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# Launching Vehicles Programme Entry to Excellence

Dr. T. ASOKAN[a]

[a]*Associate Professor, Department of History, Bharathidasan University, Tiruchirappalli- 620 024. Email id:* asokan.t@bdu.ac.in

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**Abstract**

The Indian space programme was institutionalized in 1962 with the setting up of Indian National Committee for Space Research (INCOSPAR) and it began the work on Thumba Equatorial Rocket Launching Station (TERLS), near Thiruvananthapuram.' Space research was initially allocated to the Department of Atomic Energy (DAE) in August 1961. In the following year INCOSPAR was setup by DAE, and in 1969, INCOSPAR was reconstituted2 under the Indian National Science Academy and a new organization, Indian Space Research Organization (ISRO), was formed under the DAE. The national space programme was formally organized in June 1972 with the setting up of Space Commission and the Department of Space (DoS) the Indian Space Research Organisation (ISRO) to promote the development and application of space technology and space science for the socioeconomic benefit of the nation. Indian Space Programme begins with the launching of the first sounding rocket Nike-Apache in 1963.

*Keywords: INCOSPAR, DoS, ISRO*

## 1. Introduction

Launching vehicles programme is important step in the Indian space research. Sarabhai (Architect of Indian Space Research) had clear vision about the launching vehicles technology. He wanted to create and develop the launching vehicles technology indigenously. The nature of the work of a launching vehicle is to put the satellite in to precise point. Unlike sounding rockets, consisted of single or two stages, launching vehicles consisted of four stages. Each stage has a propulsion system, either solid or liquid. When its fuel is exhausted, that stage is jettisoned and the next stage is ignited. The final stage of a launch vehicle provides the necessary velocity for a satellite to enter into precise orbit.

## 2. The SLV Programme

The abbreviation SLV stands for satellite launching vehicle. Developing an SLV was the first step in Indian Satellite Launching Vehicles Technology. SLV-3 was successfully launched in 1980. But the effort and related work were started much earlier. Sarabhai always held consultation with his colleague regarding SLV programme. In 1970s Sarabai selected Sriharikota Island in Bay of Bengal as a launch pad. In the initial period Sriharikotta was used for launching sounding rockets. As the concurrent movement SLV project started its operation.

Realising the immense socio-economic benefits of space technology, Sarabhai decided in 1969, to go full-stream ahead with the task of establishing indigenous capability in building and launching of India's own satellites (SLV).4 Prof. Sarabhai had already hand-picked a team to give shape to his dream of an Indian SLV. A. P. J. Abdul Kalam was selected as project director and also put in additional charge of designing the fourth stage. Other three stages were headed by Gowarikar for Design Project Stage-1 (DPS-1), Muthunayagam in charge of DPS-2 and Kurup of DPS-3.5 Sarabhai selected these scientists for various reasons. Dr. Kalam, who was the Director of SLV-3 project, says: "One reason seemed to be our professional background. Dr. Gowarikar was doing outstanding work in the field of composite propellants. M.R. Kurup had established an excellent laboratory for propellants, propulsion and pyrotechnics. Muthunayagam had proved himself in the field of high energy propellants. The fourth stage was to be a composite structure and called for a large number of innovations in fabrication technology, perhaps that was why I was brought in".

The primary objectives of the SLV project were design, development and operation of a standard SLV system, SLV-3, capable of reliably and expeditiously fulfilling the specified mission of launching of 40 kg satellite into a 400 kilometre circular orbit around the earth. In the meantime, the sudden demise of Sarabhai shocked entire Indian space community, and the Indian space scientists started to worry about a successful replacement. The Government of India sharply responded and appointed Satish Dhawan as the chairman of ISRO and secretary of DOS. Like Sarabhai, Dhawan wholeheartedly dedicated his service to Indian Space Programme in general and SLV project in particular.

SLV programme came to shape in the expected line. In June 1974 Centaur rocket was used to test some of the critical systems of SLV. The test was a complete success. Until then the Indian space programme had not gone beyond sounding rockets, and even knowledgeable people were not ready to see and acknowledge its efforts as anything more serious than fiddling around with meteorological instruments. In the meantime the late prime minister Indira Gandhi announced in Parliament on 24 July 1974: "The development and fabrication of relevant technologies, subsystems and hardware (to take India's first Satellite Launch Vehicle) are progressing satisfactorily. A number of industries are engaged in the fabrication of components. The first orbital flight by India is scheduled to take place in 1978".8

After five years most of the work of constructing an SLV was successfully completed. Although Prime Minister Indira Gandhi expected the launching of SLV in 1978, a major mid-term review in December 1976 revealed that the launch would be possible only in 1979.9 Considering that SLV-3 was ISRO's very first launch vehicle, its development seems to have gone remarkably smoothly, despite some unexpected result in the static- test in 1979.

The first SLV-3 lifted off from Sriharikota at 7.58 am on 10 August 1979. The first stage performed perfectly and separated without a hitch. But during the operation of the second stage, the launch vehicle began to deviate from the planned trajectory. According to Kalam "suddenly, the spell was broken. The second stage went out of control. The flight was terminated after 317 seconds and the vehicle's remains, including my favourite fourth stage with the payload splashed into the sea, 560 kilometre off Sriharikota".

A post- flight review was conducted on 11 August 1979. A detailed technical appraisal of the failure was completed. Later, the post-flight analysis committee headed by S.K Athithan pinpointed the reasons for the malfunction of the vehicle. It established that the mishap occurred because of the failure of the second stage control system. No control force was available during the second stage flight due to which the vehicle became aerodynamically unstable, resulting in altitude and velocity loss. This caused the vehicle to fall into the sea even before the other stages could ignite. Further in depth analysis of the second-stage failure identified the reason as the draining of a good amount of the Red Fuming Nitric Acid (RFNA) used as the oxidiser for the fuel power at that stage.12 After that Satish Dhawan gave green signal to start the work of re- launching of the SLV-3.

Little less than a year after the first failure, another SLV-3, designated SLV-3 (E)-02, stood on the launch pad. On 18 July 1980, at 08.03 hrs to be precise, India's first satellite launch vehicle, SLV-3, lifted off from SHAR.13 This time there were no problems of any sort. Kalam commented about this launch: "At 600 seconds after take-off, I saw the computer displaying data about stage IV giving the required velocity to the Rohini satellite (carried as payload) to enter its orbit".14 The SLV-3 put the 35 kg Rohini Satellite into a 300 kilometre by 900 kilometre elliptical orbit. The satellite had been launched eastwards. After the satellite circled the earth and rose over India's western horizon; the first radio signals from the satellite were picked up at Thiruvananthapuram 1 hour and 45 minutes after launch. VSSC, SHAR, and people of India exploded with joy and celebration; Dr Brahm Prakash, former director of VSSC, expressed his belief in the future: 'With such an achievement, future launch vehicles like advanced SLVs and PSLVS will surely become reality.15 With this success, India became the sixth nation to possess the launching vehicle technology. Two more SLVs were launched successfully during 1981 and 1983.

## 3. The Development of ASLV

After the first successful launches of the satellite launch vehicle, India proceeded with the upgrading of the launcher in order to place larger, 150 kg payloads (more than three times that of SLV-3) into 400 kilometre orbit. The SLV-3 was a very basic launch vehicle, a vital first step in developing the technological and project management capabilities required to attempt more powerful launch vehicles. However, the SLV had very limited carrying capacity and no control systems. Aiming to fulfil Sarabhai's vision of having the capability to build operational satellites for launching them, a committee was set up towards the end of 1972 to study the sort of launch vehicle. By the time of the SLV-3 launch, it had been decided that the next step would be to develop the Polar Satellite Launch Vehicle (PSLV) to put Indian remote sensing satellites into orbit. The PSLV could then become the basis for developing more powerful launchers needed to carry the INSAT satellites. The issue then arose as to whether to embark straightaway on the PSLV or have an intermediate launch vehicle between the SLV-3 and the PSLV. Moving from SLV-3 to PSLV seems to be a big technological jump. An intermediate vehicle would allow some critical technologies needed for the PSLV to be tested more cheaply. It also gives ISRO continued visibility during the ten years or so needed for the PSLV development. Against these arguments were worries about whether ISRO could pursue three launch vehicle programmes at the same time: the SLV-3 continuation programme, development of an intermediate launch vehicle and the development of PSLV.16 Ultimately, ISRO decided that the benefits of an intermediate launch vehicle outweighed its disadvantages. The result was Augmented Satellite Launch Vehicle (ASLV). The ASLV was particularly appealing because it appeared to be no more than a straightforward augmentation of the basic SLV-3.

The ASLV would have more sophisticated on board guidance system as well as a bulbous heat shield so that satellites larger than the vehicle's diameter could be accommodated. As it was capable of carrying 150 kg satellites, ASLV's payload capability was more than three times that of the SLV-3. Its better guidance system would allow the ASLV to achieve the intended 400 kilometre near-circular orbit with greater precision. Not only would the ASLV be a technological stepping stone to the PSLV, but could also, ISRO believed at one time, be used as a low-cost launcher to put small scientific and experimental satellites into orbit. Since it used the same core stages as the SLV-3, ISRO assumed that development of the ASLV would be quick and uncomplicated. The ASLV and PSLV projects were both cleared in June 1982. The ASLV's sanctioned project cost at the time was Rs. 19.73 crore and the first developmental flight was scheduled for 1985.17 Instead of the three years it had so confidently forecast, ISRO spent nearly a decade before successfully launching the ASLV. Unlike the failure of the first SLV-3 which was caused by a minor problem, there were no quick-fix solutions for the ASLV. The ASLV suffered from some basic design problems arising out of inexperience. The Indian launch vehicle teams emerged from this chastening 'agni pariksha', or trail by fire, with a deeper understanding of the complexities of launch vehicle design.

The ASLV was essentially the SLV class, but with the addition of two strap-on boosters in the first stage to provide extra thrust. The weight of an ASLV was almost 40 tonnes, the height 23.5 m. The launcher was assembled vertically on the launch pad on a 40-metre tall mobile service structure with hifts, access platforms and clean room. The strap-on boosters were first tested in flight in November 1985, when they were attached to a Rohini-300 sounding rocket. 18 The first launching of ASLV occurred at 12:09 pm on 24 March 1987, and the second launch at 2:48 pm on 13 July in 1988; both of which did not achieve its target. 19 The first stage motor failed to ignite in 1987 though the computer had given the command. ASLV-D2 was launched in July 1988 after incorporating several improvements suggested in the wake of the failure of the first ASLV. The second attempt also failed. This time, the first stage did ignite but the strap- on motors burned out a second or too soon, leading to inadequate control for a few seconds.20

A third failure would have had disastrous consequences for the entire launch vehicle programme, ISRO realised. The Failure Analysis Committee headed by ·R. Aravamudan after the first failure in 198721 and second one lead by S.C. Gupta in 198822 had clearly examined the causes for failure of ASLV-D1 and ASLV-D2 launched 1987 and 1988 respectively. Besides this, a National Expert Review Panel under R. Narasimha who recommended several measurers, it stated that "recognizing the inherent dispersion in the burn out of strap-on the ignition of the core [first stage], instead of being at a prefixed time, should be preferably linked to the event when the strap-on boosters become meffective in the tail off region"." ISRO's launch vehicle teams took these lessons to heart.

Many of the changes added to the launch vehicles weight and reduced its payload by about 40 kg. By now, however, payload which seemed so important when the launch vehicle was conceived could be compromised in the interests of achieving a successful flight. Finally, on 20 May 1992, the ASLV was launched for a third time, from Sriharikota. This time, after an uneventful flight, it put the 106 kg SROSS-C1 satellite into orbit about 450 kilometre above the earth.24 Compared of the wild jubilation which greeted the successful launch of SLV-3, there was heartfelt relief all round. ISRO had successfully crossed an important Rubicon. In May 1994, just four months before the launch of the first PSLV, once again ASLV was successfully launched and put 113 kg SROSS-C2 satellite into an elliptical orbit of 938 kilometre by 437 kilometre25 and also ISRO abandoned the ASLV programme.

## 4. The Polar Satellite Launching Vehicle (PSLV) Programme

In November 1972, a study group headed by R. M. Vasgam was set up to examine configurations for launchers which could put an Indian National Satellite (INSAT) into orbit. The committee recommended a cluster of four liquid engines, each producing a thrust of 60 tonnes, for the first stage. A similar engine would be used for the second stage. The third stage would have two cryogenic engines, each producing 7.5 tonnes thrust. The launcher had a fourth stage with a pressure-fed liquid engine to take the satellite from transfer orbit to pro stationary orbit. By the late seventies, however there was an important shift away from building a launch vehicle for putting communication satellite into geostationary orbit towards first developing a launcher to carry indigenous remote sensing satellite into sun synchronous orbit. In this connection another committee appointed in December 1977, headed by S. Srinivasan to recommend configurations for a launch vehicle which would put a 600 kg class remote sensing satellite into a 550 kilometre orbit. This committee studied thirty-five configurations before submitting its report. The report suggested that the preferred configuration involved large solid motor, 2 metre in diameter and carrying 48 tonnes of propellant. One such motor would form the first stage, with two similar motors as strap-ons. The second stage would have a liquid engine and the upper two stages both being solid. The committee submitted its report in December 1981, and it had been decided that the launch vehicle would have to put a minimum of 1000 kg in 900 kilometre polar orbit.27 On the basis of this report ISRO cleared the PSLV project in 1982.

The Polar Satellite Launch Vehicle (PSLV) is designed to place an Indian remote sensing satellite weighing one tonne in a 900 kilometre polar sun synchronous orbit. The PSLV has four stages. Solid propulsion system is used in its first and third stages and liquid propulsion motors in the second and fourth stages. The PSLV was almost ten times bigger and heavier than the ASLV, being 292 tonnes (seventeen times more than the SLV-3 and nearly eight times as much as the ASLV) in weight and 44.1 metre tall.28

The first stage, rated as the third largest solid booster in the world, is equivalent to forteen times the core of an ASLV. The stage has a 2.8-metre diameter core motor carrying 124 tonnes of solid propellant, with six solid strap-on motors with a propellant loading of about 9 tonnes each. The second stage has 37.5 tonnes of unsymmetrical dim-ethyl hydrazine and nitrogen tetroxide. The stage provided a maximum thrust of 72 tonnes. The third stage uses solid propellant with a maximum thrust of 35 tonnes.

The fourth stage has a twin-engine configuration capable of providing a thrust of 735 kg, using monomethyl hydrazine and mixed oxides of nitrogen29. Each stage has its own control systems to keep the launcher steady in the desired direction. An inertial, guidance system onboard performs the functions of navigation, guidance and attitude control as well as flight sequencing. During the atmospheric flight of 160 seconds, an open loop guidance scheme takes over, computing at every instant the velocity needed to gain the planned trajectory.30

On the morning of 20 September 1993, the PSLV lifted off from Sriharikota for the first time.31 The PSLV-D1 (the 'D1' indicating that it was the first developmental flight) carried the IRS-1E remote sensing satellite. Three seconds before lift-off, the liquid roll control engines of the first stage were ignited. Then, the first stage was fired. In less than a second, its thrust built up and the vehicle lifted off. About a second later, two of the six strap on motors were ignited and the vehicle rose vertically for 5 seconds."

The screen inside the launch control centre showed the course of the launch vehicle superimposed on the planned trajectory. There was difference between the two and the flight appeared uneventful. The remaining four strap-ons had ignited. The first stage motors and the strap-ons performed well and their separation passed off without any hitches. The second stage, with the Vikas engine, worked as planned. Soon after the second stage began operation, the launch vehicle was turned south of the polar orbit. The heat shield was jettisoned, having served to protect the satellite during the travel through the atmosphere. Tail-off of thrust as the second stage propellants became exhausted and was detected some 261 seconds post launch and initiated a sequence of 33 The separation of the second stage was carried out about 3 seconds later and ignition of the third stage commanded 12 seconds after that. When the third stage ignited, the vehicle was at an altitude of about 250 kilometre and travelling with a speed of 3.83 kilometre per second.34 Things went wrong events thereafter.

By the time of fourth stage ignition, the top of the rocket had reached an altitude of only 340 kilometre The forth stage lacked sufficient thrust to get the payload into orbit and it fell back to earth." The National Failure Analysis Committee was set up and submitted its report in January 1994. The committee concluded that the problem was due to a software error in the pitch and control loop of the on-board guidance and control processor which occurs only when the control command exceeded the specified maximum limiting value and an ultimate unintended contact between the second and third stage. It determined that the rocket's design was fundamentally sound.36 However, the expensive and valuable IRS payload was lost: the satellite was in fact the refurbished engineering model of IRS-1A. After careful examination of failure report, ISRO scientists learnt valuable lessons to avoid such a failure.

A year later, the PSLV-D2 lifted off from Sriharikota on 15 October 1994. After a flawless flight, ISR-P2 weighed 870 kg was injected successfully into 825- kilometre polar orbit.37 Emotions overflowed in the launch control centre. Tears of joy rolled down from eyes of K. Kasturirangan, who had taken over from U.R. Rao as chairman of ISRO in March 1994.38 Now ISRO was ready for the subsequent launching of PSLV. PSLV not only injected IRS satellite into polar synchronous orbit but also its capability further developed to put satellite into Geosynchronous Transfer Orbit (GTO). The last flight of PSLV-D3 launched in 1996 putting the IRS-P3 satellite into orbit. With this PSLV-D program ended and PSLV-C programme started: 'C' stands for continuation.

The Union government wholeheartedly supported the PSLV programme and more funds were allocated for this endeavour. With the help of this, PSLV-C1 was launched on 29 September 1997 carrying the IRS-1D in to an 817 kilometre polar orbit" On the morning of 26 May 1999, IRS P-4, popularly known as Oceansat, with a weight of 1050 kg lifted off by PSLV-C2 along with South Korea's Kitsat-3 weighing about 107 kg and Germany's DLR-Tub sat weighing about just 45 kg. It was India's first launch of foreign satellite, and ISRO started its commercial operation to launch the foreign satellites from Indian soil with the help of Indian launching vehicles.40 The former chairman of ISRO Kasturirangan stated in an interview after the launch of PSLV-C2 "It is a good stepping stone for future commercial ventures, besides establishing the repeatable performance of the vehicles".41

The PSLV-C3 launched on 22 October 2001 injected the Technology Experiment Satellite (TES)42 and two other commercial payloads viz., BIRD (Bispectral and Infrared Remote Detection) of Germany and PROBA (Project for On Board Autonomy) of Belgium, carried by the PSLV in their planned orbits.43 With this launch Indian space technology has now gained significant international credibility44. In 2002 on September 12, PSLV-C4 successfully launched India's first exclusive meteorological satellite, METSAT intoGTO45. It was for the first time that PSLV launched a satellite into GTO; in all its previous flights, PSLV was used to place IRS satellites and other auxiliary payloads in polar orbits.46

In its eighth flight conducted from Satish Dhawan Space Centre, Sriharikota, on 17 October 2003, ISRO's PSLV-C5 successfully launched the Indian remote sensing satellite, RESOURCESAT-1 (IRS-P6) into an 821 kilometre high polar Sun Synchronous Orbit (SSO). The 1360-kg RESOURCESAT-1 is the most advanced and the heaviest remote sensing satellite built and launched by ISRO so far. This marks the seventh successive success of PSLV.47 On 5 May 2005 ISRO launched its ninth flight of PSLV-C6 with India's remote sensing satellite, the 1, 560 kg Cartosat-1, along with a 42.5 kg piggyback satellite Hamsat, into a polar sunsynchronous orbit. For the first time the newly established second launch pad (SLP) at (SDSC) SHAR was used for a launch.48 In its tenth flight conducted from SHAR, on 10 January 2007, the PSLV-C7 carried four satellites India's CARTOSAT-2 and Space Capsule Recovery Experiment (SRE-1), (SRE-1), Indonesia's LAPAN-TUBSAT and Argentina's PEHUENSAT-1- into a 635 kilometre high polar orbit. For the first time, a Duel Launch Adopter (DLA) was used in PSLV to accommodate two primary satellites in tandem49. The 680 kg main payload, CARTOSAT-2, mounted over DLA, was the first satellite to be injected into orbit at 981.3 sec after lift-off at an altitude of 639 kilometre. About 45 seconds later, the DLA, with the 6 kg PEHUENSAT-1 mounted on it, was separated. After 120 seconds, the 550 kg Space Capsule Recovery Experiment (SRE-1) mounted inside DLA was separated and finally, 90 seconds later, the 56 kg LAPAN-TUBSAT, mounted on the equipment bay of PSLV fourth stage was separated.50

So far PSLV has made ten flights; among them nine were successful except for the first mission launched in 1993. Technologically PSLV has high configuration compared with SLV and ASLV. Its capability to launch the satellite is also higher. In the beginning PSLV launched 904 kg satellites. Its present capability enables it to launch not only high weight but also to launch four satellites in one flight. PSLV will also be used for the future of Indian lunching vehicle's programme. The first Indian lunar mission named Chandrayan-1 is likely for launch in 2008 by PSLV.

## 5. GSLV Programme

Development of GSLV represents the culmination of India's efforts to achieve complete launcher autonomy. In 1980s when ASLV and PSLV projects were in active progress ISRO deeply conceived the idea of launching vehicles to put the satellites into GTO. This was not an easy task. So ISRO depended on other space powers, especially for cryogenic engine. The simplest option turned out for GSLV was to replace the top two stages of the PSLV with a cryogenic stage. When the space mission began, India was completely dependent on other countries even for the launch of sounding rockets. However, our quest for independent and indigenous space mission has led us to build several launching vehicles, ranging from ASLV to GSLV. Through this range, the degree of dependency has also decreased. While ASLV was dependent, GSLV, launched at the beginning of this millennium, was almost indigenous.

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