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# Future Technologies

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The Centre for Land Warfare Studies (CLAWS), New Delhi, is an autonomous think tank dealing with national security and conceptual aspects of land warfare, including conventional and sub-conventional conflicts and terrorism. CLAWS conducts research that is futuristic in outlook and policy-oriented in approach.



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# Contents

# Chapter 1
# Future Technologies

The earlier years of space exploration mainly saw satellites being used for strategic objectives by the two superpowers. The evolution of related technology was gradual and the global interest in the domain was limited to a few isolated applications, such as weather forecasting and satellite broadcast. While commercialisation and technological advances in the decades of the 70s and 80s did manage to excite the sector, the major impetus was given by the first Gulf War, during which extensive use was made of space-based assets by the US and allied forces to support tactical military operations. Since then, as has been evident from succeeding Western military campaigns, the Revolution in Military Affairs (RMA) has necessitated their ever increasing integration for force enabling and force enhancement missions. Meanwhile, technological advancements in remote sensing, communication and geo-location capabilities have also stimulated commercial interest in the sector. Consequently, 60 countries presently have more than 1,000 active satellites in orbit. The domain has seen an unprecedented rate of transformation in terms of space related technologies and their applications in the last few years and this is expected to be surpassed in the times to come. Any nation that wants to exploit the maximum benefits from space needs to analyse these evolving technologies and trends, pursue the advances and incorporate them in its future plans.

Two emerging technologies will have a marked impact on the domain of space—microtechnology and nanotechnology. These technologies are not mutually exclusive and would continue to influence each other's progress. Developments would not be restricted to relentless miniaturisation only. They would affect the properties of the materials as well as their functionality and also contribute to more autonomous operations. Such capabilities would allow interesting and sophisticated applications.

## Microtechnology

Microtechnology relates to miniaturisation of technology with features equal to, or smaller than, one micrometre (one millionth of a metre). This relates to electronics and with technological advancements, to mechanical systems too.

**Electronics:** The shift from tubes to transistors commenced the movement towards 'small' in anything related to electronics. An increasing number of transistors on a single chip enabled smaller sizes of microchips with a corresponding increase in processing capacities and speed. The seemingly endless shrinking of the transistor along with an increase in the computing power has been enshrined in Moore's law of exponential increase.[1] Although there have been problems associated with the physical limitations of progressive reduction in size, till now, the trend has continued without any major variations. Research is being done into alternate materials and architectures that could enable overcoming these physical limitations and nanotechnology is going to be a major enabler towards achieving this. The quest for eternally improving processing capabilities, data storage and management and communication capabilities in ever smaller packages would continue well into the future.

**Micro-Electro Mechanical Systems:** Advances in technology have now enabled fabrication of micro-scale mechanical systems. Such mechanical components when put on a common platform with equally small electric components integrate mechanical motion with electronics and are called Micro-Electro-Mechanical Systems (MEMS). Micro-Opto-Electro-Mechanical Systems (MOEMS) are MEMS merged with micro-optics and involve sensing or manipulating optical signals on a scale of very small size. MEMS and MOEMS technologies are revolutionising system and sub-system designs by allowing the radical miniaturisation of optical, sensing, electronic and mechanical components, thereby allowing significant reduction in mass, volume and power requirements. MEMS are also enabling new approaches to applications in sensors and actuators, accelerometres, microvalves, flow controllers, combustion systems, propellant technology, turbomachinery and a host of other technologies relevant to a number of domains, including space. MOEMS have relevance to satellite attitude determination and orientation.

## Nanotechnology

Nanoscience is the study of phenomena and manipulation of materials at a nanoscale. A nanometre (nm) is one thousand millionth of a metre.[2] At this scale, the behaviour of a material differs in fundamental ways from that observed at the macro- and the micro-scales. Nanotechnology is the design, characterisation, production and application of structures, devices and systems by controlling shape and size at this scale.[3] Nanotechnology is not new; it has been explored in the past and there have also been a few diverse applications. However, it was the last decade that saw significant increase in interest in the technology because of advances that have enabled development of tools that now allow atoms and molecules to be examined and probed with great precision.[4] Improving fabrication and machining technologies that allow for very high precision and accuracy are enabling the conversion of sciences into workable models and products with implications across a broad range of domains. Nanotechnology is also enabling the opening up of totally new realms of science.

Two principal factors cause the properties of nanomaterials to differ significantly from other materials: [5]

- **Increased Relative Surface Area:** As a particle decreases in size, a greater proportion of atoms is found at the surface compared to those inside.[6] Thus, nanoparticles have a much greater surface area per unit mass compared with larger particles, resulting in materials at these sizes being more reactive chemically than the same mass of material made up of larger particles.
- **Quantum Effects:** Quantum effects can begin to dominate the properties of matter as size is reduced to the nanoscale. These can affect the optical, electrical and magnetic behaviour of materials, particularly as the structure or particle size approaches the smaller end of the nanoscale.

Nanotechnology, therefore, relates not only to reduction in sizes but also changing or enhancing properties that could provide the potential for pursuing both evolutionary as well as revolutionary applications. The major effects related to nanotechnology are improvements in information processing capabilities (discussed above), development of novel engineered materials and improving functionality of materials. Integration of these at a future date would lead to more autonomous systems and nanorobotic applications.

## New Engineered Materials

Much of nanoscience and many nanotechnologies are concerned with producing new or enhanced materials whose properties change dramatically with nanoingredients. Such materials are going to have a varied influence on developments in the future:

- **Stronger Lightweight Materials:** Composites made from nanosize particles offer the potential for much lighter materials that are also stronger than conventional materials. For example, metals with a grain size of around 10 nanometres are as much as seven times harder and tougher than their ordinary counterparts with grain sizes in the hundreds of nanometres.[7] Such materials would increase strength and durability while significantly reducing the weight of the components, thereby resulting in much lighter structures. Further developments would increase the thermal stability of these metals and alloys so that they retain their superior mechanical properties at elevated temperatures. Such durable components would allow reuse of components of various systems, thereby helping in cost reduction.
- **Improved Coatings:** Nanotechnology would enable surface coatings that would be resistant to corrosion and wear and tear and would further enhance the capacity of materials to withstand extreme temperatures. These would provide great benefits to structures that have to withstand extremes during their operation. Coatings could also be used for tribological[8] surface treatments that would improve the durability and function of internal components.
- **Multifunctional Structures:** Besides improving the inherent properties of the material, there may be changes in electronic and magnetic properties that could be used for development of smart composite structures that allow additional functionality. Such structures could also be embedded with sensors, actuators, controllers and processors to provide additional benefits such as thermal management, energy storage, health monitoring, Condition-Based Maintenance (CBM) and self-repair functions, thus, contributing to safer operations, increased system availability and

consequent cost savings. At a later stage, developments are also expected to provide adaptive and morphing structures that would permit the construction of large complex systems, such as antennae, using inflatable structures. Systems may also be able to reconfigure themselves to extend and expand the scope of their mission.[9]

- **Materials for MEMS:** Such materials with reduced fatigue or creep and surfaces with suitable friction and wear properties are essential to the successful transitioning of MEMS device technologies into their target applications.

## Increased Functionality and Autonomy

Increased functionality of materials when combined with high computational power – the ability to process complex specialised algorithms – will enable incremental degrees of autonomous capability to space systems. Such capability would reduce operating costs through elimination of much of the ground control. Reduction in communication would additionally lessen the vulnerability of the system to electronic jamming and spoofing. Autonomous capability would enhance close proximity operations, thus, opening up many more applications.

## Applications to Space Systems

**Sensing Architecture:** All satellites use sensors for maintaining their position in space, while remote sensing satellites also have mission specific earth watching payloads. Data processing and distribution form an integral part of all information gathering operations. Nanotechnology enabled miniaturisation and enhanced capabilities of sensors, communications, and information processing systems would dramatically change the sensing architectures and the way information is handled and applied:

- **Navigation Sensors:** Spacecraft rely on sensors to determine their orientation with respect to the Sun (for power), the Earth (for sensing and communication), and the stars (for spatial positioning). Many sensor types are used to determine this orientation, including optical sensors for the Sun and stars, and magnetic field sensors for determining their orientation with respect to the Earth.[10] Its Inertial Navigation Systems (INS) use accelerometres, gyroscopes, and other angular sensors to monitor their own forces and track their position and orientation. With the advent of the Global Positioning System (GPS) capabilities these have been incorporated to assist the INS in providing better positional accuracy and to improve redundancy of the satellite navigation and guidance system. MOEMS would significantly affect the requirements of optical navigation sensors. MEMS would enable smaller and more accurate inertial navigation sensors that would also allow more precise control of smaller satellites. Miniaturised GPS units have already shrunk enough to fit into smart phones or equivalent sizes. All these would help in reducing satellite sizes and weights and also bring down the power requirements. Accurate positioning and precise control would enable close proximity operations and relative positioning of satellites in arrays.

- **Electromagnetic Spectrum Sensors:** Effective Intelligence, Surveillance and Reconnaissance (ISR) operations require varied sensors to exploit all bands of the electronic spectrum, provide wide area coverage and high spectral and temporal resolutions. All types of sensor elements would gain immensely from the ongoing revolution in nanomaterials, leading to better sensitivity and resolutions, while miniaturisation would lead to smaller systems.
- **Data Handling:** The challenge is shifting from obtaining information to handling, analysing and distributing it. Miniaturised processors and GPS would enable onboard digital image processing and geo-tagging to significantly bring down the processing and analyses timings. Micro and nanotechnologies will provide more efficient data networks and better visual displays to enable disproportionate benefits for ISR efforts.

**Propulsion Systems:** The propulsion system and fuel account for between 40 and 95 percent of the initial system mass. Different size propulsion systems need to be designed for different classes of rockets and satellites. Larger satellites usually use complex monopropellants or bipropellant combustion rockets for propulsion and attitude control. Microsatellites have to use electric propulsion, compressed gas, vaporisable liquids or other innovative propulsion systems that are simple, cheap and scalable. Micro and nanotechnology applied to satellite propulsion may offer the opportunity for significant evolutionary improvements to current systems – as an enabler of new, very small propulsion and power systems – and may also enable revolutionary new concepts and capabilities. Their effect on various aspects of system propulsion would be:

- **Launch Vehicle Propulsion:** Use of nanotechnology enabled materials with improved strength-to-weight ratios would significantly decrease casing mass and allow construction of smaller and lighter engines. Nanoengineered coatings would allow better heat management of the structure, thus, providing improved thermal efficiencies and higher thrust-to-weight ratios than the conventional rocket engine.
- **Fuels:** Nanomaterials when used as propellants would allow more rapid combustion because of their increased relative surface area. Alternatively, nano additives could enhance the same in existing solid and liquid propellants. This would substantially bring down the fuel component of the total mass of the launch rocket.
- **Satellite Control:** Varied propulsion power is required to undertake satellite manoeuvring efforts that may involve minor orbital corrections or gaining altitude for station keeping[11] or for avoiding collision. The power requirement would itself vary according to the size of the satellite, from tens of milliwatts for attitude control of micro, nano and picosatellites to tens of kilowatts for orbital manoeuvring of ~3,000-kg-class spacecraft.[12] MEMS and nanotechnology would enable creation of multiple units of very small propulsion (micro-thrusters) that could be used onboard satellites for attitude control. Based on the modular concept, these micro-thrusters could be arrayed based on the size of the satellite to provide scalable thrust and power for better controlled and efficient station keeping and orbital manoeuvres.[13] Such arrays would also enable reduction in the number of components otherwise associated with conventional systems for variable power management. The modular concept would allow the same system to be used across various classes of satellites – the only difference being the size of the array – thus, leading to huge savings in Research and Development (R&D) and production costs. More efficient use of the propellant would help increase the operational life of satellites.

- **Electric Propulsion:** As the name suggests, this involves use of electric power for propulsion. Electric thrusters, when capable of developing sufficient electric power, would significantly bring down the propellant requirements for a given mission and also allow the fabrication of highly scalable thrust arrays. Electric propulsion has been successfully demonstrated as primary propulsion systems for NASA's Deep Space 1, Japan's HAYABUSA, and ESA's SMART-1 missions.[14]

**Space Power Generation:** Energy is also needed to power the sub-systems that are essential for the operations of a satellite.

- **Electric Power:** This is produced by shaft-driven generators, photovoltaic cells, thermocouple arrays, thermionic arrays, fuel cells, or batteries. Micro and nanotechnology can be applied to all of these systems to produce miniature (microwatts to watts) power systems that could be used for smaller satellites.
- **Solar Power:** The greater part of electric power generation in space is done by solar cells. Solar cell technology currently provides sunlight-to-direct-current conversion efficiencies of 15 to 18 percent, with some complicated set-ups providing up to 40 percent conversion efficiency. Nanoengineered materials are expected to provide better conversion efficiencies than those presently available.
- **Storage and Use:** The higher surface area per unit volume of nano-engineered materials speeds up chemical reactions and improves the efficiency of various processes. This, along with better materials, would enable improvements in production, storage, and use of electrical energy leading to longer lifetimes of the systems. Approaches in this direction have already resulted in more energetic batteries, with an increased ability of rechargeable lithium-ion batteries. Nanomaterials could also facilitate energy saving through nanomaterials aided efficient lighting (LEDs).

**Satellite Protection:** Providing adequate protection to satellites is gaining importance in an increasingly crowded and potentially hostile space environment and nanotechnology would offer varied solutions.

- **Radiation Shielding:** Advanced nanomaterials could pave the path to future spacecraft with nanoengineered hulls that provide effective radiation shielding. Miniaturisation would help onboard systems as electronic devices become more radiation tolerant when their dimensions are reduced. Radiation effects on diverse nanomaterials are being studied for any other benefits that could accrue or for requirements of protection.
- **Defensive Counter-Measures:** Nanotechnology could be used to improve the design of satellites to mitigate the threats posed by ground-based Directed Energy Weapons (DEWs) and high-powered microwaves. Multi-functional structures could make the satellite invisible to both optics and radar in the space environment. Nanoengineered quantum dots that are engineered to emit radiation having a radiation profile similar to that of the spacecraft, could be used to develop decoys.[15]

## Challenges

At present, however, most developments related to this knowledge intensive technology are at a very basic research and development stage. Related design and fabrication technologies are still evolving. Engineering challenges would have to be overcome for translating the unique properties of micro and nanostructures into viable products and then for progressing these towards low cost mass production. Technology demonstration under controlled conditions would have to graduate to operating under extreme conditions while still maintaining their beneficial properties. Also, most developments in the domain have been evolutionary, mainly relating to reducing the sizes and improving the capabilities of existing systems. Scientists are excited about the potential of the technology to lead to revolutionary innovations in materials, products and applications in the future.

Concerns have been voiced about the associated risks and impacts – most of which are as yet unknown or even unforeseen – on the environment and human beings involved with the life-cycle of nano-applications.[16] Globally, efforts towards an accepted framework have not yielded any result. In the absence of a sector specific regime, most developments are being regulated by the laws relating to the discipline that the concerned nanotechnology is expected to address. However, the interdisciplinary potential of the technology is going to make implementation of such regulation complicated, and sooner or later, comprehensive laws would be required. There are also concerns about the negative impact of the technology on global security, for example, the potential of some products to be used for development of Weapons of Mass Destruction (WMDs) or as chemical or biological agents.

## Indian Efforts in Nanotechnology

India had recognised the potential of nanotechnology quite early and in October 2001, the Department of Science and Technology (DST) had launched the Nano Science and Technology Initiative (NSTI). The government continued to play a dominant role in the development of the sector and the DST, in May 2007, launched the Nano Mission with an allocation of Rs. 1,000 crore for five years. Its aim was to foster, promote and develop all aspects of nanoscience and nanotechnology with potential to benefit the country. The mission is steered by the Nano Mission Council (NMC) under the chairmanship of the Bharat Ratna awardee, Professor C N R Rao. The technical programmes of the Nano Mission are also being guided by two advisory groups, the Nano Science Advisory Group (NSAG) and the Nano Applications and Technology Advisory Group (NATAG).

The Nano Mission has multiple objectives that include promotion of basic multi-disciplinary research, infrastructure development for nanoscience and technology research, establishment of public-private partnerships and nano-applications, technology development centres and Human Resource (HR) development. The potential of this technology has evoked global attention and the mission aims at exploiting this through international collaboration on research and development. The Nano Mission claims a growing number of projects, including some being funded by other ministries, with and without industry participation as also setting up of centres of excellence and major research facilities at various locations where the knowledge base exists. Efforts have also been made to improve awareness and education related to nanotechnology and to increase the human resource base through academic programmes at a number of government and private institutions.

The Nano Mission's impact has become evident on the academic front as India has emerged as one of the top five nations in the world in terms of scientific publications in nanoscience and technology. However, converting R&D into commercial products and applications is a major challenge. The Union Cabinet, on February 20, 2014, approved the continuation of the Nano Mission in its second phase during the 12th Plan period (2012-17) and sanctioned Rs 650 crore for the purpose.[17] This phase is expected to make a greater effort to promote application-oriented R&D so that useful products, processes and technologies emerge. This has underscored the government's commitment to pursue developments in this futuristic technology.

Both micro and nanotechnology have stimulated large scale commercial interest, with research and development taking place across a number of sectors such as electronics, energy, materials and manufacturing, environment, health and medicine, food technology and even defence. The aim has been to create smaller components with improved performance and capabilities, improve the characteristics of materials, and reduce the costs. There is also an associated trend of modularisation and standardisation that permits better adaptation of technology across multiple disciplines, thereby, allowing reduced expansion costs and development cycles. For utilisation in space systems, however, the challenge is to make these technologies and Commercial off the Shelf (COTS) components radiation tolerant for use in the harsh space environment.

# Chapter 2
# Microsatellites and Launchers

The technological advances in electronics, miniaturisation techniques and in the field of nanotechnology have been the key to a wide array of technology innovations with relevance to space operations. The most significant has been the impetus given to development of smaller satellites of increasing capabilities that is heralding a revolution in space.

Beginning with the Sputnik (Sputnik 1 weighed only 83.6 kg; Explorer 1 was 14 kg), earlier satellites were all small. In the ensuing years, while the resolution race encouraged more complex optical systems, the communication satellites had to cater to an ever increasing demand. Also, the requirement for longer operational lives of satellites necessitated robust structures. These advances resulted in commensurate increase in sizes, weights and costs of the spacecraft that was not helped by the fact that these stand-alone systems were government or military operated, for which costs were not a primary concern. Consequent to the increase in weight and migration of communication satellites to the geosynchronous orbits, the payload capabilities of launch vehicles had to be improved through advancements in launch technology and increasing sizes. Such large and complex satellites, with their associated requirements, restricted the technological and economic capability of space exploration to a few larger nations and also precluded commercial interest.

Reverting to smaller satellites came about due to the commercial interest in the sector. UoSAT-5, built by Surrey Satellite Technology Ltd (SSTL) of the United Kingdom (UK) and launched in 1991, was the first commercial microsatellite. Experts had dismissed the early forays into microsatellites as of little use other than academic experimentation, while warning of the concurrent increase of the orbital debris nuisance. Since then, several technology demonstrators and operational microsatellites have been launched, thus, defying the naysayers. Regular advancements in the relevant fields have made these smaller satellites ever more capable of performing complex scientific functions, communications and Earth observation

PUNEET BHALLA

missions. Besides contributing to the conventional roles, they have also stimulated thinking on innovative applications that could exploit their size and capabilities.

Small satellites can be classified under different size groupings, each with its own characteristics like costs and development time-lines.

**Table 1**

| Mass | Cost | Development | Time |
|---|---|---|---|
| Large | 10,00kg+ | $300m+ | 10 yrs+ |
| Small | 500 - 1,000kg | $50m | 3 yrs |
| Mini | 100 – 500 kg | $35m | 2 yrs |
| Micro | 10 - 100kg | $15 | 1-2 yrs |
| Nano | 1-10kg | $5m | ~1 yr |
| Pico | 100gm | > $100k | >1 yr |

**CubeSats:** Designing and deployment of nanosatellites got a shot in the arm with the CubeSats concept developed by Bob Twiggs at Stanford University in the late 1990s. It follows a standardised configuration of satellites that defines the basic single unit (1U) of 10 × 10 × 10 cm with a mass of about 1 kg. These units can be amalgamated into micro and nanosatellites – described by the number of such units that they contain (such as 1U, 2U, 3U or 6U) – for varied applications. The first CubeSat launch occurred in 2003 and the subsequent promulgation and acceptance of this standard by most government, commercial and scientific microsatellite manufacturers as well as launch operators[18] has facilitated integration of these satellites as secondary or tertiary loads with existing payloads, on varied launch vehicles. To further facilitate deployment of these satellites, the California Polytechnic State University has developed the Poly Picosatellite Orbital Deployer (P-POD). Each pod can accommodate three CubeSats or a single CubeSat of three units (3U) or any other combination totalling the same volume. The National Aeronautical Space Agency (NASA) has developed the Nanosatellite Launch Adapter System (NLAS) that can accommodate various configurations of CubeSats, totalling approximately 100 pounds, to be carried as secondary payloads into orbit.[19] The standard bus design of the CubeSat helps define an efficient combination of components that can be used as the model for all satellites, thereby allowing reprogrammable or reconfigurable systems that would provide payload flexibility to suit mission requirements. [20]

**Advantages:** Smaller satellites, including CubeSats provide a plethora of advantages over the conventional satellite systems with ensuing benefits to the domain:

- The most important have been the low development and production costs because of smaller development schedules, ease of production and use of off-the-shelf components. Low cost has allowed for manufacturing economies of scale. A minimal potential financial loss in case of failure has also meant lower insurance costs.[21] This has consequently brought down the cost of the end product significantly. For example, large expensive remote sensing satellites, costing several hundreds of millions of dollars, resulted in the cost of imagery being as high as $2,000-4,500 per scene. Over recent years, this class of mission is now capable of being performed by small satellites for tens of millions of dollars,[22] thereby, significantly bringing down the imagery costs to hundreds of dollars per scene. As the low costs stimulate interest, the larger customer base would be self-serving in further pushing the costs downwards.
- The reduced size and weight consequently enable reduced orbit deployment expenses. This could be as a result of the ability to launch them as secondary or tertiary load with larger payloads or through employment of microlaunch vehicles.
- Low cost would enable deployment of larger numbers. This, together with their increasing capabilities, would allow greater coverage of the globe both spatially and temporally.
- Microsatellites allow multiple satellite deployments in a single launch. On November 19, 2013, 28 CubeSats were launched on an Orbital Sciences Corporation Minotaur I rocket sponsored by NASA's ELana (Educational Launch of Nanosatellites) programme.[23] On November 21, a Russian Dnepr rocket carried 32 imaging satellites, with varied resolutions, into orbit. [24]
- Low cost and development cycles would also enable frequent replacement of satellites, allowing rapid technology upgrades.
- Cheaper satellites allow availability of back-ups that could be launched at short notice either to update operational systems or to replace

any damaged or ineffective satellite. While these would be ideal for replacing similar satellites that have been deployed singly or as part of constellations in orbit, their shorter service lives would restrict them to a stop-gap measure when launched to replace bigger and more expensive ones.

- Microsatellites, because of their lower mass, offer easier controllability, thereby allowing more flexible operations in space. This can be used to quickly reposition the satellite in response to a specific military requirement or a disaster or to meet a commercial demand. Such satellites would also be able to carry out more prompt evasive manoeuvres to avoid a potential threat situation.
- They provide an ideal test-bed for technology verification prior to larger investments in development programmes.
- Ability to conduct single-purpose missions would also permit cost-effective work to focus on specific areas of interest for a given user community[25], thus, empowering less affluent countries, businesses, communities or societies.
- The decreasing costs for space access and use are allowing an increasing number of less developed countries and private players, hitherto restrained because of technical and budgetary constraints, to gain technological expertise and to build capacity in space technology. Exposure to such technology would promote indigenous development that, in turn, will enhance the local knowledge and skills which would have an impact on other technology fields also.
- Even established space-faring nations stand to benefit from this 'democratisation of space' as a wider pool of developers would potentially lead to more innovations. An interesting development of proliferation of knowledge and technology is that increasingly the advanced industrial countries are seeking expertise and knowledge from some progressive developing nations while larger companies are looking at smaller ventures for the same. Increasing competition would benefit the space domain economically.
- Increased participation has already resulted in more nations with a stake in space security, thereby becoming a major catalyst for establishing space and remote sensing regulation. [26]

## Constellations

A satellite constellation basically involves a group of satellites working in concert, thereby, increasing the number of satellites and, hence, the coverage – towards a common goal. These networked satellites would be able to achieve more than single satellites. Multiple satellites could have similar sensors or complement each other's coverage across resolutions – spatial, radiometric and spectral. Data integration from these diverse sensors can provide more comprehensive and accurate data.[27] Increased numbers would mean shortened revisit times over the same point on the Earth and, hence, an increased temporal resolution, thereby improving data relevance.[28] There would also be less requirement of satellite manoeuvring to cover relevant areas. This would save on costs and precious satellite propellants, leading to longer operational lives. This concept, which seeks to replace stand-alone systems, has gained immensely from the advent of smaller satellites.

Dispersion of satellites makes them less vulnerable as a system. With greater overlap in coverage and distribution of functions, damage to, or loss of, any satellite due to natural or technical reasons or due to negation efforts, would be compensated by other satellites, thereby preventing a significant degradation of the overall capability. Efforts to replace satellites or add more numbers would also be possible without interrupting the system functionality.

Different countries or companies contributing to constellations reap disproportionate benefits i.e. enhanced capabilities at a lower cost, through economies of scale. Some constellations, besides those employed for GPS, are already operational, providing support to communication[29], remote sensing[30] and disaster management.[31] Constellations are now being looked at not merely for increasing coverage but also to provide novel operational applications.

## Tactical Exploitation

Microsatellites having applications in diverse fields like communications, remote sensing, meteorology, cartography, disaster management, and search and rescue are providing opportunities that could revolutionise military exploitation of the space domain. Most large satellites are prioritised for strategic purposes and are, therefore, not totally conducive to supporting real-time tactical operations. Microsatellites, being cheaper, can be deployed in sufficient numbers to cover specific areas of interest for the military. Multiple constellations could be made operational, each tailored to specific requirements to cater to desired areas of interest.

They could be used for force enhancement missions such as surveillance and reconnaissance and weather monitoring over areas of interest – augmenting the larger systems and, in time, replacing them. Dedicated microsatellites or constellations would, through increased revisit times, provide near real-time coverage. Multi-spectral coverage over diverse wavelengths would enable a comprehensive intelligence picture. As resolutions provided by these microsatellites continue to become finer, they would also be able to provide data inputs for targeting. Communication satellites deployed over the desired area would have military tactical applicability as nodes for battlefield communication that could support the Command and Control (C2) functions. Swarms with narrow beam antennae for communications would enable battlefield cellular communications systems. Thus, microsatellites and their constellations can be designed to support the entire spectrum of space-based Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance (C4ISR) operations, such as surveillance, navigation, communications, remote-sensing, Electromagnetic Intelligence (ELINT), and so on. While some of these functions could also be provided by Unmanned Aerial Vehicles (UAVs), satellites provide the advantage of larger coverage area and invulnerability to surface-to-aerial weapons. Countries the world over are studying the implications of their employment on the scope and scale of the military assets in space and how they can be effectively incorporated into the operational battle space.

**Offensive Counter-Space Capability:** The ability of any satellite to manoeuvre gives it an inherent ability to serve as an Anti-Satellite (ASAT). As the technology involved is not very complex, microsatellites are especially suited to this role as they are cheap and relatively more difficult to detect in space. Their dual use potential would further hide their intention till activation. These microsatellites could be used as hit-to-kill projectiles or be armed with conventional explosives.

They could act as "space mines", lying dormant in orbit till activated through spacecraft proximity or by ground control or they could be manoeuvred to a satellite for a kinetic kill or by exploding within close range. Microsatellites with soft kill capability would operate near target satellites, obtain electronic intelligence and use jamming and other Electronic Warfare (EW) methods to disrupt and degrade information transmitted from these systems.

Proximity operation ability would allow such satellites to approach other space objects to carry out visual and Infra-Red (IR) inspection or attach themselves to them to gain control or use EW methods to disrupt and degrade information transfer or to destroy them at a later date. As early as in 1950s, the US SAINT programme was designed to rendezvous with enemy satellites, inspect them with video cameras, and possibly disable or destroy them. The US Air Force (USAF) Experimental Spacecraft System (XSS) employed microsatellites to test proximity operations, including autonomous rendezvous, manoeuvring, and close-up inspection of a target. The XSS-10 in 2003 and XSS-11 in 2005 successfully manoeuvred autonomously around another space object and took images.

**Defensive Counter-Measure:** This role envisages employment of microsatellites as satellite bodyguards – fleets of small and cheap satellites that will protect high value space assets either physically or when used as decoys or by carrying counter-measure equipment. Such satellites would need to carry enough fuel to manoeuvre to intercept attacking ASATs, and this fuel could also provide the manoeuvring capability to serve as a kinetic energy ASAT.

**Challenges:** Adding a greater number of objects into space with their relatively shorter life spans has the potential to increase the problem of orbital crowding, bandwidth sharing and space debris. Appropriate debris mitigation efforts – technical, operational and legal – would, thus, need to be worked upon concurrently to catch up with the transformational technological changes. Recognition of the problems related to overcrowding and Radio Frequency (RF) spectrum usage linked to microsatellites has resulted in calls for regulation. The International Telecommunication Union (ITU), during the World Radiocommunication Conference (WRC-12), accepted that the rules were not geared for these smaller satellites and its new Resolution 757 calls on the ITU radiocommunication sector to examine procedures that apply to ITU processing of these small satellites and report to the next radio conference in 2015 (WRC-15). It also preliminarily placed the subject on the 2018 conference agenda (WRC-18) for possible changes to the ITU rules. [32]

## Commercial Viability

The advent of microsatellites revolutionised the commercial space arena as they are lighter, cheaper and more responsive and allow reduction in the associated launch and operating costs. Commercial satellite developers and operators are dispensing with the conventional approach of longevity of satellites. Instead, they intend to use the enormous cost savings made through use of microsatellites and Commercial-Off-the-Shelf (COTS) components to periodically replace the system assets with newer and more technologically updated ones. In the future, with maturing of technologies and capability demonstration of systems, microsatellites are expected to make greater inroads into the larger satellites' domains. Already, they are showing capabilities for high resolution multi-spectral remote sensing and Synthetic Aperture Radar (SAR) capability. These advancements at cheaper costs have resulted in increased interest by governments, in a market that was hitherto dominated by academic and scientific ventures. Their potential employability towards enhancement of tactical capabilities has aroused the interest of the militaries. This has been further assisted by the development of dual use technologies enabling innovation in other sectors to be utilised for military purposes. Adoption of CubeSat standards has been a big game changer for employment of nanosatellites.

According to Euroconsult, the current yearly launch average of nano/microsatellites of around 23 units per year is going to increase to about 100 to 142 (1-50 kg) launches globally in 2020, with an increasing participation by emerging countries and newer companies.[33] Government driven programmes – civil, military and scientific – are expected to dominate the demand[34] and most of these are expected to head for Low Earth Orbits (LEOs), where they are the most effective.

Technological advances and use of COTS continue to lower the costs of operational satellites that could provide viable applications. NASA, since

2009, has a PhoneSat project that is building nanosatellites using unmodified commercial smartphones, with the standard CubeSat bus, as satellites in LEO. Three such phones were launched on April 21, 2013, and one on November 21, all as secondary payloads. The latest, the PhoneSat 2.4 has a two-way radio to enable command of the satellite from the ground, solar arrays to enable it to be operational for up to a year, and a system for attitude control. These PhoneSats demonstrated imaging and communications functions, besides proving basic satellite functioning.

Reduced input and operational costs are leading to a new marketing concept wherein companies are offering data free of cost. Some of the most prominent actors in this trend are Australia, Europe, Japan, and the United States.[35] A company called Urthecast is in the process of setting up high resolution video cameras on the International Space Station (ISS) from which it is promising free near real-time streaming on its website. PlanetLabs, a US company, launched a 24-satellite constellation from the ISS in February 2014, through which it intends to supply near real-time imagery of the world, with 3-5m resolution, free of cost for socio-economic benefits.[36] Companies are expecting that wider availability of cheap or free data would enable more applications and foster demand. More such projects are in the offing. There is also an awareness of massive archives of data available with the companies that can be exploited at cheaper rates for mapping and monitoring environmental change. However, this does have a bearing on nations' concerns regarding transparency.

## Indian Microsatellites

The Third World Satellite (TWSAT) was the first microsatellite to be launched by the Indian Space Research Organisation (ISRO).[37] Since then, it has been supporting research in the field of smaller satellites and has launched microsatellites built by university students under its guidance. A list of the small satellites launched by ISRO is given in Table 2. Commercially, increasing use of microsatellites is good news for ISRO, which has a competitive edge with its cost-effective Polar Satellite Launch Vehicle (PSLV). In February 2013, PSLV 20 deployed seven small satellites into orbit.[38] It has also invited the private sector to exploit the opportunity in developing micro and nanosatellites that could be increasingly used for scientific purposes and other specific applications.

**Table 2**

| Name | Date of Launch | Weight | Mission |
|---|---|---|---|
| Anusat (Anna University Satellite) | April 20 2009 | 60×60×60cm Cubesat 38 kg | Primary payload-store and forward data communication and technology validation. |
| SRMSAT (SRM University under ISRO's guidance) | October 12, 2011 | 10.9 kg | Environment study. |
| YOUTHSAT Indo-Russian effort | April 20, 2011 | 92 kg | Study of dynamics of the Earth's upper atmosphere. |
| Jugnu, IIT-Kanpur under ISRO's guidance. | October 12, 2011 | 3kg | Near IR imaging and technology validation. |
| Student Satellite (STUDSAT) – The first Indian picosatellite, developed by a consortium of seven engineering colleges from Karnataka and Andhra Pradesh. | July 12, 2010 | Less than 1 kg | Space technology promotion in educational institutions. Imaging payload. |

Source: ISRO website.

India stands to gain the maximum – strategically, tactically and economically – from smaller satellites, and their development needs serious consideration and investment. The existing Indian initiatives, however, appear to be at a relatively nascent stage. Satellites launched by ISRO are mostly student efforts with academic roles. Even SARAL uses only an ISRO platform, while the payload is French. There needs to be a concerted effort to pursue their development and deployment, more so with consistent improvements in their capabilities. The low cost and flexibility of design would allow production of satellites that could target specific domains and applications, including military ones.

## Micro-Launch Vehicles

While there have been vast improvements in all aspects related to space operations, the launch technology and propellants have mostly remained unchanged. This has largely been due to the governments' aversion to risks and their being under little economic pressures to lower launch costs.[39] The emphasis till very recently was on increasing the satellite sizes and, consequently, the launch capacity. Limited capabilities of the microsatellites did not warrant development of dedicated smaller launch systems. Launching microsatellites by deploying them as secondary or tertiary load on larger missions has meant precious time being lost in the search for 'ideal missions' that would allow them to be launched into their desired orbits, negating the time gained through reduced development and production cycles. More sophisticated microsatellites in the future might have unique orbital and launch time requirements that cannot be met through secondary launches.

Increasing capabilities and users for microsatellites are, thus, stimulating a commensurate market for dedicated single or multiple capacity microsatellite launch vehicles that would themselves be smaller, lighter and less expensive to build and operate. Such launchers would be more responsive to microsatellite launches. Their development is being enabled through MEMS fabricated components and nanotechnology enabled materials. MEMS devices are expected to significantly improve the thrust-to-weight ratios of rocket engines through better control of gas and liquid flow while nanoadditives would reduce the weight of the propellant required. Together, these would bring down the lift-off weight with a consequent decrease in per unit launch costs. Cheaper launchers would allow launch-on-demand access to space that would, in turn, provide flexibility of operations as well as redundancy against natural and man-made threats in space.

Interest in smaller launch vehicles has also gained much from commercial interest in the satellite launch industry. Commercial operators are exploring use of COTS and developments in miniaturisation and nanotechnology to provide evolutionary improvements to current systems while also seeking revolutionary systems, all with an aim to target lower launch costs.[40] Commercial operators are developing reusable rockets which would significantly bring down the launch costs, production costs being a major portion of the total costs of launch. Space tourism has been the major driving force for these developments, which have dual use potential and could contribute significantly to military programmes.

The most revolutionary launch effort in recent times involved Japan's launch of its SPRINT-A telescope – to observe the solar system – aboard the Epsilon rocket. The Epsilon three-stage rocket weighs just 91 tonnes – about half the size of Japan's standard H2-A launcher. Owing to a new computer system with Artificial Intelligence (AI) that can perform its own checks and can be assembled quickly, the launch was coordinated from just two laptops in a control centre manned by a crew of just eight people against the 150 for the previous launch of H2-A rocket.[41] The Japan Aerospace Exploration Agency (JAXA) officials estimate the production and launch costs at 7.5 billion yen ($76 million) and expect this cheaper and more efficient launch method to provide them a competitive edge in the commercial launch industry.[42]

Lighter payloads would also allow the launch of satellites from aerial platforms, thereby offering multiple benefits. Boeing is working on its Small Launch Vehicle (SLV) developed under the US Defence Advanced Research Project Agency's (DARPA's) Airborne Launch Assist Space Access (ALASA) programme that is designed to launch small payloads of 45 kg into LEO from an aircraft.[43] There are commercial programmes that seek to use suborbital space planes, like the Swiss Space Systems' SOAR and XCOR's Lynx, to launch microsatellites into LEO orbits. CubeSats have also been launched from the International Space Station using the station's onboard JEM Small Satellite Orbital Deployer (J-SSOD).[44]

# Chapter 3
# Military Applications

Technologies become relevant to different sectors only through intelligent application. New age technologies are allowing developments that can be easily applied across different domains. Acceptability of standardisation techniques and protocols is allowing easier integration among varied disciplines. While this has allowed greater scientific and technological progress, it also has provided potential dual use capabilities to various systems. Some of the applications that have relevance to the military use of space will be discussed in this chapter.

## Operationally Responsive Systems

Micro-launch vehicles and technologies that allow production of smaller satellites would enable development of an Operationally Responsive System. Such systems would be able to deploy satellites into orbit at short notice to cater to specific needs or to replace an ageing or damaged satellite that would otherwise lead to loss of critical mission capability. Or it could be to meet emergent operational requirements such as in case of disasters or in conflict situations. An operationally responsive space (system?) would consist of three components[45]:

- Responsive satellites: smaller, lighter and cheaper satellites that could be kept as back-up in sufficient numbers.
- Responsive buses and payloads: standardised bus designs would enable a modular structure and this, along with open systems architecture, would allow flexibility of development and deployment of payload in operationally relevant time-lines. A satellite could, thus, be tailored on demand to meet the mission specific requirement at short notice.
- Affordable on-demand launchers to provide a responsive launch.

For the military, availability of all these assets in the future would allow flexible and responsive use of the space environment for both strategic and tactical missions. Their small sizes would allow stockpiling of back-up assets and on-demand launchers at multiple geographically dispersed launch areas.[46] Such dispersion would further provide system redundancy. The USAF has a joint programme office known as the Operationally Responsive Space Programme Office that involves most agencies of the US Department of Defence. The programme focusses on providing quick-response tactical space-based capabilities to the war-fighter utilising smaller satellites and launch vehicles.



## Proximity Operations

Proximity operations in space have been undertaken in the past as part of human space flight activities that involved berthing and dockings, by the United States and Russia, and more recently, by China. Miniaturisation and nanotechnology are enabling advanced sensors and increased processing power along with precise control capability in smaller satellites. This, when combined with the incremental degrees of autonomous capability, could allow a number of potential applications. In recent times, there have been a few other demonstrative programmes besides the US XSS. In 2010, Sweden had launched its PRISMA technology mission, consisting of two spacecraft, to demonstrate autonomous rendezvous, proximity operations, and formation flying. In July 2013, China launched three small satellites into orbit which carried out manoeuvres in relation to each other.

## Distributed Space Systems

Distributed Space Systems, also called Swarms, are collective arrays of satellites that function in a synchronised fashion exhibiting behaviours and performances that “emerge” from the individual activities but the collective emergent behaviour is substantially greater than the product of their individual abilities.[47] The technique involves deploying a number of microsatellites that while being placed miles apart, form part of a precisely controlled array. Their capabilities are synergised and individual data is integrated through digital wireless signal transfer to provide a seamless system. Swarms have been made possible due to advances in orientation and positional technologies and better communication and processing abilities – all having benefited from developments in MOEMS and nanotechnology. They promise unprecedented capabilities and novel applications in diverse fields.

- **Remote Sensing:** Swarms of sensors would revolutionise sensing architectures. Demand for high resolution data requires an ever increasing size of sensors in orbit. Multiple microsatellites flying in formation can form a larger virtual aperture through digital integration to increase resolution. Such microsatellites could also provide a frame for a membrane mirror.[48]
- **Communications:** Clusters of microsatellites that are linked together through an integrated secure wireless network can provide a seamless communication system. Antenna resolution is increased by increasing its size. Controlled clusters of nanosatellites with suitable coherent signal combining could simulate larger seamless antennae miles in diameter. These can then be used for communication purposes or for ELINT roles or as Ultra High Frequency (UHF) jammers. [49]
- **Position, Navigation and Timing (PNT):** Research is on to identify and analyse how constellations of smaller satellites could improve the overall GPS system performance such as accuracy, coverage, and robustness at much lower costs.

## Satellite Maintenance and Servicing

Proximity operations also enable satellite maintenance activities. The Space Shuttle had been used in the past to service important space assets like the Hubble Space Telescope. However, this was restricted to a few critical assets only. Satellite maintenance and repair offer a number of potential benefits and this has resulted in renewed interest in On-orbit Satellite Servicing (OOS) in recent years. OOS can increase the functional life of existing satellites, thereby saving the costs of building and launching new replacement satellites, as well as reducing the problems related to space debris. They can also be used to repair satellites that have been damaged due to natural causes or due to deliberate or inadvertent collisions. Other missions could look at upgrading the capabilities of existing satellites by replacing of components. Microsatellites could also attach themselves to active satellites either to compensate for any unserviceable components or to provide upgraded capability. The DARPA's Phoenix antenna harvesting / reuse programme envisages carrying of small satellites as hosted payloads on commercial satellites that, once in orbit, will attach themselves to existing satellites and take control of the old components to give them new operational life. [50]

NASA's Satellite Servicing Capabilities Office (SSCO) has been advancing the state of robotic servicing technology to enable the access and routine servicing of satellites. Its joint effort with the Canadian Space Agency, the Robotic Refuelling Mission (RRM), in May 2013, demonstrated the technologies, tools, and techniques needed to robotically service and refuel satellites in orbit, especially satellites not originally designed to be serviced. Robotic refuelling was resorted to in order to prevent exposure of astronauts to this dangerous task. The task was challenging because of the complexity of handling liquids in the near zero-gravity environment while ensuring that no space junk was added to the orbit. Mission controllers remotely commanded Dextre, the ISS' twin-armed Canadian robot, to perform cutting and manipulating protective blankets and wires, unscrewing, retrieving and stowing caps and accessing valves, transferring fluid, and leaving a new fuel cap in place. OOS is also being pursued by government and private companies in other countries such as Japan, Canada and Germany. One of the three satellites launched by the Chinese in July 2013, which carried out close proximity operations in relation to each other, was equipped with a robotic arm,[51] making some experts view this as a test of OOS capabilities.[52] Meanwhile, NASA's Notional Robotic Servicing Mission programme is studying a conceptual mission for a robotic servicing vehicle with the capability to access, repair and refuel satellites in Geosynchronous Earth Orbit (GEO).

One of the missions for SSCO is to help enable US industry for the task of servicing satellites, which the US feels has the potential to move into the commercial domain in the future. However, the economic viability of such ventures is still to be proven. In the current environment, it is cheaper to replace a satellite than to spend money on an older satellite whose technology is also dated. Most of these operations are complex and could lead to catastrophic accidents. These capabilities also have ASAT potential. Therefore, these activities pose a number of unique legal, operational, policy, safety and security challenges that need to be tackled before they can be effectively employed.

## Orbital Debris Removal

Orbital debris is a point of great global concern, as, without active involvement, objects once put in space continue to be in orbit for prolonged periods that vary with their altitude. Nearly 3,600 of the 6,600 satellites launched into orbit still remain in space, mostly occupying critical orbit space.[53] These are regularly joined by debris that, besides defunct satellites, comprises spent rocket stages, explosion or collision fragments, paint flecks, and other man-made objects. The Chinese ASAT test of 2007 has further increased the littering of these orbits. The on-orbit population today is catalogued at more than 22,000 trackable objects. In addition, an estimated 700,000 objects larger than 1 cm and 170 million objects larger than 1 mm are expected to be in Earth orbits.[54] The debris problem is most severe in the more crowded LEO, which is also the area that is most littered with spent rocket stages and other space junk. Satellite collisions are of great concern, especially the possibility that satellite collisions with fragments larger than 10 cm would release hazardous debris clouds that could set off a cascade of collisions – a series of hits creating ever larger numbers of debris and greater collision probabilities that may lead to an unstable debris environment in some orbit regions,[55] a phenomenon that is commonly known as the Kessler Syndrome. This would potentially render some orbits virtually unusable for years to come.

Regulatory mechanisms and voluntary debris mitigation efforts aim to reduce the contribution to this debris in the future. Concurrently, active measures to remove some large items, such as derelict satellites and launcher upper stages, among this debris, are also being contemplated and developed. One of the programmes is the German Space Agency project called Deutsche Orbitale Servicing Mission (DEOS) that would demonstrate the robotic capture of a tumbling object in space.[56] The European Space Agency's (ESA's) Clean Space initiative is studying the e.DeOrbit mission for removing debris in well-trafficked polar orbits.[57] The Swiss Space Centre has been exploring an Active Debris Removal (ADR) programme called Clean-mE (as part of CleanSpaceOne programme), which will remove a Swiss nanosatellite that does not comply with space debris mitigation guidelines. The technique being researched involves achieving rendezvous with a non-cooperative and tumbling spacecraft, and undertaking a servicing task or capture of a spacecraft in order to carry out controlled de-orbiting / reentry. Capture mechanisms being studied to minimise mission risk include throw nets, tentacles, harpoons and robotic arms. All ADR techniques have inherent ASAT applications.

### On-Orbit Assembly

Proximity operation capabilities would also allow undertaking tasks such as assembling structures in space. For example, the Next Generation Space Telescope envisages assembly of the sensor in space through proximity operations and autonomous assembly to achieve an aperture diameter of 20 m.[58] Structures being constructed on Earth have to be built in an environment that is different from the one they would operate in. They also have to withstand launch vibrations and 'g' loads before deployment. Scientists are now contemplating structures for use in space that are 3D printed in orbit. Structures that are constructed in orbit need not be made very robust to be fully functional in microgravity. 3D printing tools would reduce logistical requirements related to deployment of structures in space and, consequently, the costs, and also reduce the time for availability.[59] However, this is still in the conceptual stage.

### Laser Communication

Laser communication already holds great potential for deep space communication as also within space, for communication relay and to improve the effectiveness of swarms. Laser wavelengths are up to 10,000 times shorter than the RF wavelengths, providing much greater bandwidth capacity. This allows data to be transmitted across narrower, coherent beams, making them more secure and delivering the same amount of signal power to much smaller receiving antennae. Such beams also use less power over longer distances, making them ideal for space communication. Advancing technology is enabling research into the use of laser communication to complement, and, may be, replace, conventional radio communication between Earth and space in the future. It would allow higher data rate communication and would also reduce the demand on the RF spectrum that is nearing saturation in some critical bands. The resultant reduction in satellite size and mass and power requirements would allow cost savings for future missions.

In January 2013, as part of the first demonstration of laser communication with a satellite at the Moon, scientists with NASA's Lunar Reconnaissance Orbiter (LRO) beamed an image of the Mona Lisa to the spacecraft from Earth. By transmitting the image piggyback on laser pulses that are routinely sent to track the Lunar Orbiter Laser Altimeter (LOLA) instrument on the spacecraft position, the team achieved simultaneous laser communication and tracking.[60] Following up on this, in the last quarter of 2013, NASA carried out a 30-day Lunar Laser Communication Demonstration (LLCD) by undertaking communication with the Lunar Atmosphere and Dust Environment Explorer (LADEE) that is currently in orbit around the Moon using an atmosphere-penetrating AM-style modulated IR laser beam and eight ground telescopes. The test confirmed the high data transfer speeds – 622 Megabytes per second (Mbps) download and 20 Mbps upload – at such large distances. The tests were positive even at low Moon angles when the laser had to pass through a much thicker layer of atmosphere and through light clouding. NASA claims that the LLCD was able to send a Gigabyte of information to Earth in under five minutes, something that normally would have take several days. [61] In the next phase, NASA will launch the Laser Communications Relay Demonstration (LRCD) satellite in 2017 with a more advanced laser system capable of handling up to 2.880 Gigabytes per second (Gbps) from geosynchronous orbit as part of a five-year demonstration.[62]

In September 2012, France had also launched its plan of deploying and operating a 12-satellites commercial satellite communications constellation in Medium Earth Orbit (MEO), based entirely on optical wave technology.[63] The proposed capacity of the system, expected to be deployed by 2017, is 4.8 Terrabytes per second (Tbps), including sat-sat optical crosslinks and sat-ground optical up/down links of 200 Gbps.[64] As part of the development of laser communication between objects in space, a NASA and ESA programme in July 2013, used Alphasat to communicate at 300 Mbps with the German Tandem-X satellite over an experimental optical communication terminal, using laser beams.[65] There have been many other experiments by the ESA and nations such as Japan and Germany.

## Near Earth Space

Near Earth has seen renewed interest in recent years because of the advantages it offers over aerial and space-based assets. There is no clear definition of this band but the area being looked at presently is between the 17 to 22 km lower stratospheric altitudes that is marked by relatively light winds and air turbulence. Platforms may include manned or unmanned balloons, airships or airplanes. While drifting balloons serve few functions, tethered or powered airships and manned or unmanned airplanes would be able to stay aloft for prolonged periods of time, making them ideal for deployment of surveillance, communication or other payloads onto them.

## Airships

Unlike airplanes, conventional airships depend on buoyancy to gain altitude by using lightweight gases like hydrogen or helium. They can be tethered or use some form of propulsion to maintain themselves over a desired area. Propulsion involved would mainly be electric that would depend on solar power generation. Deployed at such a high altitude they can provide surveillance over hundreds of kilometres all around or support communication over a similar area. A platform deployed at 70,000 ft would have a Line-of-Sight (LoS) regional coverage of close to 650 miles in diameter with multiple payloads.

Some of the benefits that such a capability could offer over space-based assets are:

- **Persistent coverage** over a desired area. Such coverage could either be used as stand-alone or to complement other surveillance efforts.
- **Responsiveness:** Satellites have large development and deployment time-lines, whereas airships or airplanes can be deployed within hours.
- **Mission longevity** as they would be able to stay aloft for a long time without refuelling.
- **Higher resolution imagery:** Resolution of imagery is dependent on the distance; therefore, lower altitude would allow higher resolution imagery using less complicated sensors.
- **Communication:** Wireless communication using these assets would overcome the problems of latency[66] related to the satellite

communication. Less distance would also mean less propagation losses and such communication would also be relatively less affected by ionospheric effects. This would result in power saving.[67]

- **Cost-Effective:** These assets do not require costly inputs during development, or a large, dispersed infrastructure for operations.
- **Flexibility of payload:** Ability to carry multiple payloads to suit mission requirement.
- **Manoeuvrability:** Can be reassigned to adjacent area on demand.
- **Ease of Data Retrieval:** Unlike satellites, which are forever in motion in orbit, these platforms are deployed locally and, hence, data can be downloaded more easily, making it more time relevant.
- **Survivable:** These platforms are out of the range of most Surface-to-Air Missile (SAM) systems and fighter aircraft. They are vulnerable to satellite defence systems but not easy to track by radars because of the small size, at such heights and low operating speeds. Survivability can be further increased through use of stealth techniques. They also avoid risk related to space debris. However, their huge hangars are vulnerable to attacks. They are also more prone to the vagaries of weather during deployment.
- Unlike satellites in orbit, airships or airplanes can undergo regular **servicing and maintenance**.
- **Redundancy:** They are easier to replace than satellites.

Many countries have shown interest in stratospheric airships but, despite the potential benefits, they remain more a promise than reality. Programmes have been facing delays due to technical limitations and are facing budget cuts. There are significant challenges related to deployment of assets at these altitudes. Advances in miniaturisation, nanotechnology and automation capabilities are expected to address some of these challenges in the future:

- **Hull.** It needs to be light to keep the overall weight low. At the same time, it has to be strong to withstand the high thermal loads and be mouldable into a gas tight pressure vessel. Though relatively lower than space, the hull would also be exposed to high levels of radiation. Nanomaterials would contribute to these significantly.
- **Power:** Long on-station times can only be achieved through sufficient power generation. The benefits of nanotechnology to solar power

generation and more efficient storage in fuel cells and batteries that are also lighter, would enable consistent power over long periods of time. Electric propulsion is already enabling flights without the requirement of propellants. Increasing capacities combined with solar power generation would make it viable to fly them incessantly.

- Long on-station times require these satellites to be unmanned. They would, thus, benefit from the development of autonomous capabilities.

Among the number of initiatives launched for stratospheric airships, there are only two prominent ongoing programmes. One is the US Army sponsored Hi-Sentinel, six flights of which have been conducted since 2005. Five of them achieved altitudes greater than 65,000 ft. The other is the DARPA's Integrated Sensor Is Structure (ISIS). Both face delays because of technical challenges and reducing budgetary allocations.

Unmanned Aerial Vehicles (UAVs) of the High Altitude Long Endurance (HALE) type have been more successful. The most notable is the RQ-4 Global Hawk UAV that is used by the US forces for surveillance. It is powered by a turbofan engine, has a service ceiling of 20 km and endurance of 36 hours. Persistent coverage by these UAVs can only be achieved by deployment of multiple platforms.

These machines also face regulatory hurdles related to overflight of the air space of other nations. While this right has been bestowed on satellites through the Outer Space Treaty, 1967, in the case of machines operating in near space, the situation is not yet clear, mainly because the upper limit of sovereign air space has not been legally defined as yet.[68] The advent of cheaper microsatellites, with ever improving capabilities, has also affected the interest in airships. Commercial interest has been kept alive mainly for space tourism[69] and for communication operations.

Objects placed in Near Earth space do hold a lot of promise for tactical military operations. They are ideal to provide theatre level surveillance and communication and would be more responsive to the commander's requirements. High altitude airships can improve the military's ability to communicate in remote areas and in mountainous terrain. The United States' Defence Department claims that it is readying itself to issue contracts for the construction of a sophisticated, ultra-high altitude, 450-plus-ft-long blimp that will hover above the Earth's surface at 65,000 ft and remain airborne for up to 10 years.[70] It would virtually be a satellite in Near Earth space.

# Chapter 4
# Recommendations for National Security Efforts

The Indian space programme has been highly successful and has placed it among the leading space-faring nations across the world. Recent technological achievements of the Indian Space Research Organisation (ISRO) have greatly expanded its abilities in pursuance of national goals. The futuristic technologies hold a lot of promise for the Indian space sector as they provide cost-effective applications. The Indian space efforts have majorly been for peaceful civil purposes, in conformation with its standing in the world as a proponent of peaceful use of space and whose policies pursue harmony and stability in the region. However, there is now a growing tacit acceptance that the vast and diverse national security challenges that India faces across large borders as well as in the Indian Ocean Region cannot be achieved without support from space-based assets. There is also awareness that the achievements in space cannot remain immune to the developments in the military sphere that are increasingly demanding greater participation of space-based assets for enabling as well as force enhancement missions.

Deployment of assets such as GSAT-7 for the Navy and the under development GSAT-7A for the Air Force are the first steps towards accepting the inherent military aspects of space. However, the requirement is only going to go up as the defence forces' dependence on space increases. The large satellites currently being deployed are costly and have large development time-lines. Therefore, the limited numbers currently in orbit are treated as national assets whose employment is to be shared across different sectors. Restricted numbers limit their flexibility to respond to emergent situations. The existing deployment is going to prove grossly inadequate to do justice to the huge requirements related to tactical employment.

The emerging technologies and applications offer cost-effective and flexible solutions that could be utilised effectively to meet the needs of the Services.

Their relevance to the Indian security environment and recommendations related to their development and employment are:

- India has realised the potential of nanotechnology and in addition to the efforts in the civil and private domains, the Defence Research and Development Organisation (DRDO) has as many as 30 of its laboratories pursuing R&D in nanotechnology for defence related applications. While efforts by ISRO in the segment are not very explicit, they have always been at the forefront in absorbing newer technologies. A concerted national endeavour that integrates efforts by the civil, private and defence sectors would go a long way in extracting the maximum benefit from this technology that could then invigorate other defence related applications. In October 2012, the Raksha Mantri, Shri AK Antony had said, "There is a need to adopt a conglomerate, or consortium approach that involves academic institutions and industries." Such an approach would also benefit the industry which otherwise might not be able to sustain the establishment of huge scientific and technological infrastructure.
- Microsatellites would play an important role in empowering the military to undertake the desired missions in support of national security. While satellites deployed in GEO, such as the GSAT-7, might be able to meet the battlefield communication requirements, provisioning of persistent situational awareness to war-fighters would require deployment of microsatellites in large numbers in LEO, individually or as part of constellations. Standardised modular designs would ensure flexibility in producing and deploying satellites in shortened timeframes to address theatre and Service specific requirements. They could either be deployed through dedicated launches or as secondary or tertiary loads on larger launchers.
- Successful employment of microsatellites would further lead to development of smaller launchers. Indian successes in launch vehicles and ballistic missiles augur well for this segment. After the successful launch of the Agni-V in April 2012, the then DRDO chief Dr. VK Saraswat had said, "Agni-V's launch has opened a new era. Apart from adding a new dimension to our strategic defence, it has ushered in fantastic opportunities in ……launching mini/micro satellites on demand". Since

then, however, there have been few open references to this technology. Development of ORS needs to be pursued through collaborative efforts among ISRO, DRDO and the defence forces to provide responsive capability for tactical support.

- Laser communication could be a game changer for addressing the huge demands of a burgeoning economy. Its development would also enable optimising the use of the spectrum to cater to the exhaustive communication needs of the defence Services. This promising technology that could revolutionise operational communication needs to be pursued through synergised public–private ventures.
- Exploitation of Near Earth space for addressing theatre level requirements of surveillance and communication needs to be studied in detail. These would involve deployment of manoeuvrable, stratospheric airships that could stay aloft at an altitude above 65,000 ft (20 km) while remaining over a desired area for prolonged periods. Such airships should also be able to carry sufficient payload to cater to diverse missions. The R&D and production could involve a consortium involving the defence R&D organisations, the scientific and academic community and the private sector.
- Proximity operations are of great importance to ISRO for its future missions that would involve berthing and docking. Their potential for undertaking servicing and maintenance would also be looked into. The Services need to push for research and development of swarms that have the potential to enhance existing capabilities in remote sensing and communication. It would also be prudent to monitor such capabilities with the adversaries due to their ASAT potential and devise and deploy counter-measures against these.
- Technological development is best utilised through effective doctrines and strategies and a suitable institutional framework. While the three Services have individually incorporated changes in their organisations to cater to specific demands related to the space domain, developments in space are not going to be exclusive. A tri-Service institutional mechanism would help abandon segmented approaches, enable a synergised approach and define a long-term integrated perspective. The Integrated Space Cell was set up in 2010 to utilise India's space-based

assets more efficiently for military purposes and to make assessments of possible threats to these assets. While this has served its purpose during the nascent stages, there is a need for this to evolve into a more inclusive institutional structure that would control and coordinate defence assets, act as single point interface with other organisations, look after the doctrinal and training aspects and also pursue technology advancements and future requirements.

- At the same time, military commanders need to become more conscious of the increased battlefield transparency that these systems would provide to the adversaries. Increased revisit times would mean little time available to undertake movement without being detected. Counter-measures that would include camouflage and concealment, against diverse sensors would need to become integral to all defensive operations. More emphasis would have to be given to these while devising all future doctrines and plans.

## Conclusion

Technology and security have been inseparable since the advent of conflict. Technology has provided capability as also defined the threat. The nation that has successfully leveraged novel technology and its application has always held an advantage over the adversary and technological superiority has been instrumental in many a victory in battle. In the modern world, where the definition of national security has become more inclusive – involving a number of facets beyond the military – the nation's technological prowess has become integral to its national power and security. India as a nation is striving to find its rightful place in the comity of nations. Meeting its aspirations would require maintenance of a tranquil periphery as well as ensuring its energy security. This would, in turn, require building up of requisite capability that would provide credible deterrence. Such competence would also enable India to engage from a position of strength in regional and global fora.

Developing capabilities to address these concerns would necessitate exploiting the considerable leverages it enjoys in the space arena. There is a requirement to define a long-term technological roadmap with defined objectives in pursuance of futuristic technologies. As these technologies have relevance across diverse domains, concerted national efforts – that would have equal participation of the private industry and the academic community – would boost innovation and ensure optimum utilisation of resources. Standardisation and interoperability together with appropriate security measures should be the guiding principles.

For long, the Indian defence forces have defined military doctrines and plans that work towards optimum utilisation of the available equipment. This is undergoing a gradual change as heightened awareness of technology evolution, as well as revolution, is enabling them to define future acquisitions to meet their expected operational requirements. This changed mindset needs to be applied equally to space as space-based assets are going to be critical in any future conflict or even conflict-like situation. An integrated approach by the three Services for the development, deployment and operationalisation of these assets through proper institutional structures is a must. At the same time, one must not lose sight of the maxim that technology is only an enabler and its effectiveness would be dependent on effective doctrines, strategies, training and innovativeness.

## Notes

1. The observation made in 1965 by Gordon Moore, co-founder of Intel that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented. Moore predicted that this trend would continue for the foreseeable future. In subsequent years, the pace slowed down a bit, but data density has doubled approximately every 18 months. Almost every measure of the capabilities of digital electronic devices is strongly linked to Moore's law: processing speed, memory capacity… and the number of pixels in digital cameras. Source: http://www.webopedia.com/TERM/M/Moores_Law.html
2. A red blood cell is approximately 7,000 nm wide and a water molecule is almost 0.3nm across.
3. "Nanotechnology Introduction – The Significance of the Nanoscale", nanowerk, accessed at http://www.nanowerk.com/nanotechnology/introduction/introduction_to_nanotechnology_1a.php#ixzz2u9iqMwkn
4. Ibid.
5. Ibid.
6. For example, a particle of size 30 nm has 5 per cent of its atoms on its surface, at 10 nm 20 per cent of its atoms, and at 3 nm 50 per cent of its atoms.
7. n.3.
8. Tribology is the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear.
9. "Implications of Emerging Micro and Nanotechnology", accessed at http://www.nap.edu/catalog/10582.html
10. Ibid.

11. Satellites in orbit can decay from their desired orbits due to a number of reasons and require onboard propulsion to regain their position.
12 Joe Pappalardo, "How Small Can Satellites Get and Still Be Functional? From Nanosats to Femtosats", AirSpaceMag.com, September 1, 2006, accessed at http://www.airspacemag.com/need-to-know/how-small-can-satellites-get-and-still-be-functional-8884268/?no-ist
13. Ibid.

14. "Nanotechnology in Space", nanowerk, accessed at http://www.nanowerk.com/nanotechnology-in-space.php#ixzz2u9gor2zB
15. Ibid.
16. Krishna Ravi Srinivas, "Nanotechnology in India", Presentation made to Research and Information Systems for Developing Countries (RIS), Global Ethics in Science and Technology (GEST) Project Meeting, Preston, March 16, 2012, accessed at http://ris.org.in/.../Nanotechnology%20in%20India%20-%20Ravi%20Srinivas....%E2%80%8E
17. Vishwa Mohan, "Cabinet Approves Continuation of Mission on Nano Technology", TNN, February 21, 2014, accessed at http://timesofindia.indiatimes.com/india/Cabinet-approves-continuation-of-mission-on-nano-technology/articleshow/30755252.cms
18. The CubeSat Standard has been accepted by ISRO for the PSLV.
19. "NASA Launches Next Generation PhoneSat, Ames-Developed Launch Adapter", *Space Daily*, November 22, 2013, accessed at http://www.spacedaily.com/reports/NASA_Launches_Next_Generation_PhoneSat_Ames_Developed_Launch_Adapter_999.html
20. Aaron Q Rogers and Robert A Summers, "Creating Capable Nanosatellites for Critical Space Missions", accessed at http://www.jhuapl.edu/techdigest/TD/td2903/Rogers.pdf
21. Insurance costs usually form a large part of the total cost of operations because of the high risks involved in satellite launch. Some developing countries and emerging superpowers have resorted to undertaking some missions without insurance cover to keep operating costs low.
22. Giovanni Verlini, "The Bright Future of Small Satellite Technology", August 1, 2011, Via Satellite, accessed at http://www.satellitetoday.com/publications/via-satellite-magazine/features/2011/08/01/the-bright-future-of-small-satellite-technology/
23. Eight among these were US Special Operations Command (USSOCOM) technology development and demonstration satellites to explore the viability of using the CubeSat constellation to meet Special Forces mission requirements.
24. Matt Ball, "What Does the Launch of More Than 60 Microsatellites in One Week Mean for the Future of Earth Observation?", Sensors and Systems, December 2, 2013, accessed at http://sensorsandsystems.com/dialog/perspectives/32427-what-does-the-launch-of-more-than-60-microsatellites-in-one-week-mean-for-the-future-of-earth-observation.html
25. David L Glackin and Gerard R Peltzer, "Civil, Commercial, and International Remote Sensing Systems and Geoprocessing", American Institute of Aeronautics and Astronautics, El Segundo, California, accessed at http://aerospace.wpengine.netdna-cdn.com/wp-content/uploads/2012/03/bk_civil-comml-intl-remot-sens-sys_partl_ch1.pdf
26. Joanne Irene Gabrynowicz, "The Land Remote Sensing Law and Policies of National Governments: A Global Survey", The National Centre for Remote Sensing, Air and Space Law at the University of Mississippi School of Law, accessed at http://www.spacelaw.olemiss.edu/resources/pdfs/noaa.pdf
27. NASA's proposed mission called Edison Demonstration of Smallsat Networks (EDSN) aims to study geographical dispersed phenomena simultaneously, using swarms of 1.5U CubeSats and then using software to integrate it into a composite picture. Source: Edison Demonstration of Smallsat Networks (EDSN), accessed at http://www.nasa.gov/offices/oct/stp/small_satellite_subsystem_tech/edsn.html

28. With improved capabilities, larger numbers can be launched to further reduce the revisit times without compromising on imagery quality. Already, the 5 satellite constellation of RapidEye Earth-imaging satellites (each weighing 156 kg), is proposed to be replaced by 35 6U CubeSat standard satellites (each weighing 8 kg). This would provide the same resolution capability and significantly increased revisit time, 3.5 hours against a present 24 hours, at similar mission costs.
29. The Iridium satellite constellation consists of 66 active satellites in 6 LEO orbital planes and provides voice and data communication. Satellites also have limited inter-satellite links for more comprehensive coverage.
30. RapidEye (Blackbridge since November 6, 2013) operates a 5-satellite constellation producing 5 m resolution imagery. Each satellite contains identical multi-spectral imagers, travelling on the same orbital plane at an altitude of 630 km.
31. The Disaster Monitoring Constellation is a collaboration of Algeria, China, Nigeria, Spain, Thailand, Turkey, the U.K., and Vietnam. The project works on the premise that better temporal resolution is more important than higher spatial and spectral resolution for disaster observation and mitigation efforts and, thus, costly, high performance satellites are not required.
32. Gerry Oberst, "Nano- and Pico-Satellites", Via Satellite, October 01, 2012, accessed at http://www.satellitetoday.com/telecom/2012/10/01/nano-and-pico-satellites/
33. n.22.
34. Ibid.
35. n.25.
36. The company claims to have secured funding to launch an additional 72 satellites into LEO in the next 12 months, completing a 100-satellite constellation.
37. It was renamed IMS-1.The mission objective was to provide data for academic organisations and research organisations in developing countries free of cost. TWSAT carries a 4 band multi-spectral camera with a spatial resolution of 36m. The data provided by TWSAT can be used for application like resourced management in agriculture, forestry and land use and in disaster management.
38. These were 'SARAL', two micro-satellites UniBRITE and BRITE from Austria and AAUSAT3 from Denmark and STRaND from United Kingdom as also one micro-satellite (NEOSSat) and one mini-satellite (SAPPHIRE) from Canada.
39. Launch costs are the major expense in any space programme, hovering between $11,000 per kg and $22,000 per kg. Source: Theresa Hitchens, "Developments in Military Space: Movement Toward Space Weapons?" Centre for Defence Information, October 2003, Carnegie Corporation
40. There are ventures being planned by companies such as Virgin Galactic and the US-based Garvey Spacecraft and Ventions LLC to target the 15 to 100 kg market, both government and commercial. NASA's Launch Services Enabling eXploration & Technology (NEXT) programme/competition aims at developing a dedicated commercial CubeSat launch vehicle capable of putting three 3U (three unit) CubeSats with a combined mass of 15kg into polar and sun-synchronous orbits with a minimum orbital altitude of 425km.
41. The conventional launch vehicle requires many devices for ground inspection prior to launch, and, hence, a lot of time and manpower. Rocket assembly from the time the first stage rocket is positioned on the launch pad to the actual launch, with regular inspections could take anywhere up to two months.
42. Tariq Malik, "Japan's 1st Epsilon Rocket Launches Into Space On Maiden Voyage", Space.com, September 14, 2013, accessed at http://www.space.com/22806-japan-launches-epsilon-rocket.html
43. The air-launched three-stage-to-orbit launch vehicle concept aims at using a different engine at each stage. Each stage of its three-stage system uses an engine optimised for its

flight regime. The first winged tandem stage of its air-dropped vehicle uses air breathing jet propulsion to reach supersonic velocities, while the second winged stage is accelerated to near orbital velocities using scramjet technology. An expendable solid rocket upper stage is the final stage and is released from Stage 2 to finally push a payload of up to 45kg into orbit.

44. It is on the Japanese Experiment Module Kibo of the ISS and is a mechanism for deploying small satellites designed in accordance with CubeSat design specification. It first deployed five CubeSats in October 2012. In January 2014, 28 imaging 3U CubeSats of the PlanetLabs, individually known as Doves, and collectively known as Flock 1, were delivered to the ISS and were deployed in February 2014.
45. Space and the US Military: Operationally Responsive Space, *Stratfor*, April 30, 2008, accessed at http://www.stratfor.com/sample/analysis/space-and-us-military-operationally-responsive-space
46. The United States Army is developing the Soldier-Warfighter Operationally Responsive Deployer for Space (SWORDS) launcher, an "on demand" nanosatellite launcher, aimed to deploy nanosatellites into "precise orbits from almost any location at an ultra-low cost.
47. n.9.
48. Joe Pappalardo, "How Small Can Satellites Get and Still Be Functional? From Nanosats to Femtosats", *Air & Space* Magazine, Smithsonian, September 1, 2006, accessed at http://www.airspacemag.com/need-to-know/how-small-can-satellites-get-and-still-be-functional-8884268/?no-ist
49. Ibid.
50. Jeffrey Hill, "SS/L Selected for DARPA Phoenix Program Satlet Study", Satellite Today, July 30, 2012, accessed at http://www.satellitetoday.com/twitter/SSL-Selected-for-DARPA-Phoenix-Program-Satlet-Study_39210.html
51. Chinese state-run media identified the satellites as the Chuang Xin-3 (Innovation-3); the Shi Yan-7 (Experiment-7); and Shi Jian-15 (Practice-15). The Shi Jian-15 is believed to be the satellite with the robotic arm.
52. Bill Gertz, "China Launches Three ASAT Satellites", *The Washington Free Beacon*, August 26, 2013, accessed at http://freebeacon.com/china-launches-three-asat-satellites/
53. Sandrine Tranchard, "ISO Standards for Safer, Cleaner Space", accessed at http://www.iso.org/iso/home/news_index/news_archive/news.htm?refid=Ref1784 on November 15, 2013.
54. Background & Introduction, Sixth European Conference on Space Debris, ESA/ESOC, accessed at http://www.congrexprojects.com/2013-events/13a09/introduction
55. "Focus on Growing Threat of Space Debris", *Space War Daily*, April 19, 2013, http://www.spacewar.com/reports/Focus_on_growing_threat_of_space_debris_999.html
56. "Deutsche Orbitale Servicing Mission (DEOS)", SpaceTech GmbH Immenstaad, accessed at http://www.spacetech-i.com/deutsche-orbitale-servicing-mission.html on November 15, 2013.
57. A symposium on May 06 in the Netherlands will cover studies and technology developments related to e.DeOrbit, with ESA and space industry representatives presenting their research and outlining their plans.
58. Jeff Foust, "CubeSats Get Big", *The Space Review*, September 10, 2012, accessed at http://www.thespacereview.com/article/2155/1
59. See more at Jason Louv, "Will 3D Printing Revolutionize Space Travel?", Ultraculture, October 21, 2013, accessed at http://ultraculture.org/blog/2013/10/21/will-3d-printing-revolutionize-space-travel/#sthash.1w0xTYq7.AHvatyWs.dpuf
60. "NASA Beams Mona Lisa to Lunar Reconnaissance Orbiter at the Moon", January 17, 2013, accessed at http://www.nasa.gov/mission_pages/LRO/news/mona-lisa.html#.U0K3uvmSz50
61. Ibid.
62. Nancy Neal-Jones, "NASA Beams Mona Lisa to Lunar Reconnaissance Orbiter at the Moon", Goddard Space Flight Centre, January 21, 2013, accessed at http://www.spacemart.

com/reports/NASA_Beams_Mona_Lisa_to_Lunar_Reconnaissance_Orbiter_at_the_Moon_999.html

63. "World's First Space-Based Commercial Laser Communications Network Launched Today", September 11, 2012, accessed at http://www.pegasusglobalholdings.com/press-releases/space-base-commercial-laser-communications.html
64. "First Commercial Space-Based FSO Laser Communication Network to Deploy in 2017", laser focus world, September12, 2012, accessed at http://www.laserfocusworld.com/articles/2012/09/laser-light-communications-commercial-fso-2017.html
65. Steve Dent, "Cover Your Eyes: NASA, ESA Set to Bring Broadband Speeds to Space Using Lasers", July 18, 2013, Engadget, accessed at http://www.engadget.com/2013/07/18/nasa-esa-to-bring-broadband-speeds-to-space-via-lasers/
66. Most telecommunications satellites are in geostationary orbit to remain above a certain point on the Earth's surface. That orbit, however, is 22,240 miles above the Earth, which means that a signal going up to the satellite(uplink) and back to the Earth(downlink) travels nearly 45,000 miles, which equates to about a quarter of a second delay.
67. Airships are being considered by commercial telecommunication companies for localised broadcast and two way communication and data services.
68. The Karman Line puts the boundary between the Earth's atmosphere and outer space at 100 km. However, there is no international agreement on the vertical extent of sovereign air space, the boundary between outer space and the national air space and individual countries have a different take on this.
69. Daniel D Snyder, "Near-Space Tourism Takes Off", *Outside*, December 30, 2013, accessed at http://www.outsideonline.com/news-from-the-field/Tickets-Now-On-Sale-For-Near-Space-Journey-Worldview.html
70. Michael Webster, "USA Proposes New Giant Spy Airship-or Is It Already Here?", *Examiner*, June 14, 2013, accessed at http://www.examiner.com/article/usa-proposes-new-giant-spy-airship-or-is-it-already-here