a convening function to help shape discussion around the global governance of space exploration." Furthermore, the leaders expressed their joy at the NASA-ISRO Synthetic Aperture Radar (NISAR) satellite being delivered to ISRO's U.R. Rao Satellite Centre in Bengaluru, and expected the launch of NISAR from India in 2024.[2] Although, the next frontier in geopolitics and diplomacy is space, but unlike the Indo-Pacific, it is uncharted territory devoid of an international order or set of legally binding regulations. This is why it is expected that embracing the Artemis Accords widely and promptly would be crucial.

The joint statement of 2023 between the two countries emphasised on working together on critical and emerging technologies. During their first meeting, U.S. National Security Advisor Jake Sullivan and his Indian counterpart Ajit Doval started the initiative on Critical and Emerging Technology (iCET), where space remains as one of the most significant technology areas in which both the countries are looking forward to collaborate.[3]

In addition, New Delhi and Washington also urged for further economic cooperation between the American and Indian corporate sectors through the value chain of space economy. Although India's wager on this vision represents a significant step towards the adoption of these tenets globally, space diplomacy is still desperately needed.[4]

INDIA-EUROPEAN UNION SPACE ENDEAVOURS

Considering its strategic interests, EU has initiated tools which would enable it to take upon the role of a significant player in the space domain. The Earth observation component of the European Union's space mission is called Copernicus. It promotes international cooperation through its free, full, and open data policy in addition to its capacity to address global issues. Copernicus services, which were created especially to satisfy user needs, provide near-real-time data at the local, regional, and worldwide levels. It has already offered services to deal with disaster issues to countries like Australia, Belize and also to our northern adversary Pakistan.

However, in terms of using and sharing data, India remains a significant partner for EU apart from United States, Australia, Brazil, Colombia, Chile etc.[5]

India has already commenced its Earth Observation Programme with the support from Department of Space (DOS) of India and ISRO. This eventually encouraged the European Commission and India's DOS to ink a Cooperation Agreement on March 2018, which would provide mutual access to the data from the Indian Earth observation satellites and the European Union's Sentinel series of satellites.[6]

INDIA'S COLLABORATION WITH FRANCE ON SPACE

India's endeavours on space research with France dates back to the 1960s. France's role was considered very crucial in supporting India's Rohini Rocket Program. In 1998, both the countries elevated their relationship by launching the 'Indo-French Strategic Partnership' which marked the start of a new phase in space cooperation.[7] On January 2024, both the countries inked the historic 'Defence Space Agreement'. Such an agreement commences the launching of both defensive and offensive capability equipped military satellites. President Macron and Prime Minister Modi reaffirmed their commitment to enhance their space exploration and research activities. This would mostly involve innovation of technologies, launch of payloads and put more emphasis on design and production. In addition, creating connections between the start-ups and the users are of utmost significance, which the recent agreement has focused on. Both the leaders also gave their consent for the 'Letter of Intent on Defence Space Cooperation' which would endeavour to engage in more and more joint initiatives between 'Centre National d'Études Spatiales (CNES)' and 'ISRO'.[8]

In addition, analysts opine that such initiatives are commenced by concerns related to China. The country's space activities might have acute implications for the global balance of power on space. The 'India-France Defence Space Agreement', could partially be a response to such activities on the space frontier.

INDIA-RUSSIA SPACE ENDEAVOURS

Following the Gaganyaan mission, both India and Russia aspire to work together on various space projects. Moscow offered the Indian Air Force pilots with training bases which remained one of the most successful experiences. Both the countries have already commenced the setting up of ground stations within each others borders. This is mostly done keeping in mind their respective satellite navigation systems such as GLONASS (Russia's system) and NavIC (India's system). It is expected that such initiatives will enhance the accuracy of the satellite navigation especially for civilian use. India is also making an effort to make few parts for GLONASS.[9]

Furthermore, there are new opportunities opening up for space cooperation between the two countries. Zeus TEM (Transportation and Energy Module), a deep space mobility platform developed by Russia's national space agency, is one of them. It has the potential to drastically change the global trajectory of human space exploration and open up new opportunities for space cooperation between India and Russia. Historically, the space objects launched by the Soviet Union in the 70s and 80s were propelled by thermoelectric nuclear-powered engines. They were mostly used for surveillance purposes and lasted for a short period of time. However, the post-Soviet era emphasised on deep space exploration. To support that, NUKLON Space Complex was created by Roscosmos making Zeus, the nuclear powered space tug, the key component of NUKLON. Although Zeus is not the first nuclear-powered spacecraft, it has special capabilities such as, if launched once it can be in space for several years, making it more efficient than the other spacecraft which use liquid or solid fuel.

In the above backdrop, it is beneficial that New Delhi deepen its space collaboration with Moscow.[10]

In 2021, both the countries inked an agreement and promised to enhance their cooperation especially in the human spaceflight programme. The joint statement between Moscow and New Delhi emphasised on a cooperation between the Russian State Space Corporation 'Roscosmos' and the Indian Space Research Organisation (ISRO).

Four Indian astronauts have already undergone generic space flight training in Russia as part of the Gaganyaan programme, India's first manned space flight mission.[11] Furthermore, both the parties wanted to improve collaboration within the 'UN Committee on the Peaceful Uses of Outer Space' (UN COPUOS), particularly with regard to concerns about the long-term sustainability of space operations.

INDIA-JAPAN SPACE COLLABORATION

India and Japan have exhibited their friendship in the space domain since long back. Japan has hosted several annual meetings of the Asia-Pacific Regional Space Agency Forum (APRSAF) where Japan Aerospace Exploration Agency (JAXA) fostered space cooperation, space diplomacy and sharing of technological advancements. India joined APRSAF in 1992, where both the countries aspire to utilise space technology for their socio-economic development. In addition, both Tokyo and New Delhi played a significant role in execution of the Sentinel Asia Project which was advocated for the first time in 2005.

In 2019, both the countries held their first 'Japan-India Space Dialogue' meeting in New Delhi and the second meeting was held virtually in November 2021. These dialogue meetings made efforts to have a clear understanding of the space policies for both the sides. Through these dialogues, JAXA and

ISRO plan to exchange information on critical areas including space assets, space industries etc. The leaders held discussions on the Global Navigation Satellite Systems (GNSS), which are crucial for disaster management and SSA.[12]

On May 2023, when the four leaders of QUAD met in Hiroshima, space continued to be a major topic of conversation. Commercial space cooperation, space situational awareness including sharing information on climate change were deemed pivotal areas which required collaboration from all the four QUAD members.

In order to initiate good paying jobs, the leaders realised the growth of the space sector, which would also enhance the space supply chains. The QUAD members are also aware of space traffic management, and fostered sustainability of the outer space environment in the QUAD summit of 2023.[13]

Meanwhile Washington and Tokyo are cooperating on a long list of space initiatives. The level of collaboration between Tokyo and New Delhi does not appear as extensive as it is between Washington and Tokyo. On January 2023, the two spacefaring nations inked a framework agreement which would be the base of their joint human space exploration effort.

Through such agreements NASA and JAXA aim to send humans back to the moon by 2025, creating a long-term presence there to support deep space exploration and Mars missions.[14] Although New Delhi and Tokyo plan to jointly hunt for water in the lunar south pole in 2025, there are several factors which cannot match up to the Tokyo-Washington partnership.

INDIA-AUSTRALIA STRENGTHENING SPACE INITIATIVES

Australia and India have a lot of potential to work together to further their respective interests in space. It is believed that countering commercial and military competition by collaboration is the best course of action in the current times. In order to support India's Gaganyaan human spaceflight missions, the Australian Space Agency and the Indian Space Research Organisation have established a base station in the Cocos Islands of Australia. They are also involved in joint technological development. Cassandra Steer, in the

Australian Strategic Policy Institute, mentioned in September 2023, that with $20.69 million in funding over four years, Australia's International Space Investment (ISI) initiative seeks to collaborate with industrial partners and researchers in India and Australia.[15] The majority of space activities have dual uses, thus there are direct security benefits even if the Fund's primary goal is civil space cooperation. Furthermore, Australia has a long tradition of space domain awareness, developing laser communication mostly to support the military needs. Meanwhile, India possesses an exceptional capacity for rocket launches, as seen by its successful landing on the moon in 2023. These are the aspects that India and Australia should complement and collaborate on with each other.[16]

CHALLENGES IN ELEVATING INDIA'S SPACE DIPLOMACY

- Linguistic and cultural barriers remain between Indian and Japanese space industry professionals.
- COVID-19 pandemic severely impacted the trade collaborations across the globe and the space industries were not spared. Space diplomacy and scientific developments were hindered due to lack of coordination as a result of travel restrictions. Many Japanese engineers and scientists couldn't work further on collaborative projects. This has highly impacted the India-Japan space endeavours.[17]
- Japan has high regards for India's advancement in technology, especially the skilled manpower in the space domain. Despite that, the collaboration between the Japanese and the Indian space professionals is quite challenging when compared with the Americans and the Japanese collaborations.
- JAXA has several collaborative projects with the Southeast Asian countries, especially Thailand. Comparatively, India's space collaboration with Japan, despite being a technology giant, is very limited. According to Hirokazu Mori, a space business consultant from Japan, there is a lack of cash flow between the two countries which has constrained the growth between the space industries of the two countries. He also added that both

Japan and Thailand stand on an equal footing in terms of investment and exchange of geospatial information. This reciprocity is missing in India-Japan space cooperation. Therefore, although Tokyo and New Delhi has the ability to surpass space engagements with Japan and Southeast Asia, the lack of financial flow remains a barrier between the two countries.[18]

- Within QUAD, both India and Japan have different strengths. Japan is good at manufacturing small spacecrafts and has been successful in initiating space exploration missions like Hayabusa. Meanwhile, India has been able to exhibit its space prowess through its successful Chandrayaan mission. But in the current times, Japan has been facing economic limitations, while India is a country with a growing GDP along with technological advancement which is necessary for space endeavours. Mr Mori opines that if both the countries can combine their forces, they could do great in the realm of exploratory missions. Meanwhile, another member of QUAD, the US, is ahead of everyone else in terms of Earth observation and satellite communication. It is crucial for Tokyo and New Delhi to also find such niche areas where they can lead in the space domain at a global level.[19]
- The space industries in India are closely related to the government, especially in terms of fund allocation. When compared with other space faring nations including Japan, the allocation of funds in India is not transparent. Mr Mori mentions that the procurement processes like Requests for Information (RFI) and Requests for Proposals (RFP) are more straightforward and simpler in Japan. In addition, the industries in India cannot easily be a part of government funds or projects.[20]
- Since the 1990, the European government started collaborating with China, especially on space technology. In 2003, the "Joint Sino-European Satellite Navigation Cooperation Centre" was opened in Beijing. And later, they developed the Galileo, Europe's global navigation satellite system. China also promised to invest millions of dollars in space technology to make it one of the most important non-EU partners in terms of space

technology. The EU has already developed a relationship of trust with China and terms of the civilian use of space.[21]

- New Delhi's collaboration with Moscow on space, especially on the Zeus Project, might have an impact on India-US space cooperation. This might constraint India's access to significant American space technologies including commercial space activities, human spaceflight, etc.
- Russia's closeness towards China has already been a concern in the international community. India needs to exercise caution to ensure that the US and its allies do not view its cooperation as a space weapon that could lead to the implementation of sanctions.
- When compared with Russia-China space cooperation, India's cooperation with Russia is not that close and aligned. Russia has already collaborated with China on major space aspects including the creation of an 'International Lunar Research Station' (ILRS) and aims to increase the time of robotic and human presence on the Moon. They also look forward to initiating a joint mission to both Mars and the Moon. Meanwhile, India's space engagement with Russia is limited to specific projects. This could involve training Indian astronauts in missions such as the Gaganyaan.[22] In addition, India has space collaboration with other countries including the US, France, Australia, etc. This could probably limit India's scope to deepen cooperation with Russia, considering it has alternative space partners.
- Space radar capabilities have become a key feature for AUKUS Pillar II, despite nuclear powered submarines remaining as the major pillar for AUKUS. Strengthening Space Domain Agreement (SDA) networks became a crucial aspect to respond to the increased investment in space capabilities by China and Russia. In order to strengthen its space data access, the US has been actively building networks with its allies, signing over 170 non-binding agreements with different governments, businesses, academic institutions and non-governmental organisations.[23] However, India is not a party to such multilateral space partnerships. This could definitely limit India's access to cutting edge technology. Furthermore,

India might not be able to play a proactive role in the space domain if it doesn't participate in such a regional space multilateral endeavour.[24]

RECOMMENDATIONS

- India should make efforts to be a part of or develop stronger connections with multilateral space cooperation. This is mostly in the context of AUKUS Pillar II, which emphasises developing space capabilities. Such initiatives will enable India to become a part of SDA data sharing and enhance its space capabilities.
- Mr Mori added that there is also a lack of participation in the Indian Space Conferences by the Japanese Government officials and similarly, the presence of Indian officials or space professionals present in Japanese space events is very limited. Furthermore, there should be more participation of young minds in such events. However, bureaucratic red-tapism could be a barrier in promoting the young generation to foster innovation and collaboration in this field.[25]
- Although there exists a comprehensive partnership agreement between India and Japan, there lacks a full-fledged or a long term plan which could include detailed plans like 'a five year plan' or 'a ten year plan'. On the contrary, Tokyo has such detailed plans with Washington, making their relationship stronger and deeper in this domain. With India, the relationship is still limited to a few projects. It is necessary that India and Japan make proper plans for cooperation and promise to stick to those plans and make them successful.
- It is important to facilitate better collaboration between space industries and the government so that it can extend its space diplomacy with the foreign nations later.
- Today, India's success, especially after the successful landing on the moon, has gained global inspiration and attention. This has enabled India to achieve a higher position in the space club and emerge as a voice of the Global South. India can definitely utilise this as a means to explore and meet India's space diplomacy ambitions. In the space club,

India's ambitions should be to enhance its strategic partnership in deep space exploration and space technologies, which includes bridging its gaps in sectors of satellite manufacturing, space exploration technology, cutting edge technology like propulsion system, simulation of avionics & aerodynamic of system exposed to vagaries of space.[26]

- Sharing of data and infrastructure with like-minded countries is vital for India's space diplomacy. Japan and Russia could share its space data with India and in return, India could share its physical spare infrastructure and cost effective manufacturing capacities with them.
- Futuristic Mission Capabilities like human space flights, International Space Station and interplanetary human missions could be the focus areas for India to expand its space diplomacy.
- India's space achievement enables it to explore its space diplomacy in the Global South. A few initiatives like 'UNispace Nanosatellite Assembly & Training by ISRO' (UNNATI) makes an effort to educate young scientists from the Global South in space sciences.[27] India would also commence the creation of data portals specifically for Pacific region countries that are fifteen times smaller. This data portal is expected to bring in a definite change in these countries. A few visible advantages will be the prediction of an early warning water management system, urban space management and fishing. Although these would have the ability to bring direct impact in the Global South, their proper execution and implementation is of great salience to achieve the interests and the objectives.
- Countries like the US, Russia and France have advanced space programmes whereas other friendly countries like Japan & Australia are emerging space tech powers. India can collaborate with these powers in the following areas to enhance its indigenous space technology capabilities:
    - o Transfer of Technology (ToT) in Specific Areas: Indian space programme has certain gaps which could be filled through ToT, especially in terms of advanced satellite technology, telescope,

communication units, deep space exploration capabilities and human space flight expertise.[28]

- o Capability Building: This can be done by joint satellite missions, sharing of expertise and infrastructure, building a pool of skilled workforce capable of leading indigenous space mission, etc.
- o Sharing of Resources: Due to geographic layout, sharing of assets is very important. It enables round the clock connectivity. Thus sharing of such resources is significant.
- o Establish favourable regulating framework & policies that promote India's interests.
- o Learning from best practices of the space agencies of these countries.
- o Ongoing and desired cooperation is as given below:

Table 1.

Current	**Desired**
Russia • Gaganyaan manned space mission in space station	• Inter Lunar Research station • Fuel technology • Upstream capabilities
US • INDUS - X • Two projects already launched under this initiative. • Sharing of space situational awareness data. • Sharing of high precious non-military data • Artemis programme • Lunar Base	• SSA • Launch Vehicle • Space fit management (Classified Information and unclassified contexts) • Downstream application • Analytical capability
France • Structural and organisational challenges experienced in defence capabilities	

Source: Online interview with Lt Gen Karambir Brar, 28 February 2024

- To extend its space diplomacy, development of indigenous technology is salient for India. These are the following areas where India can focus on:
  - o Global tracking & data relay space.
  - o Inter satellite link communication.
  - o Reusable launch vehicles.
  - o Multiple payload satellite for ISR with global reach.
- In the QUAD grouping, all members are space powers, with the US being the most developed one and others being emerging ones. The unique geographical location of these countries makes it very conducive for them to share resources for the benefit of the world. Some of them are discussed in the following points:
  - o QUAD as a framework for use of space: QUAD can be used for norm setting and rulemaking to ensure transparency, non-proliferation & peaceful use of outer space.
  - o Technology cooperation: Technology cooperation amongst QUAD members especially in development of capabilities in the field of space law. The four QUAD members should emphasise on information sharing, which would enable them to expand their space diplomacy with each other.
  - o Establishment of Earth station in Australia: An Earth station in Australia could be of great significance considering its unique location in the Southern Hemisphere. Furthermore, Australia offers the opportunity for location of Earth station for enhanced visibility, connectivity & SSA, radar and telescope capabilities.
  - o Information sharing and confidence building: Information sharing and confidence building measures like notification mechanism, crisis communication channels, etc. need to be established.
  - o Regional organisations and multilateral forums: Engagements of regional organisations and multilateral forums for collaborative approach to space governance is very significant.
  - o Co-operation in space debris mitigation, cyber security & resilience of space system & infrastructure.

  - o Satellite communication, navigation, climate monitoring & environmental protection are certain areas where the QUAD members can jointly act on.
- Artemis Accords have strategic implications. They presently have western overtones and countries like China & Russia do not agree with these. India signed these Accords in June 2023, and firmly put its weight behind these US led initiatives. Although the basis of the Accords lies in the United Nations Treaty on Outer Space of 1967, and the principle seems to be benign, it should be noted that its signatories, except the US, Australia, Japan & India, have limited space capabilities. There are anticipations that in the future it might form an alliance amongst these four countries for sharing space resources.[29] India can play an important role in the group by actively engaging with all partner countries and focusing on the following:
  - o Transparent and inclusive space governance.
  - o Confidence building measures, to avoid any confrontations in space.
  - o Sustainable use of space resources.[30]
- Despite their difficult relationship, India and China collaborated on global issues such as climate change. In the present times, space is considered as one of the most significant frontiers and China being a significant seafaring nation could play a crucial role in terms of formulating conventions and laws, especially when it comes to governing the space. In this context it is vital that India should collaborate with such nations in development of international space laws. Furthermore, Beijing and New Delhi could launch space exploration projects that are both widely recognised and viable.

CONCLUSION

India's space endeavours with spacefaring nations such as the US, France, Japan, Australia and Russia have enabled it to become a significant member of the space community. India now has space aspirations that extend beyond its borders and prioritises peaceful exploration in order to achieve sustainability and other benefits for civilian use on a worldwide scale. However, India's space diplomacy compared to Russia-China, US-Japan or US-Europe remains limited. This is mostly due to technological disparities, limited financial flow and various other factors. But currently India's initiatives such as *Atmanirbharta*, emphasisng on indigenously built technologies, utilising frameworks such as the QUAD and other initiatives taken by ISRO could give India the leverage to utilise this final frontier and advance its space diplomacy.

Dr Ulupi Borah is a Senior Fellow at the Centre for Joint Warfare Studies (CENJOWS). Previously, Dr Borah served as an Assistant Professor at the Rashtriya Raksha University, Gandhinagar. Her expertise lies in the Indo-Pacific region, particularly Japan's security polices and availed the prestigious JASSO scholarship offered by the Japanese government in 2019. Dr Borah is also researching on Europe and the new security issues, post completion of a course at the Geneva Centre for Security Policy, Switzerland.

NOTES

1. Alex Dubin (2023), "India embraces America's vision for outer space", The Hill, https://thehill.com/opinion/international/4147887-india-embraces-americas-vision-for-outer-space/. Accessed on 12 January 2024.
2. The White House 2023, "Joint Statement from the United States and India", Government of the United States if America, URL: https://www.whitehouse.gov/briefing-room/statements-releases/2023/06/22/joint-statement-from-the-united-states-and-india/. Accessed on 12 January 2024.
3. Rajeshwari Pillai Rajagopalan (2023), "India-US Space Cooperation Gets a New Fillip", The Diplomat, https://thediplomat.com/2023/09/india-us-space-cooperation-gets-a-new-fillip/#:~:text=The%20India%2DU.S.%20joint%20statement,be%20hosted%20by%20India%20in. Accessed on 08 January 2024.
4. Alex Dubin (2023), "India embraces America's vision for outer space", The Hill, https://thehill.com/opinion/international/4147887-india-embraces-americas-vision-for-outer-space/. Accessed on 12 January 2024.
5. Copernicus (2024), "OBSERVER: Shaping EU Space Diplomacy with Copernicus", Programme of the European Union, https://www.copernicus.eu/en/news/news/observer-shaping-eu-space-diplomacy-copernicus. Accessed on 02 January 2024.
6. European Union (2018), "European Commission and Department of Space of India signed historic Cooperation Arrangement to share satellite Earth Observation data", https://www.eeas.europa.eu/node/41583_en. Accessed on 02 January 2024.

7. AK Bhatt & Frederic Parisot, (2023), "Forging a new frontier: India-France collaboration in the evolving space sector", Economic Times Satcom, https://telecom.economictimes.indiatimes.com/news/portal-in-portal/satcom/blogs/forging-a-new-frontier-india-france-collaboration-in-the-evolving-space-sector/104392482. Accessed on 14 January 2024.
8. Shishir Gupta (2024), "India, France sign pact to jointly develop, launch military satellites", Hindustan Times, https://www.hindustantimes.com/india-news/indiafrance-to-mutually-launch-military-satellites-101706406900408.html. Accessed on 30 January 2024.
9. Aditya Pareek and Andrey Gubin, "2021", "India-Russia Space cooperation: A Way Forward", Takshashila Institution, https://static1.squarespace.com/static/618a55c4cb03246776b68559/t/622866005041cb42e02390f5/1646814722652/India-Russia-Space-Cooperation-A-Way-Forward.pdf. Accessed on 12 January 2024.
10. Ibid.
11. The Economic Times, (2021), "Russia India Sign Pact to Deepen Cooperation", https://economictimes.indiatimes.com/news/science/india-russia-sign-pact-to-deepen-space-cooperation/articleshow/88130854.cms?from=mdr. Accessed on 02 January 2024.
12. Ministry of Foreign Affairs, (2021), "The Second Meeting of the Japan-India Space Dialogue", Government of Japan, https://www.mofa.go.jp/press/release/press3e_000264.html. Accessed on 22 February 2024.
13. The White House (2023), "QUAD Leader's Summit Fact Sheet", The Statements, https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/20/quad-leaders-summit-fact-sheet/. Accessed on 22 February 2024.
14. Gabriel Dominguez, (2023), "US Japan lay foundation for New era of joint space exploration", The Japan Times, https://www.japantimes.co.jp/news/2023/01/18/national/us-japan-space-cooperation/. Accessed on 22 February 2024.
15. Cassandra Steer (2023), "The untapped potential of Australia–India defence space cooperation", ASPI The Strategist, https://www.aspistrategist.org.au/the-untapped-potential-of-australia-india-defence-space-cooperation/#:~:text=Australia%20already%20has%20space%20data,security%20interests%20in%20the%20region. Accessed on 13 February 2024.
16. Ibid.
17. Hirokazu Mori, (2024), Online Interview, 20 February 2024.
18. Ibid.
19. Ibid.
20. Ibid.
21. Commission of the European Communities, (2003), "Commission Policy Paper for Transmission to The Council and The European Parliament: A Maturing Partnership-Shared Interests and Challenges in EU-China relations", https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2003:0533:FIN:EN:PDF. Accessed on 22 February 2024.
22. Mike Wall, (2022), "Not just Artemis: China and Russia plan to put boots on the moon, too", https://www.space.com/china-russia-moon-base-ilrs. Accessed on 22 February 2024.
23. Rebecca Connolly, (2024), "Space surveillance and AUKUS: The power of awareness", The Interpreter, https://www.lowyinstitute.org/the-interpreter/space-surveillance-aukus-power-awareness#:~:text=Following%20the%20December%20meeting%20of,hypersonic%20weapons%2C%20drones%20and%20cyber). Accessed on 12 March 2024.

24. Ibid.
25. Hirokazu Mori, (2024), Online Interview, 20 February 2024.
26. Lt Gen Karambir Brar (2024), Online Interview, 28 February 2024.
27. ISRO (2023), "UNispace Nanosatellite Assembly & Training by ISRO (UNNATI)", Government of India, https://www.isro.gov.in/UNNATI.html. Accessed on 19 February 2024.
28. Lt Gen Karambir Brar (2024), Online Interview, 28 February 2024.
29. Ibid.
30. Ibid.

239-255

COMPREHENDING LEGAL ASPECTS OF OUTER SPACE

Col Vijay Narayan Shukla, VSM &
Ms Arijita Sinha Roy

"We live on the shores of this tiny world, the third planet of nine, circling an average star, the Sun, which is just amongst billions in a great city of stars, the Milky Way, which itself is among a billion other stellar cities stretching on perhaps forever. The Universe is more vast than all imagining and filled with wonders more than we can dream, is a heritage for all mankind."[1]

Abstract

Outer Space activities have largely been governed by international treaties and conventions that were products influenced by Cold War geopolitical tensions. Space has emerged as a frontier posing both opportunities and threats. The growing militarisation and colonisation of space and space assets makes it detrimental to comprehend and understand existing laws, treaties and conventions. Further, the entry of commercial and private players further intensifies the call for regulatory framework concerning activities related to outer space. India, as a responsible and emerging space influence lacks a comprehensive national law addressing modalities related to space programmes and activities. This paper is an attempt to re-visit and comprehend the international treaties related to Outer Space and also analyse Space laws in the Indian context. Additionally, the paper will

also critically examine the present gaps in the legislation and outlines a suggestive framework for the adoption of a comprehensive Indian national space laws.

INTRODUCTION

Space has evolved as the next and the final frontier. Exploration driven by curiosity have pushed countries to pursue strategies enabling them to use space as force multipliers and power projections. Presently, space is plagued by several concerns from debris management to militarisation of space by countries. The launch of 'Sputnik' at the fulcrum of the Cold War was another significant indicator of how space was used as a tool of power projections. When Neil Armstrong planted his foot, almost 50 years back, the world was swept by awe and admiration. But today, the development of space has changed and become even more challenging, primarily for two reasons; one, the dynamics of geopolitics is pushing countries to go beyond low-Earth orbit and two, the intervention of private players that are changing the space games.[2] The two combined reveals how space has evolved to exist as an "uniquely hostile environment."

The term 'space' is used in many different ways. Each use of the term can have very different legal implications.[3] Neither treaties nor most laws define exactly where the atmosphere ends and space begins. For commercial purposes, there are three areas in space: the Earth's atmosphere, the edge of outer space and achieving orbit. The law regarding the atmosphere is clearly defined - nations have sovereignty over the air above their country. Through treaty agreements, no nation can claim sovereignty in outer space. The area in between remains undefined in law.[4] Additionally, the position of existing international law concerning jurisdiction and sovereignty remains clear. The Outer Space Treaty, 1967 has largely defined that states can be held accountable for only "objects and people" belonging to the state; *"rationeinstrumenti and ratione personae"* but cannot have any claim of sovereignty.[5]

The Cold War era gave rise to global space governance, as only two countries, the US and the USSR, had access to launch capability and spaceflight. Furthermore, the core of the international framework for space governance is formed by the five main UN space treaties and are "products of their respective eras", particularly dealing with averting militarisation and colonisation of space.[6] In 2015, the US passed the contentious 'Commercial Space Launch Competitiveness Act'[7] allowing the US Space firms to "own and sell natural resources" and further mine from bodies in space which may include asteroids. The act allows private players to engage in space explorations without any regulation. The act is a full-frontal assault on established concepts of space law, which are predicated on two fundamental ideas: states' rights to conduct scientific research on space and its celestial bodies and the prohibition of unrestricted, unilateral commercial use of space resources. In January 2007, China showcased its destructive Anti-Satellite Weapons (ASAT) capabilities, followed by India in 2019. Notwithstanding the US unilateral moratorium on ASAT testing, Russia tested ASAT capabilities in 2021.[9] [10]

Global Space Governance is becoming a norm. The international space laws are typically categorised into binding normative instruments and non-binding agreements that may be voluntary and non-normative too. These two types of agreements largely work in tandem to make up the global space governance framework that exists today.[11] The International space law is an outcome of numerous multinational treaties, agreements, conventions, legal precedents and in certain cases application of customary international law.

THE OUTER SPACE TREATY OF 1967

According to existing international law, "all states are free to explore and use outer space, including the moon and other celestial bodies, on a basis of equality". This also includes the right to unrestricted access to all areas of celestial bodies and the freedom to conduct scientific research in space.[12] Further, these are not subject to national appropriation by claim of sovereignty, by means of use of occupation or by any other means.[13] The same is applicable even to the states "who are not a party to this Treaty, because of United Nations General Assembly Resolution, 1962 (XVIII) entitled 'Declaration of Legal Principles Governing the Activities of States in Exploration and Use of Outer Space', which was adopted unanimously by the United Nations General Assembly in December 1963."

State parties to the treaty are prohibited from orbiting any weaponry including nuclear weapons around the Earth, from installing such weapons on celestial bodies and from stationing any weapons in space.[14] The moon and other celestial bodies are to be used exclusively for peaceful purposes. The establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military manoeuvres on celestial bodies is forbidden.[15] In the event of any accident, emergency landing or distress call on the territory of another state party or on the high seas, the astronauts must be considered as "mankind's envoys" in space and must be swiftly and safely returned to the state where the spacecraft is registered.[16] State parties to the treaty need to bear international responsibility for national activities in outer space.[17] Each such party that "launches or procures the launching of an object into outer space, including the moon and other celestial bodies and from whose territory or facility an object is launched is internationally liable for damage to another state party or to its natural or juridical persons by such object or its component parts on the earth, in air space, in outer space including the moon and other celestial bodies".[18] The jurisdiction and control over the object launched into outer space and over any personnel thereof, while in outer space or on a celestial body is to be retained by the state party on whose registry the object was launched into outer space.[19]

THE AGREEMENT ON THE RESCUE OF ASTRONAUTS, THE RETURN OF ASTRONAUTS AND THE RETURN OF OBJECTS LAUNCHED INTO OUTER SPACE 1967

This Agreement entered into force in December 1968 and provides "each contracting party which receives information or discovers that the personnel of a space craft have suffered accident or are experiencing conditions of distress or have made an emergency/unintended landing in territory under its jurisdiction/on the high seas/in any other place not under the jurisdiction of any state, needs to notify the launching authority or if it cannot identify and immediately communicate with the launching authority, immediately make a public announcement and also notify the Secretary General of the United Nations, who needs to disseminate the information without delay."[20]

If a spacecraft's crew members land in a territory under a contracting party's jurisdiction due to an accident, distress, emergency, or unintentional landing, that party must act quickly to rescue the crew members, provide all required assistance, and notify the UN Secretary General and the launching authority of the actions it is taking.[21] In such situations, if such personnel are found on the high seas or in any other place not under the jurisdiction of any state, they need to be safely and promptly returned to the representative of the launching authority.[22]

THE CONVENTION ON INTERNATIONAL LIABILITY FOR DAMAGE CAUSED BY SPACE OBJECTS, 1971

This Convention entered into force in September 1972 and makes "a launching state absolutely liable to pay compensation for damage caused by the space object on the surface of the earth or to aircraft in flight."[23] In the event of damage being caused elsewhere, the liability is only if the damage is due to its fault or the fault of persons to whom it is responsible.[24] The Convention provides for the establishment of a Claims Commission in case there is no settlement between the state, which suffers damage and the launching state.[25]

THE CONVENTION ON REGISTRATION OF OBJECTS LAUNCHED INTO OUTER SPACE, 1974

This Convention was adopted by the UN General Assembly on 12 November 1974 and provides that when a space object is launched into earth orbit or beyond, the launching state needs to register the space object by an entry in an appropriate registry, which it will maintain and inform the Secretary General of the United Nations of the same.[26] This Convention entered into force on 15 September 1976 after its ratification by USA, Bulgaria, Canada and Sweden. India acceded to the convention on 18 January 1982.[27]

THE AGREEMENT GOVERNING THE ACTIVITIES OF STATES ON THE MOON AND OTHER CELESTIAL BODIES, 1979

This Agreement entered into force on 11 July 1994 and provides that all activities on the moon, including its exploration and use, is to be carried out in accordance with international law and taking into account the Declaration of Principles of International Law concerning friendly relations and cooperation among states in accordance with the Charter of the United Nations adopted by the General Assembly on 24 October 1970.[28] The moon is to be used exclusively for peaceful purposes[29] and the exploration and use of moon is to be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development.[30]

The freedom of scientific investigation on the moon by all states parties need to be without discrimination of any kind on the basis of equality and in accordance with the international law[31] and the moon and its resources are the common heritage of mankind.[32] The moon is not subject to national appropriation by any claim of sovereignty by means of use or occupation or by other means.[33]

States parties to the Agreement need to establish an international regime, including appropriate procedures, to govern the exploitation of the natural resources of the moon.[34] The moon's natural resources must be developed in an orderly and safe manner and their management must be sensible. Additionally, opportunities for resources use must be expanded and all participating states must equally share in the benefits that these resources bring.[35] States parties need to retain jurisdiction and control over their personnel, space, vehicles, equipment, facilities, stations and installations on the moon, which is not to be affected by their presence on the moon[36] and also bear international responsibility for national activities on the moon, (whether by government agencies or by non-government entities) to assure that such activities are in conformity with the provisions of the Agreement.[37]

VIENNA CONFERENCE ON THE EXPLORATION AND PEACEFUL USES OF OUTER SPACE (UNISPACE-82 OR UNISPACE II)

The UNISPACE-82 was held at Vienna in August 1982, with 94 states participants and 45 observers and reviewed the developments in the field of outer space taking place since 1968. The conference appealed to the states, especially to "states with nuclear capability, not to increase arms race beyond Earth." A report adopted by consensus asked the states to follow Outer Space Treaty 1967, which has "prohibited the use of weapons of mass destruction in outer space". It also considered the question of monopoly of some industrialised countries in the field of science and technology and recommended increased cooperation between the developed and developing countries in this respect.[38]

UNISPACE-III

The Third UN Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE-III) was held in Vienna, Austria in July 1999, with key objectives to create a blueprint for the peaceful uses of outer space in the 21st Century. It considered future of exploration of planets, use of microwave systems of micro satellites in the exploration of outer space, security of future outer space programmes in respect of debris of outer space, maintenance and supervision of outer space- based environment and use of mobile satellite communication.[39]

SPACE LAWS: AN INDIAN PERSPECTIVE

India's Space ambitions have remained largely limited to civil use of Outer Space. Activities related to space commenced in India in 1963 when the "Thumba Equatorial Rocket Launching Station" (TERLS) was set up.[40] Since the establishment of the Indian Space Research Organisation (ISRO) in 1969, India's space explorations have advanced significantly. The Indian Government founded the Space Commission of India and Department of Space in 1972.[41] India has progressively joined a number of international space treaties, conventions and declarations, mostly as a signatory party.

The Indian Space Programme has remained well managed since its inception and primarily consists of three main components; application programmes, the space transportation system and satellites for communication and remote sensing. Missions to the Moon and Mars are strong reflections of India's Space ambitions, which will be followed by *Gaganyaan*, the nation's first human space mission.[42]

Since independence, India identified the development of space capabilities as an impetus for achieving socio-economic goals. The achievements showcased in emerging space technology have elevated India's position amongst global space players. India has made enormous progress in possessing advanced space capabilities since the launch of 'Aryabhatta' in 1975. Today, India's Space programme has moved beyond scientific research and exploration to utilisation of "space technology for socio-economic development." The Indian Space programme is largely monitored and functions under the aegis of the government, aimed for an extensive and comprehensive space programme for "peaceful purposes, based on sustained and systematic development of low-cost indigenous space capabilities."

INDIA'S DOMESTIC SPACE FRAMEWORK

A report released by Ernest & Young stated that India's space economy is expected to grow to USD 13 billion by 2025 at an annual growth rate of 6 percent.[43] Despite the promising estimates, **India lacks a framework to regulate activities in Outer Space**. The creation of Indian National Space Promotion and Authorisation Center (IN-SPACe) as a nodal medium between ISRO and private players in 2020 was a significant step towards consolidation of activities related to space in the country. However, in India, the commercialisation of space technologies at the present nascent level, has yet not attained the desired levels which "demands of the space industry and commerce to make it imperative for the government to enact national space laws."[44]

Presently India has the following provisions in place:

- **Article 51 (c) of the Indian Constitution**. Article 51 (c) states, "respect for International Law and Treaty obligation and to encourage settlement of the International dispute by way of Arbitration." The article 'obligates' the State to work in tandem with other nations and ensure "international peace and security."[45]
- **Article 253 of the Indian Constitution.** The article gives the parliament the authority to create any laws necessary to carry out any agreement, treaty, or convention with other nations or to implement any decision made by any international organisation of which India is a member.[46]
- **The Indian Space Research Organisation Act, 1969.** This Act establishes ISRO as the nodal and primary organisation responsible for "space research" in the country. The act further outlines ISRO's goals which includes advancing space research in science and technology and its application for national development. Additionally, the act charts out the roles and responsibilities of ISRO, giving the agency the authority to carry out space technology-related research and other relevant operations.[47]
- **The Satellite Communication Policy, 1997.** The policy provided guidelines for the developing satellite communication, launch vehicles and ground equipment industry in the country, making available and developing further infrastructure built through Indian National Satellite System (INSAT).[48] The policy was re-visited in 2000 and remains the only policy outlining the principles for establishment, operation and regulation of satellite communication in the country. [49] The SatCom Policy is considered a major breakthrough for inviting and regulation Foreign Direct Investments (FDI) in satellite communications.
- **Remote Data Sensing Policy, 2011.** The policy introduced in 2001 was amended in 2011 and governs the operation, acquisition and transmission of "remote sensing data" through the Department of Space (DOS). The power resides with the Antrix Corporation to grant licenses for any acquisition of 'Indian Remote Sensing Data' outside India.[50]

- **ISRO's Technology Transfer Policy.** This policy is aimed at ensuring technology transfer from ISRO's 'technical know-how' to external entities. Encouraging Indian private industry engagement in ISRO's space endeavours was the primary objective behind the genesis of this policy.
- **The Indian Space Policy, 2023.** The new policy permits 'Non-government Entities (NGEs) to "offer national and international space-based communication services, through self-owned, procured or leased Geostationary Orbit (GSO) and Non-Geostationary Orbit (NGSO) satellite systems."[51] The policy also opens the Indian space sector to private players allowing possibilities of commercial explorations. The Space Policy 2023, further holds the DOS responsible for implementing and creating pragmatic resolutions for any space disputes. Further, the policy delineates distinct functions for IN-SPACe and NewSpace India Limited (NSIL). IN-SPACe will continue to function as an "autonomous government organisation, mandated to promote, handhold, guide and authorise space activities in India", whereas, NSIL will continue as 'Public Sector Undertaking' under the DOS for activities related to commercialising "space technologies and platforms created through public expenditure."[52]

In addition to domestic legal framework, India has ratified the Outer Space Treaty in 1982, the Rescue Agreement in 1985, the Liability Convention in 1986. India has signed, but not ratified the Moon Agreement of 1979.[53] Nonetheless, India's commitment to cooperative and prudent space exploration is demonstrated by its observance of these mentioned international accords and agreements. These agreements, although archaic, encourage international collaboration in space activities and further aid in the creation of a legal framework for the sustainable and peaceful use of resources in Space. In 2023, during Prime Minister Narendra Modi's visit to the US, India signed the US led Artemis Accord.[54] NASA proposed the Artemis Accords in 2020, providing a set of principles and rules for the "civil exploration and use of the Moon, Mars and other celestial body." India signing the Artemis Accords appeared contentious in light of present geopolitical trends, however, this Accords are a "non-binding bilateral agreement based on the political understanding of the participating countries." Further, the Accord only highlights the desirability to "implement provisions of the Outer Space Treaty and set out 13 practical guidelines to advance the governance of civil exploration and use of outer space, including among other objectives the extraction of space resources and the Artemis Programme."[55]

NEED FOR A COMPREHENSIVE INDIAN NATIONAL SPACE LAW

India is emerging as a global space power and remains significant as it "strives to advance its space capabilities and contribute to global space exploration and utilisation." Today, the challenges orbiting India's Space programme largely range from technological and operational hurdles to legal and regulatory complexities. However, "with a proactive approach and strategic planning, India can overcome these challenges and shape a promising future for its space programme."

Indian perspective on space exploration have come to prioritise military and security considerations. "Space does not recognise sovereignty" and India's space programme was shaped by morality and sovereignty issues up until the 1990s; nevertheless, pragmatism and national security now dictate India's attitude to space. India's space programme has built credible launch capabilities and a combination of Intelligence, Surveillance and Reconnaissance (ISR) and Earth observation satellites for military reasons, in response to this new motive and the evolving conditions surrounding space security.[56] 'Space Wars' are no longer a possibility inspired from any science fiction movie, but rather a possibility that is shaping present norms centred around geo-politics. The rapid advancement of space technology has allowed countries "to oppress other countries for their advantage." Examples include North Korea jamming communications over the demilitarised zones, China hacking into US weather satellites, and Russia interfering with Ukraine's GPS reception.[57] These developments further consolidate arguments for India to build a strategy for outer space. Adoption of a comprehensive space law ensuring space security must remain a priority.

The establishment of IN-SPACe was a pivotal move by the Indian government to induct and establish mechanisms for engaging private players in the Space sector. However, the present mechanisms enlisted in the Space Policy 2023, does not clarify any regulatory framework for these private players while undertaking space explorations. Mechanisms for "licensing, authorisation and regulatory oversight including issues of liability, intellectual property rights and cyber security" are loosely defined and this can pose hindrance for a "secure environment for space operations" in the country. The integration of commercial space ventures into the existing framework would require planning and policy development including "regulatory processes, providing incentives for private sector participation and facilitating technology transfer from ISRO to commercial entities."[58]

Management of Space Debris have become another challenge for global space actors, including India. In 2023, ISRO's PSLV rocket debris were found on the Australian shores and details were confirmed by both ISRO and the Australian Space Agency.[59] Similarly, in 2019 India shot down one of its satellites, creating 400 pieces of orbital debris of which some fell on a Japanese village. Under the Liability Convention, 1972 any state can be held accountable for such liability but the "quantum of such damages is hard to determine".[60] Absence of a national space legislation addressing the issue of Space debris could possibly put India in a "a disadvantageous position to negotiate." The arguments underscore that the legislation of India's National Space Laws should be a summation of Space security strategy; Military space strategy; cyber-space strategy for outer space and near space; civil space strategy; and commercial space strategy.[61]

THE WAY FORWARD

The upsurge in Space Explorations and tightening geopolitical dynamics, Space laws have further become relevant in the discourse. Additionally, such laws as and when they come into force need to protect the common interests of human race and ensure the establishment and the maintenance of a viable, cooperative public order of the outer space, the moon and the other celestial bodies. The military and commercial aspects related to future use of space must also bear these things in mind. India has developed as a momentous diplomatic player and contains immense potential to become a "major global space power."[62] Strategic alliances and collaborations with partners sharing common interests can further intensify the implementation and applicability of the existing treaties and convention. The QUAD's noteworthy joint statement on outer space activities emphasises "consultations on norms of responsible behaviour and regulations."

The inclusive exploitation of space resources takes place in a sort of unorganised arena. The inclusive access to and use of outer space resources must provide freedom and equality of access to the outer space resources to all states to take full advantage of opportunities in space, subject to the limitation that activities must be peaceful and unharmful to common interest. The future of the public order of space is heavily dependent upon cooperation among states, both at the multilateral and bilateral level.[63] The United Nations plays a very important role in coordinating the activities of different States in outer space, ensuring a uniform and progressive economic and technological development of the entire world. A global policy for the Space Age is essentially needed to meet the rapid technological evolution in space and meet the increasing pressure for commercial exploitation of space resources. Such policy needs to balance the common destiny and common survival of mankind with these evolving factors. An international body may help in evolution of such a policy.

CONCLUSION

The evolving space laws need to ensure that the space remains a place that can be accessed by all states and people for their mutual benefit, be used for peaceful purposes and has freedom of scientific investigation and exploration. From an Indian perspective, the void of any legal framework regulating activities of outer space must be addressed in light of global norms and geopolitical transformations. With legally binding international treaties and conventions in action, the essentiality for any country to "regulate space activities in consonance with the dynamics of global space activities" remains a condition.

"India is going through *Amrit Kaal* and it is time for building a highly capable *Aatmanirbhar* defence space ecosystem", as stated by Chief of Defence Staff, General Anil Chauhan. However, an *Aatmanirbhar* defence space ecosystem can sustain within a consolidated and robust legal framework. India needs robust space laws and regulations that strike a balance between international cooperation, infrastructure development, private and foreign investment, certification, licensing, liability and even intellectual property rights related to outer space activities. In addition to providing a 'win-win opportunity' for all stakeholders in the developing and expanding Indian Space industry, a National Space Legislation would fortify the growing defence sector in anticipation of a 'Space war strategy'.

Col Vijay Narayan Shukla, VSM is a Senior Fellow with Centre for Joint Warfare Studies (CENJOWS), New Delhi. He is an alumnus of National Defence Academy, Indian Military Academy, Joint Military Intelligence Training Centre, Defence Intelligence Agency, Washington DC, USA and Pune University and has served in numerous infantry, intelligence and counter intelligence assignments in field and as an Instructor at Military Intelligence Training School and Depot, Pune.

Ms Arijita Sinha Roy is a Research Assistant with the Centre for Joint Warfare Studies (CENJOWS). She is researching on North East Asian security with specialisation in the Korean Peninsula. Ms Roy actively contributes to several national and international organisations of repute and is presently pursuing her post-graduation from the Department of East Asian Studies, University of Delhi.

NOTES

1. Dr SK Kapoor, International Law & Human Rights, (Prayagraj: Central Law Agency, 2021), 332.

2. The Economist, (2019) "A New Age of Space Exploration is Beginning," https://www.economist.com/leaders/2019/07/18/a-new-age-of-space-exploration-is-beginning. Accessed on 01 March 2024.
3. Henry Hertzfeld, "Current and Future Issues In International Space Law" *ILSA Journal of International & Comparative Law Vol. 15:2*, (2009), 1-2, https://nsuworks.nova.edu/cgi/viewcontent.cgi?article=1640&context=ilsajournal. Accessed on 25 February 2024.
4. Ibid.
5. Centre for Aviation and Space Laws, (2023) "Sovereignty in Space: Changing Dimensions," https://caslnujs.in/2023/08/06/sovereignty-in-space-changing-dimensions/. Accessed on 05 March 2024.
6. Wilson Center, (2021) "The Global Legal Landscape of Space: Who Writes the Rules on the Final Frontier?" https://www.wilsoncenter.org/article/global-legal-landscape-space-who-writes-rules-final-frontier. Accessed on 05 March 2024.
7. Congress.gov. "H.R.2262 – 114th Congress (2015-2016): U.S. Commercial Space Launch Competitiveness Act". 12 May 2015, https://www.congress.gov/bill/114th-congress/house-bill/2262/text
8. Gbenga Oduntan, (2015) "Who Owns Space? US Asteroid-mining Act Is Dangerous and Potentially Illegal," The Conversation, https://theconversation.com/who-owns-space-us-asteroid-mining-act-is-dangerous-and-potentially-illegal-51073. Accessed on 09 March 2024.
9. Bruce McClintock, (2022) "U.S. Decision on ASAT Testing A Positive Step Towards Space Sustainability," RAND, https://www.rand.org/pubs/commentary/2022/04/united-states-decision-on-asat-testing-a-positive-step.html. Accessed on 09 March 2024.
10. Nathaniel Roman, (2024) "Global Status of Anti-Satellite (ASAT) Weaponry and Testing | ACE," *ACE* (blog), https://ace-usa.org/blog/research/research-foreignpolicy/global-status-of-anti-satellite-asat-weaponry-and-testing/#:~:text=Several%20states%2C%20including%20the%20US,the%20issue%20of%20ASAT%20testing. Accessed on 10 March 2024.
11. Wilson Centre (n. 6).
12. United Nations Treaties and Principles on Outer Space, (United Nations Publications, 2002), 4, (Article I of Outer Space Treaty), https://www.unoosa.org/pdf/publications/STSPACE11E.pdf. Accessed on 27 February 2024.
13. United Nations Treaties and Principles on Outer Space, 4, (Article II of Outer Space Treaty).
14. United Nations Treaties and Principles on Outer Space, 4, (Article IV of Outer Space Treaty).
15. Ibid.
16. United Nations Treaties and Principles on Outer Space, 4-5, (Article V of Outer Space Treaty).
17. United Nations Treaties and Principles on Outer Space, 5, (Article VI of Outer Space Treaty).
18. United Nations Treaties and Principles on Outer Space, 5, (Article VII of Outer Space Treaty).
19. United Nations Treaties and Principles on Outer Space, 5, (Article VIII of Outer Space Treaty).
20. United Nations Treaties and Principles on Outer Space, 9, (Article 1 of the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space 1967).

21. United Nations Treaties and Principles on Outer Space, 9-10, (Article 2 of the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space 1967).
22. United Nations Treaties and Principles on Outer Space, 10, (Article 4 of the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space 1967).
23. United Nations Treaties and Principles on Outer Space, 13, (Article II of the Convention on International Liability for Damage Caused by Space Objects, 1971).
24. United Nations Treaties and Principles on Outer Space, 14, (Article III of the Convention on International Liability for Damage Caused by Space Objects, 1971).
25. United Nations Treaties and Principles on Outer Space, 17, (Article XIV of the Convention on International Liability for Damage Caused by Space Objects, 1971).
26. Goedhuis D. Conflicts in the Interpretation of the Leading Principles of the Moon Treaty of 5 December 1979. *Netherlands International Law Review*. 1981;28(1):14-29. doi:10.1017/S0165070X00014352
27. Dr SK Kapoor, International Law & Human Rights, 337-338.
28. United Nations Treaties and Principles on Outer Space, 28, (Article 2 of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1979).
29. United Nations Treaties and Principles on Outer Space, 28, (Article 3, Paragraph 1 of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1979).
30. United Nations Treaties and Principles on Outer Space, 28, (Article 4, Paragraph 1 of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1979).
31. United Nations Treaties and Principles on Outer Space, 29, (Article 6, Paragraph 1 of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1979).
32. United Nations Treaties and Principles on Outer Space, 31, (Article 11, Paragraph 1 of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1979).
33. Ibid, Paragraph 2.
34. United Nations Treaties and Principles on Outer Space, 32, (Article 11, Paragraph 5 of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1979).
35. Ibid, Paragraph 7.
36. United Nations Treaties and Principles on Outer Space, 32, (Article 12, Paragraph 1 of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1979).
37. United Nations Treaties and Principles on Outer Space, 33, (Article 14, Paragraph 1 of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1979).
38. Dr SK Kapoor, International Law & Human Rights, 339.
39. Dr SK Kapoor, International Law & Human Rights, 340.
40. R. Kaul and R.S. Jakhu, "Regulation of Space Activities in India", in R. Jakhu (eds) *National Regulation of Space Activities: Space Regulations Library Series,* Volume 5, 153 - 198 (Springer, Dordrecht, 2010).

41. Ayan Sharma and Arushi Mukherji, (2023) "Space 4.0: India'S Need for a Comprehensive Legal Framework to Regulate Space," Lexology, https://www.lexology.com/library/detail.aspx?g=d3c2bf11-493e-4215-bd3e-62820f970ee5. Accessed on 12 March 2024.
42. Ibid.
43. Prashant Singhal, (2022) "The Dawn of the Space Economy in India,"Ernst & Young, https://www.ey.com/en_in/aerospace-defense/the-dawn-of-the-space-economy-in-india. Accessed on 13 March 2023.
44. R Kaul (n. 40).
45. The Constitution of India, 1949, art. 51, https://indiankanoon.org/doc/237570/
46. The Constitution of India, 1949, art. 253, https://indiankanoon.org/doc/741672/
47. Indian Space Research Organisa1on Act, No. 32 of 1969 (India).
48. Government of India, "Norms, Guidelines and Procedures for Implementation of Satellite Communications Policy in India," 2000, https://www.isro.gov.in/media_isro/pdf/satcom-ngp.pdf.
49. Monica Shaurya Gohil, "Need for Comprehensive and Robust Indian Space Laws," *ILI Law Review Summer Issue 2021*, season-02 2021, https://ili.ac.in/pdf/3.pdf.
50. Government of India, "Remote Sensing Data Policy (RSDP – 2011)," 2011, https://sarinlaw.com/wp-content/uploads/2020/10/Remote-Sensing-Data-Policy.pdf.
51. Aswathi Pacha, (2017) "The Hindu Explains: What is the Space Activities Bill, 2017?," https://www.thehindu.com/sci-tech/science/the-hindu-explains-what-is-the-space-activities-bill-2017/article20680984.ece. Accessed on 09 March 2024.
52. Ayan Sharma and Arushi Mukherji (n 41).
53. Makam, Ganesh, An Analysis of Space Law in India: Current Developments and Future Perspectives (21 June 2023). http://dx.doi.org/10.2139/ssrn.4487755
54. Alind Chauhan, (2023) "India Signs the US-led Artemis Accords: What Does It Mean, How the Country Can Benefit," The Indian Express, https://indianexpress.com/article/explained/explained-sci-tech/why-india-sign-artemis-accords-significance-8808051/. Accessed on 10 March 2023.
55. Ibid.
56. Rajeswari Pillai Rajagopalan, (2022) "India's Space Priorities Are Shifting Toward National Security," Carnegie Endowment for International Peace, https://carnegieendowment.org/2022/09/01/india-s-space-priorities-are-shifting-toward-national-security-pub-87809. Accessed on 12 March 2024.
57. Monica Shaurya Gohil (n. 49).
58 Makam Ganesh (n. 53).
59. Amitabh Sinha, (2023) "ISRO Rocket Debris on Australian Shore: Rules Governing Space Junk," The Indian Express, https://indianexpress.com/article/explained/explained-sci-tech/isro-rocket-debris-on-australian-shore-rules-governing-space-junk-8870243/. Accessed on 12 March 2024.
60. Monica Shaurya Gohil (n. 48).
61. Ranjana Kaul (2024), "Drafting National Space Policy and Law" , SatCom Industry Association (SIA-India), https://www.sia-india.com/corner/drafting-national-space-policy-and-law/. Accessed on 13 March 2024.
62. Ayan Sharma and Arushi Mukherji (n. 40).
63. Ranbir Singh, Sanat Kaul, and Srikrishna Deva Rao, eds., "Current Developments in Air and Space Law," book (National Law University, Delhi, 2012), https://nludelhi.ac.in/download/publication/2015/Current%20Developments%20in%20Air%20and%20Space%20Law.pdf.

ADVISORY BOARD & EXECUTIVE COUNCIL CENJOWS

Printed and published by Maj Gen (Dr) Ashok Kumar, VSM (Retd) on behalf of Centre for Joint Warfare Studies (CENJOWS), 301, B-2 Wing, 3rd Floor, Pt Deendayal Antyodaya Bhawan, CGO Complex, Lodhi Road, New Delhi-110003, and printed

Editor: Maj Gen (Dr) Ashok Kumar, VSM (Retd)