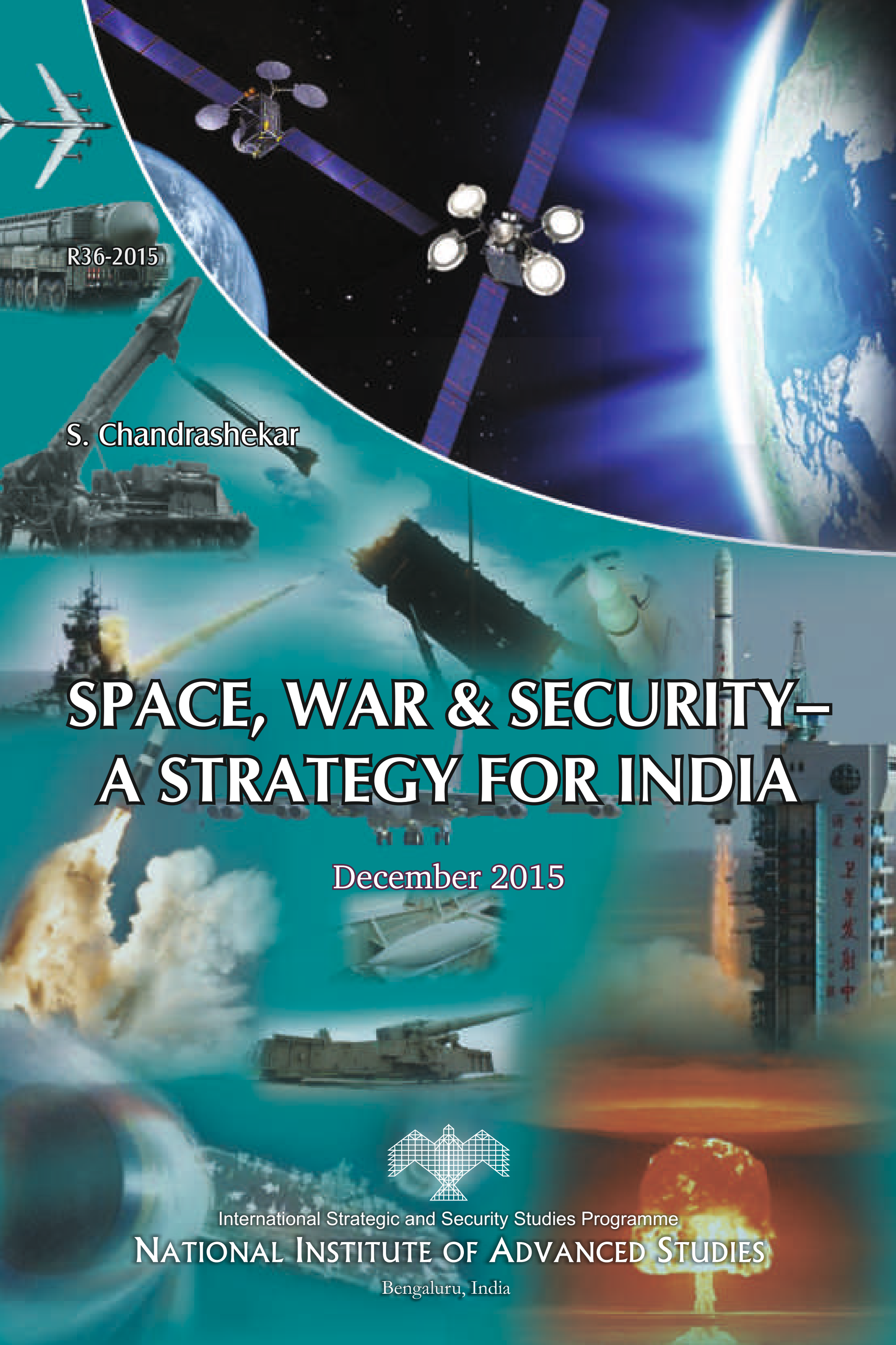


R36-2015

S. Chandrashekar

SPACE, WAR & SECURITY– A STRATEGY FOR INDIA

December 2015

International Strategic and Security Studies Programme
NATIONAL INSTITUTE OF ADVANCED STUDIES
Bengaluru, India

SPACE, WAR & SECURITY– A STRATEGY FOR INDIA

S. Chandrashekar

International Strategic & Security Studies Programme (ISSSP)
NATIONAL INSTITUTE OF ADVANCED STUDIES
Bengaluru

December 2015

Published by
National Institute of Advanced Studies
Indian Institute of Science Campus,
Bengaluru - 560012
INDIA
Tel: +91-80-2218 5000; Fax: +91-80-2218 5028

NIAS Report: R36-2015

ISBN 978-93-83566-19-8

Typeset & Printed by
Aditi Enterprises
Bengaluru - 560 023
Ph.: 080-2310 7302
E-mail: aditiprints@gmail.com

Contents

Executive Summary

India must accept and deal with the reality that conflicts and wars in today's world will be based and driven by the increasing inter-dependence between conventional, nuclear and space war.

Capabilities, Capacities, Complexity in Organization and the role of ambiguity and escalation risk in war and war deterrence strategies will be the new parameters along which the game will be played out. The China US dynamic will drive the other major powers to act in different ways to preserve and enhance their security and national power interests.

Space assets play a vital role in the formulation and implementation of great power strategies across the globe. They act as a force multiplier that can enhance national power and prestige.

The acceptance of this reality and the consequent need to re-organize and re-structure the entire National Security Complex is obviously the most important task ahead of the Indian Nation State especially if nascent ambitions to be recognized as a global power have to be realized.

The role of space-based C4ISR assets complemented by other ground based SSA components will be critical for deciding on the new national strategy for waging war and for preserving the peace through the deterrence of war.

The major space based components of this new strategy architecture would be:

- A robust SSA capability comprising radar, optical and laser tracking facilities complemented by an organizational and human resource base that is able to operationally monitor the space environment.
- A four-satellite constellation of advanced communications satellites in GSO that use ion propulsion for carrying out vital C4 functions.

- A constellation of 40 satellites in LEO that provide Internet services for the military.
- Three clusters of 3 satellites each for performing the ELINT function.
- A constellation of 12 EO and SAR satellites in appropriate Sun Synchronous Orbits (SSO) for meeting ISR needs.
- A constellation of 24 small satellites in LEO for meeting ISR needs during times of crises.
- Three TDRSS satellites in GSO for performing the tracking and data relay functions needed for a C4ISR capability.
- Two operational satellites in GSO along with 3 orbiting satellites in an 800 Km SSO for meeting operational weather requirements.
- Seven satellites in Geostationary and Geosynchronous Orbits for meeting core navigation functions.
- A 24 satellite constellation in MEO, established over a ten year period, for providing an indigenous navigation solution.

The integration of the various SSA and C4ISR capabilities into a seamless network that facilitates real time action is the key organizational and institutional component of the new strategy.

To translate the above needs into an operational capability India may need to launch 17 satellites into various GSO, SSO and other orbits every year. **(See Table 4 for details)**

In addition 28 smaller satellites may also have to be launched as part of constellations that cater to various C4ISR needs.

The Small Satellite Initiative that is needed to build small satellite capacity in the country may also need the launching of 100 small satellites in the 5 to 100 Kg class.

To meet this requirement India needs 16 PSLV , 7 GSLV and 7 Agni 5 based launchers every year. **(See Table 4 for details)**

India currently builds and launches an average of about 4 satellites a year.

A four to five fold increase in the scale of the current programme is needed to meet these emerging needs. Creating this capacity and capability to build and launch these satellites by Indian industry would be a major challenge for India.

With masses of about 2300 Kg (GSLV launch) and 3300 Kg (foreign launch) Indian Communications satellites currently fall into either the medium class category (< 2500 Kg) or the Intermediate class category (2500 -4200 Kg).

The global trend is to move away from the intermediate class of satellites to the Heavy (4200 – 5400 Kg) or Very Heavy class (>5400 Kg) of satellites.

The use of Ion Propulsion for moving the satellite from GTO to GSO is emerging as a new trend that promises to reverse the overall movement towards building heavy or very heavy satellites. By adopting it as a key component of its new strategy the current gaps in GSO satellite capabilities can be eliminated.

This approach will also ensure that the GSLV Mark 2 launcher can now launch the equivalent of an intermediate class GSO satellite and the GSLV Mark 3 launcher can launch the equivalent of a heavy class satellite. Therefore the gap between launcher capacity and satellite capabilities can also be bridged through the adoption of this approach. This is a major benefit since it makes possible a complete indigenous capability to meet various strategic needs.

The creation of an ELINT capability and a TDRSS capability are major gap areas that have to be bridged immediately.

India's capabilities for performing the surveillance and reconnaissance parts of the ISR function are good and close to global state-of-art capabilities.

However the use of integrated optics to combine the PAN and spectral functions in one sensor could be an area that may need support.

Indian capabilities for dealing with the infra-red (thermal) part of the spectrum are very limited. These need to be strengthened significantly. Apart from ISR they are used for performing many other military functions and could play an important part in any future BMD system.

Antenna Technology used for meeting SSA, SAR and C4 needs is also an area that needs national attention.

Reducing the mass of the SAR, efforts to improve throughputs in data processing especially for SAR data are other areas that may require more support.

Indian satellites providing weather services from GSO are reasonably close to global standards. India has so far not built any polar orbiting satellites to complement the GSO weather data. This is an area that will also need attention. The orbiting satellites can also be used as a base for experimenting with new weather and climate sensors to improve operational capabilities.

India also needs to make the investments necessary to increase the human resource base that can use publicly available high resolution remote sensing data for use in a number of civilian and military applications. A similar approach can also be adopted to improve the use of publicly available weather and climate data to improve weather models.

Extending the IRNSS scheme for navigation via a MEO constellation to improve navigation accuracies and eventually providing for a completely indigenous solution to the navigation problem is also a part of the suggested strategy.

The current practice of meeting both civilian and military needs for weather and navigation services via the same space segment is in tune with global trends and can continue.

Preserving various technology options for a future space weapons programme via development and limited testing should be a part of the strategy.

A number of other initiatives are suggested as a part of the strategy. Details of these can be found in **Table 5 and Section 8 of this report**.

India may find it difficult to move from its current position to a position where it can simultaneously deal both with the military aspects of space along with the human space flight programme. A sensible approach would involve according priority to the military needs while retaining technology development and testing options for the human space flight programme.

More than the technology initiatives the implementation of this strategy would require a clear aspiration on the part of the Indian nation state that it does have an important role to play on the global stage and that it will carry out the necessary organizational and institutional reforms needed for achieving this. Integrating the hard operational aspects created by the SSA and C4ISR assets with the softer strategy and doctrine part of the nation state is possibly the most difficult task confronting the country. This more than any technology is possibly India's greatest challenge.

All the components of the strategy suggested as well as the overall direction and thrust are consistent with India's current international posture of the "peaceful uses of outer space". This can be re-examined once India has made progress towards achieving the status of a full-fledged space power.

1.0 Background

There is no doubt that India has achieved a lot in space in spite of operating on a relatively smaller overall space budget. The largely development driven agenda and the civilian focus of the programme has yielded significant benefits. This approach has also been consistent with an international posture that advocates the peaceful uses of outer space though what is peaceful still remains very ambiguous.

A number of developments especially over the last decade raise serious concerns whether this continued ostrich like posture is adequate to cope with the challenges that an emerging space power like India faces. The role of space and space assets are emerging as key components of the global security architecture that includes both civilian and military uses of space. These developments pose a new set of challenges that entails a re-examination of India's largely civilian focused space strategy.

A dispassionate appraisal of India's space capabilities in the context of these challenges, raise a number of questions that may need closer scrutiny. These are related not only to gaps in capabilities but also to institutional and organizational bottlenecks that seem to come in the way of formulating and implementing a space strategy that is appropriate for the country at this point in time.

Two events stand out that reflect this state of affairs.

In January 2007 China conducted an ASAT test that destroyed a defunct weather satellite in an 800 Km Sun Synchronous Orbit (SSO) creating a huge debris cloud. Even though India has a number of IRS satellites in orbits very close to this, India did not know about this test and the consequent risk for quite some time. It was only a week or ten days after the test that the relevant Indian establishments learnt about the tests and that also from US sources.[1]

As part of its Yaogan series of military satellites, China launched a constellation of 3 satellites into an 1100 km, 63.4° inclination orbit on a CZ 4C launcher on the 5th of March 2010. The spacing of the three satellites, their altitude as well as the inclination is typical of an Electronic Intelligence (ELINT) capability.

Prior to this launch, the satellites in the Yaogan series consisted of SAR and Electro-optical imaging satellites. The launch of this 3 satellite ELINT cluster transformed the Intelligence Surveillance Reconnaissance (ISR) capabilities of the Peoples Liberation Army (PLA) from occasional sporadic surveillance of high value targets such as aircraft carriers into an operational continuous ISR system. This launch also coincided with the US declaring that China's Anti-Ship Ballistic Missile (ASBM) system had entered "Initial Operations Capability."[2]

Once again it took a fairly long time for the various security establishments in the country to take stock of this development, make reasoned judgments about the veracity of these claims and then link these to various security challenges that India needs to address.

---

1 For understanding what had happened before and after the January 11 2007 test please see Michael R Gordon & David S. Cloud, "US knew of China Missile Test but Kept Silent", New York Times, April 23 2007 at http://www.nytimes.com/2007/04/23/washington/23satellite.html?_r=1&adxnnl=1&oref=slogin&ref=asia&pagewanted=print&adxnnlx=1177412634-gIokCeqAhuEUTz6obSrvpQ

2 Andrew Erickson and Gabe Collins, "China Deploys World's First Long-Range, Land-Based 'Carrier Killer': DF-21D Anti-Ship Ballistic Missile (ASBM) Reaches 'Initial Operational Capability' (IOC)," *China SignPost™*, No. 14 (26 December 2010)

Though these cases are specific to space they are symptomatic of a deeper malaise that seems to pervade various parts of the Indian National Security Complex. At the core of this problem is an inability of the security establishments to come to grips with how linked developments between technology and strategy are changing the nature of war and conflict in the coming decades of the 21^{st} Century.

What is happening in space is just one important part of the problem. It is linked to other parts of the problem that deal with nuclear war and conventional war. Unless these connections and linkages are mapped and their consequences understood India will continue to flounder in coping with the security challenges arising from these changes in the geo-political environment.

These developments in the military uses of space provide clear evidence that a space strategy that is appropriate for India is directly linked to a nuclear and conventional war strategy.

India could of course continue to ignore and deal with these issues separately as it is currently doing. If it does so after detailed scrutiny and analyses one could rest assured that such an approach was deliberate and a part of a conscious national strategy. The available evidence however suggests that India's current space strategy appears to be one of knee jerk reactions to global developments as and when they happen. These are in part due to gaps in capabilities and knowledge about what is happening in space and how developments there can affect the security of the country. They are also partly due to the fact that the national security complex in the country is unable to identify and integrate the space component with a larger national strategy that encompasses the nuclear and conventional war domains. India's unwillingness and inabilities to deal with these challenges creates a number of vulnerabilities that could come in the way of Indian aspirations for great power status.[3]

In this paper we hope to be able to understand how linked developments between technology and strategy are shaping the connections between space, nuclear and conventional war.

Based on this understanding we then go on to study Indian space capabilities that are required to meet these challenges.

Keeping in mind India's current position and status in the global space order we then go on to suggest a set of priorities and a phased approach to meet these challenges.

We finally address how other national priorities in space such as the manned space programme could affect the creation of these capabilities.

1.1 The Sanctuary Regime in Space (1960 – 1985)[4]

The space age that began with the launch of Sputnik in 1957 transformed the nature of nuclear war and its link with conventional war in a fundamental way. Though missiles became the delivery vehicles of choice for nuclear weapons these same missiles made possible the launching of satellites that could perform a variety of functions from their vantage point in space. Reconnaissance, Communications, Navigation and Weather monitoring

[3] For a more elaborate elucidation of these problems see Bharat Karnad, "Why India Is Not A Great Power (Yet), Oxford University Press, 2015

[4] For an overview of the evolution of the various space regimes see S. Chandrashekar, "The Emerging World Space Order and its Implications for India's Security," in Subrata Ghoshroy and Goetz Neuneck, eds., *South Asia at a Crossroads:Conflict or Cooperation in the Age of Nuclear Weapons, Missile Defense and Space Rivalries* (Germany: Nomos, 2010), pp. 217–228.

were the early applications that diffused rapidly from the military into the civilian sector. The C4ISR functions[5] performed by the early military satellites played a major role in stabilizing the relationship between the two superpowers. The information they provided helped them monitor each other's nuclear arsenals in a non-obtrusive way and contributed significantly to the prevention of a conventional or nuclear war between them.

Both superpowers tested nuclear weapons in space. They also developed ASAT and Missile Defence capabilities fairly early. However their mutual need to promote nuclear stability made them restrict their actions to R&D and limited testing. They also cemented their commitment to maintaining the space environment as a regime free of weapons through a number of bilateral and multilateral agreements that linked the nuclear weapons regime with the emerging space regime.

The SALT and ABM Treaties[6] between the superpowers were negotiated to stabilize the Arms Race between them. The role of satellites that largely performed an ISR function was legitimized in these Treaties as National Technical Means of Verification. The two parties also agreed in these Treaties not to interfere with each other's National Technical Means of Verification. Under these regimes C4ISR satellites in space were seen to be agents that promoted peace and stability.

This period also saw the major steps in the evolution of an international space regime governing the activities of states in space. These Treaties

---

5 Command, Control, Communications, Computers, Intelligence, Surveillance & Reconnaissance.

6 Strategic Arms Limitation Treaty (SALT) and the Anti-Ballistic Missile (ABM) Treaty were the early treaties for ensuring strategic nuclear stability between the superpowers. They also recognized the role of space assets for preserving status quo.

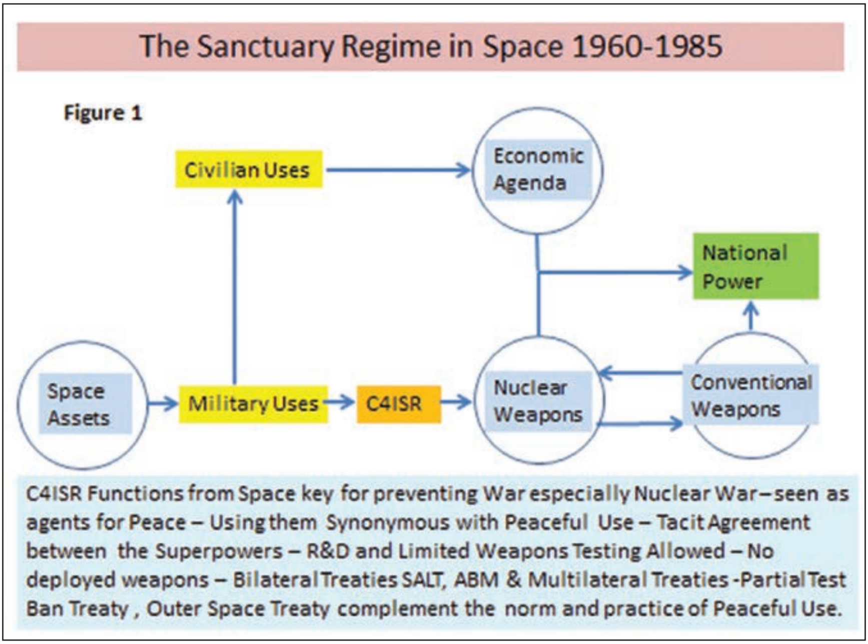
largely imposed by the superpowers on the rest of the world soon became international space law. The Partial Test Ban Treaty (PTBT), the Outer Space Treaty (OST), and a number of related space treaties came out of this effort. Though both the PTBT as well as the OST ban the testing of nuclear weapons in space they do not explicitly prohibit the testing or deployment of other kinds of weapons in space.

This combination of bilateral and multi-lateral Treaties resulted in the emergence of an international space regime that saw the military uses of space largely being restricted to the performance of C4ISR functions. Though not completely banned or prohibited by Treaty the deployment of weapons in space or elsewhere that could threaten the peace keeping function of various C4ISR space assets was seen as destabilizing and not in accordance with the national interests of the superpowers. By default it was also seen as not being in the interests of other emergent space powers. Space was therefore seen as a sanctuary where only “peaceful” activities could take place.

Though the two superpowers were competing across the world for power and influence they ensured that they never directly confronted each other in a war like situation. This resulted in a situation where the sanctuary regime was never seriously tested.[7]

This relationship between space, nuclear weapons and conventional weapons is seen in Figure 1.

[7] During the early days of the Cold War there were a number of confrontations including one major crisis over Cuba in 1962. However after this relationships between the superpowers remained more or less stable.

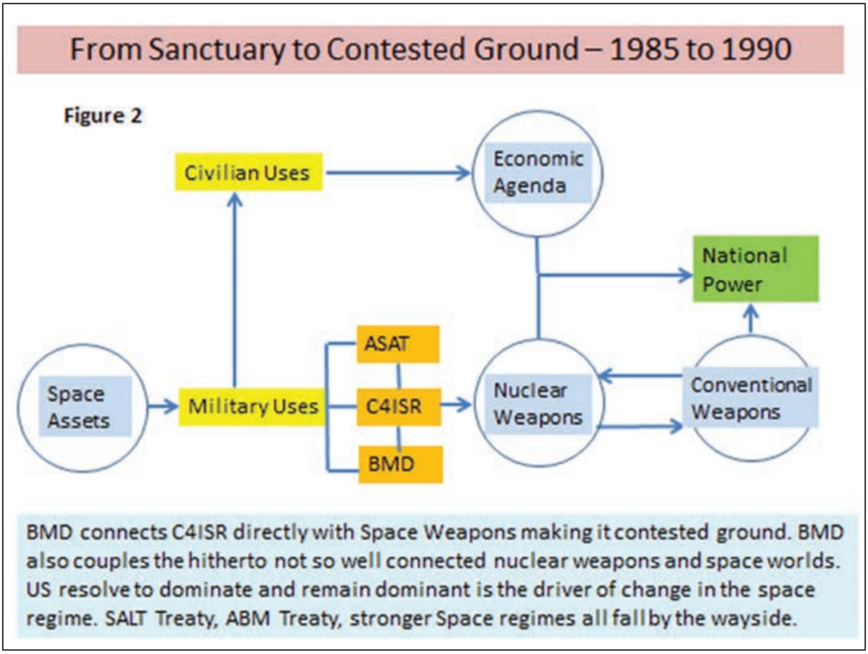


1.2 From Sanctuary to Contested Ground (1985-1990)

President Reagan's Strategic Defence Initiative (SDI) also termed as the Star Wars Programme altered in a fundamental way the status quo "peaceful "regime in space. A variety of space and other platforms based on the ground, in air and possibly even in the seas would create the perfect Ballistic Missile Defence System. This perfect defensive shield would prevent the delivery of a nuclear payload.

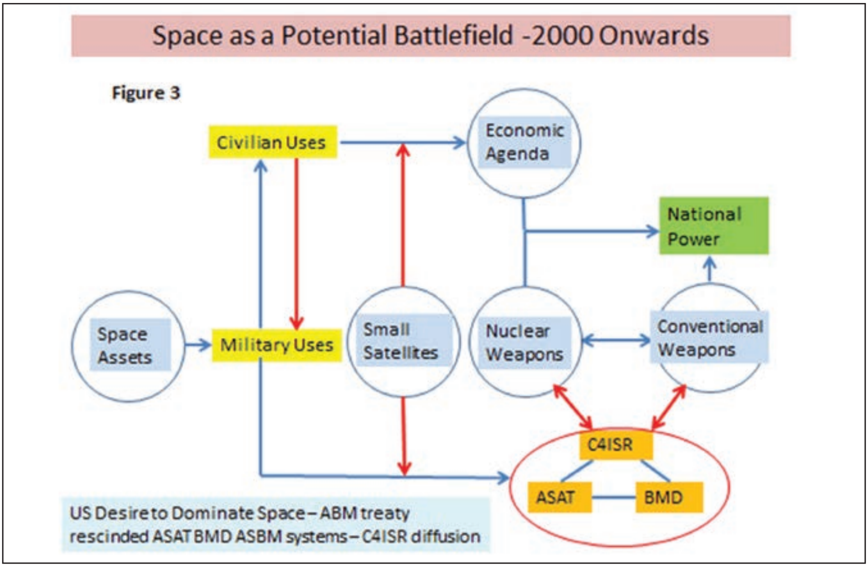
Though there were serious flaws in both the system design and in the system architecture, SDI set in motion a string of actions and reactions that destroyed the sanctuary regime in space. By directly connecting the largely peace-keeping functions of C4ISR with weapons in space and on the earth it changed the nature of space in a fundamental way. From being a sanctuary the space domain became an arena for contest and conflict. This transformation created strongly coupled links between space assets and nuclear weapons.

Though never implemented in its totality, the SDI initiative created a number of Ballistic Missile Defence (BMD) options each of which dealt with parts of the total BMD solution. It also set in motion actions to counter these BMD systems resulting in a renewed interest in Anti Satellite (ASAT) weapons and ASAT capabilities. Nuclear war and a space war thus became more connected. The Superpower common interest in preserving Space as a sanctuary free of weapons eroded with this renewed competition for dominance. **Figure 2 provides a representation of these altered connections between the uses of space with nuclear and conventional war**.



1.3 Space Contest to Space Weapons 1990 Onwards

Two major changes that took place in 1990-91 had a profound impact on the world and on the world space order. The first Gulf War saw a real life demonstration of how US Space Power could be used to win a conventional war. US space based assets especially their C4ISR capabilities directly linked space with the waging and winning of a conventional war. Space based missile surveillance capabilities also provided them with the key component of the military architecture for dealing with Scud missile launches from Iraq. This reinforced the connections between the use of Space and the waging and winning of a conventional war. It also brought into visible focus the possible role that BMD weapons would have on such wars. Space therefore became inextricably linked not only to nuclear war and nuclear deterrence but also to conventional war and conventional deterrence. **Figure 3 provides an overview of the how the architecture of waging war has changed as a consequence of the first Gulf War and improvements in civilian capabilities.**



The other major event that took place in 1991 was the break-up of the Soviet Union that completely changed the map of the world. This also fundamentally restructured the world space order reinforcing the US position as the dominant space power. **Figure 4 provides a view of how the demise of the Soviet Union has altered the power structure of the global space order**.

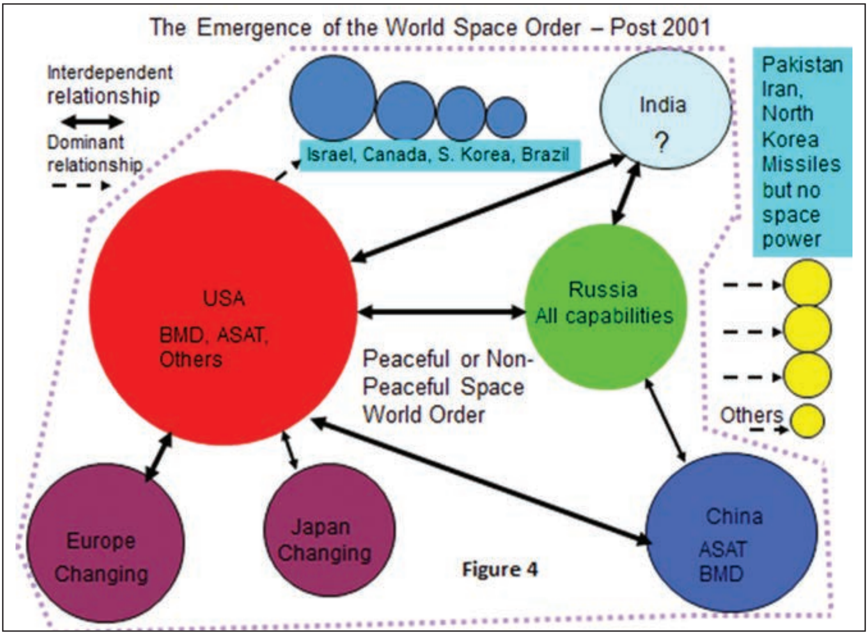


Figure 4

The period since the breakup has also witnessed the emergence of new space powers especially China and India.

1.4 China US Rivalry & the Role of Space Power

The rise of China as a major economic and military power has been spectacular. It has capitalized on a more benign geo-political global regime especially within its neighbourhood to emerge as a likely challenger to the US.[8] This proactive approach also has also witnessed a major shift in strategy that recognizes the increasingly interdependent relations between space, nuclear weapons, conventional weapons and conventional war.

The nuclear weapon component of this strategy is based on the assessment that their second generation nuclear submarines would not be able to provide an assured retaliatory capability. In order to deter an advanced adversary such as the US, China has therefore resorted to a deployment strategy that emphasizes mobility and concealment. By replacing their large liquid fuelled missiles with much more mobile and ready to use solid propellant missiles they hope to create enough "first strike uncertainty" in the minds of the adversary so as to deter them.[9]

The DF-21, the DF-21A, the DF-31, the DF-31A, the JL-2 SLBM and the DF 41 represent China's modern missile arsenal that targets the US and its allies. Their deployment is backed by a nuclear weapons testing programme that provides a spectrum of warhead yields to deal with different eventualities. Though it may still be behind the US in terms of capabilities in areas like miniaturization and MIRV China does have in place a robust retaliatory capacity that is adequate to deter a nuclear first strike from any adversary including the US.

---

[8] For an Indian perspective on China's Rise see S.Gopal & Nabeel Manceri (Editors) "Rise of China Indian Perspectives", Lancer Publishers & Distributors, 2013. Also see Mayilvaganan et al, "Asia Pacific Power Dynamics: Strategic Implications And Options For India", Workshop & Seminar Proceedings, http://isssp.in/workshop-report-asia-pacific-power-dynamics-strategic-implications-options-for-india/

[9] Wu Riqiang, "The Certainty of Uncertainty: Nuclear Strategy with Chinese Characteristics", Program On Strategic Stability Evaluation (POSSE) http://posse.gatech.edu/sites/posse.gatech.edu/files/4%20Wu%20POSSEIV.pdf

The Chinese nuclear weapons testing programme also include a number of low yield tests. This would suggest that they also possess tactical nuclear weapons that can be deployed on their short range DF-11, DF-15 ballistic missiles as well as on their cruise missiles.

China therefore has in place an array of nuclear weapon capabilities that covers the tactical, theatre and strategic geographies of engagement. The signals that they are sending out to the world through testing and deployment of their nuclear and missile arsenals are consistent with a clear strategy for deterring nuclear war at several levels.

Though China has land borders with fourteen other countries and a number of vulnerabilities arising from the geography and history of these border areas, China's major concerns have always been associated with the reclamation of Taiwan. A careful assessment of their nuclear weapons testing programme, their deployment of military and missile forces across the Taiwan straits, their demonstration of space weapons capabilities through an ASAT test and their launch and operation of the Yaogan constellation of military satellites linked to an ASBM mission[10] reveal a well-crafted carefully thought out strategy for deterring US involvement in a Taiwan crisis.[11]

There appears to be two major components to such a strategy.

[10] S.Chandrashekar & Soma Perumal, "China's Constellation of Yaogan Satellites & the Anti-Ship Ballistic Missile: January 2015 Update", http://isssp.in/chinas-constellation-of-yaogan-satellites-the-asbm-january-2015-update/

[11] A recent Rand Study provides some idea of the relative balance of power between the US and China in the event of a conflict over Taiwan. Eric Heginbotham et al, "The US China Military Scorecard Forces, Geography and the Evolving Balance of Power 1996-2017", Rand Corporation Santa Monica Calif. 2015

The first component is an Anti-Access, and Area Denial capability. The DF-21C missile with a Kinetic Energy Warhead is an ASAT weapon. It directly threatens various US C4ISR space assets. These assets are crucial for waging and winning a conventional war. The other weapon system that is used for denying area is the ASBM weapon system that has entered operational status. The ASBM links space based and ground based C4ISR capabilities with another variant of the DF-21 missile the DF-21D that can target US Aircraft Carriers in the Pacific Ocean. Together these deployed weapons threaten US military forces at stand-off distances of around 1700 to 2000 Km. [12]

The second component of China's Taiwan strategy is the element of risk introduced into the US China dynamic by deploying missiles with very similar characteristics for both nuclear and conventional war.

The DF-21 and the DF-21A carry nuclear weapons. The DF-21C ASAT and the DF-21D ASBM are missiles with non-nuclear warheads.

The introduction of these missiles into the Taiwan theatre of operations substantially raises the risk of a DF-21 with a conventional warhead being mistaken for a DF-21 or DF 21A nuclear armed missile.

Thus US intervention in a Taiwan crisis not only has to cope directly with the ASAT and ASBM (Anti-Access and Area Denial) threats it also has to worry about the fact that the conventional missiles that China may deploy in such a crisis could be easily mistaken for a nuclear weapon carrying missile. This would raise the risk of a conventional war escalating into a nuclear war.

[12] S.Chandrashekar et al, "China's Ant Ship Ballistic Missile Game Changer in the Pacific Ocean", NIAS Report, R5-11 International Strategic & Security Studies Programme (ISSSP), National Institute of Advanced Studies (NIAS) Bangalore, India November 2011.

Rather than directly threatening the US and its allies with nuclear weapons this strategy tries to deter US intervention in a Taiwan crisis by raising the risk of a conventional war escalating to a nuclear war.

While the Anti-Access and Area Denial strategy with ASAT and ASBM weapons is aimed at theatre level operations extending to about 2000 Km from China's mainland, China also has in place a strategy for dealing with conflicts at the tactical level in and around the immediate areas surrounding Taiwan. The DF-11, the DF-15 as well as some of their cruise missiles all carry conventional warheads. They can also carry nuclear warheads with relatively low yields and neutron bombs suitable for tactical war. This ambiguity in use once again raises the risk that a conventional conflict could escalate into a war with nuclear dimensions.

Through this clever manipulation of risk China hopes to deter the US from intervening in a conflict over Taiwan at both the theatre and tactical levels.[13]

China has also made sure that its theatre and tactical conflict strategies directed against the US and its allies over Taiwan does not spillover into its direct dealings with the US on the questions of nuclear and conventional war. The DF-31, the DF-31A, the JL-2 SLBM and the DF-41 are clearly and unambiguously meant for carrying nuclear weapons only.

The small size and capabilities of this arsenal are meant both to reassure the US about its intentions and also to deter a US first strike against China. This multi-tiered defense oriented strategy anchored in Anti-Access, Area

[13] For details of how an array of risk options can be used to raise the risk of a conventional war escalating to a nuclear war see Robert Powell, "Nuclear deterrence theory - The search for credibility" Cambridge University Press 1990, pp. 15-17.

Denial and ambiguity in the tactical and theatre sphere of operations is consistent with the relatively inferior position of China vis a vis the US in nuclear, space and conventional capabilities.

The US on its part has recognized these changes in China's approach to protecting its interests. Its strategy of pivoting towards Asia is meant to counter China's strategy of trying to achieve a dominant position in the Asia Pacific region.[14]

It is clear from the above analysis that the nuclear and conventional war strategies of major powers are intimately connected with the use of space assets. Therefore strategies for coping with and managing such conflicts will necessarily involve the development and deployment of weapon systems that can take care of these assets. The evidence suggests that the sanctuary regime has been replaced by a new regime where war and conflict in space maybe a precursor to a more conventional war with riskier nuclear dimensions. It is in this context that we have to look at the global space order and assess Indian capabilities and capacities for meeting some or all of these emerging challenges.

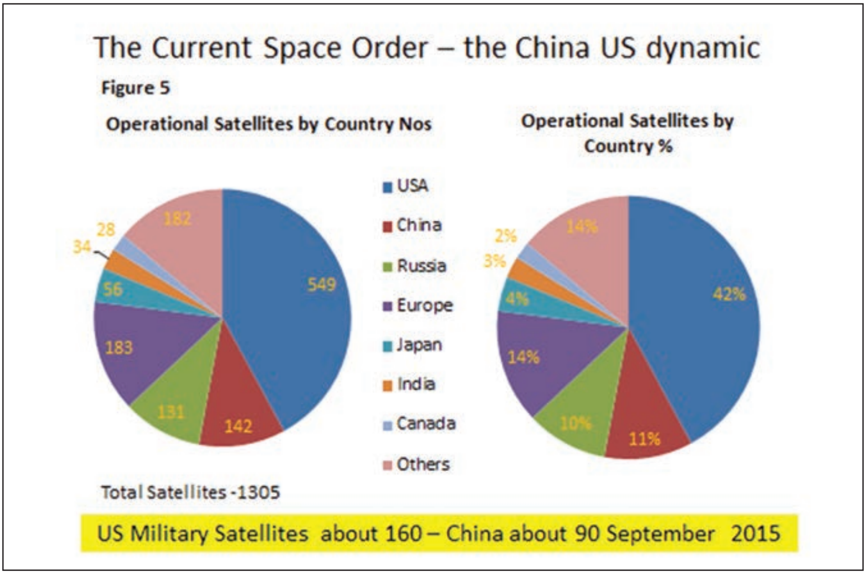
1.5 The World Space Power Structure

Figure 5 build upon the conceptual framework of Figure 4 to provide a snapshot of the world space order in terms of the number of satellites that the space powers currently operate.[15]

---

14 Ashley J Telis, "Pivot or Pirouette: the US Rebalance to Asia", available at http://isssp.in/pivot-or-pirouette-the-u-s-rebalance-to-asia-2/

15 Based on data put out by the Union of Concerned Scientists that includes satellite launches up 31st January 2015.at http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database.html#.Vgou932rHgI



The US is still the dominant power in space. China has now overtaken Russia as the second most important player in space. While Europe collectively is larger than both China and Russia it may still face problems of internal cohesion in dealing with ongoing changes in the global space order.

Japan too is re-examining the role of space in situations of conflict that it is likely to face in its neighbourhood.

From the analysis so far it appears that it is the US China dynamic that is going to dictate what is going to happen in space.

As the major space power the US will have to respond and even maybe orchestrate a number of actions to preserve its dominance.

While Russia, Europe and Japan will need to respond to this dynamic in different ways their approach will be reactive rather than proactive. The

Russia China relationship and how that will affect US actions could also be important.

There is also little doubt that space, nuclear weapons, conventional weapons and strategies of war and deterrence are now inextricably connected with each other.

For a country like India which is emerging as a space power understanding these relationships and their impact on the space component of a country's capabilities is extremely important.

Though its space assets are smaller than those of the other major powers they are not insignificant. At the very least they may need to be protected against the direct and indirect consequences of actions taken by the other space powers. [16]

Given these global trends and developments where the use of space is linked to both nuclear and conventional war what actions should India take in order to protect her national interests. This is the issue that will be addressed in the subsequent sections of the paper.

[16] One estimate placed the value of Indian space assets at 100000 crores. See K.Kasturirangan, "The Emerging World Space Order – An Indian Perspective", Keynote Address Space Security Conference, November 1-14 New Delhi. For a more rigorous economic evaluation of the benefits of the Indian Space Programme see U.Sankar, "The Economics of India's Space Programme - An Exploratory Analysis", Oxford University Press, New Delhi 2007 xiv, p.312

2.0 Indian Capacities, Capabilities & Gaps - Space Situational Awareness (SSA)

As stated earlier India was not aware of China's ASAT test till well after the test. **Though information on the orbital parameters of the Yaogan 9 A, 9 B and 9 C constellation was available in the public domain Indian establishments were apparently unable to link these to an ELINT capability.**[17]

These are symptoms of deep rooted problems in Indian capabilities to monitor and track satellites in orbit around the earth.

The current mix of Indian and foreign ground TT&C stations are adequate for tracking Indian satellites and space launches that emit radio signals. **However Indian capabilities for tracking inactive satellites and space debris are extremely limited if not non-existent.**

India has invested a fair amount of money in creating a set of space based assets for a variety of national development tasks. Even if one were to ignore the military implications of what is happening in space India needs to protect these assets from risks posed by the exponentially increasing population of dead satellites and space debris.

India therefore needs to create a suitable network of long range radars that could track space objects. A network of optical tracking and laser ranging stations would complement and enhance the capabilities of the radar network.

---

[17] North American Air Defense (NORAD) Command makes available two line elements of all satellites that enable one to propagate all orbits. See http://www.celestrak.com/NORAD/elements/

Apart from the creation of this infrastructure, India also needs to identify suitable entities within the National Security complex that would be responsible for the routine monitoring of the space environment. These entities could combine openly available information along with their primary data to provide updates and reports on what is happening in space and their implications for India. They could also issue warnings to satellite operators on possible risks arising from debris and inactive satellites.

India also needs to grow the human resource base that is able to use public domain information to provide independent assessments of what is happening in space.

These activities are best done within the University or think tank systems. While there are a number of groups across the country that deal with the political aspects of nuclear weapons and space activities there are practically no such groups that deal with the technical details of nuclear or space issues. This situation needs to be changed.

A deeper study of orbital motions around the earth can also benefit a number of scientific domains such as geodesy and astronomy.

A strengthening of these aspects at Research Centers and Universities would create the necessary human resource base needed for the above activities.

Routine monitoring and a deeper understanding of what is happening in the space environment would be a very high priority area for an emerging power like India.

3.0 Capacities, Capabilities & Gaps - Space Based C4 Assets

3.1 The Role of Space Based Assets for Command, Control, Communications & Computers (C4)

National security systems are complex systems that require a high degree of specialization. Command, Control and Communications functions are the glue that bind the various entities so that they work together to execute a particular strategy. Space based satellite communications systems provide a robust way of linking such diverse assets and organizations spread out over a large geographic area.

Developments in technologies such as encryption, frequency hopping and spread spectrum provide reliable routes for ensuring assured command, control and communications functions via both dedicated military and non-dedicated commercial satellites.

Dedicated, advanced communications satellites with multiple reconfigurable antennae beams operating in the Geo-Stationary Orbit (GSO) and catering to the C4 requirements of the military will be needed. Some of the required capacities could also be provided by commercial satellites. These satellites can cater to both mobile and fixed users and increasingly handle all kinds of digital data including images and streaming video.

The INSAT series of Geostationary Communications satellites currently provide these services to users in India including the military. There is therefore a large base of experience and capabilities in the country. If the National Security Complex in the country has to move towards a more information oriented operational capability these capacities may need augmentation.

The launch and satellite record indicate major gaps in capacities to build, launch and operate these systems. There could also be areas of technology such as secure communications, encryption, design of multiple beam satellites, electronically scanned phased array antennae etc., where available capabilities need to be strengthened.

3.2 GSO - Communications Satellites Indian Capacities, Capabilities & Trends

Figure 6 provides an overview of the various Indian built communications satellites that have been placed in GSO. These include satellites that have been launched by foreign launchers such as Ariane as well as by Indian launchers such as PSLV and GSLV Mark 1 & Mark 2.[18]

Most of these have been launched for meeting civilian needs. Only two of them the GSAT 7 launched by Ariane in 2013 and maybe the GSAT 6 launched by the GSLV Mark 2 in 2015 may have been dedicated for military use.

The maximum number of GSO communications satellites launched by India in any given year is 3 achieved in 2003 with two foreign and one indigenous GSLV Mark 1 flight.

The satellite record shows an average capacity of 1 GSO satellite per year over the whole period from 1992 to 2015.

If we take the average from 2000 onwards the average number of satellites is 1.25 per year.

---

18 Based on data collated from http://www.isro.gov.in/spacecraft/list-of-communication-satellites

If we take the even more recent record from 2010 this has increased to 1.5 satellites per year.

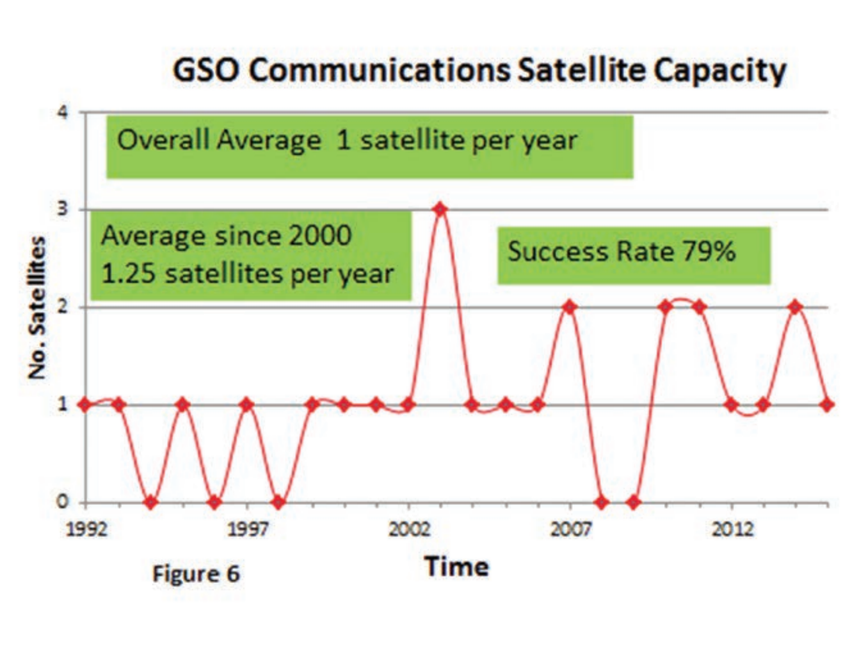


Figure 6

Capabilities

Two kinds of benchmarks may be needed to assess capabilities of today's communications satellites.

One clear benchmark is the capacity of the satellite which depends on bandwidth, modulation schemes and a whole host of other technical factors such as frequency reuse, data compression methods used etc. The capacity is also dependent on the lifetime of the satellite. Composite measures that combine these can be arrived at to compare different satellites.

In simple terms this can be termed as a capacity measure.

The other important measure is to look at how the capacity is being used to service users in different locations and the kind of services that can be provided to them. This depends on the number of beams, the geographical spread of the beams and the ability to switch between geographies and different kinds of services.

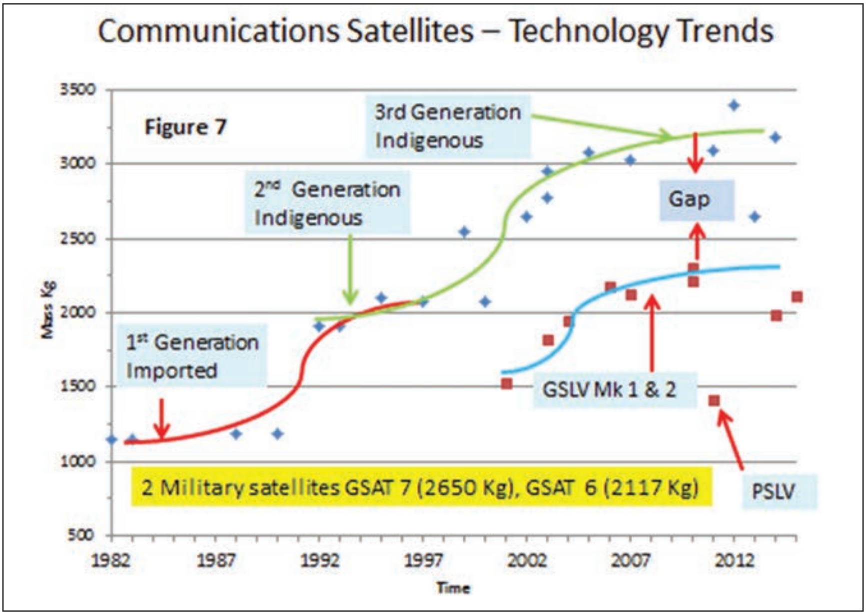
In simple terms this can be termed as a flexibility measure.

The evolution in capabilities of the satellite such as communications capacity, providing flexibility in connecting different regions of the country and even the efficiency of the use of the radio-frequency spectrum are directly correlated with the satellite mass. Therefore satellite mass is a useful surrogate measure to assess the overall evolution of the capabilities of the satellite.

Figure 7 plots the evolution of the masses of the various communications satellites placed in Geostationary Transfer Orbit (GTO) by India.[19]

Figure 7 shows that the satellites that have been placed in orbit through procured launches show an increasing trend in satellite mass. We can see three generations of communications satellites from the procured INSAT 1 generation with GTO masses of 1200 Kg through the INSAT 2 generation of 2000 Kg masses culminating in the third generation of INSAT satellites with masses of about 3200 Kg.

[19] http://www.isro.gov.in/spacecraft/list-of-communication-satellites



The Figure also reveals that the satellites launched by the GSLV Mark 1 and Mark 2 versions can only place a maximum mass of 2200 Kg in GTO. This is about a 1000 Kg below the mass of satellites that India has built but which have been launched from abroad.

This reveals a gap in indigenous launch capabilities. While this may not be important for meeting civilian needs which could be met by procured launches, it could become a problem in case the satellite has a military purpose.

The GSAT 7 and maybe even the GSAT 6 satellites launched by the Ariane and the GSLV Mark 2 respectively do suggest that most basic functions needed for a military communication function could be met with a satellite mass of 2000 to 2500 Kg.

The margins available for meeting these needs via the GSLV Mark 2 are still very thin. To meet many current operational functions additional mass may definitely be needed.

Therefore accelerating the development and operationalization of the GSLV Mark 3 four tonne (4000 Kg) class launcher becomes a crucial component of the Indian space strategy especially for meeting military needs.

Global Trends & India's Position

To place Indian communications satellites in their proper position vis a vis global developments it may be useful to look at **Figure 8.**

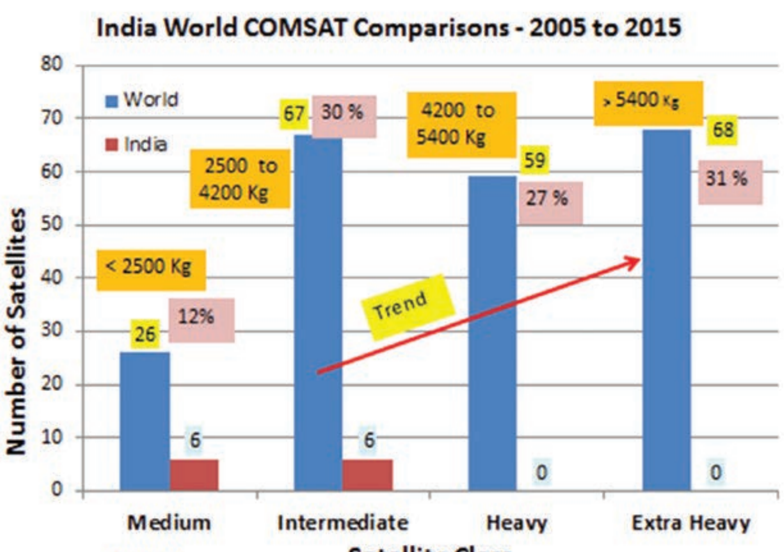


Figure 8

The market for Geostationary Communications Satellites comprises 4 market segments.

These are:

- Medium category satellites whose mass in GTO is less than 2500 Kg;
- Intermediate class satellites with GTO mass of 2500 - 4200 Kg
- Heavy satellites with masses in GTO between 4200 and 5400 Kg;
- Extra Heavy satellites with masses in GTO that is greater than 5400 Kg.

The WGS series of US Defence satellites have a launch mass of about 6000 Kg.[20] One of the largest capacity commercial communications satellite is Viasat. This has a launch mass of about 6700 Kg.[21] The overall trends both in the civilian and military domain suggest a move away from the medium and intermediate category towards the heavy and extra heavy categories.[22]

Indian Communications satellites that have been launched by foreign launchers like Ariane fall in the intermediate category. Indian Communications satellites that have been launched by the indigenous GSLV launcher fall in the medium satellite category. This relative positioning of Indian satellites vis a vis world trends suggests that Indian capabilities for Communications satellite manufacture has to grow from the intermediate class towards the heavy and extra heavy categories.

---

20 Wideband Global Satcom (WGS) is a US led global advanced satellite system with a number of participating countries. A constellation of advanced communications satellites provide global connectivity for all military operations. Australia, Canada, Denmark, Luxembourg, Netherlands and New Zealand are part of this global system. See http://www.afspc.af.mil/library/factsheets/factsheet.asp?id=5582

21 http://www.nasaspaceflight.com/2011/10/ils-proton-m-launch-highest-throughput-satellite-viasat-1/

22 For an overview of these trends in satellite masses see Federal Aviation Administration, "The Annual Compendium of Commercial Space Transportation: 2014", February 2015, PP 100-104 available at https://www.faa.gov/about/office_org/headquarters_offices/ast/media/FAA_Annual_Compendium_2014.pdf

Figure 9 provides a comparison between the Eutelsat series of satellites and the INSAT series of Indian satellites.

As we can see from Figure 9 INSAT satellites have increased in mass from about 2000 to 3000 Kg. Over the same period Eutelsat satellite masses have increased from 3000 Kg to about 6000 Kg.[23]

A matter of greater concern is that the gap between the two which was about a 1000 Kg till about 2005 has now widened to about 3000 Kg.

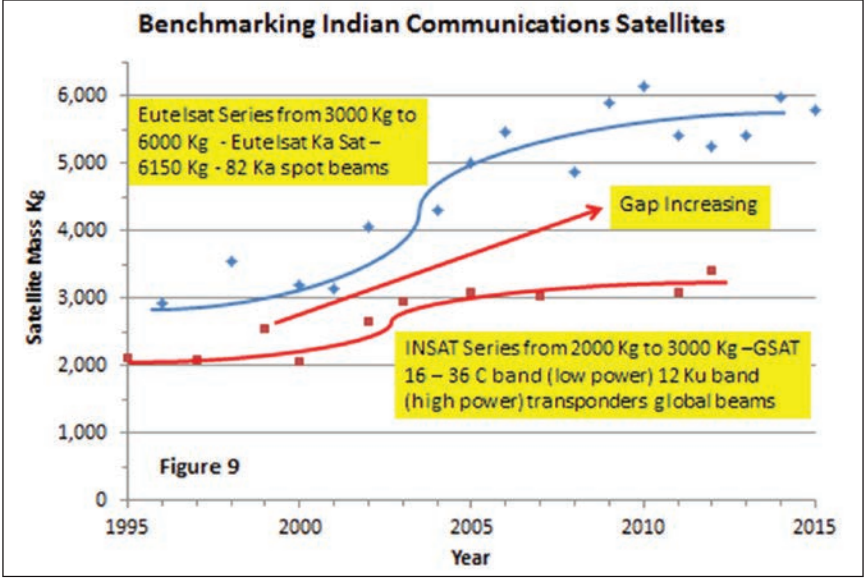


Figure 9

The analyses also seems to reaffirm the point that indigenous launch capabilities have to move quickly from the current

[23] The timeline and the satellite masses have been taken from UCS_Satellite_Database_9-1-15 at http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database.html#.Vgou932rHgI

GSLV Mark 2 with a two tonne GTO capability towards at least a four tonne class GSLV Mark 3. There also appears to be a need to also move towards a 6000 Kg GTO capability. Ways and means to redress the ever widening gap in satellite capacities and capabilities is therefore a high priority for India.[24]

3.3 The Promise of Ion Propulsion for Reducing Satellite Mass

One major technology development that shows promise in reversing the trend towards heavier satellites has been recently introduced into the communications satellite market by Boeing.

It is a well-known fact that over half the mass of a typical Geostationary Communications satellite is made up of propellant. Most of this propellant is consumed in moving the satellite from GTO to GSO.

Ion propulsion provides an alternative way of providing the thrust required to move a satellite from GTO to GSO. It involves the acceleration of ions typically xenon ions through an electric cum magnetic field and pushing it out through a suitable exit. Though ion thrusters have high specific impulse the thrust levels they provide are much lower than chemical propellants. As a consequence of this the time taken to go from GTO to GSO will take several months and if the satellite is heavy even longer. Chemical

[24] The space programme seems to be aware of this gap. It has floated a tender for the supply of a 6 tonne, Ka band communications satellite from global vendors. See http://www.thehindu.com/news/national/isro-eyes-a-6tonne-k-band-satellite/article4134039.ece. The 2014-15 Annual Report of the Department of Space has an entry for GSAT 11 that states, "GSAT-11 is an advanced communication satellite employing a new class of bus weighing 4000-6000 kg. The payload includes Ka x Ku-band Forward Link Transponders and Ku x Ka-band Return Link Transponders. Subsystem fabrication activities are in various stages of completion. A detailed qualification programme is in an advanced stage of completion."

propellants on the other hand may have lower specific impulse but provide a much higher level of thrust than ion propulsion. The journey from GTO to GSO therefore takes only days instead of months.

However the major gain from the use of ion propulsion is that the amount of propellant carried by the satellite that typically accounts for at least half the satellite mass can be more or less eliminated. Though ion propulsion also requires some mass it is significantly lighter than the heavy chemical propulsion systems that spacecraft carry. Current thinking that has been to some extent substantiated by practice suggests that this trend may become more pronounced in the next few years. [25]

In early March 2015 the first two all ion propulsion satellites were launched aboard a Falcon X launcher. The two satellites were both built by Boeing. The Asia Broadcast Satellite 3A (ABS 3A) weighed 1954 Kg with 24 C and 24 Ku band transponders.[26] The second satellite was the Eutelsat 115 W B satellite with a mass of 2205 Kg carrying 34 Ku and 12 C band transponders.[27] Because of the significant weight saving arising from the use of ion propulsion for moving the satellite from GTO to GSO they could be accommodated for a dual launch on the Falcon X. This reduced the launch cost significantly making the transition to an all ion propulsion approach economically attractive.

Both satellites are currently in the process of moving from GTO to GSO. This orbit raising operation using Boeing patented technology may take about 8 months to complete.

[25] For details see Stephen Clark, "Boeing's first two all-electric satellites ready for launch", Spaceflight Now March 1 2015.

[26] http://www.aerospace-technology.com/projects/abs-3a-communication-satellite/

[27] http://space.skyrocket.de/doc_sdat/eutelsat-115-west-b.htm

A similar satellite built by India that carried 36 C & extended C band transponders with 12 Ku band transponders the GSAT 16 launched in 2014 weighed 3182 Kg.

Ion propulsion therefore provides one way in which the gap in launcher capacity can be bridged. If the third generation communications satellites currently being built can be converted into satellites that use ion propulsion resulting in a significant reduction in the mass of the satellite they can be accommodated on the GSLV Mark 2 launcher. The fourth generation intermediate class satellites with GTO masses of 4000 Kg that could be launched by the GSLV Mark 3 can perform like the current heavy class satellites if they can be launched with ion propulsion.

This route to improving indigenous capability is not without its share of problems. Though work on ion propulsion has been going on for some time indigenous capabilities may still not be enough to meet the needs. The long time taken to move from GTO to GSO can also raise the risk of something going wrong. In spite of these issues the ion propulsion route at least provides one way for bridging the launcher and satellite gaps that exist for meeting strategic needs.

3.4 Indian GSO C4 Needs

While the use of ion propulsion will reverse the trend towards heavier satellite to some extent it will not completely eliminate the technical logic for building heavier satellites. The need for large capacities coupled with the need to make this capacity available to a multitude of users across different geographies will definitely demand heavier payloads even with ion propulsion. This is a trend that is common to meeting both civilian and military needs.

The immediate requirement from an Indian point of view is to accelerate the development of the GSLV Mark 3 launcher that will raise the satellite mass in GTO to about 4000 Kg. Even with ion propulsion such masses may be needed if India has to match global trends.

Whether India may need an even bigger launch capability than the GSLV Mark 3 for catering to the Communications needs of the country will depend on how the experience with ion propulsion unfolds in the next few years.[28] There is also a possibility that as satellites get heavier they may need to revert to standard chemical propulsion for operational reasons. These considerations may dictate a larger launch capability than that provided by the GSLV Mark 3.

The C4 needs of the Indian Armed Forces can be possibly met with one large satellite shared by all the services or separate satellites dedicated to each service.

Constraints both from both the satellite building as well from the launcher side may dictate smaller satellites.

Assuming that each service may need a dedicated system a minimum of three operational satellites with one spare in orbit may be needed.

Since the systems may need to be become operational soon all of them may be needed to be launched within a two year period.

Thus a minimum capacity of two Communications Satellites and two launchers per year may be needed to meet domestic military needs.

---

[28] The use of ion propulsion for reducing the satellite mass has been talked about by ISRO too. See comments of K.Sivan Director Liquid Propulsion Systems Centre in Dennis J. Jesudasan, "ISRO navigation satellite in orbit", The Hindu March 28, 2015.

The current civilian requirement is about 1.5 satellites per year and is likely to grow.[29]

A total capacity of 4 GSO Communications satellites along with their associated launchers may be needed in all for meeting military and civilian needs. This capacity will cater to a peak demand. Surplus capacity available during the lean period could be used for building satellites to cater to the export market or for meeting other GSO needs such as weather or navigation services.

This expansion of the military component of GSO communications capacity may also need suitable orbital slots and spectrum in the Geostationary Orbit. This aspect should also be kept in mind in formulating the country's strategy.

3.5 A New Trend –Small Satellite Constellations for C4 needs

Constellations of satellites in Low Earth Orbits could also provide connectivity. The Soviet era Strela satellite constellation that could store and forward various kinds of data has been around for a fairly long period of time.[30]

The commercial world has also seen the emergence of a number of LEO constellations such as ORBCOM, and Globalstar that provide a variety of communications services. Most of them do not operate on direct satellite to satellite links but use suitably located ground stations to route the data

[29] Available evidence from the ground suggests that there is a lot of unmet demand for transponders over India. Many TV channels in India for e.g. use transponders on foreign satellites

[30] http://www.russianspaceweb.com/strela_comsat.html

via satellite to the required destination.[31]

The Iridium constellation of 66 satellites was the first orbiting satellite based communication system that used satellite to satellite switching and communications technologies for providing global coverage.[32]

O3b is an operational system that uses 12 satellites operating in an 8063 Km orbit above the equator to provide high speed internet connectivity to users between 45 N Latitude and 45 S Latitude. It uses 12 Ka band steerable antennae along with a network of suitably located gateway stations to provide the required connectivity. Each of the satellites weighs about 700 Kg. The constellation provides a combined capacity of about 100 Gigabits per second. They are launched four at a time by Ariane's Soyuz launcher from Kourou in French Guyana.[33]

More recently a number of new start-up companies such as OneWeb are proposing to launch large constellations of small satellites for providing global broad band Internet connectivity via satellite to satellite networks.

The constellation proposed by OneWeb will have 650 satellites orbiting in 20 different planes at altitudes of 800 and 950 Km. Airbus Defence & Space has been selected as the contractor to roll out the satellites. The satellites which are expected to weigh about 175 to 200 Kg will be launched 32 to

[31] For an overview of LEO satellite systems that covers most of the current systems see Christopher Redding, "Overview of LEO Satellite Systems",1999 International Symposium on Advanced Radio Technologies, at http://www.its.bldrdoc.gov/media/30329/red_abs.pdf

[32] Kris Maine et al "Overview of Iridium Satellite network,"WESCON/'95. Conference record. 'Microelectronics Communications Technology Producing Quality Products Mobile and Portable Power Emerging Technologies' available at http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=485428

[33] http://www.o3bnetworks.com/technology/

36 at a time on board an Ariane Soyuz launcher.[34]

The satellites operate in the Ku Band for which the company has a licence.

The design of the satellite is such that interference with the Ku band transmissions of GSO satellites are within acceptable limits.

The satellites use phased array antenna with each satellite having a capacity of about 8 Gigabits per sec.

The satellites connect to users through a small terminal that connects to all users using standard radio frequencies used for mobile services. Thus cell phones, laptops and tablets can be directly connected to the Internet via these terminals. These can be added suitably to existing mobile networks to directly connect to the Internet.

These developments suggest that constellations of small satellites in low and medium altitude orbits can provide services for meeting both routine as well as crisis mode operations.

These could be dedicated to military use or could be a part of a dual use network.

India has so far no experience with orbiting constellations of communications satellites. As is the case with ISR functions the trend seems to be towards building smaller satellites and launching them more frequently.

One reasonably large constellation of orbiting satellites needs to be

[34] http://spaceflightnow.com/2015/07/01/oneweb-launch-deal-called-largest-commercial-rocket-buy-in-history/

designed, built and launched within the next two or three years to keep future options open for the country. Both civilian and military needs can be met through the creation of this capability.

A constellation of about 40 satellites in a suitable LEO orbit that provides coverage over the Asia Pacific region may be the first step that India needs to take in being able to come to terms with this emerging technology system. The satellites whose masses can be in the range of 150 to 200 Kg can be launched three or four at a time by the PSLV launcher.

In terms of capacities and assuming a two year period for the creation of the constellation this would translate into a capacity of 20 small satellites per year along with 5 launches of the PSLV vehicle.

A key requirement for an efficient operational C4 network would be the need to integrate the space part of the network which may include both geostationary and orbiting satellites with other modes of connection such as wireless and fiber optics.

Clearly a space strategy for the country should address these gaps in capabilities and capacities.

3.6 Overall Requirements of C4 Capabilities

Table 1 summarizes the C4 satellite and launcher requirements for meeting both civilian and military needs.

Table 1

C4 Satellite & Launcher Requirements for India

Orbit Type	User	Satellite Class	Constellation size	Capacity per year	Launcher per year	Comment
GSO	Military	Medium to Intermediate 2000 – 4000 Kg	4	2	GSLV Mark 2 GSLV Mark 3 2 Launchers	Ion Propulsion may enable use of GSLV Mark 2
GSO	Civilian	Medium to Intermediate 2000 – 4000 Kg	9	2	GSLV Mark 2 GSLV Mark 3 2 launchers	Ion Propulsion may enable use of GSLV Mark 2
LEO	Military Internet	150 -200 Kg	40	20	PSLV 5 launchers	Only regional coverage

There are also a number of technology areas where Indian capabilities have to be significantly enhanced to meet medium and longer term anticipated needs. These include:

- Ion Propulsion
- Satellite to Satellite links
- Secure Communications
- C4 Network Operations – integration of space and other networks
- Satellite to satellite and satellite to ground Laser Communications
- Networked LEO Communications Satellite systems architecture and design
- Operational use of GSLV Mark 3

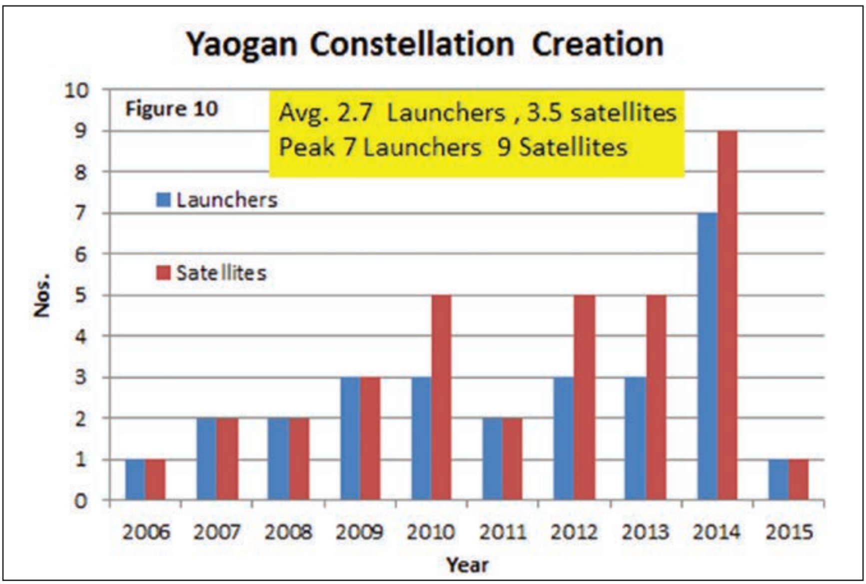
4.0 Capacities Capabilities & Gaps - Space Based ISR

4.1 Global Trends in Intelligence Surveillance & Reconnaissance (ISR)

The Third area that needs a more detailed scrutiny is the realm of Intelligence, Surveillance & Reconnaissance (ISR).

China's creation of a dedicated constellation of Yaogan military satellites provides a real world demonstration of what is needed to perform a global ISR function.

Figure 10 provides an overview of how China went about creating the current Yaogon satellite capability that directly feeds into an operational ISR function.



At any time China has in place at least 16 satellites that together enable it to monitor military activities in any part of the world in near real time.

These comprise three ELINT clusters of three satellites each, 5 SAR satellites that provide all weather, day night coverage, 4 high resolution Electro-optical satellites and another 4 medium resolution electro-optical satellites that have large area coverage. The 3500 Km broad area coverage provided by an ELINT cluster cues the optical and SAR satellites to locate identify and track objects of interest.[35]

A typical ELINT cluster consists of three satellites that are placed in a special 63.4 degree inclination orbit. The three satellites form a triangle in which the spacing between them is known.

Each of the satellites is equipped with a wide band receiver that is able to receive electronic emissions from various objects of interest on the surface of the earth. The same signal is received by the three satellites at different times. Using the time difference in the reception and the spacing between the three satellites the location of the emitting object can be fixed.

The launch and establishment of the Yaogan 9 A, 9 B and 9 C cluster in 2010 signaled China's entry into an elite group of countries that have operational ELINT systems. Currently China has at least three different ELINT clusters that are suitably spaced in orbit so as to provide it with an operational global ELINT capability.[36] A recent launch of the US provides

[35] See S.Chandrashekar & Soma Perumal, "China's Constellation of Yaogan Satellites & the Anti-Ship Ballistic Missile: January 2015 Update", http://isssp.in/chinas-constellation-of-yaogan-satellites-the-asbm-january-2015-update/

[36] For a detailed description of the ASBM system and the role of space assets see S.Chandrashekar et al, "China's Ant Ship Ballistic Missile Game Changer in the Pacific Ocean", International Strategic & Security Studies Programme (ISSSP), National Institute of Advanced Studies (NIAS) Bangalore, India November 2011.

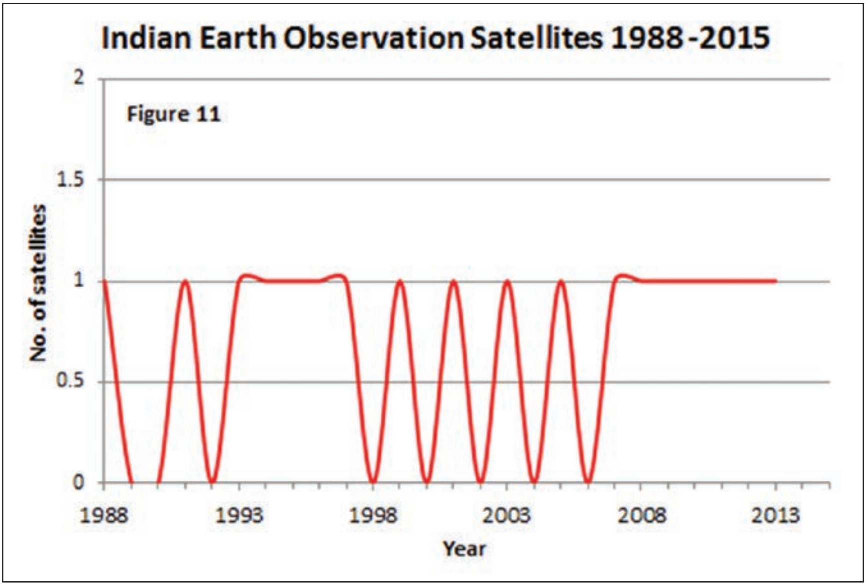
an indication of the current capabilities of the US.[37]

4.2 Indian Remote Sensing Satellite Capacities Capabilities & Trends

Capacities

India has in place a complement of remote sensing satellites equipped with both Synthetic Aperture Radar (SAR) and Electro-Optical (EO) imaging sensors. These are currently meant largely for meeting civilian needs.[38]

Figure 11 provides an overview of the various remote sensing satellites launched by India.



[37] Please see William Graham, "NROL takes a ride uphill on ULA Atlas V", October 7 2015 available at http://www.nasaspaceflight.com/2015/10/nrol-55-set-to-ride-uphill-on-ula-atlas-v/

[38] http://www.isro.gov.in/spacecraft/list-of-earth-observation-satellites

Starting from 1988 with the launch of IRS 1A India has so far launched 18 indigenously built remote sensing satellites.

Currently Resourcesat 1 & 2, Cartosat 1, 2, 2A & 2B, Oceansat 2 and Risat 1 are the indigenous satellites that provide operational services.

Risat 1 was the first indigenously built SAR satellite that India launched in 2012. Indian users also have access to data from Risat 2 a foreign built SAR satellite that was launched by PSLV.

From Figure 11 it is clear that current Indian capacities for building earth observation satellites for meeting civilian needs is about 1 satellite per year. Associated with this is also a PSLV launcher demand of one launch per year.

Indian Remote Sensing Satellite Capabilities - Trends

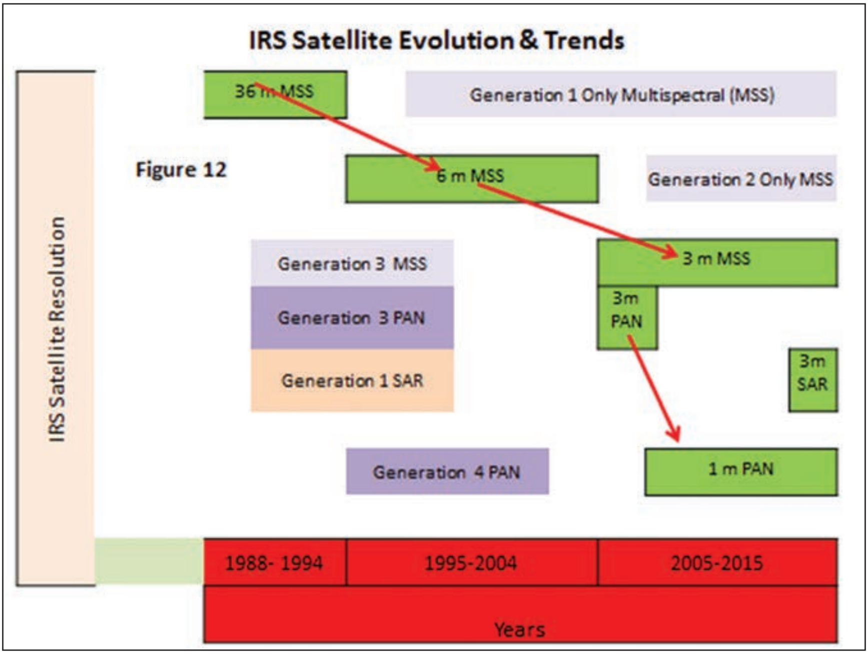
The key requirements for making comparisons relevant for the military domain are the spatial, spectral resolutions of the satellites. A related capability is whether the spatial and spectral capabilities are provided in one instrument or through several instruments. The mass of the satellite for achieving a certain spatial and spectral resolution capability is also a relevant parameter

India has built a number of EO satellites as well as one SAR satellite over the last 25 years. **An overview of the evolution of this capability is shown in Figure 12.**

From Figure 12 we can see the following trends.

After achieving a reasonable capability in both PAN and multispectral capability through the launch of IRS 1D in 1997 India has chosen to separate out the hi-spatial resolution Panchromatic capability from the multispectral capability and provide them through different satellite platforms.

The Resourcesat series provides multispectral imagery whilst the Cartosat series provides Panchromatic imagery.



In terms of multispectral capabilities starting with a resolution of 36 m in the first generation IRS satellites launched in 1988 India quickly moved into a multispectral resolution of about 6 m by 1995. During the 1995 to 2000 time frame Indian civilian resolution was possibly the best in the world. From 6 m India progressed to a multispectral resolution of about 3 m by 2005. This is reasonably close to the current global standard for multispectral data.

As far as Panchromatic imaging is concerned starting from a resolution of about 3 m in 2005 India achieved a 1 m Panchromatic resolution through Cartosat 2 launched in 2007.[39] This capability is comparable to the best in the world today.

The first indigenously built RISAT 1 SAR satellite was launched in 2012.[40] The highest resolution provided by the SAR in this satellite is about 3 m. Though adequate for meeting most operational needs this may be below the global state of art of 1 m resolution in the spotlight mode.

From a functional point of view optical imaging capabilities via separate multispectral and PAN platforms are reasonably close to the current world standard. These may also be adequate to cater to most of the ISR functions.

Globally however both PAN and multispectral imageries are provided from the same set of sensors on one platform. Whether India needs to go this route from the operational point of view is one consideration to keep in mind for meeting military needs.

4.3 Benchmarking Indian Remote Sensing Satellites

Benchmarking EO Imaging Satellites

To provide typical benchmarks for assessing Indian capabilities it may be worthwhile to look at one recent example that also has a strong Indian connection.

On July 10 2015 the PSLV Launcher placed a constellation of three identical

39 http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLVC7.pdf

40 http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLVC19.pdf

DMC3 remote sensing satellites built by Surrey Satellite Technology Limited (SSTL) into a 647 Km 98.06 degree inclination sun synchronous orbit. Each of these 447 Kg satellites carried an advance electro-optical imaging instrument that can provide 4m multispectral imagery in four bands as well as a 1 m PAN image.

The satellites are spaced 120 degrees apart in the orbit plane so as to be able to image any target area at least once in a day. The satellites do not carry chemical propellants for attitude and orbit control. They use a xenon thruster for this purpose. The entire imaging capacity of this three satellite constellation has been bought by a Chinese company called 21st Century Aerospace Technology Company which most probably will sell parts of this capacity to various users both in China as well as elsewhere in the world.[41]

If we use this as a bench mark it would appear logical to integrate the multispectral as well as PAN imaging functions into one payload. The overall weight of the satellite that performs this combined function should be around 450 Kg.

Current Indian satellites that provide PAN one metre imagery weigh around 700 Kg. Indian remote sensing that provide multispectral imagery with about 3 m resolution also carry other optical imaging payloads for many other civilian applications. These multiple camera satellites weigh around 1200 Kg.

Even after accounting for differences because of these configuration issues there are still significant gaps in terms of technology between the SSTL benchmark and Indian satellites. One reason for this difference could come about simply from the use of ion propulsion in the SSTL built satellites versus the use of conventional chemical propulsion systems on the Indian satellites.

[41] http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLV-C28.pdf

Though functionally Indian satellite capabilities are comparable to state of art they appear to be heavier than current world standards.

There may also be a need to integrate both hi resolution PAN imagery with lower resolution multispectral imagery in one camera system from the operational convenience point of view.

These areas need to be addressed through a major technology effort so that Indian satellites can meet global benchmarks both in function as well as in weight.

One other area of special concern for meeting military needs relates to the use of the infrared or thermal bands for imaging applications.

Though the INSAT weather instruments use thermal bands for weather monitoring these bands are not used on any of the imaging instruments carried by Indian orbiting remote sensing satellites**. Imported discrete detectors may be used for the IR channels of the GSO weather satellites. Trends in detectors seem to be moving towards use of arrays and mosaics. Detectors need to be cooled for efficient operation. Location of the cooler to ensure proper functioning of the detector and the imaging instrument is also a challenge. This is an area where India could become vulnerable to embargos and control regimes. Infrared detectors, active cooling systems and spacecraft architectures are therefore particular areas that may require national attention.**

Benchmarking SAR satellites

India launched its first SAR satellite in 2012. The satellite mass of 1858 Kg was one of the heaviest satellites put into orbit by the PSLV. The onboard satellite propulsion system was used to raise the initial PSLV orbit of 480 Km to the final altitude of 536 Km needed for the mission. The SAR operates in the C band.[42]

Though the overall capabilities of the Indian built SAR payload is very similar to those offered by other advanced space powers, it does not operate in the high resolution spotlight mode. It offers a strip map resolution of 3 m that is comparable to those offered by other satellites.

In terms of weight a useful benchmark for the Indian SAR satellite could be the capabilities of the Indian bought Risat 2 SAR satellite.[43] This satellite weighs 300 Kg provides all modes of SAR operation from the very high 1 m resolution spot light mode through the lower resolution strip map mode into the coarse resolution scan SAR mode. Though the frequencies of operation of the indigenous Risat 1 and the bought out Risat 2 are different this comparison suggests that Indian built SAR satellites are much heavier.

For comparison Chinese built SAR satellites weigh about 2200 Kg[44] the Italian built Cosmo Skymed X band SAR satellite weighs 1700 Kg, the German Terra SAR X band satellite weighs 1230 Kg and the Canadian Radarsat 2 weighs about 2200 Kg.[45] By these standards which are of 2007 vintage Indian capabilities are not too far from other those of some of the more advanced countries.

---

42 http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLVC19.pdf

43 http://www.isro.gov.in/Spacecraft/risat-2

44 The capacity of the Long March CZ 2C or CZ 4B that have been used is about 2100 Kg to 2200 Kg in Sun Synchronous orbit.

45 http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database.html#.Vgou932rHgI

From an ISR point of view the day night and all weather capabilities of SAR instruments on orbiting satellites are very important. Current capabilities may be adequate for meeting most of the needs. However some effort has to be made to reduce the mass of the satellites. Once again ion propulsion could play a major part in bringing down weights.

4.4 Small Satellite Constellations

An emerging trend that could play a big role in the performance of the ISR function is the growing importance of high quality imagery available from small satellite constellations launched by a number of private companies across the world.

Planet Laboratories a San Francisco based start-up company provides 3 m resolution colour imagery. It plans to provide a complete picture of the earth every day using images produced by more than 100 small satellites. These satellites weigh around 5 Kg and are launched as constellations into earth orbits of various inclinations.

Built out of low cost off the shelf components and launched in numbers they promise to provide an image of the entire planet every day.

Two major flocks of satellites have been launched. The first Flock of satellites was deployed from the International Space Station and orbits the earth at an altitude of about 400 km with an inclination of 52 degrees. The second Flock is in a 620 Km Sun Synchronous Orbit.

About 99 small Dove satellites have been launched by this company. As of March 2015 about 20 of them are operational. The quality of the images provided by these satellites is quite good and may be adequate to cater to many possible military applications as well.[46]

Skybox Imaging another US start-up recently bought by Google promises to provide very high resolution data and video from a constellation of satellites. The first two satellites of a planned constellation of 24 satellites Skysat 1 and Skysat 2 have already been launched. A PSLV launcher is also reported to launch future satellites for this company. The satellites are three axis stabilized and currently weigh around 83 Kg. Both of them have been launched as a part of a multiple satellite launch by the Dnepr and Soyuz / Fregat launchers from Russia.

Skysat 1 and Skysat 2 are in 578 Km and 635 Km sun synchronous orbits. They currently do not have onboard propulsion capabilities. Future versions will have them. They are likely to be ion propulsion modules. The first two satellites were built in-house by the company. Future satellites will be built by Space Systems Loral. [47]

The quality of the images from these satellites has also been evaluated. Their utility for use in a variety of applications including military ones appears to be good.[48]

These are just two examples of the many initiatives taken by the global space industry to make available high resolution imagery on a real time

[46] See presentation by Mike Safayan, "Overview of the Planet Labs Constellation of Earth Imaging Satellites – In Space to Help Life on Earth" at http://www.itu.int/en/ITU-R/space/workshops/2015-prague-small-sat/Presentations/Planet-Labs-Safyan.pdf

[47] https://directory.eoportal.org/web/eoportal/satellite-missions/s/skysat

[48] Pablo d'Angelo et al "Evaluation of Skybox Video and Still Image Products", The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-1, 2014, ISPRS Technical Commission I Symposium, 17 – 20 November 2014, Denver, Colorado, USA, pp 95-99.

basis. With the removal of restrictions on the commercial use of sub-meter resolution satellite images by the US Department of Commerce recently, high resolution images will become even more freely available.[49]

While dedicated military satellites will still be needed for some functions, small civilian satellites could significantly enhance and complement these military functions. The current heavy custom build ISR satellites could also be eventually replaced by smaller satellites that provide the same performance. However these capabilities are not likely to emerge on their own in a country like India. They need to be nurtured and grown through a carefully orchestrated national effort that involves both the government and Indian industry.

An experimental effort with a constellation of 24 satellites of the 100 to 150 Kg class may be needed to give a fillip to national activities in this area. This would require a capacity to build about 8 small satellites per year in order to create a constellation over the next three years. These satellites could be launched four or six at a time by the PSLV. A total of six launches of the PSLV or two launches per year may be needed for this purpose.

4.5 Role of Open Source Data

Capacity bottlenecks do not exist only in launchers and satellites.

The supply of data from dedicated military satellites as well as from a number of openly available sources will create a supply overload and open up a vast pool of various application possibilities.

[49] See Warren Fester, "US Government Eases Restrictions on DigitalGlobe", June 11 2014, at http://spacenews.com/40874us-government-eases-restrictions-on-digitalglobe/

These ISR functions have to be suitably integrated with a variety of military operations and intelligence functions within the national security complex.

The current human resource base as well as the needed capacities to assimilate and deal with these large quantities of data may need to be augmented significantly if this purpose has to be achieved. This requires a major organizational restructuring and human capacity building exercise.

4.6 Indian Intelligence Surveillance & Reconnaissance (ISR) Needs

From Figure 10 which depicts China's experience with the Yaogan series of military satellites a capacity to build 6 satellites per year along with a launch capacity of three launchers appears to be needed if India is to be able to create a minimum constellation within a three year period.

This capacity must include an ELINT capacity of three satellites. The PSLV launcher may not have the required capability to place the three ELINT satellites into the required 63.4 degree inclination 1100 km orbit that is needed for the mission. A larger capacity GSLV Mark 2 may be needed for this purpose.

Taking into account both the military and civilian needs a capacity for building 7 satellites per year may be needed. This should include a capacity of one ELINT constellation of three satellites, one hi-resolution Electro Optical (EO) satellite for military purposes, one hi-resolution SAR for military purposes and two EO or SAR satellite for meeting either civilian or military needs. The launch requirements for placing these satellites in orbit will be one GSLV Mark 2 launcher for the ELINT constellation and 6 PSLV launchers for the others

India has so far not built or launched an ELINT cluster for monitoring Electronic signals of military facilities especially over the ocean areas. This is a major gap that needs to be addressed if an operational ISR capability has to be created.

In addition to the above dedicated military satellite India may also need to build a LEO constellation of small satellites that may eventually at least partially substitute for the larger more expensive customized ISR satellites. A constellation of 24 satellites along with their associated launchers may be needed for this purpose. **Table 2** below summarizes these requirements.

Table 2

Intelligence, Surveillance Reconnaissance Needs (Civil & Military)

Orbit Type	User	Satellite Class	Constellation size	Capacity per year	Launchers per year	Comment
63.4 degree 1100 Km circular	Military	ELINT cluster in one launch 300 to 400 Kg each	3 clusters of 3 satellites each	1 cluster of 3 satellites	1 GSLV Mark2 launch	Critical for ISR needs
LEO 500 to 1200 Km SSO	Military	EO / SAR EO 500 Kg SAR 1500 Kg	12 satellites (6 SAR, 6 EO)	4 EO / SAR satellites	4 PSLV launches	Critical for ISR needs
Satellite constellation in LEO	Military	100 to 150 Kg each	24 small satellites	8 satellites	2 PSLV launches	Complements dedicated ISR satellites.

Apart from these requirements for satellites and launchers there are a number of technology areas that may require development for meeting operational needs. Some of these critical areas are:

- ELINT Technology Development
- Infrared Technologies and Imaging Sensors
- Improved Integrated Optics for Imaging sensors
- SAR weight reduction initiatives
- Small satellites related developments
- Data Processing especially SAR data processing
- Use of commercial open source data for strategic work
- Tracking Data Relay Satellite System (TDRSS) Compatibility related developments

5.0 Capacities, Capabilities & Gaps - Space Based Support Services for C4ISR

5.1 Telemetry Tracking & Data Relay Satellites (TDRSS)

In addition to the command, control and communications functions that can be carried out via satellite Networks, satellites are also used to command, control, communicate with and receive relay data from a large number of orbiting satellites that collect ISR related information from around the world.

Such command, control and data collection functions were originally carried out through a network of ground stations located suitably around the world. In spite of the use of a large number of stations, collection and relay of data from this network of ground station did not provide adequate global coverage.

Two or three Tracking and Data Relay Satellites in Geostationary Orbit located suitably over a country provide a way in which the coverage of ISR assets can be extended over a large part of the earth.

The US pioneered the use of such satellites with the first of them entering operational service in 1983.

The US currently has nine such satellites in orbit that cover the Atlantic, Pacific and Indian Oceans. The constellation comprises first generation, second generation as well as third generation satellites. The third generation satellites have a launch mass of about 3200 Kg.[50]

---

[50] UCS_Satellite_Database_9-1-15 at http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database.html#.Vgou932rHgI

The primary ground stations are located at White Sands New Mexico. The US also has a station in Guam for complete coverage.

In principle two satellites can cover all satellites in orbit from 200 Km onwards. However if both satellites have to connect to a single ground station there could be some gaps in coverage. For Low Earth Orbits between 200 and 1200 Km coverage of all satellites will be better than 85%.[51]

Russia too followed the US example and the first Luch satellite was launched in 1985. Three Luch satellites located at 16 W , 95 E and 160 W in GSO provided coverage over the Atlantic, Indian and Pacific Oceans respectively. After the break-up of the Soviet Union this capability took a back seat and only one second generation Luch satellite was launched in 1995. It stopped working in 1998. These satellites had a mass of about 2400 Kg and were directly injected into a near geostationary orbit. [52]

More recently the programme has been revived. Three satellites Luch 5A, 5B 5V are available for use by the Russian manned and military space programmes. These satellites are located at 16 W, 95 E and 167 W in GSO to provide global coverage. They have lift off masses of between 1000 to 1300 Kg and are directly injected into GSO by the Proton Launcher.[53]

Japan also has in place one experimental data relay satellite called the Kodama Data Relay Test Satellite (DRTS). This is being used to support Space

---

51 W.M.Holmes Jr., "NASA's Tracking and Data Relay Satellite System ", IEEE Communications Society Magazine, September 1978, PP 13-20 available at http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=1089760

52 http://www.russianspaceweb.com/luch.html provides an early history of the USSR / Russian Federation initiatives on TDRSS.

53 UCS_Satellite_Database_9-1-15 at http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database.html#.Vgou932rHgI

Station activities as well as data relay from Japanese remote sensing satellites. Located at 90E over the Indian Ocean it provides coverage of at least 60 % of the orbit of a LEO satellite. The satellite has a Beginning of Life mass in GSO of about 1500 Kg. This will translate into a payload of about 3500 Kg in GTO which is very similar to the third generation of US TDRSS satellites.[54]

After experimenting with satellite to satellite optical links via an experimental satellite called Artemis, Europe is poised to employ its own data relay system called the European Data Relay System (ERDS). It will be first system to use optical satellite to satellite links. One Data relay node will be deployed on the Eutelsat 9B satellite located at 9 E. The other will be deployed on another combination satellite located at 31 E. The first satellite will link data from the orbiting Sentinel series of satellites to ground stations in Europe. The satellite to satellite connections will be optical allowing higher data rates. Ka band links will also be there. The first satellite is due to be launched in 2015.[55]

China also has three TDRSS satellites in GSO located at 77.08 E, 176.72 E and16.86 E. These are meant to exercise command control and data relay functions for their manned space programme and their military ISR satellites such as those of the Yaogan series.

The first Chinese TDRSS satellite Tian Lian 1 was launched by Long March 3C launcher in 2008. It had a GTO mass of 3800 Kg. The second in the series Tian Lian 2 was launched in 2011. It had a GTO mass of 2250 Kg. The third

---

54 Details available at http://global.jaxa.jp/activity/pr/brochure/files/sat10.pdf

55 Dr. Harald Hauschildt et al, “European Data Relay System – one year to go!” Proc. International Conference on Space Optical Systems and Applications (ICSOS) 2014, S1-3, Kobe, Japan, May 7-9 (2014) at http://icsos2012.nict.go.jp/pdf/1569603307.pdf

in the series was launched in 2012 and had a mass of 2000 Kg in GTO. [56]

If India choses to enhance its ISR capabilities via space based assets it will definitely require secure channels over which data from this large constellation can be reached to a central control and command center. Between three to five operational TDRSS satellites may therefore be needed for performing these functions.

These are advanced satellites operating in several frequencies that can exercise C4 functions over an orbiting constellation of ISR satellites in a secure fashion. They are very similar to the advanced multipurpose multi frequency multi beam communications satellites. As the European example shows conventional and data relay packages can be combined in one satellite. They will have to deploy and use a number of antennae and antennae beams to provide the needed service. At some stage in the near future the satellite to satellite links may require the use of laser communications systems.

These satellites may need masses of over 3500 Kg in GTO. With the use of ion propulsion these masses could come down.

India may need three such satellites in orbit with at least two of them operational at any given time. A capacity of one intermediate class satellite weighing about 3000 to 4000 Kg along with one launcher of the GSLV Mark 3 may be needed for this purpose. With ion propulsion this could come down to a 2000 to 2500 Kg spacecraft launched by the GSLV Mark 2.

[56] UCS_Satellite_Database_9-1-15 at http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database.html#.Vgou932rHgI

India has so far not built such an advanced spacecraft. This is a gap that needs to be addressed for meeting both civilian and military needs.

5.2 Weather Satellites

Monitoring the weather is also an important component for the effective operation of any ISR system. Advanced space powers use a combination of geostationary and polar orbiting satellites to provide weather forecasts. The sensors that are carried on both these platforms and the platforms themselves have seen several generations of evolution. Imaging sensors, sounders that measure vertical profiles operating in the visible, infra-red and microwave regions of the spectrum along with specialized instruments for measuring substances like ozone and other pollutants provide a wealth of data. These are used for making short medium and long range forecasts and for monitoring the earth environment. All these satellites also come equipped with the capability to receive data from data collection platforms on the ground and reach them to a forecasting center.[57]

In the US though weather services for the military was kept separate from the civilian requirement for quite some time for operational and efficiency reasons the two capabilities have been merged. NASA, NOAA and the military now work together for providing weather data for both civilian and military users.[58]

The US operational capability at any given point in time comprises a minimum of three GOES weather satellite in GSO. Two of them provide real

[57] Gary Davis, "History of the NOAA Satellite Program", http://www.osd.noaa.gov/download/JRS012504-GD.pdf

[58] R. Cargill Hall, "A History of the Military Polar Orbiting Meteorological Satellite Programme ", Office of the Historian, National Reconnaissance Office, Center for the Study of National Reconnaissance, September 2001, available at http://www.nro.gov/history/csnr/programs/docs/prog-hist-02.pdf

time data with the third serving as an in-orbit spare. They carry imaging as well as sounding payloads operating in the visible, infrared and microwave wavelengths. They also carry a number of other instruments that provide data related to other weather and climate needs as well as space weather. The GOES 15 satellite weighs 3238 Kg at lift off.

The US also has a minimum of two polar orbiting satellites (there are currently 5 working satellites) in sun synchronous orbit. These provide data from a standard set of instruments and allow measurements that provide a better handle on forecasts over a few days. These are in an 870 Km sun synchronous orbit. Their mass is 1420 Kg.[59]

Europe too has a similar combination of geostationary and orbiting satellites for providing weather satellites. The Second Generation Meteosat (SGM) satellites have now replaced most of the first generation GSO Meteosat satellites. Europe now has five satellites of which one is an in-orbit spare that cover Europe, Africa and the Indian Ocean Area. SGM satellites have a lift off mass of around 2000 Kg and a beginning of Life Mass in GSO of 1200 Kg.

Europe also has two orbiting satellites in polar SSO the Metop A and the Mettop B. These are in 817 Km Sun Synchronous Orbit. Two of them are currently in orbit whilst the third is available for launch. The lift of mass of these satellites is 4085 Kg.[60]

There is a large degree of overlap and continuity between the various instruments carried by the US and Europe. However Europe has added a number of additional instruments in order to understand in greater scientific

[59] http://noaasis.noaa.gov/NOAASIS/ml/genlsatl.html

[60] http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Meteosat/index.html

detail climate change as well as other major issues that could affect the earth.

Russia went through major problems with its space programme after the demise of the Soviet Union. The weather satellite programme was also affected in a serious way.

The original Meteor 1 orbiting weather satellite series was replaced by the Meteor 2 series and then by the Meteor 3 Priroda and the Meteor 3 series.

The Meteor 1 and 2 series were in an 81.2 degree inclined orbit but satellites in the later series were in sun synchronous orbits at different altitudes.

The Meteor 3 M as well as the Meteor M series developed by Russia after the breakup have also had their share of problems. The first satellite of the Meteor M weather satellite series was launched by a Soyuz / Fregat launcher in September 2009. Problems have been reported with the infrared channel of the imager as well as with image correction. The satellite is reported to have failed completely by 2014.

This satellite is in an 832 Km 98.7 degree sun synchronous orbit. The satellite is reported to have a mass of between 2700 to 2900 Kg.[61]

The Soviet Union and later Russia did not have a weather satellite in GSO for quite some time though the Soviet had announced plans for them prior to the breakup. Russia did launch a GSO weather satellite in 1994 but this failed in 1998 leaving it without a GSO based weather prediction capability.

After a number of problems the Elektro L satellite was launched by a Zenit / Fragat combination from Baikonur in 2011. The satellite is working well and

[61] http://www.russianspaceweb.com/meteor.html

is located at 76 degree East in the GSO. The satellite mass in GSO is reported to be 1766 Kg which will mean a satellite mass of nearly 4000 Kg in GTO.[62] Problems with their weather satellites have forced Russia to depend on the US and European data for their weather forecasts.

China launched its first Geostationary Satellite for weather forecasting in 1997. It has since followed this up with a series of Fengyun 2 satellites that provide continuous coverage.

There are currently four Fengyun 2 satellites in orbit with three of them operational and one replacement satellite These satellites have a lift off mass of 1390 Kg and are put into a GTO orbit by the Long March 3A launcher.

China has also in place a series of orbiting Fengyun 3 satellites that are in Sun synchronous orbit of 825 Km. They provide complementary global coverage to the GSO satellites. These satellites have a liftoff mass of 2300 Kg and are put into orbit by the Long March 4 C launcher.[63]

Though India does not have any operating weather satellites in polar orbit it does have a number of satellites that provide dedicated weather services from GSO.

The INSAT 3D satellite has a complement of sensors that provides data on par with other such satellites operating across the globe.[64]

Figure 14 provides an overview of India's capabilities vis a vis some of the other players in providing weather services from

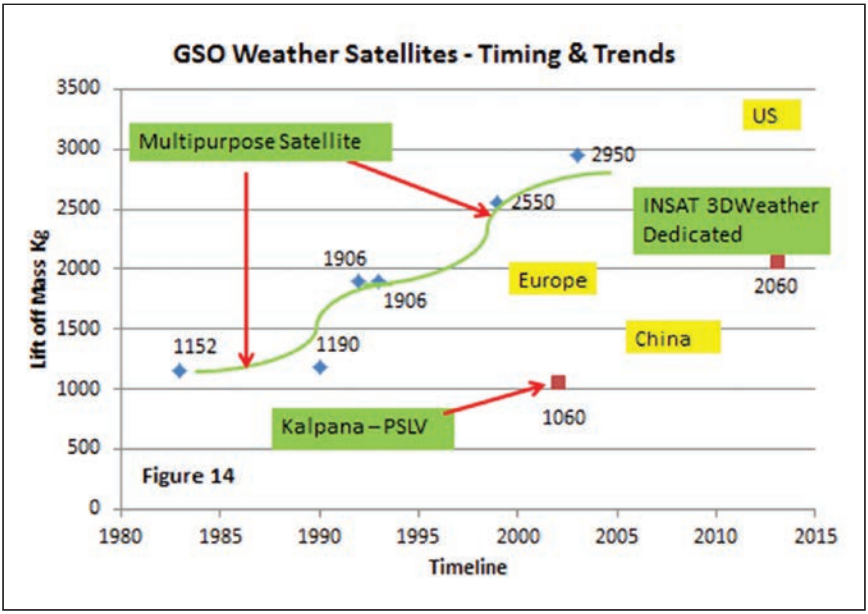
---

62 http://www.russianspaceweb.com/elektro.html

63 UCS_Satellite_Database_9-1-15 at http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database.html#.Vgou932rHgI

64 http://www.isro.gov.in/Spacecraft/insat-3d

GSO platforms. The Figure shows the Indian transition from the weather instruments being carried on a multi-purpose satellite system catering to different services towards dedicated weather service satellites.



The US with a satellite weighing about 3250 Kg is clearly the leader.

European capabilities created in 2002 through their Meteosat 2 series indicate a lift off mass of 2000 Kg. Their next generation of weather satellites that is under planning may increase this mass and move it closer to the US position.[65]

China's capability created in 2006 is about 1400 Kg in GTO. This is not too far away from the Kalpana satellite mass of 1060 Kg in GTO which India launched through the PSLV in 2002.

65 http://www.eumetsat.int/website/home/Satellites/FutureSatellites/index.html

India's INSAT 3D with a mass of 2060 Kg launched in 2013 is on par with European second generation weather satellites.

India thus appears to be on par with Europe and ahead of China with regard to weather services on GSO platforms.

As far as near polar orbiting satellites are concerned the minimum need appears to be at least two operational satellites with one spare in orbit. The US orbiting satellites with a mass of 1420 Kg appears to be the leader. European orbiting satellites are much heavier with a mass of 4085 Kg. However the instruments they carry cater to a variety of needs with many new sensors being tried out for a range of applications. These complications make comparison with other operational systems difficult. Russian orbiting satellites have masses of 2700 to 2900 Kg. They have had a number of operational problems in recent times. Chinese orbiting satellites have masses of about 2300 Kg.

As mentioned earlier India has no orbiting weather satellites. It may have to add these to its capabilities if it needs to use space assets for a C4ISR function. The IRS platform may be suitable for this purpose. However the addition of an infrared channel to the imaging instrument may create complications because of the cooling requirement for the detectors. The PSLV launcher could maybe place about 1400 to 1500 Kg in an 800 Km sun synchronous orbit. This may be adequate for meeting the needs. In case of problems these could always be launched by the more powerful GSLV Mark 2.

Based on the current record one GSO satellite may need to be built every three years to maintain the current constellation. These could be launched on the GSLV Mark 2 until the GSLV Mark 3 becomes available.

In addition a constellation of three orbiting satellites operating in an 800 km sun synchronous orbit may be needed to complement the GSO weather forecasting capabilities. It may be possible to build them within a mass of 1500 Kg compatible with a PSLV launch. In case heavier satellites are needed one may need to launch it on a GSLV Mark 2 vehicle.

Taken together both these needs will need a satellite manufacturing capability of one satellite per year along with a launch capability of one GSLV Mark 2 or one PSLV vehicle per year.

Sensor capabilities including the incorporation of infrared channels with the visible and near infrared channels typical of most current instruments may also need to be strengthened. The building and testing of other new instruments for monitoring the weather and the climate and testing on orbiting platforms before moving them to the GSO may also need support.

Globally most western countries are moving to integrate the civilian and military components of the weather function into a single constellation of satellites catering to both users. This is consistent with current Indian practice and with certain administrative arrangements in place may be adequate to take care of both civilian and military needs.

5.3 Space Based Navigation Systems

The parameters for assessing performance of satellite based navigation systems would be linked to position accuracy, velocity accuracy and timing accuracy. In our assessment the position accuracy along with the mass of the satellite has been used as the basis for evaluating capability.[66]

In view of the importance of navigation for meeting security needs many space powers are keen to establish their own system. Currently the US GPS and the Russian Glonass system offer global coverage.[67]

The use of satellites for navigation purposes has been around for quite some time. The US GPS system set a new standard for accurate position fixing using a constellation of 24 satellites in Medium Earth Orbit. It has now become a global standard. Here too the distinctions between civilian and military use are becoming increasingly blurred.

Both the GPS and Glonass systems work on the principle that at least four satellites whose positions in space are known accurately are always available to a receiver on the ground. Using the signals along with the known positions of the satellite the position of the receiver can be estimated.

The GPS satellites are in a near circular orbit at an altitude of about 20000 Km with an inclination of 55 degrees. Three generations of satellites comprise the current constellation. The masses of the satellites at liftoff range from 1630 to 2200 Kg. The current generation has a lift off mass of 1630 Kg. The lifetime of these satellites are 10 years.[68]

The Russian Glonass system consists of 28 satellites in the current constellation. They are in 19100 Km orbit with an inclination of 64.8

[66] For an overview see Gerhard Beutler, "Satellite Navigation System for Earth and Space Sciences", International Space Sciences Institute, Spatium No. 10, June 2003, pp 3-19 at http://www.issibern.ch/PDF-Files/Spatium_10.pdf

[67] https://www.princeton.edu/~alaink/Orf467F07/GNSS.pdf

[68] UCS_Satellite_Database_9-1-15 at http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database.html#.Vgou932rHgI

degrees.[69] Starting in 1982 the first complete constellation of 24 satellites was established in 1995 about a year behind the US GPS system. After a period of time during which the operational capability got diluted the entire programme got a fillip in 2001. Complete coverage was restored in 2011.

The Glonass programme has also seen three generations of navigation satellites. The first generation satellites had lift off masses of about 1260 Kg and were launched three at a time on the Proton launcher. Direct injection into the required orbit is a feature of the Proton Soyuz launches. Thus the propellant mass on the satellite could be less leading to a lower satellite mass in comparison to the launches from Western countries. The second generation satellites had a lift off mass of 1415 Kg. The mass of the third generation satellites is 930 Kg.[70]

The capabilities of the system originally meant for military use has been opened up for civilian use. Most navigation receivers are compatible with both GPS as well as Glonass. The higher inclination orbit provides better coverage at higher latitudes.

Europe is planning to set up its own Galileo Network of orbiting satellites to provide navigation services to both Europe and the rest of the world. It is in the process of establishing a constellation of 30 satellites with 24 operational and six backup in-orbit spares. The satellites are distributed equally in three orbital planes. They orbit the earth at an altitude of 23222 Km with an inclination of 56 degrees. Ten of these satellites have already been launched with the constellation due for partial service in 2018 and complete services in 2020. The satellites have a lift off mass of 733 Kg. They are launched two at a time by the Soyuz Rocket from Korou in French

[69] For the current status of the constellation see https://glonass-iac.ru/en/GLONASS/

[70] For details see http://www.russianspaceweb.com/uragan.html

Guiana. With modifications being carried out to the Ariane 5 launcher they could be launched four at a time on future flights of the Ariane 5 launcher.[71]

Japan is a country where high mountains and high buildings make access to good quality reception from GPS satellites difficult. This resulted in a different architecture for their satellite constellation. Rather than competing directly with the GPS they chose an approach that would complement and enhance GPS capabilities within their region. The system should also serve as a backup in case there were problems with the availability of the GPS system.

The Japanese system involves a constellation of seven satellites. Four of them are in inclined geosynchronous orbits. The orbit inclination is chosen in such a way that at least one satellite will always be visible to users in Japan. These along with three satellites in GSO will provide the four signals for locating the position on the ground. These satellites will transmit position and time and error correction in the same bands and frequencies as the GPS system.[72]

So far Japan has put into orbit one satellite of their Quasi Zenith Satellite System (QZSS). This satellite was launched in 2010 by the Japanese H2A launcher. The mass of the satellite is 4000 Kg and it is in a geosynchronous orbit with an inclination of 40 degrees.[73] Reports suggest that with this satellite in place and with data that comes from precisely located receivers on the ground whose separation distances are accurately known error corrections received by users via the geosynchronous satellite has improved

---

[71] http://www.esa.int/Our_Activities/Navigation/The_future_-_Galileo/What_is_Galileo

[72] Hideto Takahashi, "Regional Navigation Satellite System 'The JRANS Concept', Journal of Global Positioning Systems Vol 3, No 1-2, 259-264, 2004 at http://www.sage.unsw.edu.au/wang/jgps/v3n12/v3n12p32.pdf

[73] UCS_Satellite_Database_9-1-15 at http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database.html#.Vgou932rHgI

location accuracies from the meter to the centimeter level. Japan proposes to augment its capacity with the launch of 3 more inclined geosynchronous satellites as well the three satellites in GSO in the next few years to complete the system.[74]

China proposed a regional navigation system pushed largely by the military that initially involved only the use of Geostationary satellites for determining position on the ground. This approach largely depended on responding to signals sent out by the control station to the users via two satellites in Geostationary Orbit. The user responds to both signals which are received by the control station. The received data is processed to estimate the two dimensional position. This is then compared to a three dimensional data base and the combined data is sent back to the user as the determined position. The original system was based on two satellites with two satellites serving as a backup. The position accuracy was demonstrated to be about 100 m. The last of the satellites to be launched as a part of this experimental phase was in 2007. It is possible that with a network of ground control stations, laser tracking of the satellites in GSO as well as conventional GPS capabilities the accuracy of the position location for the users could be improved via transmission of corrections through the Geostationary satellites.

After this experimental phase China has gone ahead and is in the process of establishing a complete operational system. The proposed system will first provide a service compatible with other services such as GPS, Glonass as well as Galileo. When it is completed by about 2020 it will offer a complete global service for all users.

The proposed system will comprise 35 satellites. Five of them will be in Geostationary Orbit (GSO), three will be in an inclined 55 degree

[74] http://www.theregister.co.uk/2014/04/24/japan_satellite_qzss_enhanced_gps/

geosynchronous orbit and there will be 27 satellites in a Medium Earth Orbit (MEO) of 21540 Km. 24 of the MEO satellites will be functional with three satellites acting as in orbit spares. The 27 satellites will be in three different orbital planes inclined at 55 degrees. In a sense this new architecture combines the Japanese and US systems to provide a complete service. There will be an open service as well as a secure service for some users.[75]

So far China has launched 20 satellites as a part of its second generation system.[76] The preliminary evaluation of system performance is consistent with other comparable systems in the world.[77]

The GSO satellites have a mass of 4600 Kg at liftoff and are launched by the CZ 3C launcher.

The satellites in inclined geosynchronous orbits have a mass of 4200 Kg and are launched by the CZ 3B launcher.

The MEO can either be launched into a transfer orbit from where they are taken to the final orbit or the third stage can directly inject them in to the required 21500 Km inclined orbit. For the former case the satellite mass is 2200 Kg launched by a CZ 3A launcher. For the latter case the mass is 800 Kg and the satellites are launched two at time by CZ 3B launcher. The latest launch of September 2015 is a dual launch of the 800 kg satellite into a direct 21500 km orbit by a modified improved CZ 3B vehicle with an

---

75 https://directory.eoportal.org/web/eoportal/satellite-missions/c-missions/cnss

76 China Launches 20th Satellite for BeiDou Navigation System, Press Trust of India , 30 September 2015, http://gadgets.ndtv.com/internet/news/china-launches-20th-satellite-for-beidou-navigation-system-746510

77 Oliver Montenbruck et al, Initial assessment of the COMPASS/BeiDou-2 regional navigation, http://saegnss1.curtin.edu.au/Publications/2013/Montenbruck2013Initial.pdf

augmented upper stage.[78]

India's efforts at improved navigation are oriented around two kinds of approaches. In the first approach the existing civilian capabilities using GPS are improved in order to improve the accuracy of position fixing and navigation. The Indian system called Gagan uses a precisely positioned network of ground stations to eliminate some of the systemic errors in the reception of GPS signals. These error corrections are transmitted continuously to all users within the region via a geostationary satellite who then correct the GPS based positions. This system is being deployed in India to facilitate precision landing of aircraft.[79]

India is also in the process of setting up an Indian Regional Navigation Satellite Service (IRNSS). When completed, the system will have four satellites in a 30 degree inclination geosynchronous orbit and three other satellites in Geostationary Orbit. Together they will provide an India oriented navigation service that caters to both civilian and military uses. The system being set up may also be compatible with additional enhancements based upon improvements from a precision based ground network set up for the Gagan service.[80]

The Indian system is very similar to the original Japanese systems and also close to the initial capability proposed by the Chinese Beidou 2 system of a combination of Geostationary and inclined geosynchronous satellites.

Four satellites have been launched as a part of the regional constellation.

---

[78] For details please see https://directory.eoportal.org/web/eoportal/satellite-missions/c-missions/cnss

[79] S.V.Kibe, "Indian plan or satellite based navigation for Civil Aviation", Current Science, Vol. 84 No 11, 10 June 2003, pp 1405-1411.

[80] http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLVC22.pdf

These satellites have a liftoff mass of 1425 Kg and have been launched by the PSLV. Three more satellite launches to be carried out in the near future would complete the regional system.[81]

While it is difficult to evaluate in detail the accuracy resulting from a combination of GSO and inclined Geosynchronous orbit satellite system it is likely to be worse than the accuracy obtained from an orbiting constellation of satellites. If the regional system can also use GPS and the Gagan capabilities the resulting accuracies may be adequate for most military needs. However such an approach may make India dependent on a foreign source for meeting a military need. If the India US relationship can guarantee such a continuity of the GPS service this approach will be a good and cost efficient solution for meeting both civilian and military needs. The US has so far not put any restrictions on the civilian use of the GPS signals but whether this approach will continue under all conditions is a difficult assessment to make. One way to reduce this risk is to make the Indian system compatible with GPS, Glonass as well as the proposed European Galileo system. However at some point it may be prudent to set up our own system to meet at least the country’s military needs.

Based on the assumption that an indigenous constellation may also be needed India may need to move towards a constellation in a phased way over the next ten years. Based on the experience of other countries this may require a constellation of about 30 satellites in GSO, geosynchronous and MEO orbits.

In addition to the GSO needs this would translate into a satellite capacity of 3 satellites in a MEO every year. The dry mass of the navigation satellites launched by PSLV is 600 Kg. Based on

[81] http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLVC22.pdf

current Indian practice it may be possible to place a meaningful navigation payload into a MEO orbit through the PSLV. **Thus three PSLV launches may also be required for the constellation.**

Accurate timing is needed for the operation of satellite based navigation systems. These are provided by atomic clocks carried on all the satellites. Indigenous capabilities to make these clocks and qualify them for use in space may be important. It may be possible to design navigation systems that do not need atomic clocks. Exploring such possibilities may also be an area of interest to a country like India.

Given the importance of the navigation function in the conduct of modern war complete dependence on another country may not be desirable. China and Europe are currently setting up a full-fledged independent system that caters to their own civilian and military needs. Their systems could also service civilian users around the world. Such systems will necessarily involve a larger constellation of both orbiting and geosynchronous and geostationary satellites. If India decides to go that way to enhance its capabilities significant capacity additions to satellite and launch capacities will be needed. The projections made are on the basis that over the next ten years India would establish a full-fledged Satellite based navigation system of its own to cater to both the civilian and military needs. During this transition period existing systems could be used along with the proposed IRNSS to improve accuracies.

5.4 Space Based Support Services Overall Needs

Table 3 summarizes the satellite and launch vehicle needs for various satellite based support services needed by the military. These services need not be dedicated only for military use but could be combined with civilian needs as well. Arrangements to cope with security provisions and enhancements in performance for military use could be worked out through suitable organizational and administrative procedures.

Table 3

Space Based Support Services for C4ISR Needs

Function	Orbit Type	Satellite Class	Constellation size	Capacity per year	Launchers per year	Comment
Tracking & Data Relay	GSO	Medium to Intermediate 2000 -4000 Kg	3 Satellites in GSO	1 satellite per year	1 GSLV Mark 2 or Mark 3	Global coverage needed
Weather	GSO	Medium to Intermediate 2000 -3000 Kg	2 Satellites in GSO	Small GSO SSO satellite similar	One GSLV Mark 2 or Mark 3	One satellite every 3 years
Weather	LEO SSO	1500 Kg	3 satellites -2 operational 1 spare	1 satellite per year	1 PSLV launcher per year	Global coverage with TDRSS
Navigation	GSO	Medium 2000 Kg	7 satellites	1 satellite a year	1 GSLV Mark 2 or Mark 3	Current system uses PSLV
Navigation	MEO 50 degree inclination	1500 Kg	24 satellites	3 satellites per year	3 PSLV launches per year	Complete system 10 years

5.5 Small Satellites

In our assessments of the various C4ISR needs one common thread that comes out clearly as a major trend is the increasing importance of small satellites operating in constellations to meet many functions including military ones. Small satellites of different kinds will soon be able to substitute many of the C4ISR functions being currently performed by the larger more specialized custom built satellites.

This is an area where India needs to enhance its capabilities and capacities in a significant way for meeting both commercial and military needs.[82]

Developments in micro and nano electronics make possible increased processing and storage capabilities with lower levels of power consumption.

Integration of the sensing function with the conversion of analog to digital signals along with other processing capabilities make possible greater functional capabilities within smaller masses and lower power requirements.

Megapixel CCD based cameras are now available as off the shelf items.

Developments in Micro-Electromechanical Systems (MEMS) make possible the building of gyros and accelerometers needed for control purposes.

The availability of GPS receivers, modeling software of various kinds, the Internet as well as many low cost options for launch all contribute towards reducing various barriers in building and launching small satellites.[83]

Though India has not launched a large number of small satellites the PSLV launcher has become a work horse for providing launch services for these satellites. Many of these satellites have been taken as secondary payloads in various PSLV missions. The launch vehicle team has developed a number of different adaptors for mounting these satellites along with other bigger

82 For an understanding of how small satellites can be used for meeting military needs see Rajaram Nagappa, "The Promise of Small Satellites", NIAS Report no. R33-2015, December 2015.

83 Siegfried W Janson, "25 Years of Small Satellites", 25th Annual AIAA / USU Conference on Small Satellites, 2011, http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1117&context=smallsat

payloads.[84] Dedicated adaptors and dispensing mechanisms have also been developed for placing multiple small satellites in orbit. Over 40 satellites for 19 countries have been successfully launched by the PSLV. Most of these are in the small satellite category. From a preliminary survey many of them are the early progenitors of future C4ISR systems. [85]

The PSLV record both in terms of launch reliability as well as in meeting the global needs for small satellite launch capability has been outstanding.

Capacities for building and launching such satellites outside of the space programme are practically non-existent. A major national effort to promote the building and launching of these satellites for meeting a variety of needs has to be undertaken. Unlike most of the other advanced space powers including China that have an ecosystem that supports entrepreneurs and startups, India provides no support that encourage entrepreneurial activities in the country. Though private companies provide support to the space effort there are no independent players that can build a satellite or a launcher or even manage a mission. In spite of the proven potential of PSLV for launching small satellites the Indian record for space startups does not compare well with those of other major space powers.

A major effort to change this state of affairs will be needed. This will necessarily have to come out of initial funding support both for satellite building as well as for launching them. These requirements will be over and above those identified as part of the constellations that have to be launched for meeting the more immediate C4 and ISR needs.

An annual outlay of about Rs. 100 crore may be needed for

84 http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLVC7.pdf

85 http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLV-C28.pdf

promoting the small satellite initiative in the country. In addition to providing launch services on an available basis the Plan for small satellites should involve the launch of small satellite constellations for a variety of functions maybe through dedicated launches. The promotion of startups through this initiative should also be a high priority.

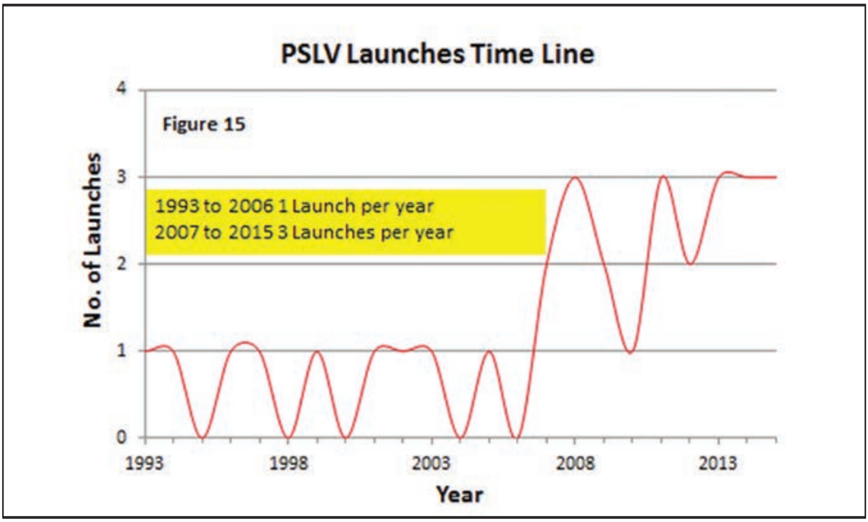
There are also other possibilities for meeting launch needs for small satellites. These call for looking at existing missile and various available rocket motors and build a satellite launch vehicle around them. These are addressed separately in the Launcher section.

6.0 Space Launch Capacities & Capabilities

6.1 PSLV

The PSLV Vehicle has been the mainstay of the Indian launch effort. It has so far been launched 31 times with 30 of them being successful launches. This translates into a reliability of 97% a record that is on par if not better than other launcher performances across the world.

Figure 15 provides a time line of various PSLV launches year wise since the launch of the first PSLV in 1993. The PSLV can place about 1750 Kg in a 600 Km sun synchronous orbit from Sriharikota (SHAR). It can also place a 1425 Kg satellite into GTO from SHAR.



Of the 31 launches carried out so far 18 launches were dedicated to earth observation missions in Sun Synchronous Orbits (SSO) between 500 to 900 Km. Two missions carried advanced SAR systems with military applications.

6 launches including four launches for the IRNSS and one launch for the Kalpana weather satellite were into GTO orbits. Two launches were for exploration of the solar system with one mission to the moon and the other to Mars. Three launches were dedicated to international scientific missions.[86]

The PSLV record has been outstanding. Over time a number of improvements have been made. Three configurations are available with different payload capabilities providing some degree of flexibility. PSLV also has been very successful in launching many small satellites as co-passengers along with the main mission.

From an ISR point of view the recent launch of PSLV C28 with three state of art remote sensing satellites built by the Surrey Satellite Technology Limited (SSTL) where three satellites spaced 120 degrees apart were put into a 647 Km Sun Synchronous Orbit is an indication of its capabilities.[87]

From the above assessment it is clear that all ISR requirements as well as many smaller satellites required for the C4 and other support functions can be met through PSLV if the country is able to augment the capacity for building and launching them in adequate numbers.

From Figure 15 it is clear that current capacity for PSLV launches is three a year. Keeping in mind the various requirements projected earlier this capacity may require significant augmentation.

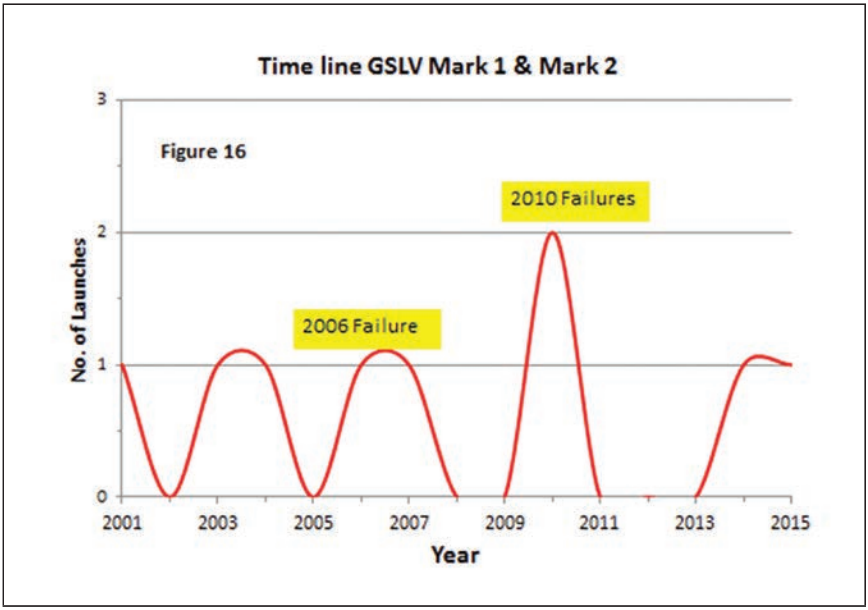
---

86 http://www.isro.gov.in/launchers/pslv

87 http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLV-C28.pdf

6.2 GSLV Mark 1 & Mark 2

Development problems with cryogenic engines have severely impacted Indian capabilities to place medium and intermediate class payloads in Geostationary Orbit. **Figure 16 provides a timeline of various launches conducted by the GSLV Mark 1 that used the Russian cryogenic stage and the GSLV Mark 2 that used a reverse engineered Russian cryogenic stage.**



There have been a total of nine flights conducted so far starting from 2001 onwards. Three of the flights have failed indicating that development and production line problems still persist. Two consecutive flights of the GSLV with the reverse engineered cryogenic upper stage failed in 2010. However the last two development flights have been successful. With one or two more demonstration flights the GSLV Mark 2 may now be ready for operational use.

The current capacity may be around 1 GSLV Mark 2 launcher per year.

The GSLV Mark 2 when operational could place a 2500 Kg payload into GTO or 5000 Kg into LEO from SHAR.[88]

Communications satellites with this mass are categorized in the medium size category.

As we had mentioned in the earlier part of this report the global trend is to move away from the medium and intermediate size categories towards the heavy and very heavy categories.

In keeping with this trend India may also have to be able to place heavier payloads in GTO especially for military applications.

With the use of ion propulsion however some short term gains at least can be achieved. Because of reduced propellant weights on the satellite more mass can be made available for satellite functions as against propulsion functions. With this capability even the GSLV Mark 2 could place the equivalent of a 4000 Kg intermediate class payload in GTO.

This is one way in which the gap in both satellite and launch capabilities can be redressed at least in the short and medium term. If this is not deemed immediately possible, either capabilities have to be designed to the launcher needs or the current practice of procured launchers can continue. While procured launches may be possible for meeting civilian needs military needs may need to depend on indigenous

[88] http://www.isro.gov.in/launchers/gslv

launch capabilities.

Superposing global trends for GTO launches on Indian capabilities for launch and satellite building the gap between satellite needs and launcher capabilities is likely to continue. Given this dynamic it may be worthwhile to take cognizance of the developments in ion propulsion to address this gap and design satellites for indigenous launch capabilities. The GSLV Mark 2 could be the first vehicle around which this convergence could take place.

6.3 GSLV Mark 3 or LVM3

The GSLV Mark 3 (also called the LVM 3) with a larger indigenous cryogenic stage and scaled up versions of solid and liquid fuel powered stages has made progress. A GSLV flight of this configuration without the cryogenic stage has already taken place with a crew recovery module carried by it successfully splashing down in the Bay of Bengal. The complete development and flight testing of this launcher would take another few years. Though some distance away it would be able to place 4000 kg in GTO and 8000 Kg in LEO from a SHAR launch.[89]

Using current global standards this translates into a capacity for launching intermediate class payloads into GTO.

Along with ion propulsion and the resulting weight reduction that it makes possible, this would push Indian capabilities into what is classified as the heavy satellite category.

Based on the of development status the GSLV Mark 3 can become operational over the next five years.

[89] http://www.isro.gov.in/launchers/lvm3

If and when this happens the indigenous convergence between satellite needs and launcher capabilities would be complete and the gaps between Indian and global benchmarks in both satellite and launchers would be considerably reduced.

Therefore the early completion of the development of the GSLV Mark 3 becomes a very high priority area for the country's space programme.

6.4 Larger Launchers & the Human in Space Programme

ISRO also has plans to develop a kerosene liquid oxygen fuelled semi-cryogenic engine to build the bigger boosters needed for the future generation of launchers. This envisages acquiring technology for building these engines from Ukraine and testing them in Russia should Indian test facilities get delayed.[90]

Configurations built around this booster along with the stages derived from the GSLV Mark 3 Launcher promise to raise the GTO payload to about 6000 Kg. This capability is on par with current heavy and very heavy satellite categories for GSO payloads. This could also be used to build the boosters required for a manned space programme.[91]

---

90 For an overview of the development of the new semi-cryogenic engine that involves co-operative arrangements with Ukraine and Russia see https://en.wikipedia.org/wiki/SCE-200. Details of the engine are also available at http://forum.nasaspaceflight.com/index.php?PHPSESSID=vikl0df4chmjdu6q8mgbns8eb4&topic=32477.0

91 For an overview of developments in the semi cryogenic engine, its link with the human spaceflight and some details of the Russian collaboration see http://isp.justthe80.com/isro-rocket-motors/semi-cryogenic-engine

While the human spaceflight programme will probably require larger launchers one is not sure that there will be a need for a GTO or GSO capability over and above the capabilities offered by the GSLV Mark 3 at least for meeting most civilian and military needs.[92]

Currently proving the GSLV Mark 2 and producing it in numbers, and developing and proving the GSLV Mark 3 are the most important components of the launcher strategy of India. Ensuring a greater convergence between satellite needs and launcher capabilities via the ion propulsion route is a promising way to redress the current gaps. This approach offers the promise that both satellite and launcher capabilities will be close to global benchmarks for GSO capabilities.

While technology options for building bigger launchers have to be kept open and even developed for the future especially for a possible human spaceflight programme these may be taken up on a priority basis once the current needs and challenges in terms of both capacities and capabilities are completed.

6.5 Role of Missile Derived Launchers for Small Satellites

Preliminary studies show that the Agni 5 missile can also put satellites of about 350 Kg into a 450 Km near polar orbit.[93]

Since the Agni 5 is a mobile missile it could be easily moved around to various locations for launch. The infrastructure and ground facilities needed for such launches may also be significantly less demanding than

[92] This is based on the assumption that ion propulsion will become the preferred choice for transfer of the satellite from GTO to GSO.

[93] These studies use publicly available information along with in-house developed trajectory software Quo Vadis.

those required for a PSLV or GSLV launch.
A number of such facilities could be set up around the country to meet military C4ISR requirements especially for the smaller categories of satellites.

The marginal modifications to the Agni 5 needed for launching both single and multiple satellites should be carried out on a crash basis.

A few demonstration launches may also be needed to establish the capabilities for satellite launches.

A significant augmentation of the capacity to produce and launch the numbers needed by the C4ISR programme may also have to be initiated.

As a part of the small satellite initiative suggested earlier an initial provision of five Agni 5 small satellite launchers per year may be needed to kick start this initiative.

7.0 Ballistic Missile Defence (BMD), Anti-Satellite (ASAT) Weapons & Space Weapons

As stated earlier the increasingly stronger inter-dependent connections between conventional, nuclear and space war seen in the post 2000 era has already made space an arena of conflict and war. Space weapons, space capabilities and capacities to counter them therefore become logical areas for support and enhancement by nation states.

Even before the initiation of the Star Wars Programme by President Reagan, the development of BMD capabilities had always been a priority area for experiments and tests by both the superpowers.

With the abrogation of the ABM Treaty the stage is now set for a renewed interest and a focus on various kinds of BMD weapons.

Since both ASAT and BMD weapons draw upon the same domains of technology and knowledge, capabilities in one also necessarily means that capabilities exist for doing the other.

The distinctions between defensive and offensive orientations are therefore blurred and grey.

At the core of this new power play is the challenge posed by China to the US presence in the Asia Pacific region especially via its Anti-access and Area Denial Strategies. In addition China is also counting on ambiguity and risk escalation of conventional war to a nuclear war through a conscious policy of equipping missiles with both conventional and nuclear warheads.

The US response to the new challenges has been to come up with a newer more comprehensive strategy in which space has a significant role. The cornerstones of the new triad are flexible, prompt global strike, BMD and enhanced flexibility that include C4ISR capabilities. Nuclear weapons, conventional weapons, space assets are all important components of this larger architecture. Its pivot to Asia is also linked to its strategy for countering China's rising power in the Asia Pacific region.[94]

Irrespective of whether these changes become part of the official doctrine or not they do suggest changes in approach and strategy arising from the US China dynamic. Space assets are therefore likely to become prime targets even in a conventional war. Space and earth based BMD and ASAT capabilities will become increasingly important in the preparations for waging a conventional war.

In response to these developments India needs to craft a strategy that takes into account these inter-related developments in technology, organization and global politics.

Though the official Indian position has always been against the Weaponization of Space, India has experimented with some components of a BMD system. Limited intercept tests just outside the atmosphere have been carried out as a demonstration of capability. The Indian missile arsenal is also adequate to demonstrate an ASAT capability to LEO if needed.

These BMD and potential ASAT capabilities only cover the space over India. Extending these capabilities to cover midcourse and boost phase BMD and to be able to target satellites at

[94] David S. McDonough, "The "New Triad" of the Bush Administration: Counter-proliferation and Escalation Dominance in US Nuclear Strategy", International Journal, Vol. 59, No. 3 (Summer 2004), pp. 613-634.

higher altitudes may require significant augmentation of both the ground infrastructure as well as space borne assets.

One of the major requirements for a more advanced BMD and ASAT system is the ability to track missiles and satellites in space. The network of long range, medium range and short range radar systems complemented by suitable optical and laser ranging stations, that we had talked about in the section on Space Situational Awareness could also be used in a BMD or ASAT role.

An additional requirement for a truly larger area coverage BMD system is a satellite in space that can track the hot plume of the missile as it exits the atmosphere and provide advance information on the trajectory of the missile. So far only the US and Russia have demonstrated the capability to do this. Satellites equipped with the appropriate infrared sensors can do this effectively. The country has some experience in building meteorological satellite that that use various parts of the infra-red spectrum for providing weather information. These by themselves may not be adequate to meet the needs of a Missile Launch Surveillance capability.

While the extension of the BMD and ASAT capabilities outside of the Indian airspace may not be an immediate priority a space strategy should keep these prospects in mind in planning for the future. [95] **The establishment of a space situational**

---

[95] S. Chandrashekar, "The Emerging World Space Order and its Implications for India's Security," in Subrata Ghoshroy and Goetz Neuneck, eds., *South Asia at a Crossroads:Conflict or Cooperation in the Age of Nuclear Weapons, Missile Defense and Space Rivalries* (Germany: Nomos, 2010), pp. 227–228.

awareness capability would go a long way in ensuring that some of these BMD and ASAT options are preserved should India need to embark on them at some future date.

The incorporation of the space weapon component into the national security architecture and its connections with conventional and nuclear war will involve additional higher order changes to the proposed integration of the SSA and C4ISR operational capabilities.

The link between the dynamic capabilities of a robust SSA & C4ISR system with the war and deterrence strategies of India at the higher level needs to be made integral to the re-organization effort. Only when this link is made seamless can the strategic and operational capabilities be linked in a dynamic way. This restructuring of the National Security System in the country to create the new information centric dynamic capabilities that are needed for dealing with the problems of today is possibly the most important priority for an aspiring power like India.

8.0 An Integrated Network Centric Space Based Strategy For India

8.1 An Integrated SSA & C4ISR Capability

Apart from the gaps in various technological capabilities and in capacities that have been identified, one of the biggest challenges confronting an emerging space power like India is the integration of the various SSA and C4ISR components into a cohesive whole.

There are a multitude of organizations that deal with different parts of it. They all have to align their activities to meet the strategic challenges posed by the new interplay between space, nuclear weapons and conventional war. They need to adapt individually and collectively as a system to the changes both in the geo-political realm as well as to changes arising from new developments in technology.

These will require more frequent changes in organization, capabilities, strategies and doctrines. Taken together we can call this combination "Dynamic Capabilities".

Realizing this goal of "Dynamic Capabilities" may involve a critical re-examination and restructuring of the current organizational arrangements within India's National Security Complex.

These organizational and institutional bottlenecks, more than any technology or capacity gap, is possibly the biggest challenge confronting India.

The US and the erstwhile USSR did this restructuring and re-orientation fairly well during the heydays of the cold war. The US has always led the way in new ways of reorganizing and restructuring the various components of its national security architecture.[96]

More recently China has successfully put in place a fairly robust architecture that tries to ensure seamless integration of the various diverse capabilities of the national security system.

The visible evidence of this capability can be seen in the architecture they have in place for one of their conventional weapons systems – the Anti-Ship Ballistic Missile (ASBM).

Figure 17 provides an overview of a typical SSA C4ISR architecture that may be needed by an advanced space power. The areas highlighted in red are major areas of concern.

The Indian experience in restructuring the existing National Security Architecture has not been particularly encouraging. Minor tinkering with the structure has generally been India's response to many of the challenges posed by the new geo-political order. This approach may no longer be adequate to meet current and future challenges in all areas that impact national security including space.

Apart from the need to bring about a major re-organization of the National Security Complex in line with the current geo-political realities there are major gaps both in capacities as well as in capabilities. The integration of capabilities has to happen at several levels cutting across several organizations to create a true seamless network based capability that is

[96] The US pivot to Asia and their new Air Sea Battle doctrine are visible proofs of this dynamism.

needed to fight and deter the wars and conflicts of today's world.

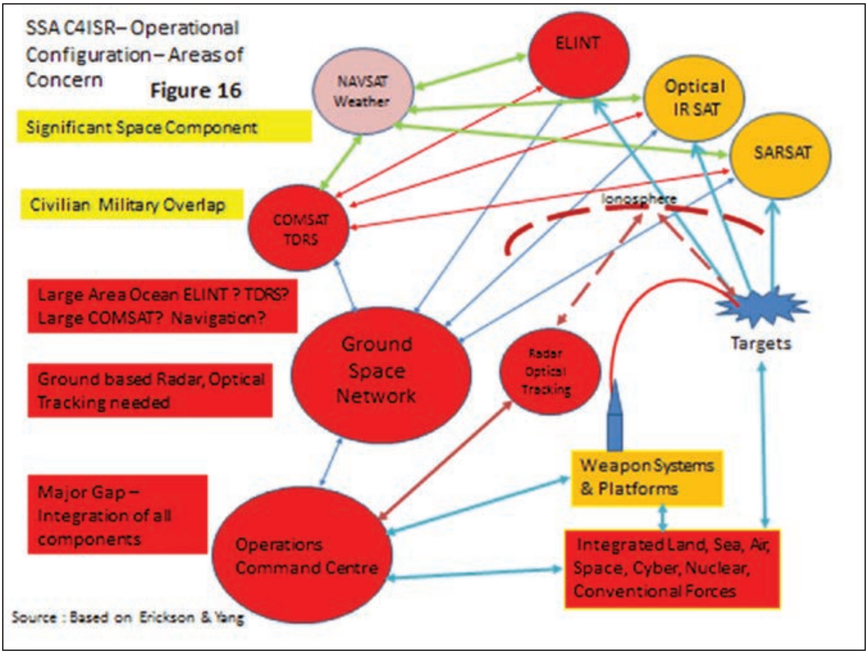


Table 4 summarizes the space and launcher needs needed for establishing a full-fledged C4ISR capability.

Table 5 provides an overview of the major enhancements in the ground based infrastructure as far as the Space Situational Awareness (SSA) component is concerned. It also lists major areas of concern related to both technology and organization that need support.

Tables 4 and 5 together provide a basis for the formulation of a suitable strategy for the country.

8.2 Key Components of a Space Strategy

Satellites & Launchers

From Table 4 it is clear that India needs four Advanced Communications Satellites, one Tracking & Data Relay Satellite as well as at least one Navigation satellite to be launched into GSO every year. All these satellites would fall in the medium to intermediate class of GSO satellites that will need a GSLV launch. Equipped with ion propulsion capabilities they can perform the same functions as the current generation of heavy satellites.

The ELINT part of the ISR function requires the simultaneous launch of three satellites. This may also require a dedicated GSLV launch.

Taken together this translates into a demand for about 9 advanced communications type satellites and 7 GSLV launchers every year.

In addition to these largely communications and electronic signals payloads, one weather satellite with a mass of about 2000 Kg may also need to be launched into GSO every three years to meet operational weather needs.

The orbiting component of the weather service may need the capacity to build one weather satellite every year. This may also need a dedicated PSLV launch.

To meet both civilian and military remote sensing needs India may also need to build and launch 2 EO satellites as well as 2 SAR satellites a year. This will need four PSLV launches per year.

The creation of LEO constellations for both C4 and ISR needs over a two to three year period for validating its utility for C4ISR functions will need the launching of 28 small satellites in the 100 to 200 Kg class every year. Seven PSLV launches and two launches of a modified Agni 5 missile may be needed for this purpose.

In addition to meeting the mainstream C4ISR requirements, PSLV launches may also be needed for establishing an orbiting constellation of 24 navigation satellites. About 3 satellites per year may need to be built and launched into MEO (20000 Km) for establishing a completely independent space based navigation service catering to both military and civilian users. This will require 3 dedicated PSLV launchers every year. With this launch rate a completely indigenous state-of-art navigation service could become available in ten years.

Adding all the numbers India may need to launch about 17 advanced satellites in addition to about 28 small satellites for meeting the operational C4ISR requirements. This will require 7 GSLV launches, 15 PSLV launches and two modified Agni 5 launches.

The promotion of the small satellite initiative to create national capability will need the establishment of very small satellite building capabilities in a number of educational and research institutions. One dedicated PSLV launch along with five launches of the Agni 5 modified missile launcher per year may be needed for this purpose.

We can see that a significant augmentation of satellite and launcher capacities may be needed to meet these requirements.

Table 4

Satellite & Launcher Requirements (Civilian +Military)

Function	Satellite Mass (Kg)	Orbit (Km)	No per year	Launchers			Comment
				PSLV	GSLV	Agni 5	
C4 Functions							
4 satellite C4 System Military	2000 -4000 Kg	GSO	2		2		Use of Ion Propulsion
Civilian Advanced Satellites*	2000 -4000 Kg	GSO	2		2		Use of Ion Propulsion
40 satellite LEO Military Internet	150 -200 Kg	LEO	20	5		1	Use of Agni 5 Launcher
ISR Functions							
3 x 3 ELINT Clusters Military	300 -400 Kg	63° 1100 Km	3		1		One cluster single GSLV launch
6 EO satellites (civilian + military)	500 Kg	500-1200 SSO	2	2			Small satellite capacity available
6 SAR Satellites (civilian + military)	1500 Kg	500 Km SSO	2	2			Dedicated launch may be needed
24 satellite LEO Military	100-150 Kg	500 Km SSO	8	2		1	Inclined orbit regional coverage
Space Support Services							
3 satellite TDRSS system	2000 -4000 Kg	GSO	1		1		Civilian & Military needs
2 Satellite GSO weather service	2000 - 3000 Kg	GSO	small		small		Civilian & Military needs
3 Satellite LEO weather service	1500 Kg	800 Km SSO	1	1			Civilian & Military needs
7 Satellite GSO Navigation service	2000 Kg	GSO	1		1		Civilian & Military needs
24 Satellite MEO Nav service	1500 Kg	20000 Km	3	3			Indian Navigation system 10 years
Small Satellite Initiative (R&D)	5 - 100 Kg	LEO	100	1		5	Multiple satellites - Many Builders
Total			**17 +128**	**16**	**7**	**7**	

*There appears to be a lot of unmet demand. Many Indian TV channels use transponders on foreign satellite to cater to domestic needs.

To provide a comparison India can currently build and launch about four advanced satellites a year along with their launchers. To go from the current capacity of four satellites and launchers to the required 17 satellites along with their launch requirements would need the capacity to increase four fold. If the small satellite constellation needs are added the satellite and launch capacities need to be multiplied at least five times to meet just the C4ISR needs of an aspiring space power.

One route for achieving this is to increase capacities within the current entities developing building and launching satellites.

The other way is to make sure that through appropriate mechanisms the capacity for building and launching satellites is created within Indian industry.

Most if not all advanced powers have all created vibrant and globally competitive space industries within their economies. This looks like the logical route for India to follow.

Critical Areas – Infrastructure, Technologies, Organization

As covered earlier the other immediate requirement and a vital component of any space strategy for India relates to Space Situational Awareness (SSA).

India needs to create a suitable network of long range radars that could track space objects.

A network of optical tracking and laser ranging stations would

complement and enhance the capabilities of the radar network.

Apart from the creation of this infrastructure, India also needs to identify suitable entities within the National Security complex that would be responsible for the routine monitoring of the space environment.

A deeper study of orbital motions around the earth can also benefit a number of scientific domains such as geodesy and astronomy. Such a programme should be supported at a number of locations.

In addition to this SSA capabilities that is crucial for India there are also a number of other areas of concern.

These comprise technologies, organization initiatives, integration issues to create a network centric capability as well as issues of strategy and doctrine.

Table 5 provides details of these areas of concern. A space strategy for India should address these needs so that current gaps can be eliminated and future options for action are preserved.

Table 5
Critical Infrastructure & Major Areas of Concern

Critical Infrastructure & Areas of Concern	Comment
Space Situation Awareness	
Radar Network for Tracking Space Objects & Debris	Major Gap area for Immediate Action
Optical & Laser Ranging Facilities for Tracking Space Objects	Major Gap area for Immediate Action
Capabilities & Capacities for Monitoring the Space Environment	Major Gap area for Immediate Action
Ship borne TTC stations for space missions	TDRSS is an alternative for future
Orbit based Scientific Studies (International Collaboration)	Geodesy, Astronomy, Global Tracking
C4 & Related Areas	
Ion Propulsion for satellite applications	Critical to redress major launcher satellite gaps
Satellite to Satellite Radio Links	Need for switching via satellite
Satellite to satellite Laser Links	Need for optical switching
Secure Communications	Encryption, Frequency hopping, Anti jamming
C4 Network Operations	Connectivity within C4 commands + Civilian
LEO C4 Internet Constellations	Architecture, Design, Validation key areas
Antennae Beam forming Beam Shaping	Major area for Advanced C4 TDRSS Satellites
ISR Related Areas	
ELINT Technology Development	Major Gap Area for Immediate Action
Infrared Technologies and Imaging Sensors	Needed for military & BMD applications Gaps
Improved Integrated Optics for Imaging sensors	Capabilities may need enhancement

Table 5
Critical Infrastructure & Major Areas of Concern

Critical Infrastructure & Areas of Concern	Comment
SAR weight reduction initiatives	Benchmarks show Scope for improvement
ISR Small satellite development	Need for Catch up
TDRSS related Compatibility capabilities	Interface issues – compatibility issues
Data Processing especially SAR data Processing	Need for speedier processing of Satellite Data
Use of commercial or open source data for strategic applications	Improve National capabilities to use Data
Space Based Support Services	
TDRSS related	Technology development compatibility issues
Infrared Microwave imagers and sounders for weather	Need to improve complement of sensors
High precision clocks for time measurement navigation	Alternatives for time measurements
Small Satellites	
A National Initiative on Small Satellites – Multiple Centers	Emerging area for military and civil use
Launchers	
Scale up Improvements PSLV	Need to produce in numbers. Industry role
Operationalization GSLV Mark 2 – Scale up for Production	Launcher production and launch by industry
Operationalization GSLV Mark 3 - Scale up for Production	Need for industrial capacity
Agni 5 modifications for Space Launch	Useful Complement – small satellite initiative

Table 5
Critical Infrastructure & Major Areas of Concern

Critical Infrastructure & Areas of Concern	Comment
Space Weapons	
Retain Develop Technology Options for BMD, ASAT	Link to good SSA – Midcourse BMD extension
Technology Development Early Warning Satellite	Option for a Possible Future
Monitor Space Geo-political Environment – other Space Players	Link to good SSA – technology assessments
Integrated SSA & C4ISR Capabilities	
Need to restructure and re-organize operational capabilities	Integrated Mission mode network operations
Strengthening the Planning & War Strategy capabilities	Link to threat scenarios wars and conflicts
Strategy & Doctrine Related	
Re-organization & Restructuring of the National Security System	Major challenge to recognize new realities
Link Challenges, Capabilities Capacities to Strategy & Doctrine	Information Centric NSC - aspiration

8.3 A Space Based Security Strategy for India

SSA and a robust C4ISR are the main pillars around which a space strategy for the country has to be formulated. Achieving parity in SSA & C4ISR with other major players is a major priority.

The technology gaps will have to be addressed along with the organizational and institutional bottlenecks that currently pervade the Indian National Security Complex. This is an internal challenge that is significantly more complex to address than any challenge from the outside.

Major structural changes in the connections between space assets, nuclear war and conventional war may be needed. The role of space assets via the C4ISR route should be the driver of this re-organization. Only such restructuring will enable India to cope with emerging developments of the current geo-political order.

Though India can build and operate medium and intermediate class multi-functional Communications satellites in GSO it may need to augment its capacity to build such satellites. While dual use civil-military systems can provide military services to some extent, India may need to provide satellite networks dedicated for military use. There are gaps in both capabilities and capacities for meeting these needs. **The use of Ion propulsion technology is one way to redress both the satellite and launcher gap and move India from its current intermediate class position towards the heavy satellite class position.** This should form a key part of India's space strategy to ensure that the launcher and satellite programmes finally converge into a total indigenous capability.

Constellations of smaller orbiting satellites that connect with each other promise to both complement and compete with the more traditional GSO based network services. They could also provide very useful connectivity services during times of crisis. India has no experience with the building and operations of such networks. These capabilities and capacities have to be created both within the official National Security Complex as well as within industry and Universities.

Satellite to satellite switching, Laser communications, secure communications are key technology areas for sustained initiatives.

India has so far not launched and operated an ELINT cluster. This is a key requirement even for a limited regional ISR.

Eliminating this gap must be taken up on a priority basis.

While India can currently build, launch and operate both SAR and optical imaging satellites that are adequate for meeting most ISR needs it does not have in place the needed capacities and supply chains for producing them and launching them in the required numbers.

Indian capabilities for dealing with the infra-red (thermal) part of the spectrum are very limited.[97] These need to be strengthened significantly. Apart from ISR they are used for performing many other military functions and could play an important part in any future BMD system.

Improved Integrated Electro-optical systems for high resolution imaging is crucial for ensuring state-of-art capabilities in space based imaging. Weight reduction initiatives for SAR and speedier processing of SAR (ISR) data are other gaps that have to be closed for improved state-of-art operations of the ISR system.

The current mode of using onboard storage and a network of suitably located ground stations is adequate for collecting ISR data over the Indian region. This may also be adequate for meeting immediate operational needs. However given the nature of the geography of the Asia Pacific Region India may soon have to move towards creating TDRSS assets in space. This will also require augmenting Indian capacities to build and operate large multiple beam satellites in GSO that are connected to other GSO and orbiting satellites.

[97] One Bangalore based startup company seems to be making an impact on the global market for night vision cameras. See Peerzada Abrar "Night-vision startup Tonbo bags multimillion dollar contracts", The Hindu, Business Section, Saturday 14 November 2015.

Advanced Communications Satellites, SAR satellites as well as TDRSS satellites along require advanced antennae as well as beam forming and beam shaping technologies. This is another area requiring significant strengthening.

Small satellites that are built in numbers and launched in constellations also promise to compete with larger custom built satellites that provide ISR capabilities. **As in the case of C4 services small satellite constellations could provide valuable ISR data in times of crisis. This again is an area where India lacks capabilities as well as capacities.**

Commercial satellite imagery suppliers currently provide high quality data that could cater to many military needs. However though there is a large amount of data available India does not have enough capacities to use this data to feed into its ISR needs. A significant augmentation of capacities to use this data within the national security complex is needed. There is also a major national need to create such capacities within industry, research centers and universities. Creating a pool of expertise within the country that uses space imagery for meeting a variety of strategic needs, would contribute in a major way towards enhancing India's security interests.

Indian capabilities in building and operating meteorological satellites in GSO that support C4ISR operations are substantial. **However India has so far not built any polar orbiting weather satellites**. If the focus is regional the GSO based assets may be adequate. However if the focus is global the GSO assets may need to be augmented with an orbiting network.

Integration of global openly available weather data with Indian data that caters to the needs of the Indian establishments could be one area of concern.

The development of more region specific micro level weather models may also be needed. Capacities for doing this have to be created both within the government establishments as well as in industry and academia.

The global trend seems to be moving away from dedicated meteorological satellites for military use towards one where military and civilian services are provided via the same set of satellites. Current Indian arrangements are already operating on such a premise. These arrangements may need to be strengthened suitably to take care of military and security needs.

The IRNSS that India is putting in place for providing navigation services for both civilian and military use is based upon a combination of geostationary and geosynchronous satellites. This architecture is very different from the architectures of the systems being established by the other major space powers. Over the next ten years India may have to add a complement of orbiting satellites in a phased way to improve accuracies. By adopting this route India may be able to get to a completely indigenous navigation system within the next ten years.

The current arrangement of meeting both civilian and military navigation needs through the same system is in tune with global trends and may not require any major restructuring or reorganizing.

National capabilities to build small satellites need to be strengthened through a small satellite initiative.

The role of PSLV as a reliable launcher for meeting ISR requirements has been well established. Its ability to launch multiple smaller satellites has also been proven. **Capacities for building and launching more PSLVs need to be created to cater to the increasing demand.**

Indian industry must build the capacities needed.

As we had mentioned earlier Indian GSO C4 satellites have to move from an intermediate class to a heavy class. Significant delays in the realization of the GSLV Mark 2 and the GSLV Mark 3 launchers has further worsened the gap between Indian and global C4 capabilities. The use of ion propulsion technology to move the satellite from GTO to GSO reduces the fuel requirements onboard the C4 satellites significantly. Thus the medium class capabilities of the GSLV Mark 2 can launch intermediate class satellites and the GSLV Mark 3 that is under development can launch the heavy class satellites that are currently state-of art. **The use of ion propulsion technology therefore promises to redress both the C4 satellite as well as the launcher gap between India and the rest of the world. Forcing this integration between launcher and satellite capabilities via the ion propulsion route should be a major component of the space strategy of the country. Here also most capacity additions have to happen in Indian industry**.

The minor modifications that are needed to convert the Agni 5 into a space launcher for smaller satellites have to be carried out on a crash basis. The capability to launch satellites from different locations within the country to cater to the increasing demand for such satellites must also be established expeditiously. The production plans for the Agni 5 should be drawn up keeping these needs in mind.

The space strategy of the country should also support a limited space weapons development programme (BMD & ASAT) that will keep technology options open for the future.

Integration of the operational part of the capability realized through the SSA and C4ISR Integration with the strategy and

doctrine part of a national strategy is obviously the most important organizational and institutional challenge facing the country. Without the aspiration of wanting to be a power that matters and a clear intent of reforming and re-structuring the existing setup the rest of the strategy including the technology capabilities that may be built up makes no sense.

All the capabilities including those on space weapons outlined in Table 5 are consistent with India's current global posture of "peaceful uses of outer space".

Achieving these capabilities will take India a period of about ten years of major effort. More than the monetary resources the internal challenges from powerful organizational and institutional lobbies will the major hurdles to overcome.

India may also have to make some hard choices on the tradeoffs between the efforts required to put a man in space and its associated benefits vis a vis the requirements to build a robust space based network centric war deterring capability. Doing both of them simultaneously may not be possible given the resources that are currently available in the country. More than money, the human and organizational resource base is likely to be the main problem area.

Irrespective of whether India eventually choses to be a pro-active or a reactive player, the creation of a strong national SSA and C4ISR capability is a minimum requirement for an aspiring power like India. In the Realpolitik world of today no country that aspires to be counted can afford to ignore the

power that comes about through a robust SSA and a C4ISR capability in which space assets will play the key role.

Once a country has a strong SSA & C4ISR capability it can then chose to use this as a force multiplier for either a pro-active (offensive) or reactive (defensive) strategy. This directly connects the SSA& C4ISR capabilities to the role and use of space weapons and its implications for India.

While technology options can be kept open on space weapons as well as on the manned space programme operational decisions on these can be deferred by a few years till a robust SSA & C4ISR capability has been built up in the country. India can then address the global challenges it encounters at that time in a more pragmatic and meaningful way.

Acknowledgements

The author would like to thank all colleagues of the International Strategic & Security Studies Programme (ISSSP) for their technical and moral support in the writing of this paper. The author would also like to specially thank Lalitha Sunderasan, Y.S.Rajan, V.Siddhartha and Gopal Raj for their comments based on a critical review of the paper.

ABBREVIATIONS

ASAT - Anti-Satellite

BMD - Ballistic Missile Defence

C4 - Command Control Communications & Computers

ELINT - Electronic Intelligence

EO - Electro-optical

GSLV - Geostationary Satellite Launch Vehicle

GSO - Geostationary Orbit

IRNSS - Indian Regional Navigation Satellite System

ISR - Intelligence Surveillance & Reconnaissance

LEO - Low Earth Orbit

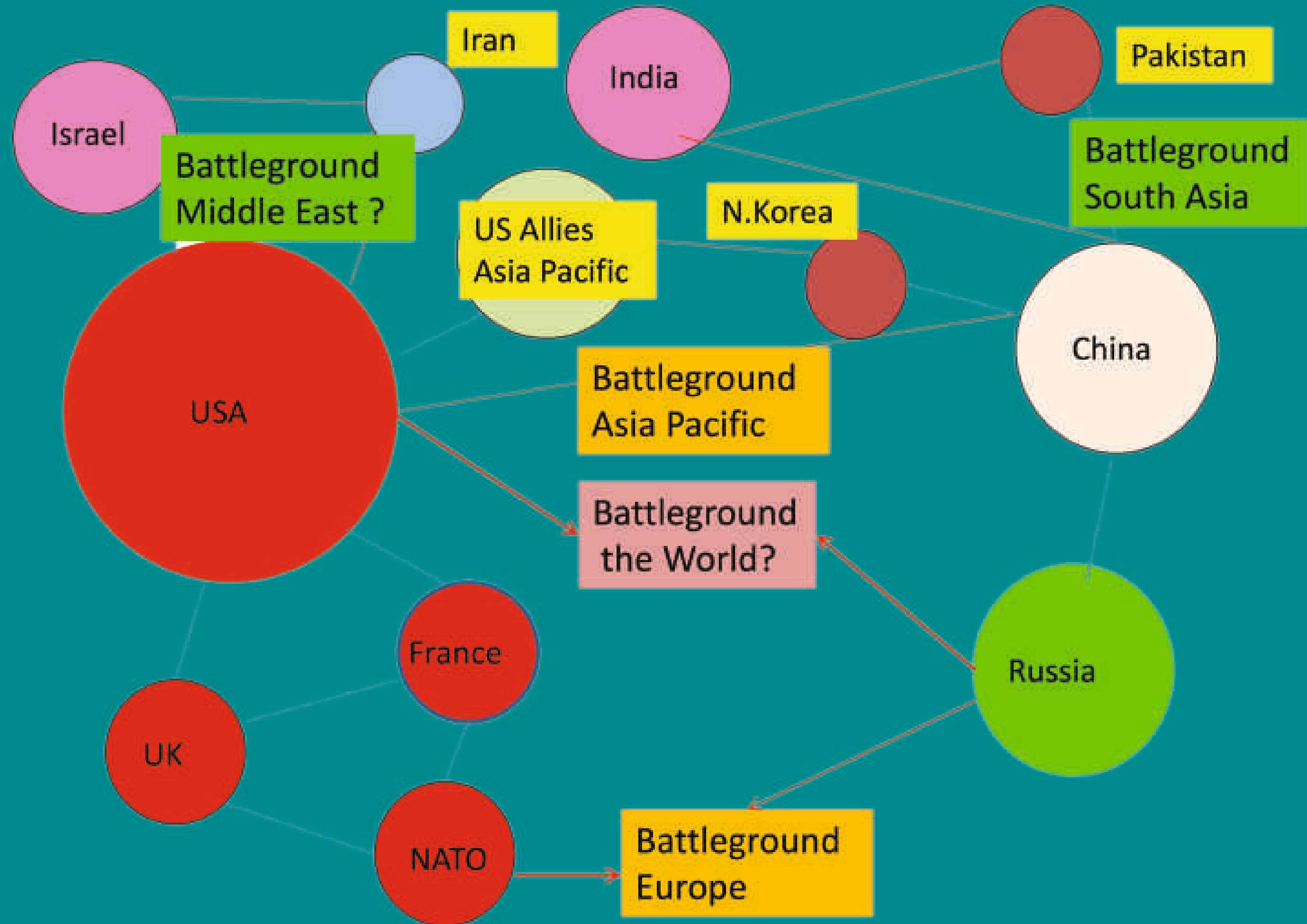
MEO - Medium Earth Orbit

PSLV - Polar Satellite Launch Vehicle

SAR - Synthetic Aperture Radar

SSO - Sun Synchronous Orbit

TDRSS - Tracking & Data Relay Satellite


Iran
India
Pakistan
Israel
Battleground
Middle East ?
US Allies
Asia Pacific
N.Korea
Battleground
South Asia
China
USA
Battleground
Asia Pacific
Battleground
the World?
France
Russia
UK
NATO
Battleground
Europe