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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.

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