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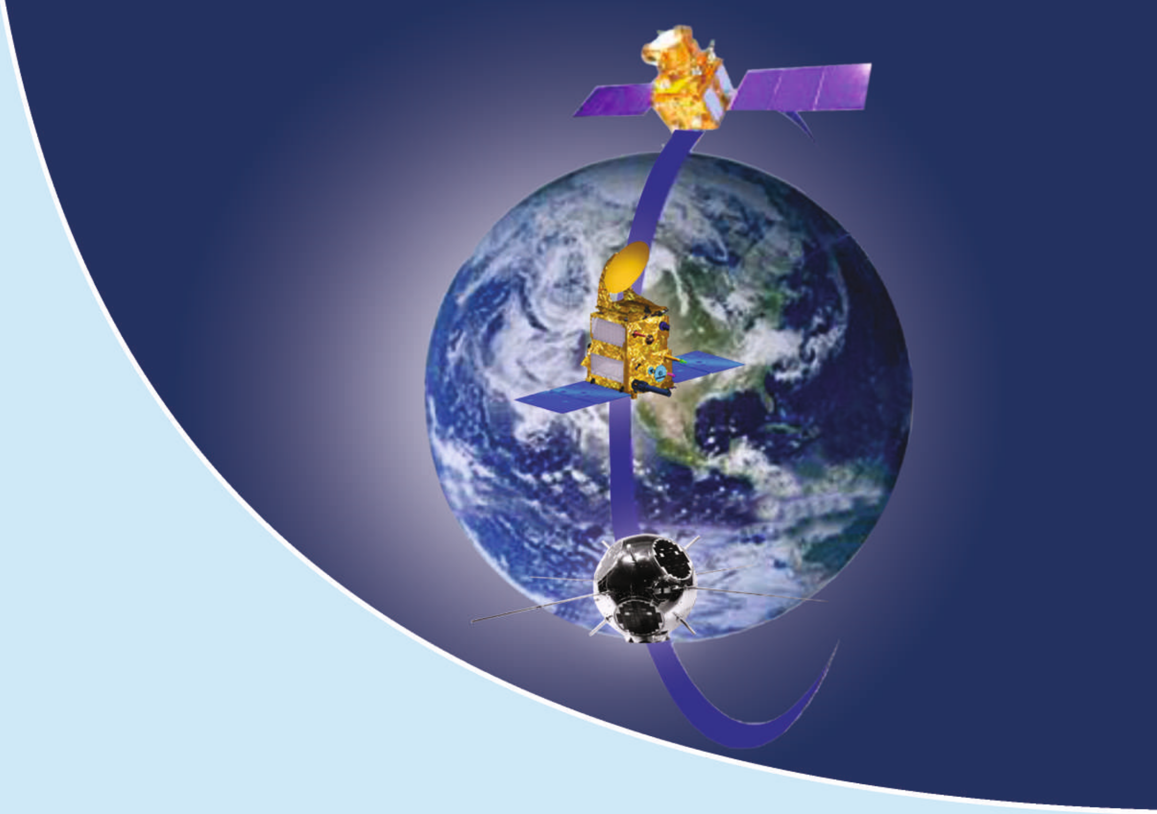

Rajaram Nagappa

The Promise of Small Satellites for National Security

December 2015

International Strategic and Security Studies Programme
National Institute of Advanced Studies
Bengaluru, India

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Summary

The Indian Space Programme has been the driver of many satellite-based applications in the civilian domain. Because of the dual use nature of space applications, the defence services have benefited from the ISRO space programmes The space services however, do not meet the total military space requirements. Small satellites are playing an important role in space applications. They are faster to build, are cost effective and better as they benefit from the use of latest technologies. Small satellite platforms can be adapted for optical and radar imaging remote sensing with good resolution. ELINT platforms can also be built around small satellite buses and an appropriate constellation of ELINT and imaging satellites can provide 24x7 surveillance of mobile targets. The potential of small satellites to meet military space requirements is described. The means of increasing the launch frequency is also studied.

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The Promise of Small Satellites for National Security

1. Introduction

The Indian Space Research Organisation (ISRO) has catered to the remote sensing, communication and meteorological application satellite requirements of the Country. It has also developed launch vehicles for placing the satellites in the desired orbit and is in a position to plan and carry out end-to-end missions. Improvements in remote sensing image resolution have kept pace with technology advancements and India is today in a position to provide sub-metre resolution images. Indian capability has also progressed into microwave remote sensing to overcome the constraints of optical satellite observations at night and under cloudy conditions. The Polar Satellite Launch Vehicle (PSLV) essentially designed for placing remote sensing satellites in sun synchronous polar orbit of 600 to 800 km has proved to be a very reliable vehicle, chalking continuous successful flights over the last 30 launches. The Geosynchronous Launch Vehicle (GSLV) can place 2.5-tonne class of satellites in geostationary transfer orbit. The vehicle is undergoing developmental flights and pending its reaching operational status, some of the satellite launch requirements are met through procured launches. Indian communication satellites cater to services in the C, extended C, Ku and Ka bands. Development of a heavy lift launch vehicle capable of placing 4-ton class of satellites in GTO is also progressing. Select communication satellites also carry meteorological payload for dispensing weather related information. An Indian Regional Navigation Satellite System (IRNSS) constellation is also taking shape to provide navigation support over the Indian land mass and to a region extending over 1500 km.

The Indian Space Research Organisation functions under the Department of Space and is a civilian Department. It owns and operates the entire space and ground infrastructure to render the required services. A large part of ISRO services are oriented towards meeting the country's developmental needs and fall in the category of public good.

Till recently, the military space requirements had not received specific attention. The dual use nature of remote sensing and communication satellites applications provides usable inputs to the defence services. Indian policy makers have generally maintained a stance against weaponisation of space. They have also realized the immense advantages the intelligence and defence services can derive from militarization of space. GSAT-7 launched on 30 August 2013 is the first satellite for the use of the Indian Navy. There are operational and resource constraints in catering to a larger military space requirement of the defence services. This paper tries to examine some of the connected issues and possible solutions.

2. Current Launch Vehicle and Satellite building capability

ISRO started developing launch vehicles in the 1970's. Since then it has developed or is developing launch vehicles for different satellite missions like remote sensing, communication, meteorology, space exploration and science. The capability and status of the launch vehicle development is summarized in table 1.

Table 1: ISRO Launch Vehicles

Launch Vehicle	Main Features	Payload/Orbit	1st Flight	Status
SLV 3	4xSPR; 1m dia x 22m long; GLOW 17t	40 kg/LEO	July 1980	Retired
ASLV	6xSPR; 1m dia (core) x 22.8 m long; GLOW 40t	150 kg/LEO	May 1992	Retired
PSLV	6s/on+2xSPR+2xLPR; 2.8 m dia (core) x 44.4 m long; GLOW 295 t	1600 kg/620 km SSPO 1050 kg/GTO	October 1994	Operational
GSLV	1xSPR+4xLPR s/on + 2LPR; 2.8 m dia (core) x 49 m long; GLOW 414 t	2000-2500 kg / GTO	April 2001	Development
GSLV Mk 3	2xSPR+2xLPR; 4.0 m dia (core) x 42.4 m long; GLOW 630 t	4000 kg /GTO	Dec 2014 (suborbital)	Development

***SPR**: Solid propellant rocket; **LPR**: Liquid propellant rocket; **s/on**: Strap-on; **GLOW**: Gross lift-off weight*

PSLV missions have mainly catered to orbiting domestic remote sensing satellites. It has also been used for select GTO missions, meterological mission, deep space missions and commercial launches. PSLV has capability for accommodating two piggyback small satellites or up to eight nano satellites along with the main satellite. These satellites can be released in the same orbit as the principal satellite. The commercial launch demand and supply scenario has essentially remained static—limited mostly due to delivery side capacity. This has in turn led to constraints in developing a sizeable customer base outside the country, despite the demonstrated reliability of PSLV.

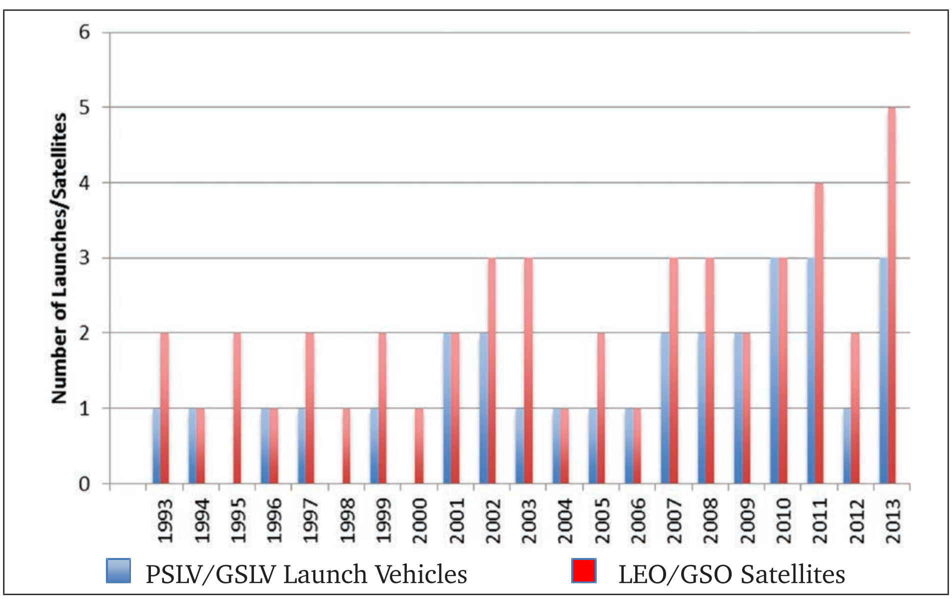
Following on its first successful flight in October 1994, PSLV has maintained a 100% successful record and has completed its 30th consecutively successful mission in September this year. While PSLV missions have mostly catered to placing remote sensing satellites in sun synchronous polar orbits, the vehicle has been used for other missions also. These include the meteorological satellite *Kalpana* in GTO; communication satellite *GSAT-12* in GTO; navigation satellite *IRNSS-1A-1D*; two deep space missions-the *Chandrayaan-1* and the *Mars Orbiter Mission;* and the recently conducted Astrosat mission. The Government recently approved[1] allocation of Rs 3090 crores to ISRO for an additional 15 flights of PSLV – C36 to C50 to be launched between 2017-2020.

1 Cabinet Nod to PSLV Programme, India in Business, Investment and Technology Promotion Division, MEA accessed on 25 May 2015 http://indiainbusiness.nic.in/newdesign/index.php?param=newsdetail/12360

The maiden flight of GSLV took place in April 2001. However, some of the subsequent flights have failed and there has been an overall delay in the realization of GSLV. The problems seem to have now been overcome as witnessed by the successful flights using the indigenously realized cryogenic upper stage on 05 January 2014 and August 2015. GSLV Mk III capable of placing 4-tonne payload in GTO is under development and is expected to join the Launch Vehicle Fleet by 2016-17. To date one sub-orbital flight of this launcher has taken place in December 2014 carrying a crew module as payload. The flight vehicle had active lower stages.

The launch vehicle flights and the satellite launch history are shown in figure 1[2]. The utilization of the launch vehicle is governed a) by the manufacturing and preparation lead-time and b) the availability of the satellite. Starting from the launch of one vehicle per year in the 1990's, capability to launch 4 vehicles (including the suborbital launch of GSLV Mk III) was achieved 2014. The number of satellites orbited in 2014 from Sriharikota was three, while the communication satellite GSAT-16 was orbited using a procured launch.

Figure 1: Vehicle and Satellite Launch History



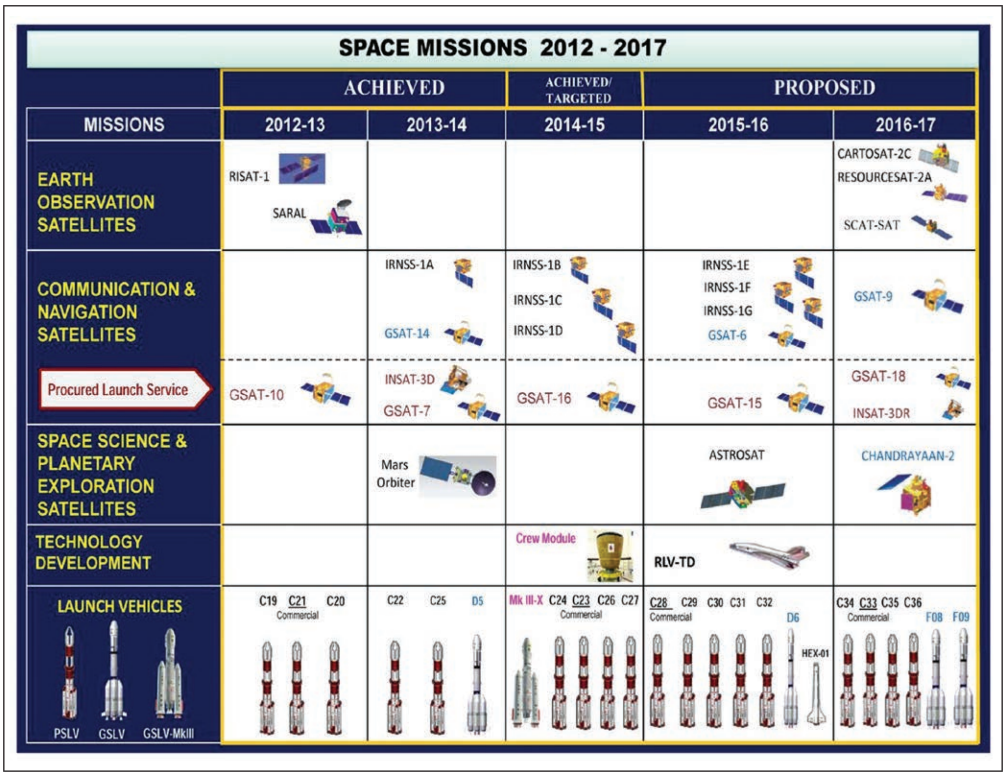
Notes: i. Failed launches are also included in the vehicle launch inventory
ii. PSLV missions include LEO, GTO and Deep Space Missions

The launch history shown in figure 1 is indicative of the satellite building capability, which can be surmised to be a maximum of 5 units per year comprising both the EO and the communication type of satellites. Some communication satellites have been orbited using procured launches because of either non-readiness of GSLV or as the satellites are of the heavier class (e.g. GSAT 16 launch weight was nearly 3.2 t).

[2] Inputs for the figure derived from information available on ISRO satellites at www.isro.gov.in/satellites/allsatellites.aspx last accessed on 02 January 2014.

The profile of missions planned and proposed by ISRO during 2012-2017 is shown in figure 2. There is scaling down from the mission profiles projected in the earlier years and the present projection is perhaps realistic in terms of the operational flights of GSLV and the maiden experimental flight of GSLV Mk III. The consequence is an increased gap between the demand and supply of communication transponders with implications on customer satisfaction[3].

Figure 2: ISRO Mission Profile



The planned targets for the subsequent years are as follows:

	2015-16	2016-17
Satellite Missions	6	7
Procured Launches	1	2
PSLV Missions	5*	4*
GSLV Missions	1	2
RLV-TD	1	-

**Includes one commercial launch*

3 In an interview, which appeared in Business Standard of 18 June 2013, Harit Nagpal, MD & CEO of Tata Sky complained that ISRO has not been able to provide him with 12 transponders even 4 years after the promised date. (http://www.business-standard.com/article/management/we-might-have-to-go-legal-against-isro-harit-nagpal-113061801000_1.html accessed 03 Jan 2015)

The mission profile now projected for 2015-16 and 2016-17 appear realistic with 5 launches of PSLV/GSLV and a slightly larger number of satellites to account for procured launches. One sub-orbital flight of the Reusable Launch Vehicle Technology Demonstrator (RLV-TD) is slated for 2015-16, while the flight test of the GSLV Mk 3 does not find place in this projection indicating a further delay in the readiness of the cryogenic stage. It would therefore appear that the number of launch vehicles readied for flight will be around 5 per year and the number of satellites built could be pegged at 7-8 per year.

3. Military Space Requirements

The military requirements for space utilization can be considered to be:

- Communication
- High resolution imagery (satellite constellation to provide frequent revisit data over regions of interest in normal circumstances; and rapid revisits and over theatre of interest for operations planning during times of conflict)
- Navigation (target location and guiding weapon systems)
- Meteorological data over region of interest
- Signal intelligence (detecting communication, radar emissions and broadcasting signals)
- Early warning

Services provided by the ISRO application satellites in the domains of communication, remote sensing, navigation and weather serve some of the above requirements. For example, the INSAT and IRS series of satellites provide communication and imagery services. The communication services are available in the C, extended C, Ku and Ka bands; IRS provides imageries covering a broad spectrum of requirements and the best resolution is in the sub-metre range. Some INSAT satellites carry the Very High Resolution Radiometer (VHRR) payload for providing meteorological services. Dedicated weather satellites like the Kalpana have also been flown by ISRO. Components of the Indian Regional Navigational Satellite System (IRNSS) are already in place and the whole system is planned to be in service by 2015-16. The dual use nature of space applications allows one to exploit these features for security purposes.

ISRO has flown GSAT-7 exclusively for use of the Indian Navy[4]. The satellite is built to the Navy's multiple-band requirements to safely link up its offshore and onshore assets in real time. However, given its own programmatic requirements and the capacity limitations, ISRO will find it difficult to accommodate all the military space requirements in a timely fashion. It should be noted that for 24x7 surveillance of mobile platforms satellite constellation comprising electronic intelligence satellites (ELINTS), optical and radar imaging satellites are required. The constellation will need 15-18 satellites, depending upon the revisit frequency.

For meeting the military space requirements, therefore utilization of a combination of assets put in place/

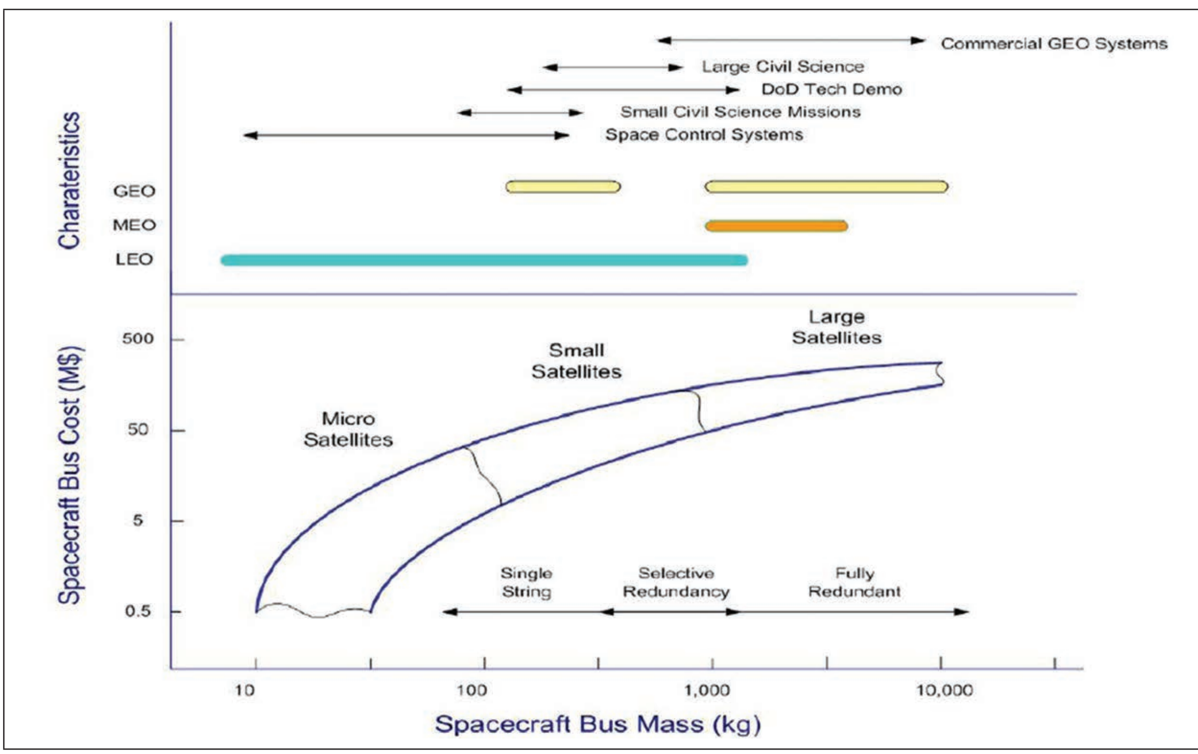
[4] "Navy's first satellite GSAT-7 now in Space", the Hindu, August 30, 2013 available at www.thehindu.com accessed 04 April 2015

planned to be put in place by ISRO and new capabilities that offer increased frequency of launch are required. The message therefore is while utilizing the capacity and capability of PSLV and GSLV, one should examine other options to meet the military space requirements. In this context, microsatellites weighing less than 150 kg are good candidates for supplementing the military space needs. It is also felt that a small satellite launcher derived from the existing rocket/missile stage modules can be configured to place such satellites in LEO.

4. Microsatellite Missions

The classification of satellites, their characteristics and normally deployed orbits is very well illustrated in figure 3[5]. As is evident and as seen from the figure, the microsatellites will, from mass, volume and cost considerations, employ limited or no redundancy in key systems. The costs[6] shown in the figure need not be taken at face value, as they will differ from country to country and among development agencies. The relative cost difference between large satellites and microsatellites, however, is quite representative.

Figure 3: Typical spacecraft characteristics



5 Reproduced from Disruptive Competitive Dynamics created by the Advent of Small Satellite Manufacturers and Operators by Adil R Jafry, http://commercialspace.pbworks.com/w/file/fetch/55473763/Adil%20Jafry%20Paper%20DIT%20for%20Small%20Sats.pdf accessed 12 January 2014

6 Microsatellites, in addition to doing away with redundancy, use Commercial-Off-The-Shelf (COTS) components, which help in keeping the costs low.

Features of an earth observation microsatellite bus[7] can be described as follows:

- Design life 1-3 years
- Avionics redundancy Limited
- Bus mass 150-300 kg
- Payload mass 100-300 kg
- Payload power 60-125 W (orbital average)
- Propellant (Hydrazine) 0-25 kg
- Pointing accuracy 0.02-0.25°
- Data storage 2-64 Gbit
- Downlink 2-4 Mbps at S band

Large number of earth observation system payloads can be fitted in a volume of 1 m^3. Characteristics of payloads typically used in some US microsatellite systems[8] are shown in table 2.

Table 2: Typical payload sensor characteristics

Space-craft	Dimensions (mm)	Mass (kg)	Power (W)	Data rate (Kbps)	Remarks
AIRS	1397x775x762	156	256	1440	
CERES	600x600x576	50*	47*	10	*per scanner
MISR	1300x900x900	149	83	3300	
ALT	460x330x280*	98	110*	24*	*Data is for the electronics
DCS	200x360x280	70	68	NA	There are a total of 3 payloads of near equal dimensions
SARSAT	390x280x200	46	70	NA	

AIRS : Atmospheric Infrared Sounder
CERES : Clouds and the Earth's Radiation Energy System
MISR : Multi-angle Imaging Spectro-Radiometer
ALT : Altimeter
DCS : Data Collection System
SARSAT : Search and Rescue Satellite Aided Tracking

The microsatellite imagery capability is best verified by examining the missions already flown. Selection of the satellite inclination can provide imagery over specific regions of interest that can supplement higher resolution data obtained from the Indian and other remote sensing satellites in SSPO. A sample of microsatellites for remote sensing missions is provided in table 3 below.

[7] Data derived from The role of small satellites in NASA and NOAA earth observation programs; see http://www.nap.educatalog/9819.html accessed on 17 January 2014

[8] ibid

Table 3: Microsatellites used in Remote Sensing

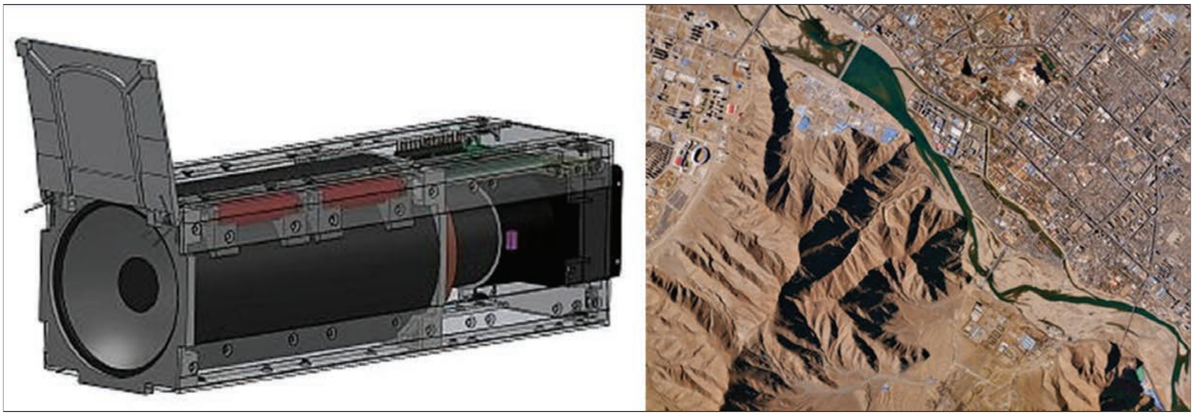
Satellite	Year	Country	Weight, kg	Orbital Parameters, km	Resolution / Swath,
Beijing1	2005	China	166	682x704/98.1°	32m MS (NIR,colour)/ 600 km; 4m Pan/24 km
TopSat	2005	UK	130	682x706/98.1°	2.5 m Pan/-
UK-DMC	2003	UK	110	676x692/98°	32m MS (NIR,colour)/ 600 km
Nigeria Sat-1	2003	Nigeria	98	675x692/98°	32m MS (NIR,colour)/ 600 km
BILSAT—1	2003	Turkey	110	675x692/98°	26 m MS/55 km 12m Pan/25 km 120 m MS/76.8 km
AlSat-1	2002	Algeria	98	675x692/98°	32m MS (NIR,colour)/ 600 km
Tsing-hua-1	2000	China	49	684x708/98°	39m MS/80 km
Tiung-Sat-1	2000	Malay-sia	50	617x622/64.6°	Wide angle camera: 1.2 km/FOV: 1200x1200 km Narrow angle camera (3 Nos.): 80 m/FOV 80x80 km
Clemen-tine	1999	France	50	606x620/98.2°	Study of earth's radio electric environment
CERISE	1995	France	50	610x620 km/ 98.2°	Military reconnaissance satellite

From the data of table 2 and 3, it is clear that microsatellites for earth observation with reasonable resolution can be configured. In fact, reasonably good imagery is available through even smaller nano-satellites. Planet Labs of USA has deployed constellations of 28 such nano-satellites called Dove-1. Each Dove-1[9] weighs just about 5.8 kg and measures 100 mm x 100 mm x 300 mm. Within this small dimension and mass, is housed the satellite's attitude determination and control system based on magnetorquers and reaction wheels. Satellite power system consists of Lithium-ion cells of 20 Ah power rating charged by body-mounted solar cells. The satellites provide images of 3-5 m resolution with same site revisit frequency higher than any other government or commercial satellite constellation. The Dove nano-satellite and imagery taken of Lhasa[10], Tibet is shown in figure 4.

[9] Dove satellite data sourced from https://directory.eoportal.org/web/eoportal/satellite-missions/d/dove accessed 06 April 2015. Also see https://www.nasa.gov/mission_pages/station/research/experiments/1326.html.

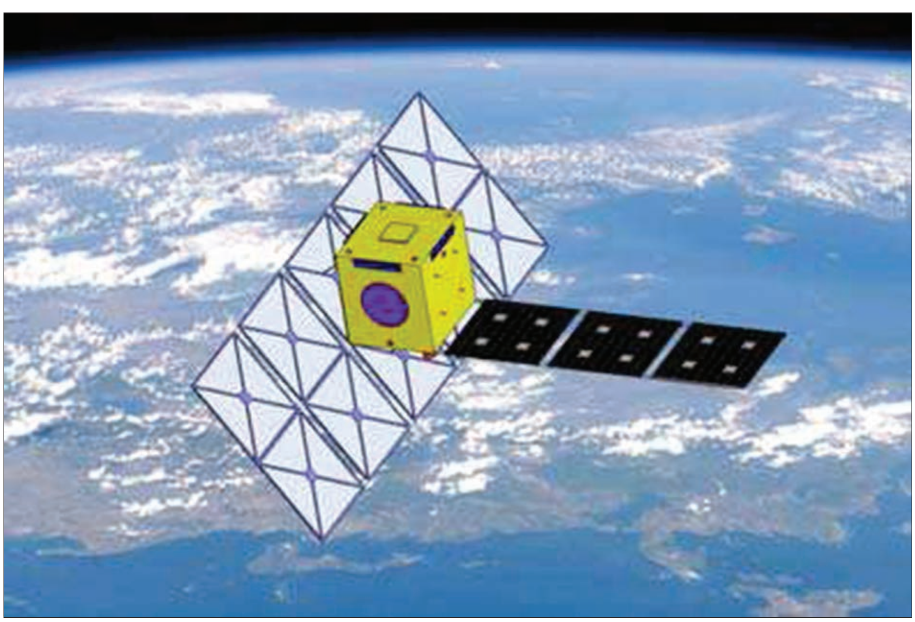
[10] Image downloaded from https://www.planet.com/gallery/lhasa/ accessed 06 April 2015

Figure 4: Planet Lab Dove Nano-satellite and Imagery over Lhasa



A constellation of satellites at a suitable inclination can provide imagery with frequent revisit capability. This data can be supplemented where required with higher resolution imagery available with Indian Remote Sensing satellite system. For obtaining imagery at night as well as under cloudy conditions, satellites equipped with synthetic aperture radar (SAR) are required. It appears that microsatellites configured to carry SAR payload are feasible. The Centre for Environmental Remote Sensing, Chiba University, Japan has proposed the development of circularly polarized SAR[11] for launch on board a small satellite in 2014. The satellite is shown in figure 5.

Figure 5: CP-SAR small satellite



CP-SAR is the main sensor for transmitting and receiving the L band chirp pulses for land deformation monitoring. GPS-SAR is an experimental passive sub sensor to study the possibility of receiving the GPS

[11] J T Sri Sumantyo, Development of Circularly Polarised Synthetic Aperture Radar (CP-SAR) onboard Small Satellite, PIERS Proceedings, pp 334-335, Marrakesh, Morocco, March 20-23, 2011

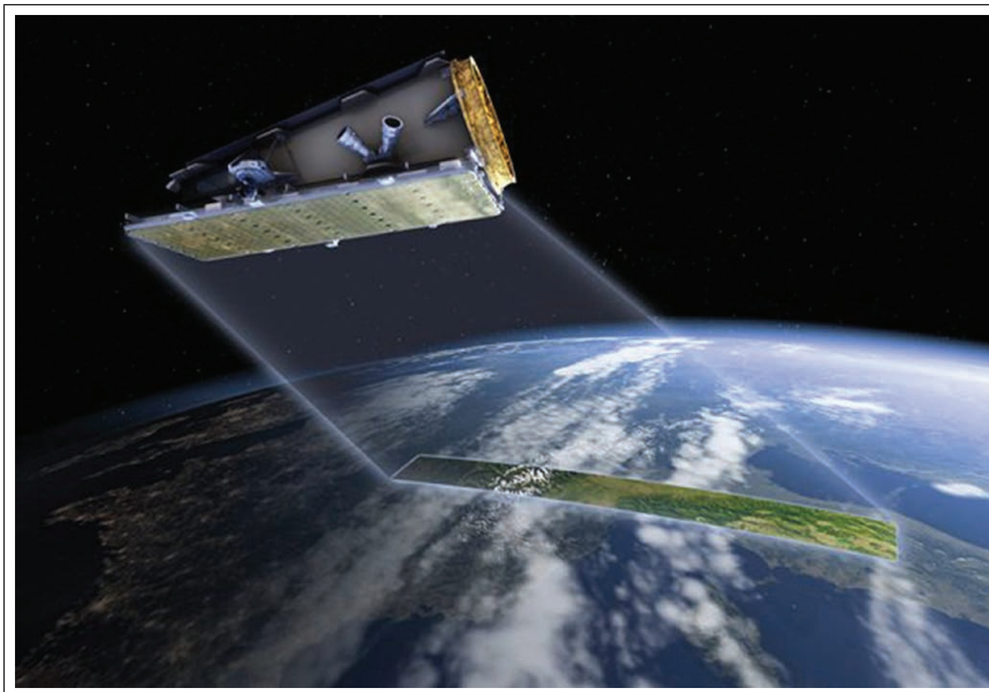
pulse and process it to retrieve the SAR image. The general characteristics of the CP-SAR satellite are shown in table 4 below.

Table 4: CP-SAR satellite characteristics

Orbit	500-700 km; 97.6° inclination
Frequency/wavelength	L Band (1.27 GHz)/24 cm
Off-nadir angle	29° (centre)
Swap width	50 km
Spatial resolution	30 m
Peak power	90-300 W
Bandwidth	Chirp pulse: 10 MHz
Platform size	1m x 1m x 1m
Mass	<100 kg
Antenna size	Elevation 2.0 m; Azimuth 5.0 m
Sensors	Main sensor: CP-SAR Sub-sensors: GP-SAR, GPS Radio Occultation (RO) Cameras

Surrey Satellite Technologies Ltd (SSTL), who have pioneered many small satellite applications have also developed the NovaSAR-S synthetic aperture radar satellite to obtain imagery of 6-30 m resolution. The satellite is shown in figure 6.

Figure 6: SSTL NovaSAR-S



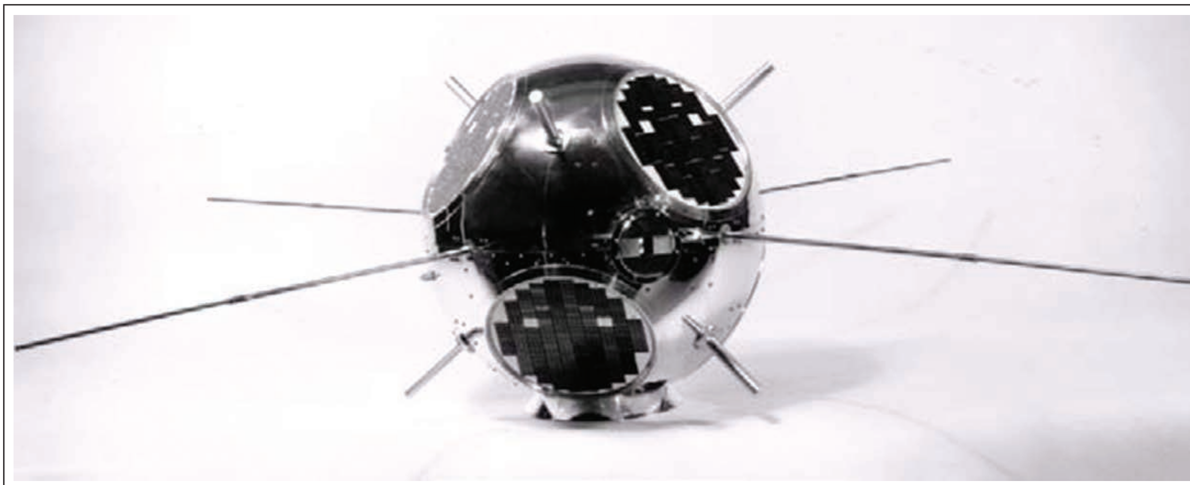
The satellite operating in S-band (3.1-3.3 GHz) orbits in a 580 km sun-synchronous or low inclination orbit and can typically cover an area of 1 million km^2 per day. The satellite is designed for 7 years life and weighs about 400 kg.

Also important from the military angle are satellites required for gathering signal intelligence. In this category also microsatellites can be designed to serve the purpose. However, in some categories of signal intelligence gathering, 3 such satellites may have to be launched simultaneously in a 62° inclination orbit. *Grab* and *Poppy* were the early signal intelligence gathering satellites of the United States. The satellites provided location and capability inputs of the radars employed by the Soviet Union; they also provided ocean surveillance information; and in conjunction with imaging reconnaissance satellite data, a more complete picture of the Soviet military threat could be assessed.

Grab, an acronym for Galactic Radiation and Background Satellite featured ELINT antennas that provided reception of radar signals. A separate and larger turnstile antenna was provided to receive commands, transmit telemetry and ELINT data. The *Grab* satellite is shown in figure 7. *Grab* satellites collected each pulse of a signal emitted by a terrestrial radar in a specified bandwidth. A corresponding signal was transponded to the NRL radio receiving and control huts at ground sites within *Grab's* field of view.

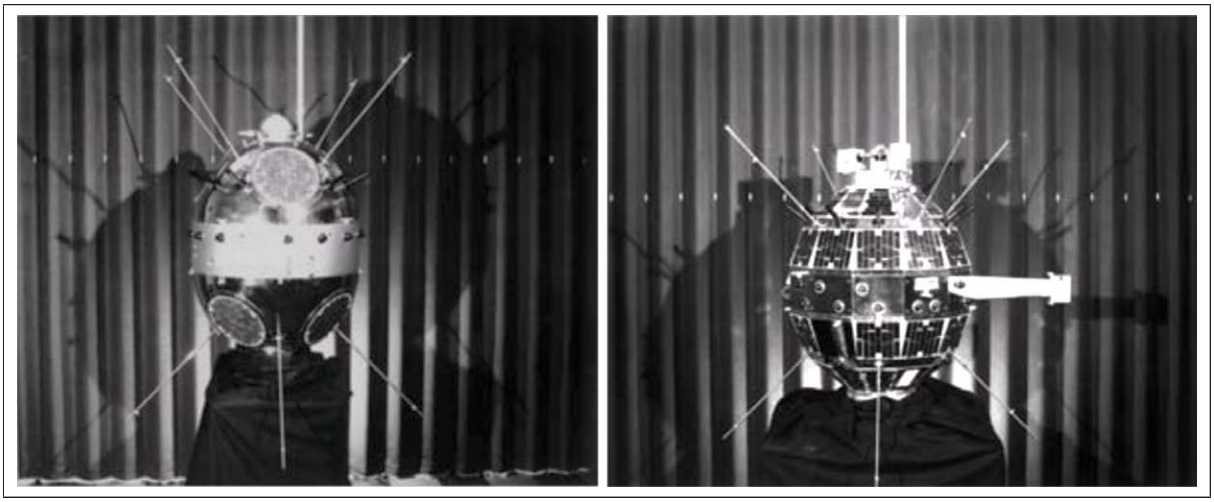
The *Grab* satellite was 500 mm wide and weighed 123 kg and could intercept radar signals upto an altitude of 960 km. Out of five *Grab* satellite missions between 1960 and 1962 two were successful. The first mission operated for three months while the second mission operated for fourteen months.

Figure 7: Grab Satellite



Grab was succeeded by *Poppy* satellite towards late 1962. Seven successful missions of *Poppy* were carried out. The *Poppy* mission satellites were of two types. One featured a stretched spherical design measuring 600 x 800 mm and weighing 59 kg. The other featured a 12-sided design measuring 685 x 864 mm and weighing 128 kg. Both versions of *Poppy* are depicted in figure 8. The first of these satellites were slightly smaller in dimensions as well lighter in mass.

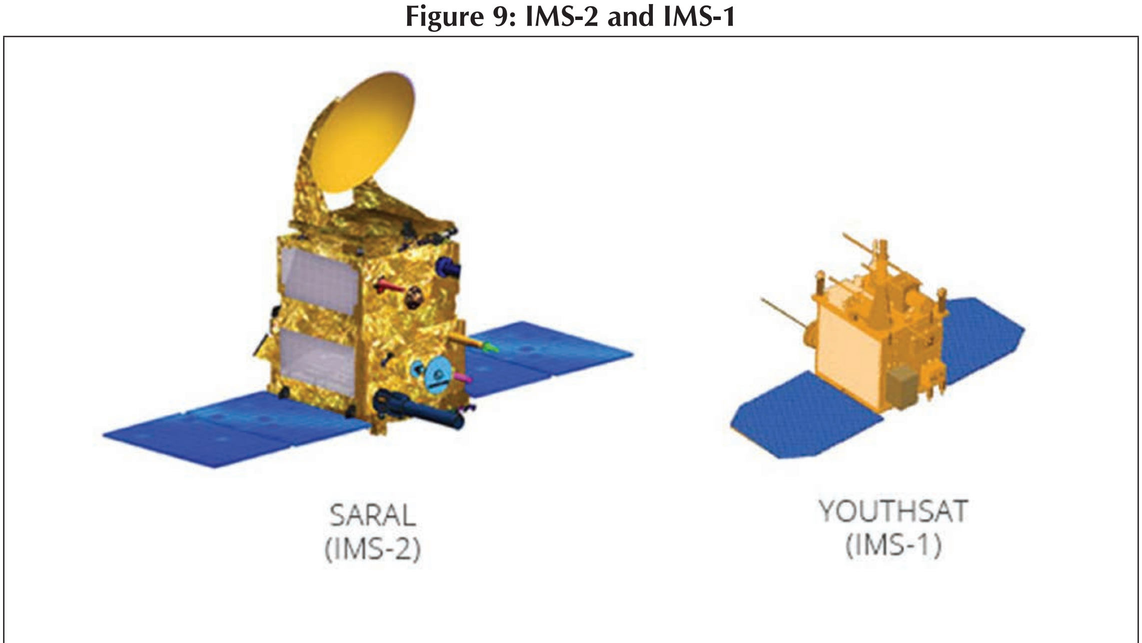
Figure 8: Poppy Satellites



Signal intelligence collection systems typically employ the use of three (sometimes four) satellites working together in close formation. Such a system provides the baseline for "time difference of arrival" between the satellites to determine transmitter geolocations on the ground of the order of a few kilometres.

For the small satellite missions required by India, adapting from the existing satellite buses can advantageously reduce development time. The ANUSAT-1 bus of Anna University and the IMS-1/2 buses of ISRO readily come to mind. Only the payload needs to be custom made for the mission in mind. The ISRO bus is more sophisticated in terms of deployable solar panels and 3-axis stabilization. The IMS-1 bus is a versatile bus of the 100 kg class and supports a payload of 30 kg mass. The IMS-2 bus is of 400 kg class with a payload capability of 200 kg. The IMS bus configurations are shown in figure 9.

Figure 9: IMS-2 and IMS-1



Satellite Launch Vehicles

The PSLV and GSLV launch vehicle capabilities have been described in an earlier section. The section also dealt with the feasible launch frequency at ISRO and described the ISRO launch manifest for the next few years. PSLV provides opportunities for launching two piggyback satellites of nominal mass 100 kg each along with the main satellite. Figure 10 shows the standard PSLV configuration of two piggyback microsatellites with the main satellite.

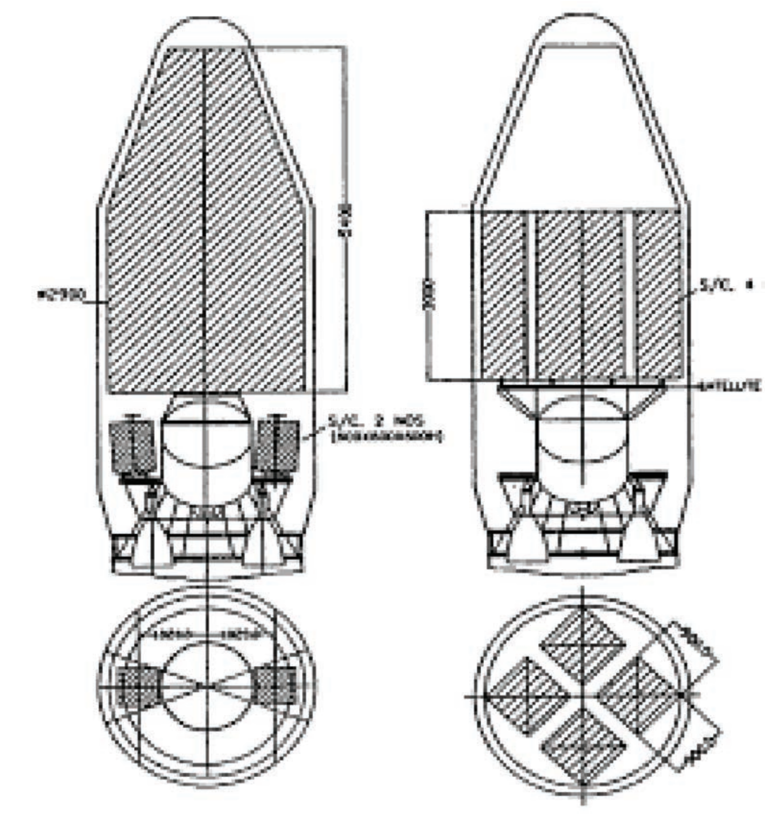
Figure 10: PSLV configuration for piggyback satellites

The total mass of the main and piggyback satellites should be within the payload capability of PSLV. PSLV is available in three versions with variations in the strap-on attachments for placing payloads in sun-synchronous polar orbit (SSPO). The payload capabilities for 620 km SSPO are indicated below:

- Core alone (no strap-ons) 1000 kg
- Standard configuration 1600 kg
- PSLV-XL (extended length strap-ons) 1750 kg

The payload bay can be reengineered to accommodate three or four small satellites like SAR satellite. For launching multiple ELINT satellites also the reengineered payload bay can be used. S Ramakrishnan et al have suggested PSLV payload bay layout options for different multi-satellite requirements as shown in figure 11.

Figure 11: PSLV Deck configurations



Baseline configuration housing

1. 1000-1300 kg satellite in envelope of 2920 mm dia x 5200 mm long
2. Two auxiliary satellites weighing 100 kg and measuring 600x600x800 mm3

Modified satellite deck for base mounting 3 or 4 small satellites of mass 500 kg in envelope of 2920 mm diameter x 2000 mm long

While the PSLV has proved to be a reliable and cost effective vehicle, it is not being produced in numbers to offer frequent launches. Similar capacity constraints hamper the number of satellites that can be turned out. This capacity constraint naturally impedes the readiness and frequency of launch required for placing large satellite constellations in orbit. It will also hamper the demand for replacement of assets in space and to meet the *launch on demand* criteria. The PSLV is also too large and therefore an expensive vehicle for individual small/microsatellite missions. It is therefore useful to have a launch vehicle capable of exclusively placing small satellites in orbit.

6. Small Satellite Launch Vehicle

Internationally, there are some operational satellite launch vehicles based on solid propellant stages and some derived from missiles. Table 5 provides details and capabilities of these vehicles.

Table 5: Solid Propellant Launch Vehicles[12]

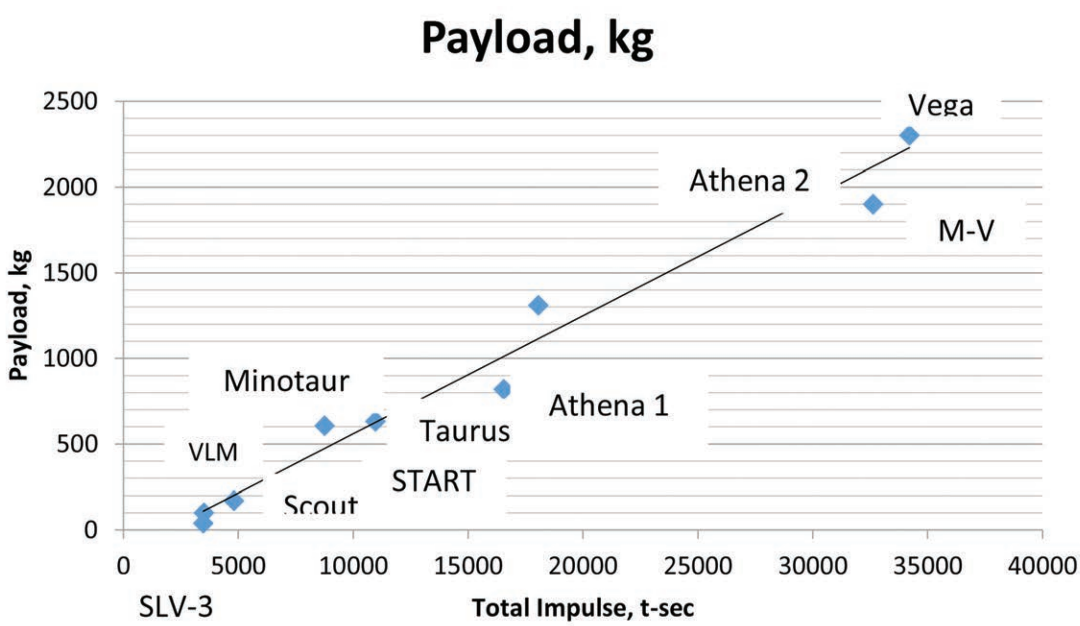
Vehicle	Country	Stages	GLOW	Performance PL/Orbit/Inclination	Launch cost
Athena I	USA	3	66.3 t	820 kg/185 km/28.5° 545 kg/185 km/90° 360 kg/800 km/SSPO	$ 40-45 m (2002)
Athena II	USA	3	120.7 t	2065 kg/185 km/28.5° 1575 kg/185 km/90° 1165 kg/800 km/SSPO	$ 45-50 m (2002)
KT-1	China	3	50 t	100 kg/?/polar orbit	Not known
M-V	Japan	3	137.5 t	1900 kg/200 km/31° 1370 kg/200 km/90° 960 kg/800 km/SSPO	$ 57 m
Minotaur	USA	4	36.2 t	607 kg/185 km/28.5° 470 kg/185 km/90° 317 kg/800 km/SSPO	$ 17-20 m
Pegasus XL	USA	3	23 t	443 kg/185 km/28.5° 332 kg/185 km/90° 190 kg/800 km/SSPO	$ 15-25 m
Shavit-1	Israel	3	30 t	350 kg/240x660km/ 143°	Not known
START	Russia	4	47 t	632 kg/200 km/52° 489 kg/200 km/90° 167 kg/800 km/SSPO	$ 9 m (1999)
Taurus	USA	4	73 t	1310 kg/200 km/28.5° 1000 kg/200 km/90° 660 kg/800 km/SSPO	$ 25-47 m
VEGA	ESA	4	130 t	1395 kg/800 km/SSPO	$ 20 m
VLM	Brazil	4	15.9 t	100 kg/200 km/5° 67 kg/200 km/90°	$ 4 m

[12] Steven J Isakowitz et. al. International Reference Guide to Space Launch Systems, 4th edition, AIAA, 2004.

Pegasus is mounted on a wide body aircraft (modified L1011) and released at an altitude of 11.9 km and with an initial M No of 0.8. After release the first stage is ignited for normal launch vehicle operations. Brazil has one more 4-stage launch vehicle, designated VLS capable of placing 380 kg payload in 200 km orbit with 5° inclination. The vehicle has had a poor success rate and is not included in the table, even though its development has not been stopped.

The specific impulse of a solid propellant rocket motor is its figure of merit and this along with the inert weight (including the airframe, insulation, control system and staging hardware) governs the performance of the vehicle. The value of the specific impulse and the ratio of loaded to empty mass have a bearing on the velocity achieved and therefore the performance of the vehicle. Keeping this in mind an attempt was made to compute the total energetics of the launch vehicles and plot it against the payload achieved by the launch vehicle. This is shown in figure 12.

Figure 12: Payload vs Total Impulse



It can be seen that the sum total of the Total Impulse of the constituent stages when plotted against the payload achieved by the vehicle falls along a straight line. The inputs used for generating the graph in figure 11 are shown in table 6. All the payload data in the graph is for 185 or 200 km orbit and for 28.5° inclination. Exceptions are the VLM and Vega, which have lower inclination and START, which has a higher inclination. It is felt using the plot, it should be possible to estimate at a preliminary level, the performance of a new launch vehicle configuration.

Table 6: Launch vehicle performance data

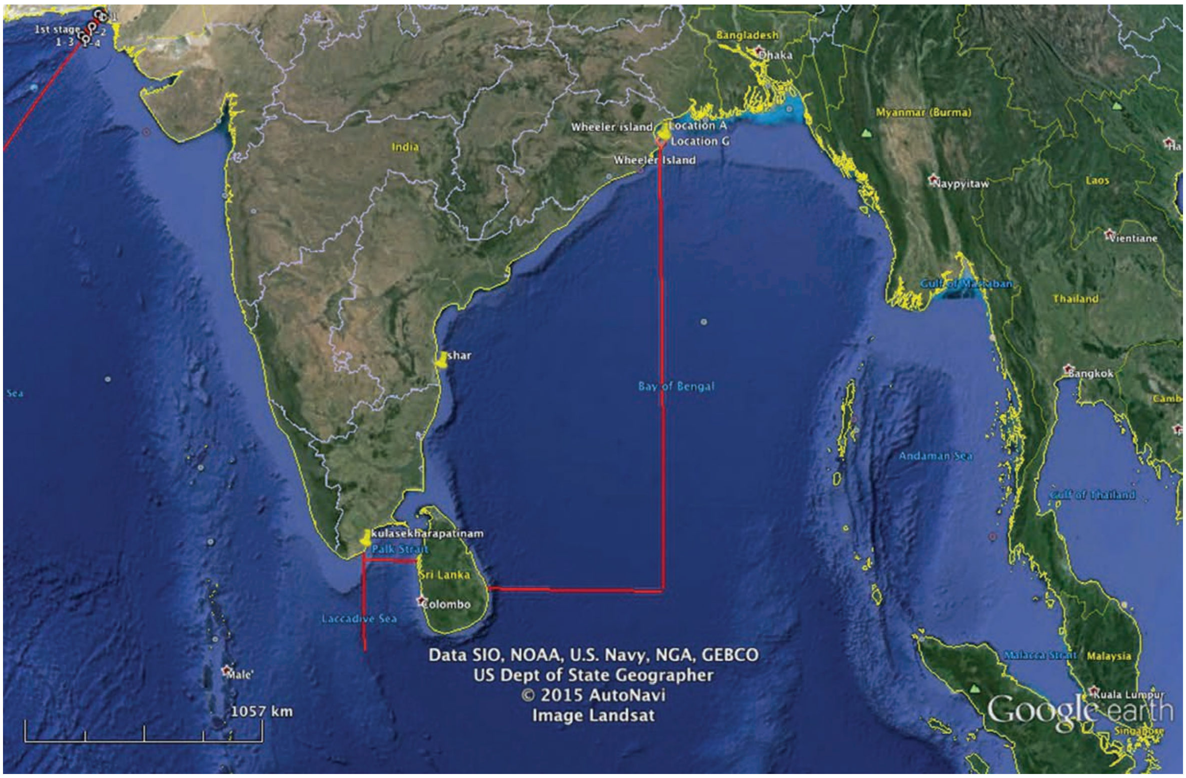
Vehicle	No. of Stages	Total Impulse (Ton-sec)	Payload (kg)	Remarks
Athena I	3	16553	820	Orbit Adjust Module (OAM) forms the 3rd stage with variable mono-propellant hydrazine loading between 236-354 kg
Athena II	3	30137	2065	OAM is in addition to 3 solid stages
M-V	4	32625	1900	
Minotaur	4	8758	607	
START	4	10963	632	
Taurus	4	18052	1310	
Vega	3	34203	2300	Inclination of 10°
VLM	4	3504	100	Inclination of 5°
Scout	4	4806	170	
SLV-3	4	3477	40	

It would appear from the above analysis that a 3 or 4 stage vehicle with total impulse from all the stage motors in the region of 10000 ton-sec should be able to place a small satellite of 500 kg mass in LEO. Further examination of the data shows that the 3-stage vehicles mostly employ a booster of about 2.0m in diameter, housing about 50 t of propellant. 4-stage vehicles manage with lower diameter in the region 1.6 m with booster propellant in the region of 20 t. Solid propellant stages available in the Country (with both DRDO and ISRO) can be considered for deriving an all-solid launch vehicle. By appropriate combination of such stages, it should be possible to get a cumulative total impulse of 10,000 t-sec and hence a payload in the region of 500 kg. By appropriate choice from amoung the solid propellant stages available with ISRO and DRDO, a launch vehicle could be configured and designated Small Satellite Launch Vehicle (SSLV-1). The performance of SSLV-1 was estimated using the in house developed trajectory-modeling programme *QuoVadis.* The performance runs show that SSLV-1 is capable of putting a 350 kg satellite in a polar orbit of 511 km x 497 km orbit and a 400 kg satellite in an orbit of 425 x 401 km (higher payloads are possible in equatorial orbit). This payload capability allows the launch of microsatellites with optical imaging and radar imaging payloads as well as individual intelligence satellites. Satellite life for the 400 kg mass satellite may be short in the 400 km orbit.

7. Launch Location

It can be safely said that SSLV-1 would be most useful for orbiting polar satellites and bulk of the missions of interest to military space will fall in this category. ISRO launch facility at Sriharikota is an obvious choice. Launch from Sriharikota calls for a due east launch followed by a dog-leg maneuver southward after clearing Sri Lankan EEZ. Some payload performance loss will accrue on account of this maneuver. An alternate site will be the DRDO's missile launch facility at Wheeler Island off the Odisha coast. A third possibility exists at the Southern tip of the Country. Media has mentioned the advantages of Kulasekarapattinam in Tamil Nadu as a launch location. The three locations are shown in the Google earth image at figure 13 along with the approximate distance of the rocket track from the Sri Lankan coast.

Figure 13: Launch locations



Range safety considerations form an important parameter for launch site preference. From this consideration it is best to avoid overflying the Sri Lankan Exclusive Economic Zone (EEZ) extending 200 nautical miles (370.4 km) from the coast. It is found that a due south launch from Wheeler Island comfortably meets this criterion. Launch from Kulasekarapattinam falls short of clearing the EEZ (the Western Tip of Sri Lanka is about 180 km from the southerly line from Kulasekharapattinam). If the launch vehicle can be mounted on a TEL type of platform, its mobility will be an added feature for managing multiple launches and can add to the capacity building exercise. It may be worthwhile to explore the possibility of overflying the Sri Lankan EEZ through discussions at the political and diplomatic level.

It would not be necessary to create major infrastructure in the launch locations. The vehicle can be integrated in a central location, checked out and then transferred to the designated launch facility. The country's telemetry and tracking stations can be effectively used and only the minimum addition/ augmentation need to be carried out in the new potential launch sites.

8. Constraints

It is obvious that in the realization of SSLV-1 or the small satellites, there are no major technical constraints. Major constraint exists however, in capacity generation. Assuming there are no technology limitations in building ELINT, Radar and optical imaging satellites within the mass and volume limitations of the vehicle, a constellation of 15-18 satellites needs to be built, tested and launched within a short time. The readiness of the SSLV-1 vehicle stages and subsystems also needs to be carried out at the same time. The added requirement of integration, transportation, ground infrastructure, range instrumentation requirements, TTC also will need structured and planned approach. Obviously, the necessary financial outlay also has to be taken care of in addition to the human resources.

In respect of launch vehicle hardware, specialty materials, fabrication, chemicals and processing, adequate capacity is available in the Country. If required either augmentation or creation of additional facilities is doable – one has to make allowance for the lead-time. However, domains of hazardous operations, inspection, testing, integration and checkout, launch operations and maintenance will normally be carried out departmentally. For satellite realization also some industrial capacity has been built up, but needs to be augmented to take up subsystem realization, test and qualification, integration and checkout activities. Both capacity and manpower resources can be expected to be constraints in the realization of larger production levels. The same can be said of range facilities for providing the tracking, telemetry and telecommand network services to support a higher launch frequency and space segment services for the satellites in orbit.

Off-loading larger segments of production requirement to industry would be the right answer. Besides addressing the capacity problem, the involvement of industry will a) free resources within DRDO and ISRO for increased research content, b) create more employment opportunities and c) create possible export avenues.

It would be useful to do a detailed exercise to gauge the gap between demand and supply in all spheres of launch vehicle and satellite; obtain measure of additional capacity required; extent of work that can be handled by Indian industry; infrastructure and support for creating the industrial base; the manpower resources and training requirement; test and inspection services; and the extent of funds required. This can be expected to be expensive but must be viewed from a long-term perspective.

9. Conclusion

A need for higher satellite capacity to meet ISR requirements exists, but presently the country is not geared to meet such requirements. While utilizing the outputs of the ISRO satellites, it is suggested that emphasis be laid on micro/small satellites to meet ELINT and earth observation requirements. Additional launch capacity should be created by crafting a Small Satellite Launch Vehicle – SSLV-1 using the ISRO/DRDO vehicle resources. A mobile TEL mounted launcher is recommended to take advantage of launch from multiple locations. An inclusive and enlarged industry participation is recommended.

10. List of Abbreviations

AIRS	Atmospheric Infrared Sounder
ALT	Altimeter
ASLV	Augmented Satellite Launch Vehicle
CERES	Clouds and the Earth's Radiation Energy System
CP-SAR	Circularly Polarised Synthetic Aperture Radar
DCS	Data Collection System
DRDO	Defence Research and Development Organisation
EEZ	Exclusive Economic Zone
ELINT	Electronic Intelligence Satellite
FOV	Field of View
GLOW	Gross lift-off weight
GPS-SAR	Global Positioning System Synthetic Aperture Radar
GSLV	Geosynchronous Satellite Launch Vehicle
GTO	Geostationary Transfer Orbit
IMS	Indian Mini Satellite
INSAT	Indian National Satellite System
IRNSS	Indian Regional Navigation Satellite System
IRS	Indian Remote Sensing Satellites
ISRO	Indian Space Research Organisation
LEO	Low Earth Orbit
LPR	Liquid propellant rocket
MISR	Multi-angle Imaging Spectro-Radiometer
MS	Multispectral
NIR	Near Infra Red
OAM	Orbit Adjust Module
Pan	Panchromatic
PSLV	Polar Satellite Launch Vehicle
RLV-TD	Reusable Launch Vehicle Technology Demonstrator
SARSAT	Search and Rescue Satellite Aided Tracking
SLV	Satellite Launch Vehicle
SSLV	Small Satellite Launch Vehicle
SPR	Solid Propellant Rocket
SSPO	Sun-Synchronous Polar Orbit
SSTL	Surrey Satellite Technologies Ltd.
TEL	Transporter Erector Launcher
TTC	Telemetry, Tracking and Command
VHRR	Very High Resolution Radiometer
VLM	Veículo Lançador de Microssatélites
VLS	Veículo Lançador de Satélites