Development of space technology: Indian experience and future prospects

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India's entry into the space age was the result of its deep commitment to 'big science' during the post-independence period. Nehru's approval of the applications of space technology in the early sixties, in the absence of operational systems and in view of the newness and complexity of the technology at that time, is considered to be an act of extraordinary foresight and courage[1].

Early choices

The choice regarding the path to be followed by India's space programme was almost made when the programme was born in the mid-sixties. The programme was to be strongly oriented towards national applications for communications, television broadcasting and distribution, meteorology and remote sensing. Constant references to these applications can be found in Vikram Sarabhai's early writings and speeches. These specific choices were made at a time when these applications had only begun to surface even in the US and the (then) USSR. The programme also envisaged acquisition of capabilities in the means that are crucial to these applications, i.e. satellite and launch vehicle technologies. Thus the profile for the seventies for the space programme stipulated building of satellites, launch vehicles, the Satellite Instructional Television Experiment (SITE), as well as the INSAT satellite system. While broad schedules and outlays were indicated, the programme was not precise on the type of projects to be undertaken, size of launch vehicles, satellites, etc.

Decade profile of the seventies

The precise details of the steps to be followed were identified during the seventies during actual implementation of the profile. The mantle of the space programme had fallen on the shoulders of Satish Dhawan after the sudden demise of Vikram Sarabhai in December 1971. Some of the projects undertaken during the seventies were 'targets of opportunities'. But they were well within the overall objectives laid down earlier and in fact enhanced the Indian capability to realize the ultimate goals in a systematic manner. For example, while the Sarabhai profile envisaged SITE, the joint telecommunication experiments, called STEP, between the Indian Space Research Organisation (ISRO) and the Post & Telegraph Department (P&T) using the Franco-German Symphonie satellite, was conceived later. It was a very useful step in experimenting with several engineering elements of the future INSAT system. Transportable and mobile earth stations were built. Several modulation techniques were experimented with. Above all, STEP also developed excellent working relationships between ISRO and user ministries, like telecommunication and information & broadcasting, so vital for the future INSAT.

Similarly the opportunity to build the experimental geosynchronous satellite APPLE resulted from ISRO's winning the competitive selection process for payloads on one of the European Space Agency's ARIANE developmental flights. The fact that ISRO was able to capture this opportunity in the later half of the seventies just after one successful flight of Aryabhata, and when it was embarked on the construction of Bhaskara, an earth observation satellite, was a sign of the maturity of the organization.

Interconnectivity of projects

It is worthwhile noting several important features connected with the APPLE project. These were typical of other space projects as well.

(a) The project used several elements of other projects thus minimizing the input costs and integrating the organization's experience. Important examples are that, besides using Aryabhata and Bhaskara experience, APPLE used the STEP ground segment and the fourth stage of SLV-3 as its apogee motor. Thus APPLE clearly demonstrated the excellent interconnectivity within India's space programme.

(b) India had to establish her own tracking systems for APPLE outside the country—some by hiring and also by placing her own tracking stations abroad.

(c) The achievements in this body-stabilized satellite led to many important technology elements making it possible for India to design, develop and build the contemporaneous and world-class Indian remote sensing satellite IRS-1A, which is currently functioning in orbit for more than three years.

(d) When APPLE was underway three Bhaskara and Rohini satellites were simultaneously being built. Major efforts in defining future satellites and launch vehicles were also under way. At that time the organization clearly demonstrated excellent managerial capability for handling multiple projects and activities, without in any way sacrificing the efforts of future planning to define the 1980–90 profile or without compromising its stated purpose to involve industries in a major way to build elements of launch vehicles, satellites and ground systems.

(e) The stock of ISRO with the international agencies was very high.

(f) India's governmental system has provided an excellent example of flexibility and forward thinking.

(g) Even when the solar array of the APPLE spacecraft developed anomalies after launch the mission team could manage the spacecraft well to realize the core objectives.

Major milestones since 1975

It is also commendable that ISRO faced the failure of the first experimental flight of SLV-3 in 1979 with courage and *determination to march ahead with its project*. The details of ISRO's projects are well documented especially in the annual reports of the Department of Space[2]. A recent article[3] may also be referred to. Table 1 lists the major milestones of the programme since the seventies.

Overall performance

The descriptions of success and failure given in Table 1 are broad indications of the achievement of the overall mission. There may not be a clear consensus on such cryptic descriptions. The successes have not all been without problems. In Dhawan's words[4], during the adventure of the seventies, there were some transitory reverses, but in the end all tasks were successfully completed. A quick look at Table 1 would indicate that the time-intensity of events during the late seventies to the mid-eighties was high; there was considerable decline subsequently. There was a crowding during 1988. Perhaps events may again crowd during the early nineties. It is also to be noted that the number of failures during the later period is high but not limited to Indian-make satellites or launch vehicles alone — two foreign-procured satellites also failed. While analyses of the complex space programme cannot and should not be done with such macro data, it is worth bearing in mind that after the mid-eighties India's space programme has *attempted much more complex missions* with more difficult success criteria. As against project costs of below rupees 100 million for Aryabhata, and Bhaskara satellites and below rupees 200 million for APPLE, the IRS-1 project cost is around rupees one billion and that of the indigenous INSAT-II around rupees two billion. These figures sometimes include special developmental costs and are in current prices. The costs indicated are only in orders of magnitude. But they indicate the complexity.

As regards failures it should be borne in mind that space technology is still a risky business. It will take several years before it can be made relatively risk-free. The experience of other space-faring nations bears this out. However, it does not mean that failures need not be studied and corrective measures, even managerial ones, wherever necessary, not taken. A good perspective regarding the management of a major space programme can be obtained from the report of the Advisory Committee on the Future of the US Space Program (called the Augustine Report)[5]. The *report was released in December 1990.*

Table 1.

Project	Launch date or period	Remarks
Aryabhata	19 April 1975	Success
Bhaskara-I	7 June 1979	Success
SLV-3 (first experimental flight)	10 August 1979	Failure
SLV-3 (second experimental flight) + Rohini RS-1	18 July 1980	Success
SLV-3 (first developmental flight) + *Rohini RS-D1*	31 May 1981	Success
APPLE	19 June 1981	Success
Bhaskara-II	20 November 1981	Success
INSAT-1A (procured satellite)	10 April 1982	Failure
SLV-3 (second developmental flight) + Rohini satellite RSD2	17 April 1983	Success
INSAT-1B (procured satellite)	30 August 1983	Success Full lifetime
ASLV (first flight) + SROSS satellite	24 March 1987	Failure
IRS-1A	19 March 1988	Success Full lifetime
ASLV (second flight) + SROSS satellite	13 July 1988	Failure
INSAT-1C (procured satellite)	22 July 1988	Failure
INSAT-1D (procured satellite)	12 June 1990	Success
IRS-1B	29 August 1991	Success
INSAT-IIA (Indian-made INSAT satellite)	Scheduled for mid-1992	

An assessment of the developmental decade

Dhawan[4] stated that during the first profile period India made an entry into space and sustained its position with successive forays in this new domain. He hoped to see space technology with its diverse applications truly coming of age in India by the end of the developmental decade (1980–90). By and large his statement regarding the coming of age of diverse space applications has come true. Space applications have come to stay in India. Excellent management systems like the Insat Coordination Committee (ICC) and the National Natural Resources Management System (NNRMS) have been established to promote and sustain applications. Linkages with industries are much better compared to those in several other Indian S&T agencies.

However, an important fact is that major services for communications, television and meteorology are still being run with foreign-procured satellites and would be so till the mid-nineties. The profile of the 1980–90 period only stipulated the replacement of the imported first-generation space segment of INSAT at the earliest. India had also borrowed transponders from ARABSAT to tide over problems arising out of INSAT-IC's failure. These realities have to be compared to the aspirations that are reflected in the profile of the seventies *though there is a tempering in the later profile.* Only the successful launch of (Indian-make) INSAT-II and subsequent decisions to have only Indian-make satellites in the INSAT series will realize the early dreams.

In the field of remote sensing full self-reliance has been obtained in ground *segments and in satellites. This is a* proud achievement for the country placing it with select countries like the US, France, the (former) USSR and Japan. However it should be noted that most of the remote-sensing applications can sustain some break in availability of satellites. The real benefits of remote-sensing applications in developmental planning and scientific appraisal of natural resources are not as well known to the 'common public' as the applications of INSAT cloud-cover data or satellite-based television distribution. Because of the very nature of knowledge-oriented output of remote sensing, though it is very valuable to the economy and welfare of the country, such a situation will continue for many more years though a large number of users will depend on remote sensing increasingly.

In the field of launch-vehicle technology, India has not made a successful launch after 1983, though there have been several successful tests of various subsystems of the Polar Satellite Launch Vehicle (PSLV). The first stage motor of PSLV is the third largest solid motor in the world and it has been successfully ground-qualified. India is the only country other than the US that has made such a large solid motor. The second stage, which has a large liquid engine, has also been qualified successfully. Despite these significant developments, the real assessment of India's capability in the launch-vehicle area can be done only after about two successful launches of PSLV. It appears that this is possible only close to the middle of the nineties. It is also to be seen whether operational remote-sensing satellites will be launched by indigenous vehicle by the mid-nineties. India perhaps has to go a much longer way to acquire the capability to launch the Indian-make (geosynchronous) INSAT satellite.

A reality concerning the components and devices needed for use in space should be borne in mind. The statement in the National Paper of India for the second United Nations Conference on Exploration (UNISPACE-82)[6] — 'There is one area in which the country has not been able to make significant headway. This relates to the manufacture of electronics components and devices of the required quality and specifications needed for use in space. So far import has been the only way out. Apart from high costs involving scarce foreign exchange, a number of other considerations such as delays and, the monopoly of suppliers abroad make it an unsatisfactory arrangement.' — almost remains unchanged even to date. This situation is primarily due to the nature of the electronics industry in the country. The long-term implications of this situation can be significant for the direction of the space programme.

International scenario

Before proceeding to assess the future prospects of India's space programme, it is necessary to review the direction of the space programmes of the major space-faring nations. An excellent set of articles can be found in an issue of *Space Policy*[7]. The issue surveys an update on Japan's space policy, China's space programme including her launch services, the changing structure of the Soviet space programme, and cooperative prospects for the twentyfirst century in defence space activities. It is difficult to summarize the major elements. However, one common thread is an increasing accent on joint efforts in major space endeavours. China's space programme is poised to provide internationally competitive space services. On the other hand one can see from NASA's (1991) Aeronautics and Space Report of the (US) President 1989–1990 (ref. 8) that the Tracking and Data Relay Satellite System (TDRSS) became fully operational. This network provides communication and tracking for over 85 per cent of each spacecraft orbit around the earth. With the previous ground-tracking network the coverage was limited to only 15 per cent of spacecraft orbit. This operational network allowed the US's National Aeronautics & Space Administration (NASA) to close or transfer to other agencies the four ground stations.

The TDRSS system can remove opportunities for some traditional forms of cooperation in the space activities of nations, i.e. the location of tracking stations in countries based on their global geography. Coupled with the fact that ground systems for space applications such as communication, television, remote sensing and meteorology are becoming regular commercial products of major electronics companies of many countries, cooperation between major space-faring nations and other countries, which existed during the sixties, seventies and even eighties, may undergo some fundamental changes. While the major space-faring nations may cooperate in projects of space exploration and space transportation, many other countries may have to depend for space segments and launch services from these countries. Competition between the space-faring nations may be tempered because of their mutual dependence on large space projects. They may offer the services to other countries on commercial terms; sometimes other, noncommercial considerations may affect these transactions. At the same time it is not possible for many of the non-space-faring countries to avoid space applications as these applications have some unique and distinct advantages in civilian applications. Considerations of military applications add an entirely new dimension to space applications.

Despite several well-publicized failures of major space missions, it should be noted that the space business is a growing one. As noted in *Space Technology International*[9]: 'Pessimists should note that despite all their internal upheavals the Soviets still made 75 space launches in 1990 — one more than in 1989; the US total of 27 was that country's highest for 12 years, and is set to go on rising. Europe's Arianespace made five launches, China five, Japan three and Israel one. The total 155 satellites they launched, likely to be exceeded in 1991, could be conservatively estimated to represent an expenditure of over $20 billion. On top of that of course are the long-term investments in space infrastructure — the new generations of expendable launchers and spaceports — to encourage international industry to develop its capabilities to make use of these facilities. Progress on the development of a commercial spaceport in Florida, and of an international spaceport in Queensland, Australia, using a Soviet launcher....'

Even at the applications end business is no less. The turnover of SPOTIMAGE, whose earnings is from the sale of data products or images from the French SPOT satellite during 1990, which was FF 163 million was up 33% on the 1989 figure. In 1986 the turnover was around FF 40 million[10].

However, there are questions that are not amenable to easy answers: Will this boom in business be limited only to those countries and firms who have already consolidated the commercial aspects of the space technology? Will it be possible for the new commercial entrants to make a niche, if not become major competitors? A judgement on the answers to these questions are crucial to the future of the Indian space programme.

Future prospects for India's space programme

It is against the above backdrop that an assessment of the role of India's space programme in the nineties and beyond has to be made. Dependence on foreign countries for launch services and also for components and devices has some implications. At the same time, it may not be possible to remove this dependence in a very short time. Perhaps it is necessary to study the competitive elements between the present space-faring nations, mainly the US, the (former) USSR, France, China and Japan, and arrive at some strategic alliances based on our needs and strengths. It may involve Indian contributions in terms of some space subsystems to the big programmes undertaken by these countries. Indian experience in these efforts is minimal. The recent attempt to bid for INMARSAT is only one aspect. But this competitive business is much more than mere ability to design and develop satellites, launch vehicles and support services. Involvement by Indian industry would have helped in dealing with these commercial aspects. While ISRO has perhaps performed the best among India's scientific agencies in involving industries in a major way, still the industries have mostly worked on a job-order mode[11]. They are yet to take up the challenges of design, development and marketing of space subsystems to given specifications and quality standards.

There are two other crucial aspects. One concerns finances. The budget for the space programme is about one-sixth of the overall Central Government investment on science and technology in the country. The rate of increase during the mid-eighties was around 40%. Even in comparison with the developed countries, India's expenditure on space activities is not trivial. So much so *The Economist*[12] listed India as one of the star spenders in space. Will the country sustain it or increase it in the coming years? Can it find the necessary foreign exchange resources as well? In general, the launch-vehicle projects, though more expensive in rupee terms, require low foreign exchange. Satellite projects, on the contrary, require considerable foreign exchange, especially for components. Can India export space services? Can we continue the military applications of space technology, e g. missiles, separately? What about an aerospace industry? Another aspect concerns human resources. The average age of the space organization, which was between 25 and 30 years during the Aryabhata and SLV-3 days, is above 40 now. Will this ageing have an impact?

India's space programme, which has done well so far, is at the crossroads in the nineties. The problems it would face are not insurmountable. *The challenges require new approaches and some basic changes in the present forms of goal-setting.* Given a creative outlook it is possible for India's space programme to orient itself to the new technological, commercial, business and global-political realities. But the transition may be through a difficult process of restructuring the work. Some integrated aspects of the Programme in future can be maintained only if it is able to respond to commercial 'targets of opportunities' in the global market. An ability to blend the grand plan of a decade profile with the demand pulls of global market forces requires different forms of techno-managerial skills and attendant policy-making and administrative systems. During the adventure of the seventies and the developmental decade of the eighties, the confidence, trust and hope reposed by the government and the people of India have not been belied. By and large, ISRO and the people who constitute it retain the spirit and inspiration the founders bequeathed. The nineties is going to be the decade of consolidation of space services, facing global-commercial realities, and diversification. The recently announced industrial policy does not address space-related technologies or industries specifically though some of them can be covered through electronics industries, chemicals, metals, etc. But it may be necessary to address the question of the role of space technology-related industry and trade in the context of defining the policies of the nineties and beyond. The Bhabha–Sarabhai vision may require a revisit after three decades. The trio of political masters, technology managers and industry leaders should rise to meet the challenges. The latter especially has more to gain and to contribute if they can realize and seize the opportunities. It is necessary that a new national strategy for space be identified and enunciated soon.

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