CHAPTER IV
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INDIA'S SPACE EXPLORATION

In general, 'space' may be described as the volume outside planetary and stellar atmospheres, extending in all directions with no known limits. 'Outer space' may refer to space beyond the earth’s atmosphere or space beyond the solar system. For the purpose of discussion in this chapter, 'space' is defined as 'the region beyond the limits of earth’s atmosphere which is the operating environment for a spacecraft'.

Man has always fancied about reaching the unreachable and exploring the unexplorable. Outer space is one of the most fascinating places that man could reach only through wild fantasies. During the epic age in Indian tradition, in Rama Kingdom there were 'vimanas.' These vimanas are flying machines that were circular in shape with double-dock, potholes, and a dome – much similar to a flying saucer. These have been documented in the Indian epic Ramayana. Silappathikaram, one of the Epics in Tamil, mentions that Kannagi, the protagonist, flew a ‘spaceship’:

\[ \text{தாஞ்சன் பிள்ளைக் கோங்கன் கோலச்} \]
\[ \text{காண்கு என்னை பற்றி} \]
\[ \text{காட்சியும் போல் கழிவுகள் தாங்கல்} \]

While these works only mentions the existence of 'flying machines,' *True History* by Lucian (Loukianos) gives a full-length account of a flying ship in 160 AD. The story is about a ship lifted from the ocean which is carried to the moon by a powerful whirlwind. It was only fictional at that time. Even the author warns in the introduction that the book was fictional. "So all the readers beware," he concluded, "Don't believe any of it." 4 *Sleep*, written by Johannes Kepler, was published in 1634, which like *True History* recounted the experiences during an imaginary visit to the moon. Almost simultaneously with the posthumous publication of *Sleep* there appeared the first original book on space travel in the English language. It was written by Bishop Francis Godwin and was called *The Man in the Moone*. Two other novels appeared in 1657 and 1662, written by the French satirical writer Savinien Cyrano de Bergerac, described visits to the moon and the sun, respectively.5 However, at the turn of the twentieth century, these fictional accounts turned out to be true. Man has in fact travelled to space. Not only that, he started exploring the outer space and even beyond.

This chapter explains how man started exploring space. As could be expected, man himself had not ventured into a space travel. Rockets are the first man-made

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objects that reached the sky. Then came ‘machines’ that could carry objects. Man soon started replacing these objects and he himself travelled to heights. The thirst to fly has not stopped at this point. He wanted to know what exactly is in the dark space beyond the space known to him. This sowed the seeds for sending missions to outer space.

This chapter will discuss India’s development in space exploration: from the first sounding rocket, “borrowed” from NASA, to launching vehicle technology. Indian space exploration is still marching forward.

**ORBITS**

An *orbit* is the path of any body describing a definite curve around the centre of a force, and it is “the imaginary path of a moving celestial body or satellite in space”. It is “in fact a trajectory which is periodically repeated”, where *trajectory* is the path traced by a satellite.

According to celestial mechanics, Sun being in the centre, the planets revolve around the Sun following Kepler’s laws. There are satellites to each of these planets, which revolve around their respective planets. These satellites, too, obey Kepler’s Laws. The orbits of these satellites are fixed in every respect: orientation, plane of orbit, inclination to equator, size of orbit, etc.
In case of artificial satellites that revolve around the earth, the force central is in the centre of the earth. One can fix the orbits in any of the four geometrical structures: circle, ellipse, parabola, and hyperbola. But by their very own structure, parabola and hyperbola are not closed and they will take the satellites away from the earth. Hence there can be only two alternatives: a circular orbit or an elliptical orbit. A circular orbit takes the centre of earth as the centre of orbit, whereas for an elliptical orbit the centre of earth is at a focus of the orbit. According to one of the Kepler's Laws, planets revolve around the sun in elliptical orbits.

Geostationary Orbits

Consider a satellite that orbits at 11,060 km/h (or 3075 m/s) at an altitude of 35,781 kilometre above the equator. The speed of this satellite is now synchronized with the speed at which the earth rotates on its axis (1620 km/h, or 450 m/s). Imposing two other conditions that the satellite should orbit from the west to the east, as does the earth, and the plane of the orbit coincides with the earth's equatorial plane the satellite can seem stationary to an observer on earth. The orbit is so named geostationary because its speed and the earth's speed are synchronized. The orbital period of a geosynchronous satellite is twenty-four hours, as that of the earth. The satellite will be at about 42,160 kilometre away from the centre of the earth.

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A geosynchronous satellite is only apparently stationary; in reality, it moves with other celestial bodies of the universe. Moon being closer to the earth, will create certain disturbances in the orbit of the satellite. This may affect the relatively stable nature of the satellite. However, these perturbations can be eliminated by properly \textit{correcting the trajectory of the satellite}.

The Russian scientist K.E. Tsiolkovsky already described about the existence of these orbits. However, he did not mention their usefulness. It was the British science fiction writer Arthur C. Clarke who elaborated the idea of geosynchronous orbits and presented a systematic proposal for creating a global communication satellite network for television and telecommunications using this orbit. In his honour, this orbit is also known Clarke's Orbit.\footnote{Samuel Glasstone, \textit{Op.cit.}, pp.47-55.}

If a rocket carrying a satellite can reach the above mentioned altitude of 35,781 kilometre directly and the satellite can be rejected from the rocket's payload chamber with an eastward velocity of 3075 miles per second, then the orbit of the satellite describes a geosynchronous orbit, and the satellite remains stationary to the earth. In reality, this process is not simple.
Satellites to be put in geosynchronous orbits have a built-in rocket engine, which is usually called the “apogee boost motor” (ABM), accordingly as the rocket fuel is solid or liquid. Generally, liquid-filled engines are preferred as they can be ignited and put-off as and when necessary and hence fuel can be saved. Some satellites carry an additional “perigee assist module” (PAM).

As a first stage, the satellite is launched into low earth orbits (which will be discussed soon). This is a circular orbit and is called the “critical orbit” or the “parking orbit”. From a point on this orbit, a slightly higher velocity is imparted so that the satellite leaves the circular orbit and describes an elliptical orbit. As the satellite moves higher up in the sky, the velocity decreases and becomes minimum at the apogee. This elliptic orbit is called “transfer orbit” or “Hohmann ellipse”. If the apogee is at the required stationary orbit, the velocity required for the circular orbit at this attitude. The orbit thus obtained is the geostationary orbit, provided the plane of orbit is in the equatorial plane.

If the altitude of the apogee of the transfer orbit is less than the geostationary altitude, the LAM is fired at the apogee to give an incremental velocity to get a new transfer orbit. This is repeated. Between the firings, the satellite flies in intermediate elliptic orbits with higher perigees and higher apogees. This is continued until the apogee attains the geostationary altitude. The circular orbit at this altitude is the geostationary orbit.
A geosynchronous satellite experiences an eclipse when it is hidden from the
sun by the earth. Eclipse periods occur on forty-five successive days in a year around
vernal and autumnal equinoxes. Each eclipse period generally lasts 10–72 minutes a
day during which time onboard batteries provide power supply to the spacecraft.\footnote{Mohan Sundara Rajan, \textit{India in Orbit}, (New Delhi: Publication Division, Ministry of Information and Broadcasting, 1997), p.10-11.}

\textbf{Sunsynchronous Orbit}

Before discussing sunsynchronous orbits it is necessary that one has a fair
knowledge about the shape of the earth. By the 1950s, it was known that the North
and South Poles are nearer to the earth’s centre by about 21 kilometres than is the
equator. An analysis of satellite paths around the earth in 1958 showed that the polar
diameter was shorter than the equatorial diameter. This extra radius makes the
difference for certain orbits near the earth. If a satellite goes from southern to
northern hemisphere, in a west-to-east direction, its orbital plane will swing westward
under the influence of the gravitational pull at the equator. If the satellite goes to the
northern hemisphere in an east-to-west direction, the orbital plane will swing
eastward. This perturbation is known as \textit{regression}.\footnote{Jay M. Pasachoff, \textit{Astronomy: From the Earth to the Universe}, (Philadelphia: W.B.Saunders,1971) ,pp.114-115.}

Besides, the nodal shift the orbital plane has another apparent rotation to an
observer on the earth. This is due to the daily rotation of the earth around its axis. By
the time a satellite makes one full rotation, the earth would have turned by 22° to the 
est. An observer will see the plane of the orbit shifted westward by the same angle.

This equatorial "bulge" of the earth facilitates the sunsynchronous orbit. The 
westward shift due to the annual movement around the sun, which is described 
above, is nearly 1° a day. As a result, the satellite's orbital plane always makes the 
same angle to the sun-earth line throughout the year. Such an orbit is called 
sunsynchronous orbit. The inclination of the orbit is measured by the angle formed 
by the orbital plane of the satellite and the equatorial plane. As the orbital plane will 
always maintain its position relative to the sun, the satellite will have constant 
ilumination throughout the year. Moreover, the satellite crosses the equator at the 
same local time, every time.\(^\text{12}\)

A frame of reference for a satellite's orbit is fixed along three mutually 
perpendicular axes: one along the equator from the earth's centre, one along the line 
from the earth's centre to North Pole and one along the line from the earth's centre 
towards the First Point of Aries in the sky. An elliptical orbit around the earth is 
defined by six elements, and the satellite's position is accordingly monitored and 
corrected whenever necessary.

Natural disturbances and earth’s drag change the apogee and perigee of a sunsynchronous orbit. If uncorrected, this difference in perigee will vary from the nominal height, resulting in a variation in the satellite’s altitude over different latitudes. This will not let us receive same scale of the imageries between various orbits. Hence the perigee is “frozen” by controlling its height at a specified distance by using onboard thrusters.

Several sunsynchronous orbits are possible. For example, a satellite at 893 kilometre and at an orbital inclination of 99° will make 14 orbits a day. The angle of inclination of the orbital plane to the equator will vary depending on the altitude of the orbit. Satellites in orbits at about 80° inclination cover most of the inhabited regions of the world. Strictly polar orbits at 90° inclination do not seem to be in great demand, but orbits in at inclinations between 95° and 105° are commonly used for remote sensing applications.\(^\text{13}\)

Perturbations in the sun synchronous orbits are also caused by, besides the earth’s oblateness, residual atmospheric drag. This results in a cumulative deformation of the shape of the orbit, which can be nullified by selecting the initial orbit. Air drag reduces a satellite’s orbital velocity, its altitude, and the duration of its orbit. Inclination of the orbit will also slowly decrease mainly because of the

\(^{13}\text{Mohan Sundara Rajan, } \text{Space Today, pp.11-12.}\)
gravitational forces of the sun and moon. Orbit corrections are needed to compensate for air drags as well as to counter deviations in the inclinations.

Near Earth Orbit

Besides the geosynchronous orbit (at 36,000 kilometre away from the equator)\(^{14}\) and the sun synchronous polar orbits, near earth orbits are used for providing mobile and global personal communications. A low-cost satellite-based system is envisaged to provide every subscriber with global reach from a hand-held terminal. The system is designed to deliver voice, data, paging, messaging, and geolocation services to mobile users worldwide, irrespective of where the users are located.

If this type of service is to be provided by satellite in the GEO, then such satellites would need large antennas and a lot of power on board. Voice links, in particular, demand high power. The transmit power of a hand-held quasi-omni directional antenna should ensure minimum, acceptable exposure of the user to radiation. Further, satellites in GEO do not efficiently cover latitudes above 60° north or south, where increased traffic from the most developed regions of the world is expected. The elevation angles (the worst-case angle in which a user sees the satellite) are below 10–20° and often cause signal propagation problems. The round-trip delays

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in the transmission of signals to the satellite and back are also quite high, about 0.6 second.\textsuperscript{15}

The design of satellites in low earth orbits (LEO) depends on two important considerations: the orbital height and the minimum elevation angle. For a given altitude, if the elevation angle is increased, then the service area will be reduced; so that the transmission will be technically better. Below 2000 kilometre, a very large number of satellites (50–100) are needed for global 24-hour coverage and the minimum elevation angle will be less than 10°. The short orbital period and the frequent ‘handovers’ from one satellite to another to continue the link will limit the quality of service.

Highly eccentric orbits (HEO) are difficult to use because of the earth’s oblateness that will not keep the perigee steady. Moreover, HEO systems need to be complemented with GEO satellites for global coverage. As HEO apogees are in the region of 20,000–30,000 kilometre, very large spacecraft will be needed for working with hand-held telephones and the satellites will often pass through Van Allen radiation belts.\textsuperscript{16}

Though improved techniques may be used to operate in LEO and HEO, the popular system today on the basis of well-proven technology seems to be in the

medium earth orbit (MEO), around 10,000 kilometre, with high minimum elevation angles (about 50–60°). Such a system can be operated with only fourteen satellites, each with a six-hour period over a service area. An HEO system can provide effective links with mobile as well as personal hand-held terminals.17

Several types of orbits are envisaged for operating the system. The LEO systems are designed to operate at an altitude of 400–1000 kilometre, while intermediate circular orbit (ICO) and MEO satellites will be in the range of 7000–12000 kilometre above the earth. The HEO systems will take satellites to a distance of 20,000 kilometre at the farthest and 500 kilometre at the closest to the earth.18

The number of satellites required to cover the entire earth in LEO or MEO depends on the distance of the orbit. The further away the satellites are, the fewer would be needed because of the reduced air drag and gravity. Moreover, the region between 2000 and 9,000 kilometre is subject to high radiation. Satellites will have to stay below 1,500 kilometre or be within 8000–12000 kilometre or go beyond 20,000 kilometre in order to stay away from the radiation belts that surround the earth. By choosing a low-inclination orbit, the satellites in LEO can avoid the high radiation area called the South Atlantic Anomaly, over southern Atlantic.19

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SOUNDING ROCKETS

Indian Space Programme formally began with the launching of the first sounding rocket Nike-Apache in 1963. This section gives a brief background of sounding rockets, their nature and their uses. Further, the section analyses Indian sounding rocket programme.

A sounding rocket, often called a research rocket that sends equipment into the upper atmosphere or near space on a suborbital trajectory, takes measurements and returns to the ground. Sounding rockets take their name from the nautical term 'to sound'\(^{20}\) which means to take measurements. The rockets are commonly used to take readings or carry instruments from 50 to 1500 kilometres (from 30 to 932 miles) above the surface of the earth the altitude in between weather balloons and satellites; balloons reach a maximum altitude of approximately 40 kilometres and the minimum altitude that can be reached for satellites is approximately 120 kilometres (75 miles). A common sounding rocket consists of a solid-fuel rocket motor and a payload.\(^{21}\) After launch, as the rocket motor uses its fuel, it separates from the payload and falls back to earth. Meanwhile, the payload continues into space and begins conducting the experiment.

\(^{20}\) Available at http://www.daviddarling.info/encyclopedia/.
\(^{21}\) Available at http://www.en.wikipedia.org.
In most cases, after the payload has re-entered the atmosphere, it is brought gently down to earth by way of a parachute and is then retrieved. By recovering parts of the payload, it can be refurbished and flown again, resulting in great savings. Data is often collected and returned to earth by telemetry links, which transfer the data from the payload directly to researchers on the ground. Such rockets have been employed extensively for atmospheric and meteorological studies and their approximately vertical trajectories make possible a serious of measurements above selected location.

Indian sounding rocket programme started as a humble note with the launching of Nike-Apache in 1963. Vikram Sarabhai on his vision regarding sounding rocket was to create and launch indigenously from Indian soil. At the initial period Vikram Sarabhai and his team did not possess deep knowledge about such a technology. Hence India depended on other countries such as USA, France, erstwhile USSR, for launching sounding rockets. In order to start the sounding rocket programme, Sarabhai took the first step of sending a team of young scientists to the Goddard Space Flight Centre and at the Wallops Island to learn sounding rocket technology. The training provided information only on assembling imported sounding rockets and their scientific payloads, procedures for the safe launch of these

\[22\] Available at http://www.deviddarling.info/encyclopedia/.

rockets, tracking the flight of the rockets, receiving data radioed down during flight and collecting, other scientific information required. After their successful trip, these young scientists involved in the work of assembling the first sounding rocket Nike Apache provided by USA. Nike Apache is a two stage rocket, with a Nike rocket as the first stage and Apache rocket as the upper stage.

The two stage rocket, weighing 715 kg and powered by solid propellants, soared to an altitude of 207.6 kilometre. It had a sodium vapour payload supplied by France. The Nike Apache rocket was fired up over the fishing village of Thumba on 21 November 1963 at 6.25 pm; it heralded the birth of Thumba Equatorial Rocket Launching Station (TERLS) and India’s modest entry into the world of space science and technology. The first Nike Apache was fired by the U.S. Air Force on 17 February 1961. Until August 1966, the USAF launched several of them for aeronomy and ionosphere experiments. Primarily, the Nike Apache was the standard NASA sounding rocket of the 1960s and 1970s and until the final flight in September 1978, a total of 697 Nike Apaches had been launched.

Soon after launching its first sounding rocket, India made another important step to launch further sounding rockets. In 1964 India entered into the agreement

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signed with a French company to produce their Centaure sounding rockets under license in India. Subsequently a small team of scientists under M.R.Kurup went to France to learn two-stage Centaure sounding rocket technology. After returning from France, this team of scientists assumed responsibility for designing and fabrication of Centaure rocket. The Indian scientists had to design the buildings, keeping in mind safety requirements, based largely on what they had observed at the French facilities. The rocket motor casing and other metal parts for the indigenous centaur rockets were initially fabricated at the central workshop of the Bhabha Atomic Research Centre (BARC) in Trombay. Two of the first three Centauries made at this workshop were filled with imported propellant. One of these rockets was launched from Thumba on 26 February 1969 with an Indian payload to measure the rocket’s performance. The rocket reached a height of 145 kilometre and its 31 kg payload also included a scientific experiment for measurements in the upper atmosphere. In February 1969 the Rocket Propellant Plant (RPP) was commissioned, and the first ground test of the RPP propellant was successfully carried out on a 40 kg propellant block on 2 March 1969. Subsequently, a full-size Centaur booster was also made and ground tested. The first Centaure with propellant made at RPP launched on 7 December 1969. The successful indigenization of Centaure technology was a major

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landmark in establishing sounding rocket capability. This was made possible due to the availability of the Rocket Fabrication Facility at Thumba since 1970.

Apart from this initial effort India continually depending on foreign power to launch the sounding rockets including American *Dual Hawk*, *Nike Tomahawk*, *Aries* and *Judi Dart rockets*, the British *Skua* and *Penta* rockets and the French *Dragon* Rockets. In the mean time, the Indian scientists were involved in indigenously developing fabrication its own rockets. This effort became successful in 1967, when RH-75 was launched from Tumba.

**Rohini Sounding Rockets**

The first indigenous sounding rocket, Rohini-75, was launched in November 1967 from Thumba. RH means Rohini, and ‘75’ referred the rockets diameter in millimeters. It consisted of a single solid propulsion motor weighing mere 32 kg. It lifted a nominal 7 kg payload to an altitude of about 10 kilometre. Cordite, a mixture of nitroglycerine and nitrocellulose, was used as solid propellant in the Rohini rocket. Rohini-75 was considered as a plaything if compared to the GSLV which was 40,000 times heavier, but it helped Indian space scientists establish a strong foundation in rocketry. Subsequently, RH-100, RH-125, RH-200, RH-300 and

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RH-560 were put in service. The aluminized PVC propellant was used for developing the two stage RH-500. This rocket, modeled on the French Dragón sounding rocket, is the largest of the Rohini series. Each and every Wednesday RH-200 is being launched from TERLS.

Besides these, other sounding rockets were launched from Thumba, such as Pencil, Menaka and Paper-Wound rockets. Still the sounding rocket programme is continued at Thumba to study weather changes and the middle atmosphere. Not only that the similar technology is also used for launching vehicles, to put satellite into the orbit.

**LAUNCHING VEHICLES PROGRAMME**

Launching vehicles programme is another important step in the Indian space research. Sarabhai had clear vision about the launching vehicles technology. He wanted to develop and create 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

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34 Eye witnessed by the Scholar on 18.04.07 at the Launching 09.15.pm.
final stage of a launch vehicle provides the necessary velocity for a satellite to enter into precise orbit.\(^{35}\)

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).\(^{36}\) 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

\(^{35}\) Eye witnessed by the Scholar on 08.02.07 in the Space Museum of TERLS, VSSC, Thiruvananthapuram.

Project Stage-1 (DPS-1), Muthunayagam in charge of DPS-2 and Kurup of DPS-3. Sarabhai selected these scientists for various reasons. Dr. Kalam, who was the director of SLV-3 project, said “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”.38

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.39 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.

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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".40

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 1979.41 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 1979.42 The first stage performed perfectly and separated without a hitch. But during the

42 Mohan Sundara Rajan, *Space Today*, p. 44.
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".43

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.44 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. 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.” 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.” With this success, India became the sixth nation to possess the launching vehicle technology. Two more SLVs were launched successfully during 1981 and 1983.

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.

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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. 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. 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 lifts, 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. 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. 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.

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 1987 and second one lead by S.C. Gupta in 1988 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

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54 “Dr. S.C. Gupta Talks to Countdown, on ASLV-D2 Failure”, *Countdown*, No.110, June 1989, pp.2-3.
the inherent dispersion in the burn out of strap-on boosters, 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 ineffective 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. 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 kilometre and also ISRO abandoned the ASLV programme.

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 tones, 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 tones thrust. The launcher had a fourth stage with a pressure-fed liquid engine to take the satellite from transfer orbit to geostationary 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 tones 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. 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 tone 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 tones (seventeen times more than the SLV-3 and nearly eight times as much as the ASLV) in weight and 44.1 metre tall. The first stage, rated as the third largest solid booster in the world, is equivalent to fourteen times the core of an ASLV. The stage has a 2.8-metre diameter core motor carrying 124 tones of solid propellant, with six solid strap-on motors with a propellant loading of about 9 tones each. The second stage has 37.5 tones of unsymmetrical dim-ethyl hydrazine and nitrogen tetroxide. The stage provided a maximum thrust of 72 tones. The third stage uses solid propellant with a maximum thrust of 35 tones. The fourth stage has a twin-engine configuration capable of providing a thrust of 735 kg, using monomethyl hydrazine and mixed oxides of nitrogen. 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

59 “Polar Satellite Launch Vehicle, Project, December 1981, PSLV-VSSC-PJ-04-08”, Prepared by Dr.S. Srinivasan, Project Director, PSLV.
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.62

On the morning of 20 September 1993, the PSLV lifted off from Sriharikota for the first time.63 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.64

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 events. 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. Things went wrong 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. 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.

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65 Mohan Sundara Rajan, India In Orbit, p.58.
66 Mohan Sundara Rajan, Space Today, p.66.
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. 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. 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 Oceansat1, 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 satellites, and ISRO started its commercial operation to launch the foreign satellites from Indian soil with the help of Indian

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launching vehicles.\textsuperscript{72} 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.”\textsuperscript{73}

The PSLV-C3 launched on 22 October 2001 injected the Technology Experiment Satellite (TES)\textsuperscript{74} and two other commercial payloads \textit{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.\textsuperscript{75} With this launch Indian space technology has now gained significant international credibility\textsuperscript{76}. In 2002 on September 12, PSLV-C4 successfully launched India’s first exclusive meteorological satellite, METSAT into GTO\textsuperscript{77}. 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.\textsuperscript{78}

In its eighth flight conducted from Satish Dhawan Space Centre, Sriharikota, on 17 October 2003, ISRO’s PSLV-C5 successfully launched the Indian remote

\textsuperscript{73} A Stepping stone for Commercial Ventures’ \textit{Frontline},Vol.16,Issue.12,June05-18,1999,pp.6-8.
\textsuperscript{75} \textit{Teletrack},Vol.5, No.4, October-December 2001,pp.3-4.
\textsuperscript{76} \textit{Propulsion Today}, Vol.VII, No.1, Jan-April1996, p.3.
\textsuperscript{77} \textit{Teletrack}, Vol.6, No.243, April-September 2002, p.20.
\textsuperscript{78} PSLV launches METSAT’, \textit{Space India}, July-September 2002,pp.2-3.
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. 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.

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), Indonesia’s LAPAN-TUBSAT and Argentina’s PEHUENSA1-1 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 tandem. 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 PEHUENSA1 mounted on it, was separated. After 120 seconds, the 550 kg Space Capsule Recovery Experiment (SRE-1) mounted

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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.82

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.

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.

Background of Cryogenics

Cryogenics is the science and technology of producing any liquid that is used to maintain very low temperatures.83 The term cryogenics is derived from the Greek

82 PSLV-c7 Cartosat-2/SRE Mission’ Brochure, Documentation Section, VSSC, Thiruvananthapuram.
The superiority of cryogenic propellants was well established even at the beginning of the space activities. American Professor Dr. Robert H. Goddard, credited with the first rocket flight in 1926, used liquid oxygen as oxidizer in his maiden venture. Initial activities were confined to semi-cryogenic propulsion system that used liquid oxygen in conjunction with an earth storable liquid fuel, such as kerosene, gasoline, alcohol, etc. After the Second World War, both USA and the erstwhile USSR took serious initiatives to develop cryogenic propulsion technology, using liquid hydrogen as the fuel and liquid oxygen as oxidizer. In 1960s and 1970s USA clearly demonstrated her capability in the cryogenic engine technology.

84 Ganpathi Rao, “Know about Cryogenics”, Countdown, No.52, August 1984, pp.3-6.
Followed by erstwhile USSR achieved the same technology and other space powers European Space Agency, China and Japan became part of the same club.\textsuperscript{86}

ISRO needed Cryogenic technology in 1990s, when GSLV programme was conceived. It is obvious that ISRO might depend on other nations who possess such a technology. India's agreement with Glavkosmos regarding cryogenic in 1990s resulted unsuccessful because of the pressure come from Missile Technology Control Regime (MTCR). Its consequence will be described in the later part of this chapter. While depending on other nations for the cryogenic technology India embarked on indigenously developing the technology. In February 2000, the first test of India's home grown cryogenic rocket had to be prematurely terminated because of a hydrogen leak.\textsuperscript{87} Six years later on 28 October 2006, India successfully tested the first integrated stage level test of the indigenously developed cryogenic upper stage. This was carried out at the LPSC test complex at Mahendragiri. After this test ISRO chairman Madhavan Nair announced, “We had a very successful first cryogenic stage test at Mahendragiri. It is a major milestone in the development of rocket systems in the country”.\textsuperscript{88} With this India partially achieved the cryogenic technology for the GSLV rocket.

\textsuperscript{87} Countdown, No.237-238, January-February 2000, p.2. \\
The geosynchronous satellite launch vehicle project was initiated in 1990 with the objective of acquiring launch capability for geo-synchronous satellites. The GSLV is intended to eventually launch INSAT-type satellites for India, to make India less dependent on foreign rockets for INSAT launches. The GSLV accommodated the improvements on the performance of the PSLV with the addition of liquid strap-on boosters and a cryogenic upper stage. The solid first and liquid second stages are carried over from the PSLV. The GSLV initially used a cryogenic upper stage supplied by Russia.\(^89\)

The GSLV-D1 was the first of this kind. It has the configuration of 49 metre tall and 401 tonnes weight at lift off, putting 1540 kg geo-synchronous satellite, GSAT-1 into an elliptical GTO on 18 April 2001.\(^90\) This was the first time a satellite was launched into GTO from Indian-soil. The second developmental test flight of India’s geosynchronous satellite launch vehicle, GSLV-D2, was successfully carried out on 8 May 2003, making a milestone in the Indian space programme.\(^91\) The flight revalidated the various systems of the vehicle and the improvements carried out since its successful first launch. The 414 tonne, 49m tall GSLV, carrying an experimental satellite, the 1825 kg GSAT-2, lifted off from Sriharikota precisely at the start of the

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\(^89\) Available at http://spaceandtech.com/spacedat/.
\(^91\) ‘GSLV-D2 launched Successfully’, Countdown, No.277, May 2003, p.2.
launch window at 4.58 pm IST. About seventeen minutes after lift-off, GSAT-2 was successfully placed into the orbit.\[^{92}\]

On 20 September 2004 India’s GSLV successfully launched EDUSAT, the country’s first thematic satellite dedicated exclusively for educational services, into a GTO from Sriharikota. This was the first operational flight of GSLV (GSLV-F01) and the third in the GSLV series. The 49 metre tall, 414 tonne, three-stage vehicle injected the 1950 kg DUSA into GTO.\[^{93}\] However, two years later on 10 July 2006, the GSLV-F02 carried the INSAT-4C satellite, from SHAR. This was the second operational flight of GSLV and the fourth in GSLV series. Fifty five seconds after lift off the launching vehicle started deviating significantly from its nominal flight path resulting in the vehicle breaking up at 62 sec and the debris fell in to Bay of Bengal. The failure of GSLV-F02 seems to be major set back of GSLV project.\[^{94}\]

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\[^{92}\] *Space India*, April-June 2003, p.5.