# II

# CREATION

[ 1963 – 1980 ]

# 4

# Achievers

I started my work at NASA at the Langley Research Centre (LRC) in Hampton, Virginia. This is primarily an R&D centre for advanced aerospace technology. One of my most vivid memories of LRC is of a piece of sculpture depicting a charioteer driving two horses, one representing scientific research and the other technological development, metaphorically encapsulating the interconnection between research and development.

From LRC I went to the Goddard Space Flight Centre (GSFC) at Greenbelt, Maryland. This Centre develops and manages most of NASA's earth-orbiting science and applications satellites. It operates NASA's tracking networks for all space missions. Towards the end of my visit, I went to the Wallops Flight Facility at Wallops Island in East Coast, Virginia. This place was the base for NASA's sounding rocket programme. Here, I saw a painting prominently displayed in the reception lobby. It depicted a battle scene with a few rockets flying in the background. A painting with this theme should be the most commonplace thing at a Flight Facility, but the painting caught my eye because the soldiers on the side launching the rockets were not white, but dark-skinned, with the racial features of people found in South Asia. One day, my curiosity got the better of me, drawing me towards the painting. It turned out to be Tipu Sultan's army fighting the British. The painting depicted a fact forgotten in Tipu's own country but commemorated here on the other side of the planet. I was happy to see an Indian glorified by NASA as a hero of warfare rocketry.





My impression of the American people can be summarized by a quotation from Benjamin Franklin, "Those things that hurt instruct!" I realised that people in this part of the world meet their problems head on. They attempt to get out of them rather than suffer them.

My mother had once narrated an incident from the Holy Book—after God created man, he asked the angels to prostrate themselves before Adam. Everybody prostrated themselves except Iblis, or Satan, who refused. "Why did you not prostrate yourself?" Allah asked. "You created me of fire and him of clay. Does not that make me nobler than Adam?" Satan contended. God said, "Be gone from paradise! This is no place for your contemptuous pride." Satan obeyed, but not before cursing Adam with the same fate. Soon Adam followed suit by becoming a transgressor after eating the forbidden fruit. Allah said, "Go hence and may your descendants live a life of doubt and mistrust."

What makes life in Indian organizations difficult is the widespread prevalence of this very contemptuous pride. It stops us from listening to our juniors, subordinates and people down the line. You cannot expect a person to deliver results if you humiliate him, nor can you expect him to be creative if you abuse him or despise him. The line between firmness and harshness, between strong leadership and bullying, between discipline and vindictiveness is very fine, but it has to be drawn. Unfortunately, the only line prominently drawn in our country today is between the 'heroes' and the 'zeros'. On one side are a few hundred 'heroes' keeping nine hundred and fifty million people down on the other side. This situation has to be changed.

As the process of confronting and solving problems often requires hard work and is painful, we have endless procrastination. Actually, problems can be the cutting edge that actually distinguish between success and failure. They draw out innate courage and wisdom.

As soon as I returned from NASA, India's first rocket launch took place on 21 November 1963. It was a sounding rocket, called Nike-Apache, made at NASA. The rocket was assembled in the church building I have referred to earlier. The only equipment available to transport the rocket was a truck and a manually operated hydraulic crane. The assembled rocket was to be shifted from the church building to the launch pad by truck. When the rocket was lifted by the crane and was about to be placed on the launcher, it started tilting, indicating a leak in the hydraulic system of the crane. As we were fast approaching the launch time, 6 p.m., any repairs to the crane had to be ruled out. Fortunately, the leak was not large and we managed to lift the rocket manually, using our collective muscle power and finally placing it on the launcher.

In the maiden Nike-Apache launch, I was in charge of rocket integration and safety. Two of my colleagues who played a very active and crucial role in this launch were D Easwardas and R Aravamudan. Easwardas undertook the rocket assembly and arranged the launch. Aravamudan, whom we called Dan, was in charge of radar, telemetry and ground support. The launch was smooth and problem-free. We obtained excellent flight data and returned with a sense of pride and accomplishment.

When we were relaxing the next evening at the dinner table, we received news of the assassination of President John F Kennedy in Dallas, Texas. We were appalled. The Kennedy years were a significant era in America, when young men were at the helm of affairs. I used to read with interest about Kennedy's moves in the missile crisis of late 1962. The Soviet Union built missile sites in Cuba, from which it would have been possible to launch attacks on American cities. Kennedy imposed a blockade or 'quarantine', barring the introduction of any offensive missiles to Cuba. America also threatened to respond to any Soviet nuclear attack from Cuba on any country in the Western Hemisphere by retaliating against the USSR. After fourteen days of intense drama, the crisis was resolved by the Soviet Premier Khrushchev ordering that the Cuban bases be dismantled and the missiles returned to Russia.

The next day, Prof. Sarabhai had a detailed discussion with us on future plans. He was creating a new frontier in the field of science and technology in India. A new generation, scientists and engineers in their 30s and early 40s, was being charged with an unprecedented dynamism. Our biggest qualifications at INCOSPAR were not our degrees and training, but Prof. Sarabhai's faith in our capabilities. After the successful launch of Nike-Apache, he chose to share with us his dream of an Indian Satellite Launch Vehicle.

Prof. Sarabhai's optimism was highly contagious. The very news of his coming to Thumba would electrify people and all laboratories, workshops and design offices would hum with unceasing activity. People would work virtually round the clock because of their enthusiasm to show Prof. Sarabhai something new, something that had not been done before in our country—be it a new design or a new method of fabrication or even an out-of-the-way administrative procedure. Prof. Sarabhai would often assign multiple tasks to a single person or a group. Though some of those tasks would appear totally unrelated in the beginning, they would, at a later stage, emerge as deeply interconnected. When Prof. Sarabhai was talking to us about the Satellite Launch Vehicle (SLV), he asked me, almost in the same breath, to take up studies on a rocket-assisted take-off system (RATO) for military aircraft. The two things had no apparent connection except in the mind of this great visionary. I knew that all I had to do was to remain alert and focussed on my purpose, and sooner or later, an opportunity to do a challenging job would enter my laboratory.

Prof. Sarabhai was ever-willing to try out novel approaches and liked to draw in young people. He had the wisdom and judgement which enabled him to realise not only if something was well done, but also when it was time to stop. In my opinion, he was an ideal experimenter and innovator. When there were alternative courses of action before us, whose outcome was difficult to predict, or to reconcile varying perspectives, Prof. Sarabhai would resort to experimentation to resolve the issue. This was precisely the situation at INCOSPAR in 1963. A bunch of young, inexperienced, but nevertheless energetic and enthusiastic persons were given the task of fleshing out the spirit of self-reliance in the field of science and technology in general, and of space research in particular. It was a great example of leadership by trust.

The rocket launch site later blossomed into the Thumba Equatorial Rocket Launch Station (TERLS). TERLS was established through active collaboration with France, USA and USSR. The leader of the Indian space programme—Prof. Vikram Sarabhai—had comprehended the full implications of the challenge and had not balked at taking it on. Right from the day INCOSPAR was formed, he was aware of the need to organize an integrated national space programme, with the equipment for the manufacture of rockets and launch facilities developed and produced indigenously.

With this in view, a wide-ranging programme for scientific and technological development in rocket fuels, propulsion systems, aeronautics, aerospace materials, advanced fabrication techniques, rocket motor instrumentation, control and guidance systems, telemetry, tracking systems and scientific instruments for experimentation in space were launched at the Space Science and Technology Centre and the Physical Research Laboratory at Ahmedabad. Incidentally, this laboratory has produced a large number of Indian space scientists of extremely high calibre over the years.

The real journey of the Indian aerospace programme, however, had begun with the Rohini Sounding Rocket (RSR) Programme. What is it that distinguishes a sounding rocket from a Satellite Launch Vehicle (SLV) and from a missile? In fact, they are three different kinds of rockets. Sounding rockets are normally used for probing the near-earth environment, including the upper regions of the atmosphere. While they can carry a variety of scientific payloads to a range of altitudes, they cannot impart the final velocity needed to orbit the payload. On the other hand, a launch vehicle is designed to inject into orbit a technological payload or satellite. The final stage of a launch vehicle provides the necessary velocity for a satellite to enter an orbit. This is a complex operation requiring on-board guidance and control systems. A missile, though belonging to the same family, is a still more complex system. In addition to the large terminal velocity and onboard guidance and control, it must have the capability to home onto targets. When the targets are fast-moving and capable of manoeuvring, a missile is also required to carry out target-tracking functions.

The RSR programme was responsible for the development and fabrication of sounding rockets and their associated on-board systems for scientific investigations in India. Under this programme, a family of operational sounding rockets were developed. These rockets had wide ranging capabilities, and to date several hundreds of these rockets have been launched for various scientific and technological studies.

I still remember that the first Rohini rocket consisted of a single solid propulsion motor weighing a mere 32 kg. It lifted a nominal 7 kg payload to an altitude of about 10 km. It was soon followed by another, to which one more solid propellant stage was added to dispatch multi-experiment payloads weighing nearly 100 kg to an altitude of over 350 km.

The development of these rockets had resulted in a fully indigenous capability in the production of sounding rockets as well as their propellants. This programme had brought into the country technology for the production of very high-performance solid propellants, like those based on polyurethane and polybutane polymer. It later resulted in the setting up of a Propellant Fuel Complex (PFC) to manufacture strategic chemicals required for rocket engines, and a Rocket Propellant Plant (RPP) to produce propellants.

The development of Indian rockets in the twentieth century can be seen as a revival of the eighteenth century dream of Tipu Sultan. When Tipu Sultan was killed, the British captured more than 700 rockets and subsystems of 900 rockets in the battle of Turukhanahally in 1799. His army had 27 brigades, called Kushoons, and each brigade had a company of rocket men, called Jourks. These rockets had been taken to England by William Congreve and were subjected by the British to what we call 'reverse engineering' today. There were, of course, no GATT, IPR Act, or patent regime. With the death of Tipu, Indian rocketry also met its demise—at least for 150 years.

Meanwhile, rocket technology made great strides abroad. Konstantin Tsiolkovsky in Russia (1903), Robert Goddard in USA (1914) and Hermann Oberth in Germany (1923) gave rocketry new dimensions. In Nazi Germany, Wernher von Braun's group produced V-2 short range ballistic missiles and showered fire on the Allied Forces. After the war, both the USA and the USSR captured their share of German rocket technology and rocket engineers. With this booty, they started to run their deadly arms race with missiles and warheads.

Rocketry was reborn in India thanks to the technological vision of Prime Minister Jawaharlal Nehru. Prof. Sarabhai took the challenge of giving physical dimensions to this dream. Very many individuals with myopic vision questioned the relevance of space activities in a newly independent nation which was finding it difficult to feed its population. But neither Prime Minister Nehru nor Prof. Sarabhai had any ambiguity of purpose. Their vision was very clear: if Indians were to play a meaningful role in the community of nations, they must be second to none in the application of advanced technologies to their real-life problems. They had no intention of using it merely as a means to display our might.

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# 5

# Dreamers

During his frequent visits to Thumba, Prof. Sarabhai would openly review the progress of work with the entire team. He never gave directions. Rather, through a free exchange of views, he led us forward into new terrain which often revealed an unforeseen solution. Perhaps he was aware that though a particular goal might be clear to himself, and he could give adequate directions for its accomplishment, his team members might have resisted working towards a goal that made no sense to them. He considered the collective understanding of the problem the main attribute of effective leadership. He once told me, “Look, my job is to make decisions; but it is equally important to see to it that these decisions are accepted by my team members.”

In fact, Prof. Sarabhai took a series of decisions that were to become the life-mission of many. We would make our own rockets, our own Satellite Launch Vehicles (SLVs) and our own satellites. And this would not be done one-by-one but concurrently, in a multi-dimensional fashion. In the development of payloads for the sounding rockets, instead of getting a certain payload and then engineering it to fit into the rocket, we discussed the matter threadbare with the payload scientists working in different organ-izations and at different locations. I may even say that the most significant achievement of the sounding rocket programme was to establish and maintain nation-wide mutual trust.

Perhaps realising that I preferred to persuade people to do as they were told rather than use my legitimate authority, Prof. Sarabhai assigned me the task of providing interface support to payload scientists. Almost all physical laboratories in India were involved in the sounding rocket programme, each having its own mission, its own objective and its own payload. These payloads were required to be integrated to the rocket structure so as to ensure their proper functioning and endurance under flight conditions. We had X-ray payloads to look at stars; payloads fitted with radio frequency mass spectrometers to analyse the gas composition of the upper atmosphere; sodium payloads to find out wind conditions, its direction and velocity. We also had ionospheric payloads to explore different layers of the atmosphere. I not only had to interact with scientists from TIFR, National Physical Laboratory (NPL), and Physical Research Laboratory (PRL), but also with payload scientists from USA, USSR, France, Germany and Japan.

I often read Khalil Gibran, and always find his words full of wisdom. “Bread baked without love is a bitter bread that feeds but half a man’s hunger,”—those who cannot work with their hearts achieve but a hollow, half-hearted success that breeds bitterness all around. If you are a writer who would secretly prefer to be a lawyer or a doctor, your written words will feed but half the hunger of your readers; if you are a teacher who would rather be a businessman, your instructions will meet but half the need for knowledge of your students; if you are a scientist who hates science, your performance will satisfy but half the needs of your mission. The personal unhappiness and failure to achieve results that comes from being a round peg in a square hole is not, by any means, new. But there are exceptions to this like Prof. Oda and Sudhakar, who bring to their work a personal touch of magic based upon their individual character, personality, inner motives, and perhaps the dreams crystallized within their hearts. They become so emotionally involved with their work that any dilution of the success of their effort fills them with grief.

Prof. Oda was an X-ray payload scientist from the Institute of Space and Aeronautical Sciences (ISAS), Japan. I remember him as a diminutive man with a towering personality and eyes that radiated intelligence. His dedication to his work was exemplary. He would bring X-ray payloads from ISAS, which along with the X-ray payloads made by Prof. UR Rao, would be engineered by my team to fit into the nose cone of the Rohini Rocket. At an altitude of 150 km, the nose cone would be separated by explosion of pyros triggered by an electronic timer. With this, the X-ray sensors would be exposed to space for collecting the required information about the emissions from stars. Together, Prof. Oda and Prof. Rao were a unique blend of intellect and dedication, which one rarely sees. One day, when I was working on the integration for Prof. Oda’s payload with my timer devices, he insisted on using the timers he had brought from Japan. To me they looked flimsy, but Prof. Oda stuck to his stand that the Indian timers be replaced by the Japanese ones. I yielded to his suggestion and replaced the timers. The rocket took off elegantly and attained the intended altitude. But the telemetry signal reported mission failure on account of timer malfunction. Prof. Oda was so upset that tears welled up in his eyes. I was stunned by the emotional intensity of Prof. Oda’s response. He had clearly put his heart and soul into his work.

Sudhakar was my colleague in the Payload Preparation Laboratory. As part of the pre-launch schedule, we were filling and remotely pressing the hazardous sodium and thermite mix. As usual, it was a hot and humid day at Thumba. After the sixth such operation, Sudhakar and I went into the payload room to confirm the proper filling of the mix. Suddenly, a drop of sweat from his forehead fell onto the sodium, and before we knew what was happening, there was a violent explosion which shook the room. For a few paralysed seconds, I did not know what to do. The fire was spreading, and water would not extinguish the sodium fire. Trapped in this inferno, Sudhakar, however, did not lose his presence of mind. He broke the glass window with his bare hands and literally threw me out to safety before jumping out himself. I touched Sudhakar’s bleeding hands in gratitude, he was smiling through his pain. Sudhakar spent many weeks in the hospital recuperating from the severe burns he had received.

At TERLS, I was involved with rocket preparation activities, payload assembly, testing and evaluation besides building subsystems like payload housing and jettisonable nose cones. Working with the nose cones led me, as a natural consequence, into the field of composite materials.

It is interesting to know that the bows found, during archaeological excavations at different sites in the country, reveal that Indians used composite bows made of wood, sinew, and horn as early as the eleventh century, at least 500 years before such bows were made in medieval Europe. The versatility of composites, in the sense that they possess very desirable structural, thermal, electrical, chemical and mechanical properties, fascinated me. I was so enthused with these man-made materials that I was in a hurry to know everything about them almost overnight. I used to read up everything available on related topics. I was particularly interested in the glass and carbon Fibre Reinforced Plastic (FRP) composites.

An FRP composite is composed of an inorganic fibre woven into a matrix that encloses it and gives the component its bulk form. In February 1969, Prime Minister Indira Gandhi visited Thumba to dedicate TERLS to the International Space Science Community. On this occasion, she commissioned the country's first filament winding machine in our laboratory. This event brought my team, which included CR Satya, PN Subramanian and MN Satyanara-yana, great satisfaction. We made high-strength glass cloth laminates to build non-magnetic payload housings and flew them in two-stage sounding rockets. We also wound and test flew rocket motor casings of up to 360 mm diameter.

Slowly, but surely, two Indian rockets were born at Thumba. They were christened Rohini and Menaka, after the two mythological dancers in the court of Indra, the king of the sky. The Indian payloads no longer needed to be launched by French rockets. Could this have been done but for the atmosphere of trust and commitment which Prof. Sarabhai had created at INCOSPAR? He brought into use each person's knowledge and skills. He made every man feel directly involved in problem solving. By the very fact of the team members' participation, the solutions became genuine and earned the trust of the entire team resulting in total commitment towards implementation.

Prof. Sarabhai was matter-of-fact and never tried to hide his disappointment. He used to talk with us in an honest and objective manner. Sometimes I found him making things look more positive than they actually were, and then charming us by his almost magical powers of persuasion.



When we were at the drawing board, he would bring someone from the developed world for a technical collaboration. That was his subtle way of challenging each one of us to stretch our capabilities.

At the same time, even if we failed to meet certain objectives, he would praise whatever we had accomplished. Whenever he found any one of us going over his head and attempting a task for which he did not have the capability or skill, Prof. Sarabhai would reassign activity in such a way so as to lower pressure and permit better quality work to be performed. By the time the first Rohini-75 rocket was launched from TERLS on 20 November 1967, almost each one of us was in his own groove.

Early next year, Prof. Sarabhai wanted to see me urgently in Delhi. By now I was accustomed to Prof. Sarabhai's working methods. He was always full of enthusiasm and optimism. In such a state of mind, sudden flashes of inspiration were almost natural. On reaching Delhi, I contacted Prof. Sarabhai's secretary for an appointment and was asked to meet him at 3.30 a.m. at Hotel Ashoka. Delhi being a slightly unfamiliar place, with an unfriendly climate for someone like me, conditioned to the warm and humid climate of South India, I decided to wait in the hotel lounge after finishing my dinner.

I have always been a religious person in the sense that I maintain a working partnership with God. I was aware that the best work required more ability than I possessed and therefore I needed help that only God could give me. I made a true estimate of my own ability, then raised it by 50 per cent and put myself in God's hands. In this partnership, I have always received all the power I needed, and in fact have actually felt it flowing through me. Today, I can affirm that the kingdom of God is within you in the form of this power, to help achieve your goals and realise your dreams.

There are many different types and levels of experience that turn this internal power reaction critical. Sometimes, when we are ready, the gentlest of contacts with Him fills us with insight and wisdom. This could come from an encounter with another person, from a word, a question, a gesture or even a look. Many a time, it could come even through a book, a conversation, some phrase, even a line from a poem or the mere sight of a picture. Without the slightest warning, something new breaks into your life and a secret decision is taken, a decision that you may be completely unconscious of, to start with.

I looked around the elegant lounge. Somebody had left a book on a nearby sofa. As if to fill the small hours of that cold night with some warm thoughts, I picked up the book and started browsing. I must have turned only a few pages of the book, about which I do not remember a thing today.

It was some popular book related to business management. I was not really reading it, only skimming over paragraphs and turning pages. Suddenly, my eyes fell on a passage in the book, it was a quotation from George Bernard Shaw. The gist of the quote was that all reasonable men adapt themselves to the world. Only a few unreasonable ones persist in trying to adapt the world to themselves. All progress in the world depends on these unreasonable men and their innovative and often non-conformist actions.

I started reading the book from the Bernard Shaw passage onwards. The author was describing certain myths woven around the concept and the process of innovation in industry and business. I read about the myth of strategic planning. It is generally believed that substantial strategic and technological planning greatly increases the odds of a 'no surprises' outcome. The author was of the opinion that it is essential for a project manager to learn to live with uncertainty and ambiguity. He felt that it was a myth to hold that the key to economic success is computability. A quotation from General George Patton was given as a counterpoint to this myth—that a good plan violently executed right now is far better than a perfect plan executed next week. It is a myth that to win big one must strive to optimize, the author felt. Optimization wins only on paper, but would invariably lose later in the real world, the book said.

Waiting in the hotel lobby at 1 a.m. for an appointment two hours later was certainly not a reasonable proposition, neither for me nor for Prof. Sarabhai. But then, Prof. Sarabhai had always exhibited a strong component of unorthodoxy in his character. He was running the show of space research in the country—under-staffed, overworked—nevertheless in a successful manner.

Suddenly, I became aware of another man who came and sat down on the sofa opposite mine. He was a well-built person with an intelligent look and refined posture. Unlike me—always disorderly in my dress—this man was wearing elegant clothes. Notwithstanding the odd hours, he was alert and vivacious.

There was a strange magnetism about him which derailed the train of my thoughts on innovation. And before I could get back to the book, I was informed that Prof. Sarabhai was ready to receive me. I left the book on the nearby sofa from where I had picked it up. I was surprised when the man sitting on the opposite sofa was also asked to come inside. Who was he? It was not long before my question was answered. Even before we sat down, Prof. Sarabhai introduced us to each other. He was Group Captain VS Narayanan from Air Headquarters.

Prof. Sarabhai ordered coffee for both of us and unfolded his plan of developing a rocket-assisted take-off system (RATO) for military aircraft. This would help our warplanes to take off from short runways in the Himalayas. Hot coffee was served over small talk. It was totally uncharacteristic of Prof. Sarabhai. But as soon as we finished the coffee, Prof. Sarabhai rose and asked us to accompany him to Tilpat Range on the outskirts of Delhi. As we were passing through the lobby, I threw a cursory glance at the sofa where I had left the book. It was not there.

It was about an hour's drive to the Range. Prof. Sarabhai showed us a Russian RATO. "If I get you the motors of this system from Russia, could you do it in eighteen months time?" Prof. Sarabhai asked us. "Yes, we can!" Both Gp Capt VS Narayanan and I spoke almost simultaneously. Prof. Sarabhai's face beamed, reflecting our fascination. I recalled what I had read, "He will bestow on you a light to walk in."

After dropping us back at the Hotel Ashoka, Prof. Sarabhai went to the Prime Minister's house for a breakfast meeting. By that evening, the news of India taking up the indigenous development of a device to help short run take-offs by high performance military aircraft, with myself heading the project, was made public. I was filled with many emotions—happiness, gratitude, a sense of fulfilment and these lines from a little-known poet of the nineteenth-century crossed my mind:

*For all your days prepare*
*And meet them ever alike*
*When you are the anvil, bear –*
*When you are the hammer, strike.*

RATO motors were mounted on aircraft to provide the additional thrust required during the take-off run under certain adverse operating conditions like partially bombed-out runways, high altitude airfields, more than the prescribed load, or very high ambient temperatures. The Air Force was in dire need of a large number of RATO motors for their S-22 and HF-24 aircraft.

The Russian RATO motor shown to us at the Tilpat Range was capable of generating a 3000 kg thrust with a total impulse of 24500 kg-seconds. It weighed 220 kg and had a double base propellant encased in steel. The development work was to be carried out at the Space Science and Technology Centre with the assistance of the Defence Research and Development Organization (DRDO), HAL, DTD&P(Air) and Air Headquarters.

After a detailed analysis of the available options, I chose a fibreglass motor casing. We decided in favour of a composite propellant which gives a higher specific impulse and aimed at a longer burning time to utilize it completely. I also decided to take additional safety measures by incorporating a diaphragm which would rupture if the chamber pressure for some reason exceeded twice the operating pressure. Two significant developments occurred during the work on RATO. The first was the release of a ten-year profile for space research in the country, prepared by Prof. Sarabhai. This profile was not merely an activity plan laid down by the top man for his team to comply with, it was a theme paper meant for open discussions, to be later transformed into a programme. In fact, I found it was the romantic manifesto of a person deeply in love with the space research programme in his country.

The plan mainly centred around the early ideas which had been born at INCOSPAR; it included utilization of satellites for television and developmental education, meteorological observations and remote sensing for management of natural resources. To this had been added the development and launch of satellite launch vehicles.

The active international cooperation dominant in the early years was virtually eased out in this plan and the emphasis was on self-reliance and indigenous technologies. The plan talked about the realisation of a SLV for injecting lightweight satellites into a low earth orbit, upgrading of Indian satellites from laboratory models to space entities and development of a wide range of spacecraft subsystems like the apogee and booster motors, momentum wheel, and solar panel deployment mechanism. It also promised a wide range of technological spin-offs like the gyros, various types of transducers, telemetry, adhesives, and polymers for non-space applications. Over and above, there was the dream of an adequate infrastructure that would be capable of supporting R&D in a variety of engineering and scientific disciplines.

The second development was the formation of a Missile Panel in the Ministry of Defence. Both Narayanan and I were inducted as members. The idea of making missiles in our own country was exciting, and we spent hours on end studying the missiles of various advanced countries.

The distinction between a tactical missile and a strategic missile is often a fine one. Generally, by ‘strategic’, it is understood that the missile will fly thousands of kilometres. However, in warfare, this term is used to denote the kind of target rather than its distance from missile launch. Strategic missiles are those that strike at the enemy’s heartland, either in counter-force attacks on their strategic forces or in counter-value attacks on the society, which in essence means his cities. Tactical weapons are those that influence a battle, and the battle may be by land, sea or air, or on all three together. This categorization now appears nonsensical, as the US Air Force’s ground-launched Tomahawk is used in a tactical role, notwithstanding its range of some 3000 km. In those days, however, strategic missiles were synonymous with intermediate range ballistic missiles (IRBMs) with ranges in the order of 1500 nautical miles or 2780 km and inter-continental ballistic missiles (ICBMs) with a capability of going even further.

Gp Capt Narayanan had an ineffable enthusiasm for indigenous guided missiles. He was a great admirer of the strong arm approach of the Russian Missile Development Programme. “When it could be done there, why not here, where space research has already prepared the soil for a bonanza of missile technology?” Narayanan used to needle me.

The bitter lessons of the two wars in 1962 and 1965 had left the Indian leadership with little choice in the matter of achieving self-reliance in military hardware and weapon systems. A large number of Surface-to-Air Missiles (SAMs) were obtained from the USSR to guard strategic locations. Gp Capt Narayanan passionately advocated the development of these missiles in the country.

While working together on RATO motors and on the Missile Panel, Narayanan and I played the roles of student and teacher interchangeably wherever required. He was very eager to learn about rocketry and I was very curious to know about airborne weapon systems. The depth of Narayanan's conviction and his force of application were inspiring. Right from the day of our pre-dawn visit to the Tilpat Range with Prof. Sarabhai, Narayanan was always busy with his RATO motor. He had arranged everything that was required before being asked. He obtained funding of Rs 75 lakhs with a further commitment towards any unforeseen costs. "You name the thing and I will get it for you, but do not ask for time," he said. At times, I often laughed at his impatience, and read for him these lines from T.S. Eliot's Hollow Men:

*Between the conception*
*And the creation*
*Between the emotion*
*And the response*
*Falls the Shadow.*

Defence R&D at that time was heavily dependent on imported equipment. Virtually nothing indigenous was available. Together, we made a long shopping list and drew up an import plan. But this made me unhappy—was there no remedy or alternative? Was this nation doomed to live with screwdriver technology? Could a poor country like India afford this kind of development?

One day, while working late in the office, which was quite routine after I took up the RATO projects, I saw a young colleague, Jaya Chandra Babu going home. Babu had joined us a few months ago and the only thing I knew about him was that he had a very positive attitude and was articulate. I called him into my office and did a bit of loud thinking. "Do you have any suggestions?" I then asked him. Babu remained silent for a while, and then asked for time until the next evening to do some homework before answering my question.

The next evening, Babu came to me before the appointed time. His face was beaming with promise. "We can do it, sir! The RATO system can be made without imports. The only hurdle is the inherent inelasticity in the approach of the organization towards procurement and sub-contracting, which would be the two major thrust areas to avoid imports." He gave me seven points, or, rather, asked for seven liberties—financial approval by a single person instead of an entire hierarchy, air travel for all people on work irrespective of their entitlement, accountability to only one person, lifting of goods by air-cargo, sub-contracting to the private sector, placement of orders on the basis of technical competence, and expeditious accounting procedures.

These demands were unheard of in government establishments, which tend to be conservative, yet I could see the soundness of his proposition. The RATO project was a new game and there was nothing wrong if it was to be played with a new set of rules. I weighed all the pros and cons of Babu's suggestions for a whole night and finally decided to present them to Prof. Sarabhai. Hearing my plea for administrative liberalization and seeing the merits behind it, Prof. Sarabhai approved the proposals without a second thought.

Through his suggestions, Babu had highlighted the importance of business acumen in developmental work with high stakes. To make things move faster within existing work parameters, you have to pump in more people, more material and more money. If you can't do that, change your parameters! Instinctive businessman that he was, Babu did not remain long with us and left ISRO for greener pastures in Nigeria. I could never forget Babu's common sense in financial matters.

We had opted for a composite structure for the RATO motor casing using filament fibre glass/epoxy. We had also gone in for a high energy composite propellant and an event-based ignition and jettisoning system in real-time. A canted nozzle was designed to deflect the jet away from the aircraft. We conducted the first static test of RATO in the twelfth month of the project initiation. Within the next four months, we conducted 64 static tests. And we were just about 20 engineers working on the project!

* * *

# 6

# Movers

The future satellite launch vehicle (SLV) had also been conceived by this time. Recognising the immense socio- economic benefits of space technology, Prof. Sarabhai decided in 1969, to go full-steam ahead with the task of establishing indigenous capability in building and launching our own satellites. He personally participated in an aerial survey of the east coast for a possible site for launching satellite launch vehicles and large rockets.

Prof. Sarabhai was concentrating on the east coast in order to let the launch vehicle take full advantage of the earth's west to east rotation. He finally selected the Sriharikota island, 100 km north of Madras (now Chennai), and thus the SHAR Rocket Launch Station was born. The crescent-shaped island has a maximum width of 8 km and lies alongside the coastline. The island is as big as Madras city. The Buckingham Canal and the Pulicat lake form its western boundary.

In 1968, we had formed the Indian Rocket Society. Soon after, the INCOSPAR was reconstituted as an advisory body under the Indian National Science Academy (INSA) and the Indian Space Research Organization (ISRO) was created under the Department of Atomic Energy (DAE) to conduct space research in the country.

By this time, Prof. Sarabhai had already hand-picked a team to give form to his dream of an Indian SLV. I consider myself fortunate to have





been chosen to be a project leader. Prof. Sarabhai gave me the additional responsibility of designing the fourth stage of the SLV. Dr VR Gowarikar, MR Kurup and AE Muthunayagam were given the tasks of designing the other three stages.

What made Prof. Sarabhai pick a few of us for this great mission? One reason seemed to be our professional background. Dr Gowarikar was doing outstanding work in the field of composite propellants. MR 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.

I laid the foundation for Stage IV on two rocks—sensible approximation and unawed support. I have always considered the price of perfection prohibitive and allowed mistakes as a part of the learning process. I prefer a dash of daring and persistence to perfection. I have always supported learning on the part of my team members by paying vigilant attention to each of their attempts, be they successful or unsuccessful.

In my group, progress was recognized and reinforced at every tiny step. Although I provided access to all the information that my co-workers in Stage IV needed, I found I could not spend enough time to be a useful facilitator and a source of support. I wondered if there was something wrong with the way in which I managed my time. At this stage, Prof. Sarabhai brought a French visitor to our work centre to point out the problem to me. This gentleman was Prof. Curien, President of CNES (Centre Nationale de Etudes Spatiales), our counterpart in France. They were then developing the Diamont launch vehicles. Prof. Curien was a thorough professional. Together, Prof. Sarabhai and Prof. Curien helped me set a target. While they discussed the means by which I could reach it, they also cautioned me about the possibilities of failure. While I arrived at a better awareness of Stage IV problems through the supportive counselling of Prof. Curien, Prof. Sarabhai's catalytic intervention led Prof. Curien to reinterpret his own progress in the Diamont programme.

Prof. Curien advised Prof. Sarabhai to relieve me of all the minor jobs which posed little challenge and to give me more opportunities for achievement. He was so impressed by our well-planned efforts that he inquired if we could make the Diamont's fourth stage. I recall how this brought a subtle smile to Prof. Sarabhai's face.

As a matter of fact, the Diamont and SLV airframes were incompatible. The diameters were quite different and to attain interchangeability, some radical innovations were required. I wondered where I should start. I decided to look around for solutions among my own colleagues. I used to carefully observe my colleagues to see if their daily routine reflected their desire to constantly experiment. I also started asking and listening to anyone who showed the slightest promise. Some of my friends cautioned me about what they termed as my naivete. I made it an unfailing routine to make notes on individual suggestions and gave handwritten notes to colleagues in engineering and design, requesting concrete follow-up action within five or ten days.

This method worked wonderfully well. Prof. Curien testified, while reviewing our progress, that we had achieved in a year's time what our counterparts in Europe could barely manage in three years. Our plus point, he noted, was that each of us worked with those below and above in the hierarchy. I made it a point to have the team meet at least once every week. Though it took up time and energy, I considered it essential.

How good is a leader? No better than his people and their commitment and participation in the project as full partners! The fact that I got them all together to share whatever little development had been achieved—results, experiences, small successes, and the like—seemed to me worth putting all my energy and time into. It was a very small price to pay for that commitment and sense of teamwork, which could in fact be called trust. Within my own small group of people I found leaders, and learned that leaders exist at every level. This was another important aspect of management that I learned.

We had modified the existing SLV-IV Stage design to suit the Diamont airframe. It was reconfigured and upgraded from a 250 kg, 400 mm diameter stage to a 600 kg, 650 mm diameter stage. After two years' effort, when we were about to deliver it to CNES, the French suddenly cancelled their Diamont BC programme. They told us that they did not need our Stage IV anymore. It was a great shock, making me re-live the earlier disappointments at Dehra Dun, when I failed to get into the Air Force, and at Bangalore, when the Nandi project was aborted at ADE.

I had invested great hope and effort in the fourth stage, so that it could be flown with a Diamont rocket. The other three stages of SLV, involving enormous work in the area of rocket propulsion were at least five years away. However, it did not take me long to shelve the disappointment of Diamont BC Stage IV. After all, I had thoroughly enjoyed working on this project. In time, RATO filled the vacuum created in me by the Diamont BC Stage.

When the RATO project was underway, the SLV project slowly started taking shape. Competence for all major systems of a launch vehicle had been established in Thumba by now. Through their outstanding efforts, Vasant Gowarikar, MR Kurup and Muthunayagam prepared TERLS for a big leap in rocketry.

Prof. Sarabhai was an exemplar in the art of team-building. On one occasion, he had to identify a person who could be given the responsibility for developing a telecommand system for the SLV. Two men were competent to carry out this task—one was the seasoned and sophisticated UR Rao and the other was a relatively unknown experimenter, G Madhavan Nair. Although I was deeply impressed by Madhavan Nair's dedication and abilities, I did not rate his chances as very good. During one of Prof. Sarabhai's routine visits, Madhavan Nair boldly demonstrated his improvised but highly reliable telecommand system. Prof. Sarabhai did not take much time to back the young experimenter in preference to an established expert. Madhavan Nair not only lived up to the expectations of his leader but even went beyond them. He was to later become the project director of the Polar Satellite Launch Vehicle (PSLV).

SLVs and missiles can be called first cousins: they are different in concept and purpose, but come from the same bloodline of rocketry. A massive missile development project had been taken up by DRDO at the Defence Research & Development Laboratory (DRDL), Hyderabad. As the pace of this surface-to-air missile development project increased, the frequency of the Missile Panel meetings and my interaction with Gp Capt Narayanan also increased.

In 1968, Prof. Sarabhai came to Thumba on one of his routine visits. He was shown the operation of the nose-cone jettisoning mechanism. As always, we were all anxious to share the results of our work with Prof. Sarabhai. We requested Prof. Sarabhai to formally activate the pyro system through a timer circuit. Prof. Sarabhai smiled, and pressed the button. To our horror, nothing happened. We were dumbstruck. I looked at Pramod Kale, who had designed and integrated the timer circuit. In a flash each of us mentally went through an anlysis of the failure. We requested Prof. Sarabhai to wait for a few minutes, then we detached the timer device, giving direct connection to the pyros. Prof. Sarabhai pressed the button again. The pyros were fired and the nose cone was jettisoned. Prof. Sarabhai congratulated Kale and me; but his expression suggested that his thoughts were elsewhere. We could not guess what was on his mind. The suspense did not last for long and I got a call from Prof. Sarabhai's secretary to meet him after dinner for an important discussion.

Prof. Sarabhai was staying at the Kovalam Palace Hotel, his usual home whenever he was in Trivandrum. I was slightly perplexed by the summons. Prof. Sarabhai greeted me with his customary warmth. He talked of the rocket launching station, envisaging facilities like launch pads, block houses, radar, telemetry and so on—things which are taken for granted in Indian space research today. Then he brought up the incident that had occurred that morning. This was exactly what I had feared. My apprehension of a reproach from my leader, however, was unfounded. Prof. Sarabhai did not conclude that the failure of the pyro timer circuit was the outcome of insufficient knowledge and lack of skill on the part of his people or of faulty understanding at the direction stage. He asked me instead, if we were unenthused by a job that did not pose sufficient challenge. He also asked me to consider if my work was possibly being affected by any problem of which I was hitherto unaware. He finally put his finger on the key issue. We lacked a single roof to carry out system integration of all our rocket stages and rocket systems. Electrical and mechanical integration work was going on with a significant phase difference—both in time and in space. There was little effort to bring together the disparate work on electrical and mechanical integration. Prof. Sarabhai spent the next hour in re-defining our tasks, and, in the small hours of the morning, the decision to set up a Rocket Engineering Section was taken.

Mistakes can delay or prevent the proper achievement of the objectives of individuals and organizations, but a visionary like Prof. Sarabhai can use errors as opportunities to promote innovation and the development of new ideas. He was not especially concerned with the mistake in the timer circuit, least of all with pinning the blame for it. Prof. Sarabhai's approach to mistakes rested on the assumption that they were inevitable but generally manageable. It was in the handling of the crises that arose as a consequence that talent could often be revealed. I later realised by experience, that the best way to prevent errors was to anticipate them. But this time, by a strange twist of fate, the failure of the timer circuit led to the birth of a rocket engineering laboratory.

It was my usual practice to brief Prof. Sarabhai after every Missile Panel Meeting. After attending one such meeting in Delhi on 30 December 1971, I was returning to Trivandrum. Prof. Sarabhai was visiting Thumba that very day to review the SLV design. I spoke to him on the telephone from the airport lounge about the salient points that had emerged at the panel meeting. He instructed me to wait at Trivandrum Airport after disembarking from the Delhi flight, and to meet him there before his departure for Bombay the same night.

When I reached Trivandrum, a pall of gloom hung in the air. The aircraft ladder operator Kutty told me in a choked voice that Prof. Sarabhai was no more. He had passed away a few hours ago, following a cardiac arrest. I was shocked to the core; it had happened within an hour of our conversation. It was a great blow to me and a huge loss to Indian science. That night passed in preparations for airlifting Prof. Sarabhai's body for the cremation in Ahmedabad.

For five years, between 1966 to 1971, about 22 scientists and engineers had worked closely with Prof. Sarabhai. All of them were later to take charge of important scientific projects. Not only was Prof. Sarabhai a great scientist, but also a great leader. I still remember him reviewing the bi-monthly progress of the design projects of SLV-3 in June 1970.

Presentations on Stages I to IV were arranged. The first three presentations went through smoothly. Mine was the last presentation. I introduced five of my team members who had contributed in various ways to the design. To everybody's surprise, each of them presented his portion of the work with authority and confidence. The presentations were discussed at length and the conclusion was that satisfactory progress had been made.

Suddenly, a senior scientist who worked closely with Prof. Sarabhai turned to me and enquired, "Well, the presentations for your project were made by your team members based on their work. But what did you do for the project?" That was the first time I saw Prof. Sarabhai really annoyed. He told his colleague, "You ought to know what project management is all about. We just witnessed an excellent example. It was an outstanding demonstration of team work. I have always seen a project leader as an integrator of people and that is precisely what Kalam is." I consider Prof. Sarabhai as the Mahatma Gandhi of Indian science —generating leadership qualities in his team and inspiring them through both ideas and example.

After an interim arrangement with Prof. MGK Menon at the helm, Prof. Satish Dhawan was given the responsibility of heading ISRO. The whole complex at Thumba, which included TERLS, the Space Science and Technology Centre (SSTC), the RPP, the Rocket Fabrication Facility (RFF), and the Propellant Fuel Complex (PFC) were merged together to form an integrated space centre and christened the Vikram Sarabhai Space Centre (VSSC) as a tribute to the man to whom it owed its existence. The renowned metallurgist, Dr Brahm Prakash, took over as the first Director of VSSC.

The RATO system was successfully tested on 8 October 1972 at Bareilly Air Force station in Uttar Pradesh, when a high performance Sukhoi-16 jet aircraft became airborne after a short run of 1200 m, as against its usual run of 2 km. We used the 66th RATO motor in the test. The demonstration was watched by Air Marshal Shivdev Singh and Dr BD Nag Chaudhury, then the Scientific Adviser to the Defence Minister. This effort was said to have saved approximately Rs 4 crores in foreign exchange. The vision of the industrialist scientist had finally borne fruit.



Before taking up the responsibility of organizing space research in India and becoming the chairman of INCOSPAR, Prof. Sarabhai had established a number of successful industrial enterprises. He was aware that scientific research could not survive in isolation, away from industry. Prof. Sarabhai founded Sarabhai Chemicals, Sarabhai Glass, Sarabhai Geigy Limited, Sarabhai Merck Limited, and the Sarabhai Engineering Group. His Swastik Oil Mills did pioneering work in the extraction of oil from oilseeds, manufacture of synthetic detergents and of cosmetics. He geared Standard Pharmaceuticals Limited to enable large-scale manufacture of penicillin, which was imported from abroad at astronomical costs at that time. Now with the indigenization of RATO, his mission had acquired a new dimension—independence in the manufacture of military hardware and the potential saving of crores of rupees in foreign exchange. I recalled this on the day of the successful trial of the RATO system. Including trial expenses, we spent less than Rs. 25 lakhs on the entire project. The Indian RATO could be produced at Rs.17,000 apiece, and it replaced the imported RATO, which cost Rs. 33,000.

At the Vikram Sarabhai Space Centre, work on the SLV went on at full swing. All the subsystems had been designed, technologies identified, processes established, work centres selected, manpower earmarked and schedules drawn. The only hitch was the lack of a management structure to effectively handle this mega-project and coordinate activities which were spread over a large number of work centres with their own ways of working and management.

Prof. Dhawan, in consultation with Dr Brahm Prakash, picked me for this job. I was appointed the Project Manager—SLV, and reported directly to the Director, VSSC. My first task was to work out a project management plan. I wondered why I was selected for this task when there were stalwarts like Gowarikar, Muthunayagam, and Kurup around. With organizers like Easwardas, Aravamudan, and SC Gupta available, how would I do better? I articulated my doubts to Dr Brahm Prakash. He told me not to focus on what I saw as other people's strengths compared to my own, but instead, to attempt to expand their abilities.

Dr Brahm Prakash advised me to take care of the performance degraders and cautioned me against outrightly seeking optimal performance from the participating work centres. “Everyone will work to create their bit of SLV; your problem is going to be your dependency on others in accomplishing the total SLV. The SLV mission will be accomplished with, and through, a large number of people. You will require a tremendous amount of tolerance and patience,” he said. It reminded me of what my father used to read to me from the Holy Qur’an on the distinction between right and wrong: “We have sent no apostle before you who did not eat or walk about the market squares. We test you by means of one another. Will you not have patience?”

I was aware of the contradiction that often occurred in such situations. People heading teams often have one of the following two orientations: for some, work is the most important motivation; for others, their workers are the all-consuming interest. There are many others who fall either between these two positions or outside them. My job was going to be to avoid those who were interested neither in the work nor in the workers. I was determined to prevent people from taking either extreme, and to promote conditions where work and workers went together. I visualized my team as a group in which each member worked to enrich the others in the team and experience the enjoyment of working together.

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 a 40 kg satellite into a 400 km circular orbit around the earth.

As a first step, I translated the primary project objectives into some major tasks. One such task was the development of a rocket motor system for the four stages of the vehicle. The critical problems in the completion of this task were: making an 8.6 tonne propellant grain and a high mass ratio apogee rocket motor system which would use high-energy propellants. Another task was vehicle control and guidance. Three types of control systems were involved in this task—aerodynamic surface control, thrust vector control and reaction control for the first, second and third stages and the spin-up mechanism for the fourth stage. Inertial reference for control systems and guidance through inertial measurement was also imperative. Yet another major task was the augmentation of launch facilities at SHAR with systems integration and checkout facilities and development of launch support systems such as launchers and vehicle assembly fixtures. A target of ‘all line’ flight test within 64 months was set in March 1973.

I took up the executive responsibility of implementing the project within the framework of policy decisions taken, the approved management plan, and the project report; and also within the budget and through the powers delegated to me by the Director, VSSC. Dr Brahm Prakash formed four Project Advisory Committees to advise me on specialized areas like rocket motors, materials and fabrication, control and guidance, electronics, and mission and launching. I was assured of the guidance of outstanding scientists like DS Rane, Muthunayagam, TS Prahlad, AR Acharya, SC Gupta, and CL Amba Rao, to name a few.

The Holy Qur’an says: “We have sent down to you revelations showing you an account of those who have gone before you and an admonition to righteous men.” I sought to share the wisdom of these extremely brilliant people. “Light upon light. Allah guides to His light whom He will. He has knowledge of all things.”

We made three groups to carry out the project activities—a Programme Management Group, an Integration and Flight Testing Group and a Subsystems Development Group. The first Group was made responsible for looking after the overall executive aspects of SLV-3: project management, including administration, planning and evaluation, subsystems specifications, materials, fabrication, quality assurance and control. The Integration and Flight Testing Group was assigned the tasks of generation of facilities required for integration and flight testing of SLV-3. They were also asked to carry out the analysis of the vehicle, including mechanical and aerodynamic interface problems. The Subsystems Development Group was given the job of interacting with various divisions of VSSC and was made responsible for ensuring that all technological problems in the development of various subsystems were overcome by creating a synergy amongst the available talent in these divisions.

I projected a requirement of 275 engineers and scientists for SLV-3 but could get only about 50. If it had not been for synergistic efforts, the whole project would have remained a non-starter. Some young engineers like MSR Dev, G Madhavan Nair, S Srinivasan, US Singh, Sunderrajan, Abdul Majeed, Ved Prakash Sandlas, Namboodiri, Sasi Kumar, and Sivathanu Pillai developed their own ground rules designed to help them work efficiently as a project team, and produced outstanding individual and team results. These men were in the habit of celebrating their successes together—in a sort of mutual appreciation club. This boosted morale, and helped them a great deal to accept setbacks and to revitalize themselves after periods of intense work.

Each member of the SLV-3 project team was a specialist in his own field. It was natural therefore that each one of them valued his independence. To manage the performance of such specialists the team leader has to adopt a delicate balance between the hands-on and the hands-off approach. The hands-on approach takes an active interest on a very regular basis in the members' work. The hands-off approach trusts team members and recognizes their need for autonomy to carry out their roles, as they see fit. It hinges on their self-motivation. When the leader goes too far with the hands-on approach, he is seen as an anxious and interfering type. If he goes too far hands-off, he is seen as abdicating his responsibility or not being interested. Today, the members of the SLV-3 team have grown to lead some of the country's most prestigious programmes. MSR Dev heads the Augmented Satellite Launch Vehicle (ASLV) project, Madhavan Nair is the chief of the Polar Satellite Launch Vehicle (PSLV) project and Sandlas and Sivathanu Pillai are Chief Controllers in DRDO Headquarters. Each one of these men rose to his present position through consistent hard work and rock-like will power. It was indeed an exceptionally talented team.

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# 7

# Thrusters

Having taken up the leadership of executing the SLV-3 project, I faced urgent and conflicting demands on my time—for committee work, material procurement, correspondence, reviews, briefings, and for the need to be informed on a wide range of subjects.

My day would start with a stroll of about 2 km around the lodge I was living in. I used to prepare a general schedule during my morning walk, and emphasize two or three things I would definitely like to accomplish during the day, including at least one thing that would help achieve long-term goals.

Once in the office, I would clean the table first. Within the next ten minutes, I would scan all the papers and quickly divide them into different categories: those that required immediate action, low priority ones, ones that could be kept pending, and reading material. Then I would put the high priority papers in front of me and everything else out of sight.

Coming back to SLV-3, about 250 sub-assemblies and 44 major subsystems were conceived during the design. The list of materials went up to over 1 million components. A project implementation strategy had become essential to achieve sustained viability of this complex programme of seven to ten years' duration. From his side, Prof. Dhawan came up with a clear statement that all the manpower and funds at

VSSC and SHAR would have to be directed to us. From our side, we evolved a matrix type of management to achieve productive interfacing with more than 300 industries. The target was that our interaction with them must lead to their technology empowerment. Three things I stressed before my colleagues—importance of design capability, goal setting and realisation, and the strength to withstand setbacks. Now, before I dwell on the finer aspects of the management of the SLV-3 project, let me talk about the SLV-3 itself.

It is interesting to describe a launch vehicle anthropomorphically. The main mechanical structure may be visualized as the body of a human being, the control and guidance systems with their associated electronics constitute the brain. The musculature comes from propellants. How are they made? What are the materials and techniques involved?

A large variety of materials go into the making of a launch vehicle—both metallic and non-metallic, which include composites and ceramics. In metals, different types of stainless steel, alloys of aluminium, magnesium, titanium, copper, beryllium, tungsten and molybdenum are used. Composite materials are composed of a mixture or combination of two or more constituents which differ in form and material composition and which are essentially insoluble in one another. The materials which combine may be metallic, organic or inorganic. While other material combinations possible are virtually unlimited, the most typical composites in launch vehicles are made of structural constituents, embedded in a matrix. We used a large variety of glass fibre reinforced plastic composites and opened avenues for the entry of Kevlar, polyamides and carbon-carbon composites. Ceramics are special types of baked clay used for microwave transparent enclosures. We considered using ceramics, but had to reject the idea then due to technological limitations.

Through mechanical engineering, these materials are transformed into hardware. In fact, of all the engineering disciplines which feed directly into the development of rocketry, mechanical engineering is perhaps the most intrinsic one. Be it a sophisticated system like a liquid engine or a piece of hardware as simple as a fastener, its ultimate fabrication calls for expert mechanical engineers and precision machine tools. We decided to develop important technologies like welding techniques for low-alloy stainless steel, electroforming techniques, and ultra-precision process tooling. We also decided to make some important machines in-house, like the 254-litre vertical mixer and the groove machining facility for our third and fourth stages. Many of our subsystems were so massive and complex that they implied sizeable financial outlays. Without any hesitation, we approached industries in the private sector and developed contract management plans which later became blueprints for many government-run science and technology business organizations.

Coming to the life part of the SLV, there is the complex electrical circuitry, which sets the mechanical structure in motion. This vast spectrum of activities, encompassing simple electrical power supplies to sophisticated instrumentation as well as guidance and control systems is collectively referred to in aerospace research as ‘Avionics’. Development efforts in avionic systems had already been initiated at VSSC in the field of digital electronics, microwave radars and radar transponders, and inertial components and systems. It is very important to know the state of the SLV when it is in flight. SLV brought a new surge of activity in the development of a variety of transducers for measurement of physical parameters like pressure, thrust, vibration, acceleration, etc. The transducers convert the physical parameters of the vehicle into electrical signals. An on-board telemetry system processes these signals suitably and transmits them in the form of radio signals to the ground stations, where they are received and deciphered back to the original information collected by the transducers. If the systems work according to design there is little cause for concern; but in case something goes wrong, the vehicle must be destroyed to stop it from making any unexpected moves. To ensure safety, a special tele-command system was made to destroy the rocket in case it malfunctions, and an interferrometer system was developed to determine the range and position of the SLV, as a added means to the radar system. The SLV project also initiated the indigenous production of sequencers which time the various events, such as ignition, stage separation, vehicle altitude programmers which store the information for the rocket manoeuvres, and auto-pilot electronics which take appropriate decisions to steer the rocket along its predetermined path.

Without the energy to propel the whole system, a launch vehicle remains grounded. A propellant is usually a combustible substance that produces heat and supplies ejection particles in a rocket engine. It is both a source of energy and a working substance for expanding energy. Because the distinction is more decisive in rocket engines, the term propellant is used primarily to describe chemicals carried by rockets for propulsive purposes.

It is customary to classify propellants as either solids or liquids. We concentrated on solid propellants. A solid propellant consists essentially of three components: the oxidizer, the fuel and the additives. Solid propellants are further classified into two types: composite and double base. The former consists of an oxidizer or inorganic material (like ammonium perchlorate) in a matrix of organic fuel (like synthetic rubber). Double base propellants were distant dreams those days but nevertheless we dared to dream about them.

All this self sufficiency and indigenous manufacture came gradually, and not always without pain. We were a team of almost self-trained engineers. In retrospect I feel the unique blend of our untutored talent, character, and dedication suited SLV development the most. Problems surfaced regularly and almost consistently. But my team members never exhausted my patience. I recall writing after winding up a late night shift:

*Beautiful hands are those that do*
*Work that is earnest and brave and true*
*Moment by moment*
*The long day through.*

Almost parallel to our work on SLV, the DRDO was preparing itself for developing an indigenous surface-to-air missile. The RATO project was abandoned because the aircraft for which it was designed became obsolete. The new aircraft did not need RATO. With the project called off, Narayanan was DRDO's logical choice to lead the team for making the missile. Unlike us at ISRO, they preferred the philosophy of one-to-one substitution rather than technology development and performance upgrading. The Surface-to-Air Missile SA–2 of Russian origin was chosen to acquire detailed knowledge of all the design parameters of a proven missile and to establish, thereby, the necessary infrastructure required in the organization. It was thought that once one-to-one indigenization was established, further advances in the sophisticated field of guided missiles would be a natural fall-out. The project was sanctioned in February 1972 with the code name Devil and funding of about Rs. 5 crore was made available for the first three years. Almost half of it was to go in foreign exchange.

By now promoted to Air Commodore, Narayanan took over as Director, DRDL. He mobilized this young laboratory located in the south-eastern suburbs of Hyderabad to take up this enormous task. The landscape dotted with tombs and old buildings started reverberating with new life. Narayanan was a man of tremendous energy—a man always in the boost phase. He gathered around him a strong group of enthusiastic people, drawing many service officers into this predominantly civilian laboratory. Totally preoccupied with the SLV affairs, my participation in the Missile Panel meetings gradually dwindled, and then stopped altogether. However, stories about Narayanan and his Devil were beginning to reach Trivandrum. A transformation of an unprecedented scale was taking place there.

During my association with Narayanan in the RATO project, I had discovered that he was a hard taskmaster—one who went all out for control, mastery and domination. I used to wonder if managers like him, who aim at getting results no matter what the price, would face a rebellion of silence and non-cooperation in the long run.

New Year's day, 1975, brought with it an opportunity to have a first-person assessment of the work going on under Narayanan's leadership. Prof. MGK Menon, who was working then as Scientific Advisor to the Defence Minister and was head of the DRDO, appointed a review committee under the chairmanship of Dr Brahm Prakash to evaluate the work carried out in the Devil Project. I was taken into the team as a rocket specialist to evaluate the progress made in the areas of aerodynamics, structure and propulsion of the missile. On the propulsion aspects, I was assisted by BR Somasekhar and by Wg Cdr P Kamaraju. The committee members included Dr RP Shenoy and Prof. IG Sarma who were to review the work done on the electronic systems.

We met at DRDL on 1 and 2 January 1975, followed by a second session after about six weeks. We visited the various development work centres and held discussions with the scientists there. I was greatly impressed by the vision of AV Ranga Rao, the dynamism of Wg Cdr R Gopalaswami, the thoroughness of Dr I Achyuta Rao, the enterprise of G Ganesan, S Krishnan's clarity of thought and R Balakrishnan's critical eye for detail. The calm of JC Bhattacharya and Lt Col R Swaminathan in the face of immense complexities was striking. The zeal and application of Lt Col VJ Sundaram was conspicuous. They were a brilliant, committed group of people—a mix of service officers and civilian scientists—who had trained themselves in the areas of their own interest out of their driving urge to fly an Indian missile.

We had our concluding meeting towards the end of March 1975 at Trivandrum. We felt that the progress in the execution of the project was adequate in respect of hardware fabrication to carry out the philosophy of one-to-one substitution of missile subsystems except in the liquid rocket area, where some more time was required to succeed. The committee was of the unanimous opinion that DRDL had achieved the twin goals of hardware fabrication and system analysis creditably in the design and development of the ground electronics complex assigned to them.

We observed that the one-to-one substitution philosophy had taken precedence over the generation of design data. Consequently, many design engineers had not been able to pay adequate attention to the necessary analysis which was the practice followed by us at VSSC. The system analysis studies carried out up to then had also been only of a preliminary nature. In all, the results accomplished were outstanding, but we still had a long way to go. I recalled a school poem:

*Don't worry and fret, fainthearted,*
*The chances have just begun,*
*For the best jobs haven't been started,*
*The best work hasn't been done.*

The committee made a strong recommendation to the Government to give Devil a further go-ahead. Our recommendation was accepted and the project proceeded.

Back home at VSSC, SLV was taking shape. In contrast to the DRDL which was sprinting ahead, we were moving slowly. Instead of following the leader, my team was trekking towards success on several individual paths. The essence of our method of work was an emphasis on communication, particularly in the lateral direction, among the teams and within the teams. In a way, communication was my mantra for managing this gigantic project. To get the best from my team members, I spoke to them frequently on the goals and objectives of the organization, emphasizing the importance of each member's specific contribution towards the realisation of these goals. At the same time, I tried to be receptive to every constructive idea emanating from my subordinates and to relay it in an appropriate form for critical examination and implementation. I had written somewhere in my diary of that period:

*If you want to leave your footprints*
*On the sands of time*
*Do not drag your feet.*

Most of the time, communication gets confused with conversation. In fact, the two are distinctly different. I was (and am) a terrible conversationalist but consider myself a good communicator. A conversation full of pleasantries is most often devoid of any useful information, whereas communication is meant only for the exchange of information. It is very important to realise that communication is a two-party affair which aims at passing on or receiving a specific piece of information.

While working on the SLV, I used communication to promote understanding and to come to an agreement with colleagues in defining the problems that existed and in identifying the action necessary to be taken to solve them. Authentic communication was one of the tools skilfully used in managing the project. How did I do that ? To begin with, I tried to be factual and never sugar-coated the bitter pill of facts. At one of the Space Science Council (SSC) review meetings, frustrated by the procurement delays, I erupted into an agitated complaint against the indifference and red-tape tactics of the controller of accounts and financial advisor of VSSC. I insisted that the systems of work followed by the accounts staff had to change and demanded the delegation of their functions to the project team. Dr Brahm Prakash was taken aback by the bluntness of my submission. He stubbed out his cigarette and walked out of the meeting.

I spent the whole night regretting the pain my harsh words had caused Dr Brahm Prakash. However, I was determined to fight the inertia built into the system before I found myself being dragged down with it. I asked myself a practical question: could one live with these insensitive bureaucrats? The answer was a big no. Then I asked myself a private question: what would hurt Dr Brahm Prakash more, my seemingly harsh words now, or the burial of the SLV at a later stage? Finding my head and heart agreeing, I prayed to God for help. Fortunately for me, Dr Brahm Prakash delegated financial powers to the project the next morning.

Anyone who has taken up the responsibility to lead a team can be successful only if he is sufficiently independent, powerful and influential in his own right to become a person to reckon with. This is perhaps also the path to individual satisfaction in life, for freedom with responsibility is the only sound basis for personal happiness. What can one do to strengthen personal freedom? I would like to share with you two techniques I adopt in this regard.

First, by building your own education and skills. Knowledge is a tangible asset, quite often the most important tool in your work. The more up-to-date the knowledge you possess, the freer you are. Knowledge cannot be taken away from anyone except by obsolescence. A leader can only be free to lead his team if he keeps abreast of all that is happening around him—in real time. To lead, in a way, is to engage in continuing education. In many countries, it is normal for professionals to go to college several nights every week. To be a successful team leader, one has to stay back after the din and clutter of a working day to emerge better-equipped and ready to face a new day.

The second way is to develop a passion for personal responsibility. The sovereign way to personal freedom is to help determine the forces that determine you. Be active! Take on responsibility! Work for the things you believe in. If you do not, you are surrendering your fate to others. The historian Edith Hamilton wrote of ancient Greece, “When the freedom they wished for most was freedom from responsibility, then Athens ceased to be free and was never free again”. The truth is that there is a great deal that most of us can individually do to increase our freedom. We can combat the forces that threaten to oppress us. We can fortify ourselves with the qualities and conditions that promote individual freedom. In doing so, we help to create a stronger organization, capable of achieving unprecedented goals.

As work on the SLV gained momentum, Prof. Dhawan introduced the system of reviewing progress with the entire team involved in the project. Prof. Dhawan was a man with a mission. He would effortlessly pull together all the loose ends to make work move smoothly. At VSSC the review meetings presided over by Prof. Dhawan used to be considered major events. He was a true captain of the ISRO ship—a commander, navigator, housekeeper, all rolled into one. Yet, he never pretended to know more than he did. Instead, when something appeared ambiguous, he would ask questions and discuss his doubts frankly. I remember him as a leader for whom to lead with a firm, but fair hand, was a moral compulsion. His mind used to be very firm once it had been decided on any issue. But before taking a decision, it used to be like clay, open to impressions until the final moulding. Then the decisions would be popped into the potter’s oven for glazing, never failing to emerge hard and tough, resistant and enduring.

I had the privilege of spending a great deal of time with Prof. Dhawan. He could hold the listener enthralled because of the logical, intellectual acumen he could bring to bear on his analysis of any subject. He had an unusual combination of degrees—a B.Sc. in Mathematics and Physics, an M.A. in English Literature, B.E. in Mechanical Engineering, M.S. in Aeronautical Engineering followed by a Ph.D. in Aeronautics and Mathematics from the California Institute of Technology (Caltech) in USA.

Intellectual debates with him were very stimulating and could always mentally energize me and my team members. I found him full of optimism and compassion. Although he often judged himself harshly, with no allowances or excuses, he was generous to a fault when it came to others. Prof. Dhawan used to sternly pronounce his judgements and then pardon the contrite guilty parties.

In 1975, ISRO became a government body. An ISRO council was formed consisting of Directors of different work centres and senior officers in the Department of Space (DoS). This provided a symbolic link as well as a forum for participative management between the DoS which had the Governmental powers and the centres which would execute the jobs. In the traditional parlance of Government departments, ISRO's centres would have been subordinate units or attached offices, but such words were never spoken either at ISRO or DoS. Participative management, which calls for active interaction between those who wield administrative powers and the executing agencies, was a novel feature of ISRO management that would go a long way in Indian R&D organizations.

The new set-up brought me in contact with TN Seshan, the Joint Secretary in the DoS. Till then, I had a latent reservation about bureaucrats, so I was not very comfortable when I first saw Seshan participating in a SLV-3 Management Board meeting. But soon, it changed to admiration for Seshan, who would meticulously go through the agenda and always come for the meetings prepared. He used to kindle the minds of scientists with his tremendous analytical capability.

The first three years of the SLV project was the period for the revelation of many fascinating mysteries of science. Being human, ignorance has always been with us, and always will be. What was new was my awareness of it, my awakening to its fathomless dimensions. I used to erroneously suppose that the function of science was to explain everything, and that unexplained phenomena were the province of people like my father and Lakshmana Sastry. However, I always refrained from discussing these matters with any of my scientist colleagues, fearing that it would threaten the hegemony of their meticulously formed views.

Gradually, I became aware of the difference between science and technology, between research and development. Science is inherently open-ended and exploratory. Development is a closed loop. Mistakes are imperative in development and are made every day, but each mistake is used for modification, upgradation or betterment. Probably, the Creator created engineers to make scientists achieve more. For each time scientists come up with a thoroughly researched and fully comprehended solution, engineers show them yet another lumineu, yet one more possibility. I cautioned my team against becoming scientists. Science is a passion—a never-ending voyage into promises and possibilities. We had only limited time and limited funds. Our making the SLV depended upon our awareness of our own limits. I preferred existing workable solutions which would be the best options. Nothing that is new comes into time-bound projects without its own problems. In my opinion, a project leader should always work with proven technologies in most of the systems as far as possible and experiment only from multiple resources.

* * *

# 8

# Expedients

The SLV-3 project had been formulated in such a way that the major technology work centres, both at VSSC and at SHAR could handle propellant production, rocket motor testing and launch of any large diameter rocket. As participants in the SLV-3 project, we set three milestones for ourselves: development and flight qualification of all subsystems through sounding rockets by 1975; sub-orbital flights by 1976; and the final orbital flight in 1978. The work tempo had picked up now and the atmosphere was charged with excitement. Wherever I went, our teams had something interesting to show me. A large number of things were being done for the first time in the country and the ground-level technicians had had no prior exposure to this kind of work. I saw new performance dimensions growing among my team members.

Performance dimensions are factors that lead to creation. They go beyond competencies such as the skills and knowledge of the individual. Performance dimensions are broader and deeper than what a person must know and be able to do in order to function well in his or her job. They include attitudes, values and character traits. They exist at various levels of the human personality. At the behavioural level—at the outermost ring of the tree—we can observe skills and measure knowledge. Social roles and self-image dimensions are found at the intermediate level. Motives and traits exist at the innermost or core level. If we can identify those performance dimensions which are most highly correlated with





job success, we can put them together to form a blueprint for outstanding performance in both thought and action.

Although SLV-3 was still in the future, its subsystems were being completed. In June 1974, we used the Centaur sounding rocket launch to test some of our critical systems. A scaled down heat shield of SLV, Rate Gyro Unit, and Vehicle Attitude Programmer were integrated into the Centaur rocket. The three systems involved wide-ranging expertise—composite materials, control engineering and software, none of them ever having been tried before in the country. 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. For the first time, we inspired the confidence of the nation. Prime Minister Indira Gandhi told Parliament on 24 July 1974, “The development and fabrication of relevant technologies, subsystems and hardware (to make 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.”

Like any other act of creation, the creation of the SLV-3 also had its painful moments. One day, when my team and I were totally engrossed in the preparation of the static test of the first stage motor, the news of a death in the family reached me. My brother-in-law and mentor Jenab Ahmed Jallaludin, was no more. For a couple of minutes, I was immobilized, I could not think, could not feel anything. When I could focus on my surroundings once more and attempted to participate in the work, I found myself talking incoherently—and then I realised that, with Jallaluddin, a part of me had passed away too. A vision of my childhood reappeared before me—evening walks around the Rameswaram temple, shining sand and dancing tides in the moonlight, stars looking down from an unlit sky on a new moon night, Jallaluddin showing me the horizon sinking into the sea, arranging money for my books, and seeing me off at Santa Cruz airport. I felt that I had been thrown into a whirlpool of time and space. My father, by now more than a hundred years old, pall-bearer for his son-in-law, who had been half his age; the bereft soul of my sister Zohara, her wounds from the loss of her four-year-old son still raw—these images came before my eyes in a blur, too terrible for me to comprehend. I leaned on the assembly jig, composed myself and left a few instructions with Dr S Srinivasan, Deputy Project Director, to carry on with the work in my absence.

Travelling overnight in a combination of district buses, I reached Rameswaram only the next day. During this time, I did my best to free myself from the very past which appeared to have come to an end with Jallaluddin. But the moment I reached my house, grief assailed me afresh. I had no words for Zohara or for my niece Mehboob, both of whom were crying uncontrollably. I had no tears to shed. We sorrowfully put Jallaluddin's body to rest.

My father held my hands for a long time. There were no tears in his eyes either. "Do you not see, Abul, how the Lord lengthens the shadows? Had it been His will, He could have made them constant. But He makes the sun their guide, little by little He shortens them. It is He who has made the night a mantle for you, and sleep a rest. Jallaluddin has gone into a long sleep—a dreamless sleep, a complete rest of all his being within simple unconsciousness. Nothing will befall us except what Allah has ordained. He is our Guardian. In Allah, my son, put your trust." He slowly closed his wrinkled eyelids and went into a trance-like state.

Death has never frightened me. After all, everyone has to go one day. But perhaps Jallaluddin went a little too early, a little too soon. I could not bring myself to stay for long at home. I felt the whole of my inner self drowning in a sort of anxious agitation, and inner conflicts between my personal and my professional life. For many days, back in Thumba, I felt a sense of futility I had never known before—about everything I was doing.

I had long talks with Prof. Dhawan. He told me that my progress on the SLV project would bring me solace. The confusion would first lessen and would later pass away altogether. He drew my attention to the wonders of technology and its achievements.

Gradually, the hardware began emerging from the drawing boards. Sasi Kumar built a very effective network of fabrication work centres. Within days of getting a component drawing, he would embark on the fabrication with what was available. Namboodiri and Pillai were spending their days and nights at the propulsion laboratory developing four rocket motors simultaneously. MSR Dev and Sandlas drew up meticulous plans for mechanical and electrical integration of the vehicle. Madhavan Nair and Murthy examined the systems developed by the VSSC electronics laboratories and engineered them into flight sub- systems wherever it was possible. US Singh brought up the first launch ground system, comprising of telemetry, tele-command, and radar. He also chalked out a detailed work plan with SHAR for the flight trials. Dr Sundararajan closely monitored mission objectives and concurrently updated the systems. Dr Srinivasan, a competent launch vehicle designer, discharged all my complementary and supplementary functions as the SLV deputy project director. He noticed what I had overlooked, heard the points I failed to listen to, and suggested possibilities that I had not so much as visualized.

We learned the hard way that the biggest problem of project management is to achieve a regular and efficient interfacing between the different individuals and work centres. Hard work can be set at nought in the absence of proper coordination.

I had the fortune of having YS Rajan from the ISRO headquarters as my friend in those times. Rajan was (and is) a universal friend. His friendship embraced with equal warmth turners, fitters, electricians and drivers as well as scientists, engineers, contractors and bureaucrats. Today when the press calls me a 'welder of people', I attribute this to Rajan. His close interaction with different work centres created such a harmony in SLV affairs that the fine threads of individual efforts were woven into a mighty fabric of great strength.

In 1976, my father passed away. He had been in poor health for quite some time due to his advanced age. The death of Jallaluddin had also taken a toll on his health and spirit. He had lost his desire to live, as though after seeing Jallaluddin return to his divine source, he too had become eager to return to his.

Whenever I learnt about my father's indifferent health, I would visit Rameswaram with a good city doctor. Every time I did so, he would chide me for my unnecessary concern and lecture me on the expenses incurred on the doctor. "Your visit is enough for me to get well, why bring a doctor and spend money on his fees?" he would ask. This time he had gone beyond the capabilities of any doctor, care or money. My father Jainulabdeen, who had lived on Rameswaram island for 102 years, had passed away leaving behind fifteen grandchildren and one great-grandson. He had led an exemplary life. Sitting alone, on the night after the burial, I remembered a poem written on the death of Yeats by his friend Auden, and felt as if it was written for my father:

*Earth, receive an honoured guest;*
*William Yeats is laid to rest:*
. . . . . . . . . . . . . . . . . . .
*In the prison of his daysTeach the*
*free man how to praise.*

In worldly terms, it was the death of just another old man. No public mourning was organized, no flags were lowered to half-mast, no newspaper carried an obituary for him. He was not a politician, a scholar, or a businessman. He was a plain and transparent man. My father pursued the supreme value, the Good. His life inspired the growth of all that was benign and angelic, wise and noble.

My father had always reminded me of the legendary Abou Ben Adhem who, waking one night from a deep dream of peace, saw an angel writing in a book of gold the names of those who love the Lord. Abou asked the Angel if his own name was on the list. The Angel replied in the negative. Disappointed but still cheerful, Abou said, "Write my name down as one that loves his fellowmen". The angel wrote, and vanished. The next night, it came again with a great wakening light, and showed the names of those whom the love of God had blessed. And Abou's name was the first on the list.

I sat for a long time with my mother, but could not speak. She blessed me in a choked voice when I took leave of her to return to Thumba. She knew that she was not to leave the house of her husband, of which she was the custodian, and I was not to live with her there. Both of us had to live out our own destinies. Was I too stubborn or was I excessively preoccupied with the SLV? Should I not have forgotten for a while my





own affairs in order to listen to her? I regretfully realised this only when she passed away soon afterwards.

The SLV-3 Apogee rocket, developed as a common upper stage with Diamont, scheduled to be flight tested in France was mired in a series of knotty problems. I had to rush to France to sort them out. Before I could depart, late in the afternoon, I was informed that my mother had passed away. I took the first available bus to Nagarcoil. From there, I travelled to Rameswaram spending a whole night in the train and performed the last rites the next morning. Both the people who had formed me had left for their heavenly abode. The departed had reached the end of their journey. The rest of us had to continue walking the weary road and life had to go on. I prayed in the mosque my father had once taken me to every evening. I told Him that my mother could not have lived longer in the world without the care and love of her husband, and therefore had preferred to join him. I begged His forgiveness. "They carried out the task I designed for them with great care, dedication and honesty and came back to me. Why are you mourning their day of accomplishment? Concentrate on the assignments that lie before you, and proclaim my glory through your deeds!" Nobody had said these words, but I heard them loud and clear. An inspiring aphorism in the Qur'an on the passing away of souls filled my mind: "Your wealth and children are only a temptation whereas: Allah! with Him is an eternal award." I came out of the mosque with my mind at peace and proceeded to the railway station. I always remember that when the call for namaz sounded, our home would transform into a small mosque. My father and my mother leading, and their children and grandchildren following.

The next morning I was back at Thumba, physically exhausted, emotionally shattered, but determined to fulfill our ambition of flying an Indian rocket motor on foreign soil.

On my return from France, after successfully testing the SLV-3 apogee motor, Dr Brahm Prakash informed me one day about the arrival of Wernher von Braun. Everybody working in rocketry knows of von Braun, who made the lethal V-2 missiles that devastated London in the Second World War. In the final stages of the War, von Braun was captured by the Allied Forces. As a tribute to his genius, von Braun was given a top position in the rocketry programme at NASA. Working for the US Army, von Braun produced the landmark Jupiter missile, which was the first IRBM with a 3000 km range. When I was asked by Dr Brahm Prakash to receive von Braun at Madras and escort him to Thumba, I was naturally excited.

The V-2 missile (an abbreviation of the German word Vergeltungswaffe) was by far the greatest single achievement in the history of rockets and missiles. It was the culmination of the efforts made by von Braun and his team in the VFR (Society for Space Flight) in the 1920s. What had begun as a civilian effort soon became an official army one, and von Braun became the technical director of the German Missile Laboratory at Kummersdorf. The first V-2 missile was first tested unsuccessfully in June 1942. It toppled over on to its side and exploded. But on 16 August 1942, it became the first missile to exceed the speed of sound. Under the supervision of von Braun, more than 10,000 V-2 missiles were produced between April and October 1944 at the gigantic underground production unit near Nordhausen in Germany. That I would be travelling with this man—a scientist, a designer, a production engineer, an administrator, a technology manager all rolled into one—what more could I have asked for?

We flew in an Avro aircraft which took around ninety minutes from Madras to Trivandrum. von Braun asked me about our work and listened as if he was just another student of rocketry. I never expected the father of modern rocketry to be so humble, receptive and encouraging. He made me feel comfortable right through the flight. It was hard to imagine that I was talking to a giant of missile systems, as he was so self-effacing.

He observed that the length to diameter L/D ratio of the SLV-3, which was designed to be 22 was on the higher side and cautioned me about the aero-elastic problems which must be avoided during flight.

Having spent the major part of his working life in Germany, how did he feel in America? I asked this of von Braun who had become a cult figure in the States after creating the Saturn rocket in the Apollo mission which put man on the moon. “America is a country of great possibilities, but they look upon everything un-American with suspicion and contempt. They suffer from a deep-rooted NIH—Not Invented Here—complex and look down on alien technologies. If you want to do anything in rocketry, do it yourself,” von Braun advised me. He commented, “SLV-3 is a genuine Indian design and you may be having your own troubles. But you should always remember that we don’t just build on successes, we also build on failures.”

On the topic of the inevitable hard work that goes with rocket development and the degree of commitment involved, he smiled and said with a glint of mischief in his eyes, “Hard work is not enough in rocketry. It is not a sport where mere hard work can fetch you honours. Here, not only do you have to have a goal but you have to have strategies to achieve it as fast as possible.”

“Total commitment is not just hard work, it is total involvement. Building a rock wall is back-breaking work. There are some people who build rock walls all their lives. And when they die, there are miles of walls, mute testimonials to how hard those people had worked.”

He continued, “But there are other men who while placing one rock on top of another have a vision in their minds, a goal. It may be a terrace with roses climbing over the rock walls and chairs set out for lazy summer days. Or the rock wall may enclose an apple orchard or mark a boundary. When they finish, they have more than a wall. It is the goal that makes the difference. Do not make rocketry your profession, your livelihood—make it your religion, your mission.” Did I see something of Prof. Vikram Sarabhai in von Braun? It made me happy to think so.

With three deaths in the family in as many successive years, I needed total commitment to my work in order to keep performing. I wanted to throw all my being into the creation of the SLV. I felt as if I had discovered the path I was meant to follow, God’s mission for me and my purpose on His earth. During this period, it was as though I had pushed a hold button—no badminton in the evenings, no more weekends or holidays, no family, no relations, not even any friends outside the SLV circle.

To succeed in your mission, you must have single-minded devotion to your goal. Individuals like myself are often called ‘workaholics’. I question this term because that implies a pathological condition or an illness. If I do that which I desire more than anything else in the world and which makes me happy, such work can never be an aberration. Words from the twenty-sixth Psalm come to mind while I work: “Examine me, O Lord, and prove me.”

Total commitment is a crucial quality for those who want to reach the very top of their profession. The desire to work at optimum capacity leaves hardly any room for anything else. I have had people with me who would scoff at the 40-hours-a-week job they were being paid for. I have known others who used to work 60, 80 and even 100 hours a week because they found their work exciting and rewarding. Total commitment is the common denominator among all successful men and women. Are you able to manage the stresses you encounter in your life? The difference between an energetic and a confused person is the difference in the way their minds handle their experiences. Man needs his difficulties because they are necessary to enjoy success. All of us carry some sort of a super-intelligence within us. Let it be stimulated to enable us to examine our deepest thoughts, desires, and beliefs.

Once you have done this—charged yourself, as it were, with your commitment to your work—you also need good health and boundless energy. Climbing to the top demands strength, whether to the top of Mount Everest or to the top of your career. People are born with different energy reserves and the one who tires first and burns out easily will do well to reorganize his or her life at the earliest.

In 1979, a six-member team was preparing the flight version of a complex second stage control system for static test and evaluation. The team was in countdown mode at T-15 minutes (15 minutes before the test). One of the twelve valves did not respond during checkout. Anxiety drove the members of the team to the test site to look into the problem. Suddenly the oxidizer tank, filled with red fuming nitric acid (RFNA), burst, causing severe acid burns to the team members. It was a very traumatic experience to see the suffering of the injured. Kurup and I rushed to the Trivandrum Medical College Hospital and begged to have our colleagues admitted, as six beds were not available in the hospital at that point of time.

Sivaramakrishnan Nair was one among the six persons injured. The acid had burned his body at a number of places. By the time we got a bed in the hospital, he was in severe pain. I kept vigil at his bedside. Around 3 o’ clock in the morning, Sivarama-krishnan regained consciousness. His first words expressed regret over the mishap and assured me that he would make up the slippage in schedules caused by the accident. His sincerity and optimism, even in the midst of such severe pain, impressed me deeply.

Men like Sivaramakrishnan are a breed apart. They are the strivers, always reaching higher than the last time. And with their social and family life welded to their dream, they find the rewards of their drive overwhelming—the inherent joy of being in flow. This event greatly enhanced my confidence in my team; a team that would stand like a rock in success and failure.

I have used the word ‘flow’ at many places without really elaborating its meaning. What is this flow? And what are these joys? I could call them moments of magic. I see an analogy between these moments and the high that you experience when you play badminton or go jogging. Flow is a sensation we experience when we act with total involvement. During flow, action follows action according to an internal logic that seems to need no conscious intervention on the part of the worker. There is no hurry; there are no distracting demands on one’s attention. The past and the future disappear. So does the distinction between self and the activity. We had all come under the current of the SLV flow. Although we were working very hard we were very relaxed, energetic and fresh. How did it happen? Who had created this flow?

Perhaps it was the meaningful organization of the purposes we sought to achieve. We would identify the broadest possible purpose level and then work towards developing a feasible target solution from a variety of alternatives. It was this working backwards to develop a creative change in the problem solution, that used to put us in ‘flow’.

When the SLV-3 hardware started emerging, our ability to concentrate increased markedly. I felt a tremendous surge of confidence; in complete control over myself and over the SLV-3 project. Flow is a by-product of controlled creativity. The first requirement is to work as hard as you can at something that presents a challenge and is approved by your heart. It may not be an overwhelming challenge, but one that stretches you a little, something that makes you realise that you are performing a task better today than you did yesterday, or the last time you tried to do it. Another prerequisite for being in flow is the availability of a significant span of uninterrupted time. In my experience, it is difficult to switch into the flow state in less than half an hour. And it is almost impossible if you are bedevilled by interruptions.

Is it possible to switch yourself into flow by using some sort of a conditioning device in much the same way that we condition ourselves to learn effectively? The answer is yes, and the secret is to analyse previous occasions when you have been in flow, because each person has his or her unique natural frequency which responds to a particular stimulus. You alone can identify the common denominator in your case. Once you have isolated this common denominator, you can set the stage for flow.

I have experienced this state many times, almost every day of the SLV mission. There have been days in the laboratory when I have looked up to find the laboratory empty and realised that it was way past the quitting time. On other days, my team members and I have been so caught up in our work that the lunch hour slipped by without our even being conscious that we were hungry.

Analysing such occasions in retrospect, I find them similar in the sense that this flow was experienced when the project was nearing completion, or when the project had reached that phase when all the necessary data had been gathered and we were ready to start summing up the problem, outlining the demands made by conflicting criteria and the various positions presented by opposing interests and making our recommendations for action. I also realised that this tended to happen on days that were relatively quiet in the office, with no crises or meetings. Such spells increased steadily in frequency, and the SLV-3 dream was finally realised in the middle of 1979.





We had scheduled the first experimental flight trial of SLV-3 for 10 August 1979. The primary goals of the mission were to realise a fully integrated launch vehicle; to evaluate on-board systems like stage motors, guidance and control systems and electronic subsystems; and to evaluate ground systems, like checkout, tracking, telemetry and real-time data facilities in launch operations built at the Sriharikota launch complex. The 23 metre-long, four-stage SLV rocket weighing 17 tonnes finally took off elegantly at 0758 hours and immediately started following its programmed trajectory.

Stage I performed to perfection. There was a smooth transition from this stage to the second stage. We were spellbound to see our hopes flying in the form of the SLV-3. 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 km off Sriharikota.

The incident caused us profound disappointment. I felt a strange mix of anger and frustration. Suddenly, I felt my legs become so stiff that they ached. The problem was not with my body; something was happening in my mind.

The premature death of my hovercraft Nandi, the abandoning of the RATO, the abortion of the SLV-Diamont fourth stage—all came alive in a flash, like a long-buried Phoenix rising from its ashes. Over the years, I had somehow learned to absorb these aborted endeavours, had come to terms with them and pursued fresh dreams. That day, I re-lived each of those setbacks in my deep despondency.

“What do you suppose could be the cause of it?” somebody asked me in the Block House. I tried to find an answer, but I was too tired to try and think it out, and gave up the effort as futile. The launch was conducted in the early morning, preceded by a full night’s count-down. Moreover, I had hardly had any sleep in the past week. Completely drained—mentally as well as physically—I went straight to my room and slumped onto the bed.

A gentle touch on my shoulder woke me up. It was late in the afternoon, almost approaching evening. I saw Dr Brahm Prakash sitting by my bedside. “What about going for lunch?” he asked. I was deeply touched by his affection and concern. I found out later that Dr Brahm Prakash had come to my room twice before that but had gone away on finding me asleep. He had waited all that time for me to get up and have lunch with him. I was sad, but not alone. The company of Dr Brahm Prakash filled me with a new confidence. He made light conversation during the meal, carefully avoiding the SLV-3, but gently providing me solace.

* * *





# 9

# Builders

Dr Brahm Prakash helped me endure this difficult period. In practice, Dr Brahm Prakash employed the front-line damage control principle: “Just get the fellow home alive. He’ll recover.” He drew the entire SLV team close and demonstrated to me that I was not alone in my sorrow at the SLV-3’s failure. “All your comrades are standing by you,” he said. This gave me vital emotional support, encouragement, and guidance.

A post-flight review conducted on 11 August 1979 was attended by more than seventy scientists. A detailed technical appraisal of the failure was completed. Later, the post-flight analysis committee headed by SK Athithan pinpointed the reasons for the malfunction of the vehicle. It was 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 Red Fuming Nitric Acid (RFNA) used as the oxidizer for the fuel power at that stage. Consequently, when the control force was demanded, only fuel was injected resulting in zero force. ‘A solenoid valve in the oxidizer tank remaining open due to contamination after the first command at T-8 minutes', was identified as the reason for the draining of RFNA.

The findings were presented to Prof. Dhawan at a meeting of top ISRO scientists and were accepted. Everybody was convinced by the technical cause-and-effect sequence presented and there was a general feeling of satisfaction about the whole exercise of failure-management measures taken. I was still unconvinced though and felt restless. To me, the level of responsibility is measured by one's ability to confront the decision-making process without any delay or distraction.

On the spur of the moment, I stood up and addressed Prof. Dhawan, "Sir, even though my friends have technically justified the failure, I take the responsibility for judging the RFNA leak detected during the final phase of countdown as insignificant. As a Mission Director, I should have put the launch on hold and saved the flight if possible. In a similar situation abroad, the Mission Director would have lost his job. I therefore take responsibility for the SLV-3 failure." For quite some time there was pin-drop silence in the hall. Then Prof. Dhawan got up and said, "I am going to put Kalam in orbit!", and left the place signalling that the meeting was over.

The pursuit of science is a combination of great elation and great despair. I went over many such episodes in my mind. Johannes Kepler, whose three orbital laws form the basis of space research, took nearly 17 years after formulating the two laws about planetary motion around the sun, to enunciate his third law which gives the relation between the size of the elliptical orbit and the length of time it takes for the planet to go around the sun. How many failures and frustrations must he have gone through? The idea that man could land on the moon, developed by the Russian mathematician Konstantin Tsiolkovsky, was realised after nearly four decades—and by the United States, at that. Prof. Chandrasekhar had to wait nearly 50 years before receiving the Nobel Prize for his discovery of the 'Chandrasekhar Limit', a discovery made while he was a graduate student at Cambridge in the 1930s. If his work had been recognized then, it could have led to the discovery of the Black Hole decades earlier. How many failures must von Braun have gone through before his Saturn launch vehicle put man on the moon? These thoughts helped to give me the ability to withstand apparently irreversible setbacks.

Early in November 1979, Dr Brahm Prakash retired. He had always been my sheet-anchor in the turbulent waters of VSSC. His belief in team spirit had inspired the management pattern for the SLV project, which later became a blueprint for all scientific projects in the country. Dr Brahm Prakash was a very wise counsellor who gave me valuable guidance whenever I deviated from my mission objectives.

Dr Brahm Prakash not only reinforced the traits which I had acquired from Prof. Sarabhai, but also helped me give them new dimensions. He always cautioned me against haste. "Big scientific projects are like mountains, which should be climbed with as little effort as possible and without urgency. The reality of your own nature should determine your speed. If you become restless, speed up. If you become tense and high-strung, slow down. You should climb the mountain in a state of equilibrium. When each task of your project is not just a means to an end but a unique event in itself, then you are doing it well," he would tell me. The echo of Dr Brahm Prakash's advice could be heard in Emerson's poem on Brahma:

*If the red slayer think he slays,*
*Or, if the slain think he is slain,*
*They know not well, the subtle ways*
*I keep, and pass, and turn again.*

To live only for some unknown future is superficial. It is like climbing a mountain to reach the peak without experiencing its sides. The sides of the mountain sustain life, not the peak. This is where things grow, experience is gained, and technologies are mastered. The importance of the peak lies only in the fact that it defines the sides. So I went on towards the top, but always experiencing the sides. I had a long way to go but I was in no hurry. I went in little steps—just one step after another—but each step towards the top.

At every stage, the SLV-3 team was blessed with some extraordinarily courageous people. Along with Sudhakar and Sivaramakrishnan, there was also Sivakaminathan. He was entrusted with bringing the C-Band transponder from Trivandrum to SHAR for integration with the SLV-3. The transponder is a device fitted with the rocket system to give the radar signals which are powerful enough to help it track the vehicle from the take-off site to the final impact point. The SLV-3 launch schedule was dependent on the arrival and integration of this equipment. On landing at the Madras airport, the aircraft which Sivakami was travelling in skidded and overshot the runway. Dense smoke engulfed the aircraft. Everyone jumped out of the aircraft through emergency exits, and desperately fought to save themselves—all except Sivakami, who stayed in the aircraft till he removed the transponder from his baggage. He was among the last few persons, the others being mostly aircraft crew, to emerge from the smoke and he was hugging the transponder close to his chest.

Another incident from those days that I recall clearly relates to Prof. Dhawan's visit to the SLV-3 assembly building. Prof. Dhawan, Madhavan Nair and I were discussing some finer aspects of the SLV-3 integration. The vehicle was kept on the launcher in a horizontal position. When we were moving around and examining the readiness of the integrated hardware, I noticed the presence of big water-ports for extinguishing fire in case of an accident. For some reason, I felt uncomfortable at the sight of the ports facing the SLV-3 on the launcher. I suggested to Madhavan Nair that we could rotate the port so that they were apart by a full 180o. This would prevent the freak possibility of water gushing out and damaging the rocket. To our surprise, within minutes of Madhavan Nair getting the ports reversed, powerful water jets gushed out of the ports. The Vehicle Safety Officer had ensured the functioning of the fire-fighting system without realising that it could have wrecked the entire rocket. This was a lesson in foresight. Or did we have divine protection?

On 17 July 1980, 30 hours before the launch of the second SLV-3, the newspapers were filled with all kinds of predictions. One of the newspapers reported, "The Project Director is missing and could not be contacted." Many reports preferred to trace the history of the first SLV-3 flight, and recalled how the third stage had failed to ignite because of lack of fuel and the rocket had nosedived into the ocean. Some highlighted SLV-3's possible military implications in terms of acquiring the capability for building IRBMs. Some were a general prognosis of all that ailed our country and related it to the SLV-3. I knew that the next day's launch was going to decide the future of the Indian space programme. In fact, to put it simply, the eyes of the whole nation were on us.

In the early hours of the next day, 18 July 1980—at 0803 hrs to be precise, India's first Satellite Launch Vehicle, SLV-3 lifted off from SHAR. At 600 seconds before 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. Within the next two minutes, Rohini was set into motion in a low earth orbit. I spoke, in the midst of screeching decibels, the most important words I had ever uttered in my life, "Mission Director calling all stations. Stand by for an important announcement. All stages performed to mission requirements. The fourth stage apogee motor has given the required velocity to put Rohini Satellite into orbit". There were happy cries everywhere. When I came out of the Block House, I was lifted onto the shoulders of my jubilant colleagues and carried in a procession.

The whole nation was excited. India had made its entry into the small group of nations which possessed satellite launch capability. Newspapers carried news of the event in their headlines. Radio and television stations aired special programmes. Parliament greeted the achievement with the thumping of desks. It was both the culmination of a national dream, and the beginning of a very important phase in our nation's history. Prof. Satish Dhawan, Chairman ISRO, threw his customary guardedness to the winds and announced that it was now well within our ability to explore space. Prime Minister Indira Gandhi cabled her congratulations. But the most important reaction was that of the Indian scientific community—everybody was proud of this hundred per cent indigenous effort.

I experienced mixed feelings. I was happy to achieve the success which had been evading me for the past two decades, but I was sad because the people who had inspired me were no longer there to share my joy—my father, my brother-in-law Jallaluddin, and Prof. Sarabhai.

The credit for the successful SLV-3 flight goes, first, to the giants of the Indian space programme, Prof. Sarabhai in particular, who had preceded this effort; next to the hundreds of VSSC personnel who had through sheer will-power proved the mettle of our countrymen and also, not least, to Prof. Dhawan and Dr Brahm Prakash, who had led the project.

We had a late dinner that evening. Gradually, the din and clatter of the celebrations calmed down. I retired to my bed with almost no energy left. Through the open window, I could see the moon among the clouds. The sea breeze seemed to reflect the buoyancy of the mood on Sriharikota island that day.

Within a month of the SLV-3 success, I visited the Nehru Science Centre in Bombay for a day, in response to an invitation to share my experiences with the SLV-3. There, I received a telephone call from Prof. Dhawan in Delhi, asking me to join him the next morning. We were to meet the Prime Minister, Mrs Indira Gandhi. My hosts at the Nehru Centre were kind enough to arrange my ticket to Delhi, but I had a small problem. It had to do with my clothes. I was dressed casually as is my wont and wearing slippers—not, by any standards of etiquette, suitable attire in which to meet the Prime Minister! When I told Prof. Dhawan about this problem, he told me not to worry about my dress. “You are beautifully clothed in your success,” he quipped.

Prof. Dhawan and I arrived at the Parliament House Annexe the next morning. A meeting of the Parliamentary Panel on Science & Technology chaired by the Prime Minister was scheduled. There were about 30 Members of the Lok Sabha and Rajya Sabha in the room, which was lit by a majestic chandelier. Prof. MGK Menon and Dr Nag Chaudhuri were also present. Shrimati Gandhi spoke to the Members about the success of the SLV-3 and lauded our achievement. Prof. Dhawan thanked the gathering for the encouragement given by them to space research in the country and expressed the gratitude of the ISRO scientists and engineers. Suddenly, I saw Shrimati Gandhi smiling at me as she said, “Kalam! We would like to hear you speak.” I was surprised by the request as Prof. Dhawan had already addressed the gathering.

Hesitantly, I rose and responded, “I am indeed honoured to be in this great gathering of nation-builders. I only know how to build a rocket system in our country, which would inject a satellite, built in our country, by imparting to it a velocity of 25,000 km per hour.” There was thunderous applause. I thanked the members for giving us an opportunity to work on a project like the SLV-3 and prove the scientific strength of our country. The entire room was irradiated with happiness.

Now that Project SLV-3 had been successfully completed, VSSC had to re-organize its resources and redefine its goals. I wanted to be relieved of the project activities, and consequently Ved Prakash Sandlas from my team was made the Project Director for the SLV-3 Continuation Project, which aimed at making operational satellite launch vehicles of a similar class. With a view to upgrade the SLV-3 by means of certain technological innovations, the development of Augmented Satellite Launch Vehicles (ASLVs) had been on the cards for some time. The aim was to enhance the SLV-3 payload capability from 40 kg to 150 kg. MSR Dev from my team was appointed Project Director ASLV. Then, to reach the sun-synchronous orbit (900 km), a PSLV was to be made. The Geo Satellite Launch Vehicle (GSLV) was also envisaged, though as a distant dream. I took up the position of Director, Aerospace Dynamics and Design Group, so that I could configure the forthcoming launch vehicles and technology development.

The existing VSSC infrastructure was inadequate to handle the size and weight of the future launch vehicle systems and the implementation of all these projects was going to require highly specialized facilities. New sites were identified for the expanded activities of VSSC, at Vattiyoorkavu and Valiamala. Dr Srinivasan drew up a detailed plan of the facilities. Meanwhile, I carried out an analysis of the application of SLV-3 and its variants with Sivathanu Pillai, and compared the existing launch vehicles of the world for missile applications. We established that the SLV-3 solid rocket systems would meet the national requirements of payload delivery vehicles for short and intermediate ranges (4000 km). We contended that the development of one additional solid booster of 1.8 m diameter with 36 tonnes of propellant along with SLV-3 subsystems would meet the ICBM requirement (above 5000 km for a

1000 kg payload). This proposal was, however, never considered. It nevertheless paved the way for the formulation of the Re-entry Experiment (REX) which, much later on, became Agni.

The next SLV-3 flight, SLV3-D1, took off on 31 May 1981. I witnessed this flight from the visitors' gallery. This was the first time I witnessed a launch from outside the Control Centre. The unpalatable truth I had to face was that by becoming the focus of media attention, I had aroused envy among some of my senior colleagues, all of whom had equally contributed to the success of SLV-3. Was I hurt at the coldness of the new environment? Perhaps yes, but I was willing to accept what I couldn't change.

I have never lived off the profits of others' minds. My life, in keeping with my nature, has never been that of a ruthless achiever. The SLV-3 was made not by force and manipulation, but through consistent collective effort. Then why this sense of bitterness? Was it peculiar to the VSSC top level or a universal reality? As a scientist, I was trained to reason out reality. In science, reality is that which exists. And because this bitterness was real, I had to reason it out. But can these things be reasoned out?

Were my post-SLV experiences leading me into a critical situation? Yes and no. Yes, because the glory of SLV-3 had not gone to everyone who deserved it—but hardly anything could have been done about that. No, because a situation can be considered critical for a person only when realisation of the internal necessity becomes impossible. And that certainly was not the case. In fact, the concept of conflict is built upon this basic idea. In retrospect, I can only say that I was fully aware of a great need for actualization and renewal.

In January 1981, I was invited by Dr Bhagiratha Rao of the High Altitude Laboratory (now the Defence Electronics Applications Laboratory (DEAL)), Dehra Dun to give a lecture on the SLV-3. The renowned nuclear scientist, Prof. Raja Ramanna, whom I had always admired, and who was then the Scientific Adviser to the Defence Minister, presided over the gathering. He spoke on India's efforts in generating nuclear energy and the challenge in conducting the first nuclear test for peaceful purposes. As I had been so closely involved with SLV-3, it was natural that I was soon in full spate about it. Later, Prof. Raja Ramanna invited me for a private meeting over tea.

The first thing that struck me when I met Prof. Ramanna was his genuine pleasure at meeting me. There was an eagerness in his talk, an immediate, sympathetic friendliness, accompanied by quick, graceful movements. The evening brought back memories of my first meeting with Prof. Sarabhai—as if it was yesterday. The world of Prof. Sarabhai was internally simple and externally easy. Each of us working with him was driven by a single-minded need to create, and lived under conditions which made the object of that need directly accessible. Sarabhai's world was tailor-made to our dreams. It had neither too much nor too little of anything needed by any one of us. We could divide it by our requirements without a remainder.

My world, by now, had no simplicity left in it. It had become an internally complex and externally difficult world. My efforts in rocketry and in achieving the goal of making indigenous rockets were impeded by external obstacles and complicated by internal wavering. I was aware that it required a special effort of the will to sustain my trajectory. The coordination of my present with my past had already been jeopardised. The coordination of my present with my future was uppermost in my mind when I went to have tea with Prof. Ramanna.

He did not take long to come to the point. The Devil Missile programme had been shelved in spite of tremendous achievements made by Narayanan and his team at DRDL. The entire programme of military rockets was reeling under a persistent apathy. The DRDO needed somebody to take command of their missile programmes which had been stuck at the drawing board and static test bed stages for quite a while. Prof. Ramanna asked me if I would like to join DRDL and shoulder the responsibility of shaping their Guided Missile Development Programme (GMDP). Prof. Ramanna's proposal evoked a mixture of emotions in me.

When again would I have such an opportunity to consolidate all our knowledge of rocketry and apply it?

I felt honoured by the esteem in which Prof. Ramanna held me. He had been the guiding spirit behind the Pokharan nuclear test, and I was thrilled by the impact he had helped create on the outside world about India's technical competence. I knew I would not be able to refuse him. Prof. Ramanna advised me to talk to Prof. Dhawan on this issue so that he could work out the modalities of my transfer from ISRO to DRDL.

I met Prof. Dhawan on 14 January 1981. He gave me a patient hearing, with his typical penchant for weighing everything carefully to make sure he didn't miss a point. A markedly pleasant expression came to his face. He said, "I am pleased with their appraisal of my man's work". He then smiled. I have never met anyone with a smile quite like Prof. Dhawan's—a soft white cloud—you could picture it in any shape you wanted to.

I wondered how I should proceed. "Should I formally apply for the post so that DRDL could send the appointment order?" I enquired of Prof. Dhawan. "No. Don't pressurise them. Let me talk to the top-level management during my next visit to New Delhi," Prof. Dhawan said. "I know you have always had one foot in DRDO, now your whole centre of gravity seems to have shifted towards them." Perhaps what Prof. Dhawan was telling me had an element of truth in it, but my heart had always been at ISRO. Was he really unaware of that?

Republic Day, 1981 brought with it a pleasant surprise. On the evening of 25 January, Mahadevan, Secretary to Prof. UR Rao, rang up from Delhi to inform me about the Home Ministry announcement about the conferment of the Padma Bhushan award on me. The next important call was from Prof. Dhawan to congrat-ulate me. I felt blissfully elated as it was from my guru. I rejoiced with Prof. Dhawan at his receiving the Padma Vibhushan and I congratulated him wholeheartedly. I then rang up Dr Brahm Prakash and thanked him. Dr Brahm Prakash chided me for the formality and said, "I feel as if my son has got the award." I was so deeply touched by Dr Brahm Prakash's affection that I could no longer keep my emotions in check.

I filled my room with the music of Bismillah Khan's shehnai. The music took me to another time, another place. I visited Rameswaram and hugged my mother. My father ran his caring fingers through my hair. My mentor, Jallaluddin, announced the news to the crowd gathered on Mosque Street. My sister, Zohara, prepared special sweets for me. Pakshi Lakshmana Sastry put a tilak on my forehead. Fr. Solomon blessed me holding the holy cross. I saw Prof. Sarabhai smiling with a sense of achievement— the sapling which he had planted twenty years ago had finally grown into a tree whose fruits were being appreciated by the people of India.

My Padma Bhushan evoked mixed reactions at VSSC. While there were some who shared my happiness, there were others who felt I was being unduly singled out for recognition. Some of my close associates turned envious. Why do some people fail to see the great values of life because of sadly twisted thought processes? Happiness, satisfaction, and success in life depend on making the right choices, the winning choices. There are forces in life working for you and against you. One must distinguish the beneficial forces from the malevolent ones and choose correctly between them.

An inner voice told me that the time had come for a long felt, but ignored, need for renewal. Let me clean my slate and write new 'sums'. Were the earlier sums done correctly? Evaluating one's own progress in life is not an easy task. Here the student has to set his own questions, seek his own answers and evaluate them to his own satisfaction. Judgement aside, eighteen years at ISRO was too long a stay to leave without pain. As for my afflicted friends, the lines by Lewis Carroll seemed very appropriate:

*You may charge me with murder –*
*Or want of sense*
*(We are all of us weak at times):*
*But the slightest approach to a false pretence*
*Was never among my crimes!*

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