India's Space Enterprise –
A Case Study in Strategic Thinking and Planning

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It is a matter of proud privilege and honour for me to be invited to deliver the 2006 Narayanan Oration at the Australia South Asia Research Centre (ASARC) of the Australian National University (ANU). It is with profound regret and sorrow that we had to confront Mr. K.R. Narayanan's demise recently on 9th November 2005. Whenever I met him, he left in me an indelible impression of his awe inspiring and deep erudition and his extraordinary passion and commitment to uplift underprivileged segments of the society. Nonetheless, he also pursued relentless efforts to achieve excellence in all walks of life. His holistic approach to science and technology has been candidly revealed in his speech on the eve of Golden Jubilee celebrations of the Indian Republic

> We cannot and ought not halt movement in the trajectories of our modern progress. Factories will and must rise, satellites must and will soar to the heavens, and dams over rivers will rise to prevent floods, generate electricity and irrigate dry lands for cultivation. But that should not cause ecological and environmental devastation and the uprooting of human settlements, especially of tribals and the poor. Ways and methods can be found for countering the harmful impact of modern technology on the lives of the common people. I believe that the answer to the ill-effects of science and technology is not to turn our back on technology, but to have more science and technology that is directed to human needs and for the betterment of the human condition.

It is my good fortune that I could pay my own humble tribute to this noble soul through this oration instituted in his honour. I also thank the ASARC of ANU and its Executive Director, Professor Raghbendra Jha for this invitation.

2. Early History

Modern Space science had its beginnings around 1946 when scientists started the deployment of instruments to the outer fringes of the earth's atmosphere using balloons and rockets to study radiations from outer space as well as geophysical phenomena. In spite of the professed scientific goals for the first earth satellite missions, the launch of SPUTNIK on 4 October, 1957 by the then Soviet Union added a new dimension (Logsdon 2001) to the cold war between the US and the Soviet Union. The early scientific satellite missions of the US also had implicit goals of pursuing US interest in establishing the international legal principle that national sovereignty did not extend to the altitudes at which the satellite would orbit. Thus there was no obstacle in international law to the over flight of a reconnaissance satellite over Soviet territory. Against this back drop, it is significant to note that the early inspiration for the Indian space program came not from any military objectives, but from the interests of a large scientific community who have been actively engaged in research programs related to geophysics and astrophysics. When Vikram Sarabhai and Homi Bhabha suggested support to space science and technology for possible application to Indian problems, in 1962, the Sputnik era was just five years old. Pandit Nehru's approval for the application of space technology in India was an act of extraordinary foresight and courage. This decision in the absence of experience with operational systems, the newness and complexity of the technology and the high risks involved, could have only been based on a vision of the future and an abiding faith and confidence in the Indian scientists and people.

3 The Vision

The vision of space that Dr Vikram Sarabhai gave for India is extra-ordinary for its realism and pragmatism, unique for its deep insights into the socio-economic context of the country, extensive in the level of details and identification of different dimensions and remarkable for the display of his own conviction. In the annals of our Science and Technology endeavour, very rarely has one come across such a vision that has withstood the test of time — in this case over more than four decades. Some glimpses of his vision (Sarabhai 1979) are in order at this juncture, as an early example in strategic thinking.

The vision recognized that promotion of space research, besides contributing to societal benefits and enrichment also results in intangible benefits coming out of the need to develop high technologies for economic development and security. The vision also identified space's unique ability to create leadership and the benefits of international collaborations. Further, it could help develop the nucleus of a new culture where a large group of persons in diverse activities learn to work together for the accomplishment of a single objective. Establishing a synchronous satellite over the Indian Ocean to improve meteorological forecasting, critical to agricultural operations and evolving national plans using space technologies for resource survey were also visualized as important for India. The vision called for an exciting development of a synchronous direct television broadcasting satellite that could serve as the most powerful means of mass communication to reach a large segment of the population in an economically depressed region of the world. Early in the conceptualization of a satellite based communication and broadcasting system, issues of system choice including the financial implications and the economic benefit were recognized as important. The establishment of strong linkages with key user agencies was central to this vision. Dr Sarabhai's emphasis on self-reliance made it the life current of the Indian space program and enabled the program to overcome numerous challenges in the course of its journey towards operational applications of space. His vision was not merely restricted to technology and application, but also to the attendant needs of new organizational structures on one side, and the fundamental issue of the role of humans in space on the other (Sarabhai 1966).

Development of this vision itself was spread over a decade from 1961. This period was characterized by consultation among the various stakeholders (ISRO Report 1972) — using professionals across the world as sounding boards — for detailed assessments of the different dimensions of the envisaged program through experimentation, analysis and simulation that factored in the socio-economic context of the country. In retrospect, it is gratifying to note that such an elaborate and carefully formulated vision helped to grow the program, in a directed manner over the next three decades without any major deviations, except for small midcourse corrections on some specific parts of the program. It is also of interest to note that this entire decade accounted for an expenditure, that is less than 1% of the total investment in the space program up to 2006 (constant price basis).

4. Present Dimensions of Indian Space Program

The Indian space program today is a large integrated program, which is self-reliant and applications driven, maintaining vital links to the user community and committed to excellence in scientific endeavours.

The program developed capabilities to produce world-class satellites and launch vehicles and to apply them in diverse areas relevant to national development. India has established two operational space systems. The Indian National Satellite (INSAT) system, currently made up of nine satellites in orbit is one of the largest domestic satellite communication system in the world. The Indian Remote Sensing satellite (IRS) system, with a constellation of seven satellites, comprises some of the best satellites in the world for generating information on natural resources. Space launch vehicles developed by India are aimed towards providing autonomous launch capability to orbit these classes of satellites. India's Polar Satellite Launch Vehicle (PSLV) is well proven through eight successive successful flights and it provides the capability to orbit remote sensing satellites of the 1.4 tone class in polar sun synchronous orbits. The Geo synchronous Satellite Launch Vehicle (GSLV), capable of launching 2 to 2.5 tone class of INSAT satellites, has been operationalised with three successful flights in a row, making India one of the six countries in the world to demonstrate capabilities for geo-stationary satellite launch.

Both IRS and INSAT satellites have benefited the country in various areas of national development. INSAT satellites are the main stay for the Television broadcasting and provide connectivity to more than 1100 TV transmitters. They also network radio stations, provide rural area communications, business communications and Tele-education and Tele-medicine services. They are also used to relay cyclone warnings, gather meteorological data, assist weather forecasting for emergency communication support during disasters and providing search and rescue support. The imageries and data from the IRS satellites are used for vital applications such as locating zones for availability of ground water in habitations having no access to drinking water, monitoring agricultural crops, providing advisories to coastal fishermen on potential zones for fishing, planning water shed, rural development and waste land management programs as well as disaster management support.

Front ranking scientific investigations are being carried out in the fields of astronomy, atmospheric sciences and long-term climatic research using satellites, balloons, sounding rockets and ground instruments. India has also embarked on an ambitious planetary exploration program, the flagship mission of which is Chandrayaan-1. This mission aims to place a satellite around the Moon for physical and chemical mapping of the lunar surface.

India has forged bilateral co-operative arrangements with more than 20 countries including Australia, China, France, Germany, Russia and USA. The scope of the international co-operation is multi-dimensional in nature, which includes conduct of joint missions, offering opportunity for flight of instruments onboard Indian satellites, exchange of meteorological data and offering education and training in the area of Space. It is worth noting that six scientific instruments from the USA and Europe are being flown in India's Lunar Mission Chandrayaan-1. India has established a Centre for Space Science, Technology and Application Education for Asia and Pacific, affiliated to the UN and is offering well-structured educational programs.

An entity called Antrix Corporation has been established to promote commercial use of the space assets of ISRO and to help Indian space industries achieve global competitiveness. Global marketing of IRS data, launching of four foreign small satellites by PSLV, leasing of INSAT transponder capacity to commercial operators including INTELSAT, supply of spacecraft subsystems and mission support services of Indian ground stations are some of the highlights of the Antrix space business. It has also recently established an alliance with Europe's leading satellite manufacturer, EADS Astrium, to jointly manufacture communication satellites using the INSAT bus for selling in global markets.

India piloted a satellite communication policy in 1997 paving the way for use of INSAT capacity by private users and for private ownership of communications satellite assets. Further, a comprehensive remote sensing data policy on acquisition and distribution of remote sensing data for civilian users is also in place. Remote sensing data from satellites have been accepted as legal evidence in many States of the country for purposes such as environment impact assessment for site clearances, forest encroachment and infrastructure development.

Linkages with academia have also been an important aspect of Indian space program. More than 80 universities and academic institutions of higher learning are involved in a variety of research projects related to space science, technology and applications.

In a nutshell, these multifaceted contributions from the Indian Space program, which has been developed and run with modest budgets, make it particularly significant in the modern context.

5. Evolving Strategies

The evolution of the Indian space program over the past four decades represents a systematic and phased approach to building knowledge, technological capacity and an organizational system to ensure effective application of sophisticated technologies to national development (Dhawan 1985; Kasturirangan 2001).

Beyond the first decade of vision and initiation, the space program evolution can be broadly categorized under three distinct phases. The first phase related to proof of concept demonstration, the second dealt with the realization of end-to-end systems at an experimental level that then led into the current operational phase. In what follows, we discuss briefly some of the examples of strategic thinking and planning while progressing through these phases.

5.1 Proof of Concept Phase

The proof of concept phase of the Indian space program was characterized by the use of foreign space systems, configuring the ground system to suit national needs and conditions as well as working closely with the potential user community. We illustrate the nature of the activities in this phase through three examples.

The first is an experiment to develop, test and manage a satellite based instructional television system, to demonstrate the utility of satellite television for mass communication with a specific emphasis on remote rural areas communications. Known as the Satellite Instructional Television Experiment (SITE), it used the American Satellite, ATS-6 specially moved over Indian Ocean to conduct this experiment in 1975–76. The responsibility of design, development, deployment, operation and maintenance of ground equipment was entirely that of India and it involved nearly 2400 direct reception television stations in six clusters. India also undertook development of instructional programs, in the areas of family planning, agriculture, national integration, primary education, and teacher training. While departmental boundaries are often difficult to cross in a bureaucratic system, in a multi-disciplinary project such as SITE, it often became necessary to work across conventional boundaries and sort out the interface problems. SITE gave very valuable inputs as to how TV, a new extension tool can be integrated into the existing organization of the user agencies. Social research and evaluation design was also carried out for impact survey of target populations. Further, the experiment helped arriving at cost estimates for a national operational satellite system.

The second example related to the Satellite Telecommunication Experimental Project (STEP). This project, undertaken primarily to understand the issues of interfaces between space and ground systems for communication, was conducted with a Franco-German satellite, Symphonie. STEP helped in concretizing our initial thinking on ‘Disaster Warning Systems’, radio networking concepts and transporatable terminal developments, and provided vital inputs to the planning of INSAT.

The third example relates to space based earth observation system. Landsat, launched by USA in 1972 provided an unique opportunity to test out the utility of a satellite based earth observation system for obtaining timely, accurate and precise information of earth resources. The exercise of establishing ground systems, integrating space based data with conventional aerial and ground based data and working closely with user community, such as the Geological Survey of India, Agriculture, Forestry and Water resources users provided several crucial insights for planning the future operational remote sensing systems.

In summary, the proof of concept demonstrations enabled evaluating the potential of the vantage point of Space for addressing the country’s developmental needs and issues of scalability at the national level. An important outcome was the evaluation of uniqueness of space in providing new services, or for assessment of their superiority vis-à-vis conventional approaches. Further, this phase enabled a short turn around time and a low cost strategy for evaluating the concepts, the systemic issues including technologies, the institutional frameworks and the user interfaces.

5.2. Experimental Phase

The experimental phase was identified with a strategy to derive an end-to-end experience in the realization of space systems where the potential of its use at the national level had already been clearly demonstrated in the proof of concept phase. Here the strategy took due cognizance of the fact that space systems are inherently complex, carry high risks and are investment intensive. Further the creation of a heritage in hardware, human resource and methods are critical to develop confidence for operational systems. There was also a need to minimize the impact of probable early failures in the public mind and the political system. This phase additionally facilitated competence building at the core level, helped in the detailed evaluation of issues for scaling the effort to the national level and set the rules relating to the overall practices in system engineering. The overall demonstration of the systemic approach in this phase paved the way for the country to create national systems at a much larger scale with bigger and more sustained investments. We briefly discuss the nature of two satellite missions, Bhaskara and Apple, that were accomplished based on these considerations.

The Bhaskara Satellites (two of which were built and launched in 1979 and 1981), were earth observation satellites with a low resolution of 1 Km operating in two spectral bands. The Bhaskara program at a cost of Rs.60 million, and spread over six years gave valuable experience of building imaging camera systems, realizing satellite platform to take pictures from space, receiving the image information and processing these on the ground through appropriate ground infrastructure. Further, the mission enabled evaluating application interface methodologies with users in resource areas such as vegetative cover, geology and hydrology.

The Ariane Passenger Payload Experiment (APPLE) conducted in 1981, provided experience in satellite communications, including building of a body stabilized geosynchronous satellite. The involvement of the user agencies early in the program, had a very significant influence on the adoption of the satellite communication technology in operational communication systems of India in the subsequent years.

The experimental phase also saw some very significant progress in the design and development of launch vehicles. Systematic efforts in building capabilities, studies of configurational options, issues of phasing the program, development of relevant infrastructure were all part of both the proof of concept and the experimental phases. The strategy for developing the launch vehicle was dictated by the country’s decision to have autonomy in accessing space. Before going for the realization of a full-fledged launch capability, the need to have a phased development was recognized as necessary both for building competence and for developing the needed confidence. Successful realization of India’s first launch vehicle SLV-3, with a modest payload capability of 40 kg and initiation of the augmented capability version ASLV with 150 kg payload capability took place in this phase. Valuable experience and inputs from both SLV-3 and ASLV, provided the basis for planning, configuring and implementing strategies for the current operational launch vehicles, the PSLV and GSLV (Gupta 2006).

The proof of concept and experimental phases together accounted for an expenditure of 8% of the total expenditure as on 2006 (constant price basis).

5.3 Operational Phase

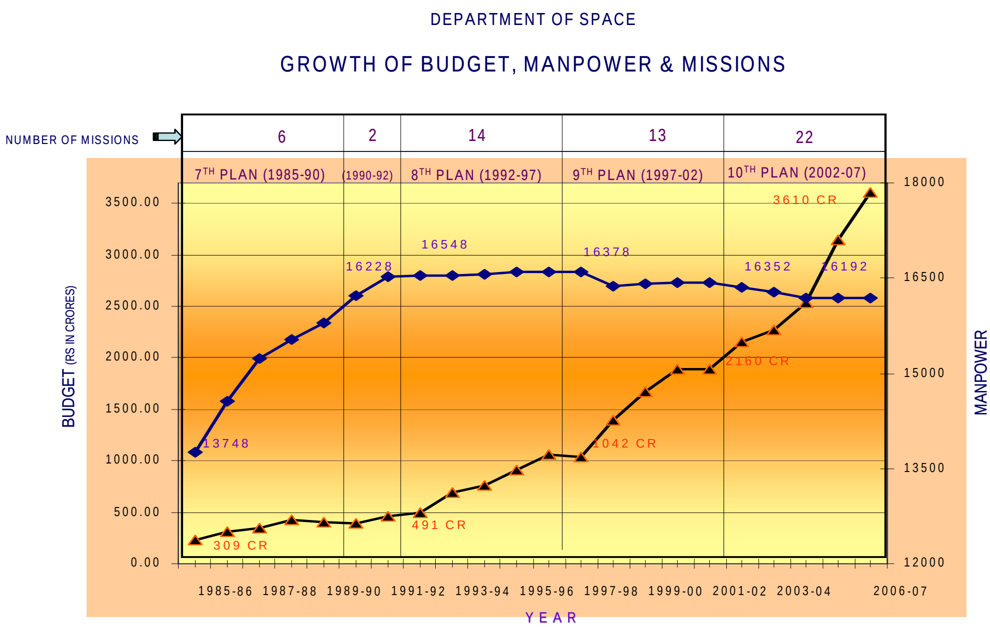
The operational phase, as described in section-4 called for certain unique strategies and decision making. Let me give a couple of examples in this connection. Encouraged by the lessons of the SITE experiment and recognizing the potential of a space-based communication and broadcasting system for meeting the developmental needs of the country (Kale et al. 1971), India decided to go for a space-based communication and broadcasting system. Taking into account, the time frame for indigenous design and development of an operational Indian National Satellite (INSAT) and recognizing the urgency to initiate services in this area, India decided to go for a bought out option for the first generation INSAT systems, even as we embarked on the design and development of the second generation systems. The four satellites of the first generation were thus procured, launched and operated for providing space based communication and broadcasting services for meeting national needs. The subsequent three generations of satellites, many of which are currently in service, were all designed and built indigenously. The strategy adopted was different in the case of earth observations. Although the then operating foreign satellites were used for developing the remote sensing applications in the country, the special requirements of earth observations, peculiar to our country as well as cost and strategic considerations called for an indigenous design and development route for the realization of operational remote sensing satellite systems. 'Bhaskara' missions provided the necessary confidence to undertake such an effort. The implementation of this strategy has resulted in India's own world class IRS series of satellites.

Another example is about the decision, in the early phase itself, to de-couple the time frame for the development of the launch vehicles from their role in providing operational support for satellite launches. Considering the complexities and the longer time frames for the development of launch vehicles, India consciously decided to seek launch support services for operational satellites from outside agencies. Such a strategy enabled the timely establishment of space services and also provided specific inputs for sizing the launch systems for these classes of satellites. The present capabilities of PSLV and GSLV and their future versions are based on the evolutionary requirements coming out of the IRS and INSAT programs.

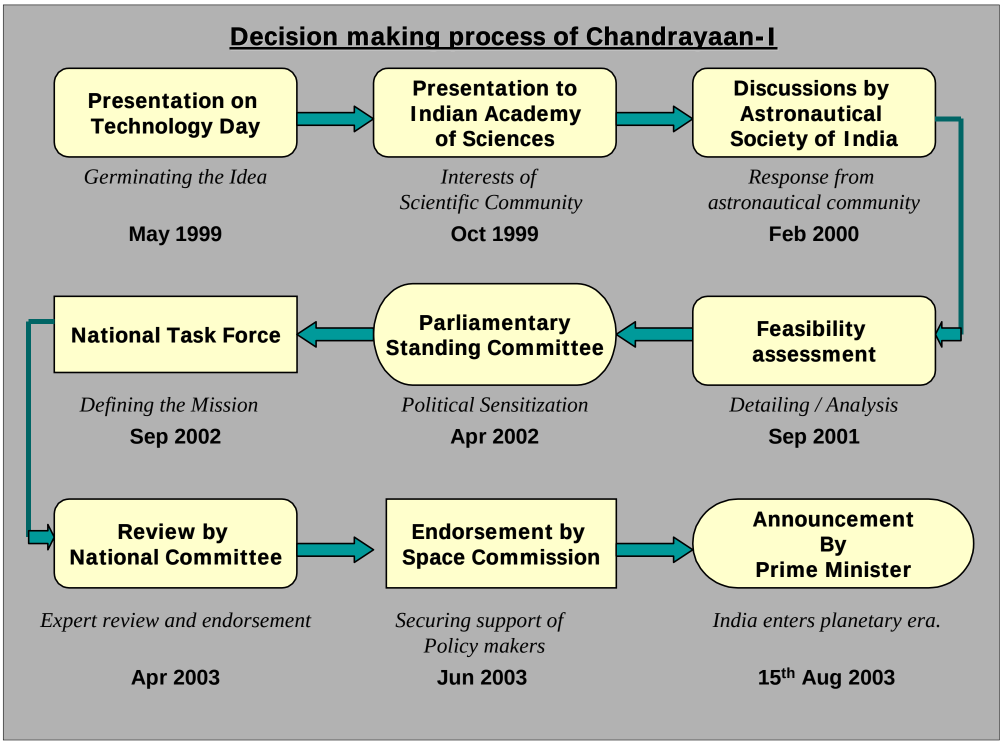
The above considerations, relating to the introduction of high technology systems for meeting developmental and other innovative service goals, therefore called for pragmatic strategies. This in turn required understanding and analyzing the complex interplay of several issues. First was a detailed assessment and evaluation of alternate approaches to arrive at the most optimal solutions. The second was to decide on exercising buy or build options taking into account the time frame for the introduction of services. In the case of buy options, a parallel indigenous development plan was created to achieve self-reliance goals.

Coming to the organizational systems (Kasturirangan 2001; Narasimha and Kalam (eds) 1988), experience from earlier experiments involving broadcasting, communication and remote sensing, and dealing with the user communities, provided valuable inputs for the creation of innovative formal institutional frameworks. In the case of remote sensing, the institutional framework involved setting up of the Planning Committee of the National Natural Resources Management System (NNRMS), which at the overall level is mandated to provide directions for the creation of space based remote sensing capabilities for the country. NNRMS consists of Secretaries of the line departments of the Government of India dealing with natural resources and is headed by a Member of Planning Commission. Such a structure enables the involvement of major user communities to address issues of ensuring the use of such systems in their own areas of thematic applications, while at the same time facilitating the incorporation of this new and powerful technique into conventional approaches. Similarly the INSAT Coordination Committee, with the Secretaries of the user departments (Information and Broadcasting, Communication, Information Technology and Science & Technology) working along with the Secretary of the Space Department, was created as an apex body to address the development of space communication, broadcasting and meteorology and planning their utilization. In the context of Space Science, the Advisory Committee On Space Sciences (ADCOS) represented by some of the leading space scientists in the country provides directions for space science research. The three structures identified above have no parallel, anywhere else in the world and have played a crucial role in sustaining the various space endeavours. Being user driven also means the beginning of a culture of accountability and transparency. Another important aspect is that the overall space program in India is overseen by a high level body, known as the Space Commission, chaired by the Head of the Space organization and reporting directly to the Prime Minister. This structure ensures that the space program derives strength from the highest level and that the policy directions are duly integrated by different government agencies.

Another aspect of the organisational strategy was to create an industrial base for supporting the space program (Dhawan 1983 and 1988) and for carrying out relatively routine operations, while the space agency concentrated on pushing the internal output up the value chain by enhancing the quality and content of research and development output. This also enabled us to progressively increase the strength of highly qualified professionals without increasing the overall size of the organization. Also, in successive five-year plan periods, the organization could deliver increasingly larger number of complex missions, as illustrated in the **Fig 1**.



There have also been instances where the justification for initiating a new activity based on measurable direct benefits is lacking. At the same time the intangible benefits that could come from some of these programs could be convincing or not so convincing. An interesting case in point is the recent Indian initiative for planetary exploration Chandrayaan-I (Kasturirangan 2004a). We had to go through an elaborate process of consultation and justification with the scientific community, academics, the political system and the public media before this mission was given the go ahead. The steps that were taken are shown in **Fig 2**.



This process, spread out over four years, culminated in the announcement by the Prime Minister of India on August 15, 2003 (India's independence day) on the nation's decision to enter the new era of planetary exploration. This is also a good example of a practice of ethics of decision making in science involving consultation of a large cross-section of society and ensuring transparency.

6. Relevance of Space to South Asia

Although applications of space technology have taken deep roots in society and practiced for well over four decades, many countries in the developing world are yet to fully experience the excitement and take full advantage of space systems. In this context, the experience of India could be relevant for a developing country wanting to realize a cost effective and socially relevant program.

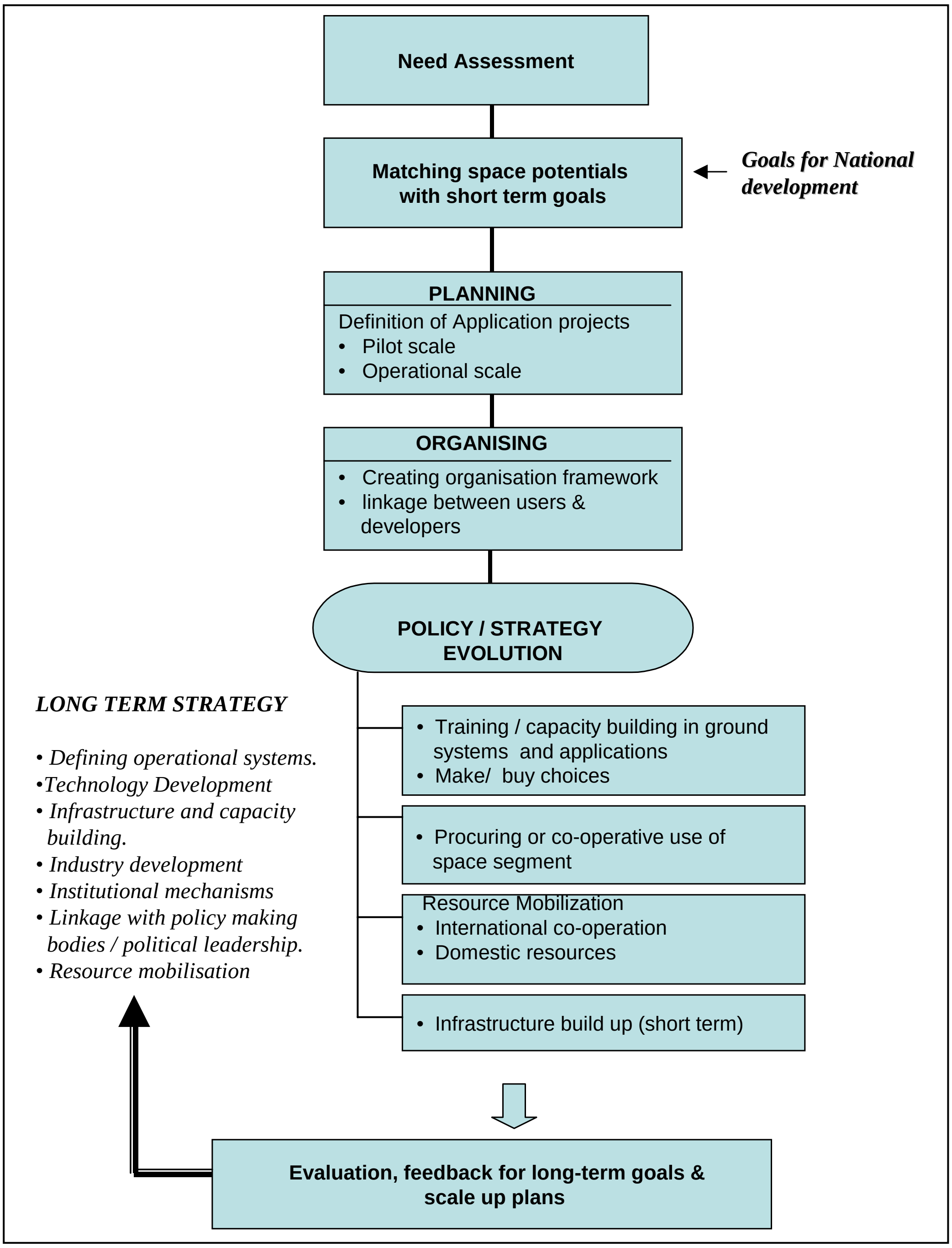
Turning to the development needs and priorities in South Asia, it is not difficult to realize that an appropriate application of space technology and creation of services based on space technology are highly relevant. South Asia comprising Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka have a combined population of 1.45 billion, which is about 22% of the global population. Because of the agrarian focus of a predominant proportion of their populations, efficient use of natural resources such as land and water assumes great importance. The high population density places tremendous pressure on environment, requiring sound strategies for sustainable management (Rao 1995). There is also the issue of a divide between urban and rural areas in terms of access to health and education facilities. Common to all these countries, there is the major issue of response to natural disasters that are adversely impacting their economic growth. For ensuring equity-oriented development in such situations, there is a need to adopt high technologies such as space.

Some of the Space technology inputs that relate to the needs of South Asia in terms of providing solutions are highlighted below (Kasturirangan et al. 2004).

Needs	**Areas where Space Technology can help**
Improving Food Security	• Water shed management • Optimal Land use strategy plan • Control of Land degradation • Drought mitigation and proofing • Recovery of irrigation systems • Monitoring of crops and cropping systems • Ground water targeting • Siting water harvesting structures • Fisheries forecasting
Infrastructure development	• Road connectivity analysis • Selection of site • Land use mapping / monitoring • Urban mapping • Community Information Kiosks • VSAT communications network
Health and Education – bridging gaps and improving quality	• Tele Medicine Network • Tele Education Network
Disaster Management and Response	• Cyclone warning (Land falls) • Flood damage assessments • Flood plain GIS/Flood zoning analysis • Drought monitoring • Land slide zoning
Environment management	• Vegetation monitoring • Forest mapping, a forestation plans • Coastal zone regulation monitoring • Mining impacts • Urban sprawl and Land use monitoring • Monitoring desertification. • Weather watch • Water conservation and management • Atmospheric pollution monitoring

It is pertinent to note that information inputs from space technology lead to better decision-making and interventions. Both long term and short term goals are to be set in order to realize practical solutions in the shortest possible time and to build capacity for sustaining the programs. An appropriate organizational nucleus has to be created to plan and implement space activities.
A conceptual framework for use of space for development is shown in **Fig 3.**

A CONCEPTUAL MODEL FOR USE OF SPACE FOR DEVELOPMENT



Use of space technology, with an accent on capacity building, is sine qua non for its progress. The conceptual framework given above is based on the experience of India, and the relevant strategies described in the earlier sections are quite relevant for wider application in the region as well as other developing parts of the world.

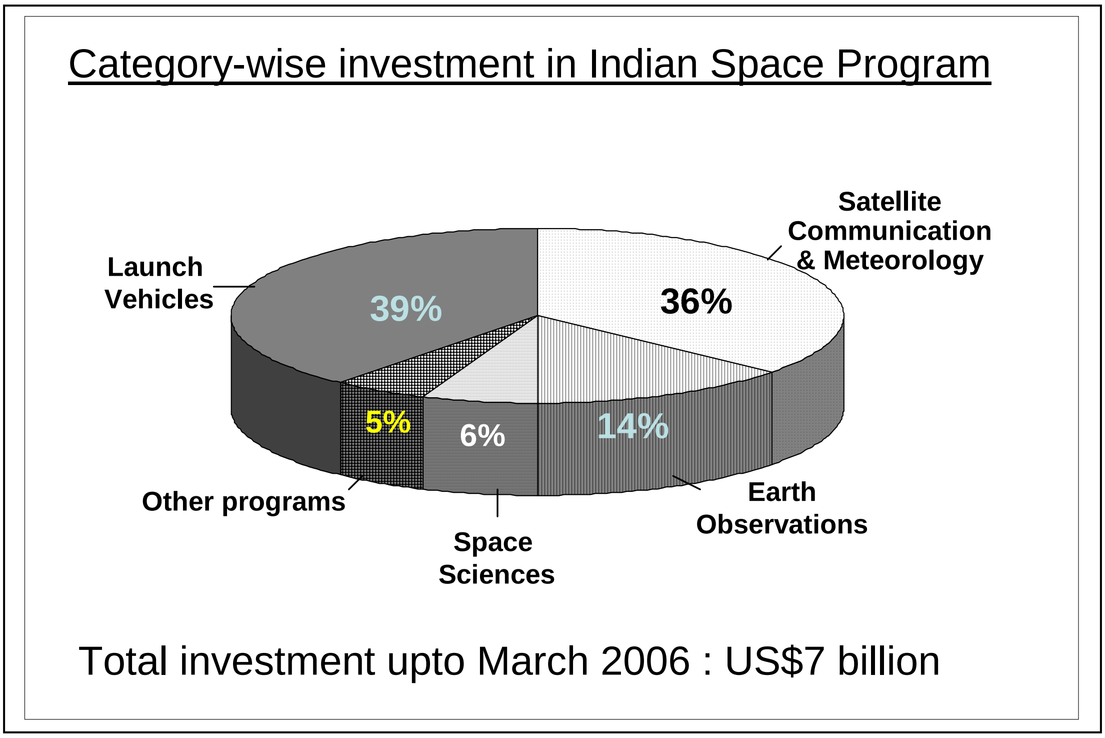
7. Economic Aspects of India's Space Program

By the early nineties, all the four major components of the space programe, namely, Satellite Communications, Meteorology, Earth Observations and Launch Vehicles had entered the operational stage.

The Satellite-based Communication Services (SATCOM) Policy of 1997 and the Remote Sensing based value added services envisaged opening of the space industry to the private sector. Therefore it was considered timely and appropriate to commission a study on the economic aspects of the Indian space program through the Madras School of Economics (Sankar 2006a; 2006b; Sankar et al. 2003).

7.1 Space Expenditures

Accumulated space expenditures since inception to the last fiscal year ending on March 31, 2006 amounted to US$ 7 billion. These expenditures category-wise are given in **Fig 4**.

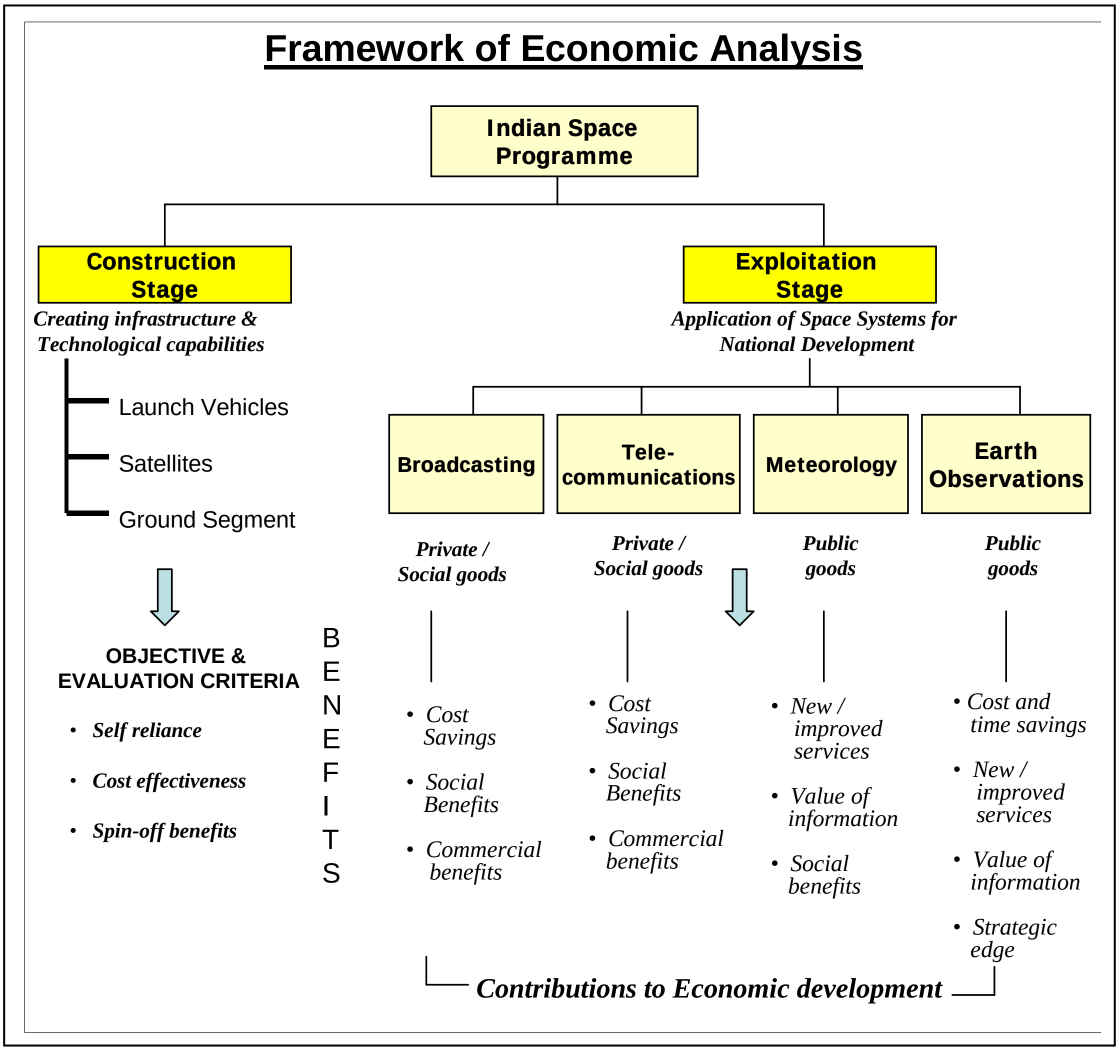


As is obvious from the figure, 39% investment is on launch vehicles, 36% on Satellite communications and meteorology, 14% on earth observations, 6% on space sciences and the balance on other items. About three-fourth of the total expenditure was incurred towards development of technology in the case of launch vehicles, whereas in the case of satellite communications, meteorology and earth observations, three-fourth of the investment is for building operational systems based on service needs of the country.

The space expenditure of India as a percentage of gross domestic product (GDP) today stands at 0.09% . Compared with the current annual government space budgets of US $2.5 billion for Japan, and US$1.5 billion for France, India's space budget is US$0.60 billion.

7.2 Methodology

For the purposes of economic analysis, it is useful to classify space activities into two stages, namely, (i) design, development, testing, manufacturing and launch of spacecrafts into desired orbital slots (construction stage), and (ii) applications of satellite services to different uses (exploitation stage). The output basket of the space program contains a mix of private goods, public goods, social goods and strategic/incommensurable goods. Research in space sciences, most meteorological services and information are public goods. Equity considerations are important in provision of certain goods e.g. access to public telephone, access to radio and TV. The social goals dominate in public sector radio and TV programs. Use of the space program as an instrument for guaranteeing strategic, political, scientific and economic leadership yields strategic and incommensurable benefits. The methodology adopted for the two stages, category-wise, is given in **Fig. 5**.



Regardless of the nature of goods / services provided and whether it is produced by a public firm or private firm, cost minimization is a valid criterion. The economic costing methodology requires (i) a rational basis for allocation of costs among the payloads of a multi-purpose satellite (ii) apportionment of common and joint costs amongst various ongoing programs of the organization / institution (iii) investment expenditure, their time pattern and cost of capital and (iv) output streams, their time pattern and discount rates for present value.

The global market for communication transponders is generally competitive with many private and public suppliers and many customers buying the transponders. Government induced market distortions are relatively less in this market. Hence, the international market prices can serve as a benchmark for assessing the cost effectiveness of INSAT transponders. A detailed study on economic costing of INSAT transponders with 10% cost of capital on investments and 5.5% discount factor on future returns has brought out the cost advantage of INSAT transponders by at least 25% of the prevailing international prices. The cost performance of INSAT system has been considered to be commendable keeping in view the relatively high capital cost in India and the dependence on some foreign components in the production of the satellites.

A comparative analysis of remote sensing satellites and launch vehicles is rather difficult due to non-availability of reliable estimates of the costs of foreign systems and also due to differences in capabilities. However, preliminary estimates show that the costs of Indian Remote Sensing Satellite (IRS-1D) is very much lower than the reported costs of similar LANDSAT and SPOT satellites. Similarly, the development cost of India's PSLV and GSLV is US $1.3 billion as compared to about US $ 4 billion for the European Ariane 1 to 4, though there are some capacity variations in these systems.

7.4 Exploitation Stage

For measurement of the benefits, the role of satellite technology is considered under three different categories: (a) where the technology is unique, (b) where the technology is a substitute to existing technologies, and (c) where the technology is complementary to existing technologies. In the second case, one can measure cost savings due to satellite technology compared with the existing technology. If the technology is superior to the existing one, one has to estimate the incremental value of the improvement. Where the space technology is used in conjunction with many other technologies, one has to rely on a cost allocation procedure or a benefit sharing method or on expert opinion to estimate the benefit attributable to the space technology.

The INSAT system has played a key role in augmenting Broadcasting, Telecommunications and Meteorological services in the country and has contributed immensely to economic and social development. Satellite communication technologies are terrain and distance independent and they enable governments to achieve goals such as the development of backward and remote areas at low costs and in a short time and thereby achieve technological leapfrogging.

7.4.1 Television

The Major benefits of the INSAT system to Doordarshan (public TV) are expansion in area coverage from 14% in 1983 to 78% in 2005, population coverage from 26% in 1983 to 90% in 2005, increase in the number of channels from 2 to 32, remote area coverage, satellite news gathering, dissemination of weather and cyclone warning and use of TV as a media for training and education.

A detailed analysis show that for enhancing the population coverage further from 90% to 100% with the distribution of a bouquet of 20 DD channels by the public broadcaster Doordarshan, the capital cost and annual operating cost through terrestrial technology is Rs.34560 million and Rs.5184 million respectively while a satellite based solution with direct reception at homes, would involve a capital cost of Rs.6380 million and annual operating cost of Rs.357 million. Thus, given the unique physiographical feature of India, the satellite communications is the least-cost option for achieving 100% population coverage.

The growth of satellite TV has also aided in the emergence of new economic activities. The advent of satellite TV contributed to the growth of several industries like the manufacturing of TV sets, cables, receiving antenna and other equipment and program production. There are about 100,000 cable TV operators and about 35 million cable TV households in the country. The gross earnings of cable TV operators is nearing Rs. 10 billion.

7.4.2 Telecommunications

Remote area communication is an important objective of public policy. There is considerable cost savings due to use of satellite technology compared with the alternative of optical fiber cable network in remote area communication. The cost of connecting 393 remote areas, currently served by INSAT, by optical fibre cable would be Rs.23580 million while the comparable cost for satellite technology would be Rs.10460 million. It may be noted that there are 30,000 remote villages of similar nature needing connectivity. The other uses of satellite technology are: alternative media back up for terrestrial services, business communications, portable terminals for disaster management, Tele-medicine and Satellite Aided Search and Rescue.

Apart from the cost saving, there are many external benefits which are diffused economy-wide. In case of Andaman and Nicobar (AN), rapid expansion of telecom since the mid-nineties facilitated the integration of AN with the mainland thereby boosting the growth of industry, trade and tourism and raising the growth rate of gross state domestic product to more than 8% .

7.4.3 Meteorology

Satellites have made significant contributions to the generation of meteorological information by extending observation to oceans and remote areas on land, enabling generation of new types of observations, facilitating new concepts of data assimilation into models, reducing costs of a few types of observations and enhancing the reliability of certain types of data.

Meteorological services are recognized as public goods. The major contributions of satellite technology are in the areas of weather technology (cloud motion vector, wind-sea surface temperature and outgoing long wave radiation) and tropical cyclone (identification of genesis and current position, intensity of change and transmission of cyclone warnings). A comparative study of 1977 (before INSAT) and 1990 (after INSAT) cyclones which hit Andhra Pradesh, shows that even though the two cyclones are similar, due to the successful tracking of the cyclone in 1990 with the INSAT imaging instrument (VHRR) and the success of preparatory steps taken by the government, the loss of lives in 1990 was only 817 compared with 10,000 in 1977. This is an important incommensurable benefit of satellite technology.

7.4.4. Remote Sensing

The advantages of remote sensing are synoptic coverage, multi-spectral capability, multi-temporal capability and digital capture of data. Remote sensing technology is being used in three different situations. It is an exclusive tool for estimation of snow melt run-off, rapid assessment of areas affected by natural disasters, identification of potential fishing zones in offshore areas and mapping of inaccessible areas. It is a substitute tool to conventional methods in mapping of land use, waste lands, and urban land use; preparing ground water prospect maps, watershed development plan, coastal zone management plan etc; and in monitoring forest cover, urban sprawl, status of environment etc. It is a complement in cases like area and crop forecasting and urban development plans. Its advantage is that it yields unbiased, timely and enhanced information. Based on case studies of applications of remote sensing in India's development programs, Table 3 provides estimates of investments, direct returns, and economic benefits.

Apart from the major benefits enumerated above, the policy of self-reliance has also enabled internal competence building and technology development and spin-offs to non-space sectors. For example, the spin-off outputs till 2005 include 224 Technology Transfers, 165 patents, 10 trademarks and 17 copyrights. ISRO has nurtured a symbiotic partnership with more than 500 Indian firms. The flow of funds to industry currently is about 40% of the space budget. This partnership has generated significant spin-off effects to the industries in terms of improved manufacturing processes, quality control and management practices.

8. Concluding Remarks

Space, in India, has become deeply intertwined with many facets of the national developmental endeavour. As we continue into the 21st Century, the relevance of space as demonstrated by India is becoming even more applicable to a large number of countries across the world, faced with the daunting problems of development and improving the quality of life. Further, the growing role of space in addressing issues of environment and sustainability of development as well as in the formulation of the related policies, treaties and conventions adds to the importance of this endeavour on a global scale (Kasturirangan 2004b). It is in this context that I thought it worthwhile to provide a model for organizing space research activities addressing particularly the peculiar problems of a developing country. Our approach to growing a world class space program highlights the fact that bold and imaginative adoption of new technologies to accelerate the process of development is realistic even with modest investment. Space, thus is well within the reach of the developing world, and even more important could be a sustainable endeavour. What is needed is a vision, forward looking leadership and above all the political will. I hope the pragmatic approaches, elucidated here, will serve to inspire embarking on such an exciting and meaningful venture by countries not touched by its innovative consequences.

Table 3: Investments and Benefits in Remote Sensing

A.	*Investments*	Rs. Millions
	Operational Missions	10,080
	Data Reception, Processing and Applications	5,540

B.	*Direct Returns*	
1.	Returns from sale of Satellite Data and Value Added Products by NDC	1,600
2.	Returns from ANTRIX through access fees and royalty	600
3.	Opportunity cost (Cost of foreign satellite data equivalent to IRS data used).	~ 5,000
4.	Cost saving due to value addition	~ 12,000
5.	Cost saving due to mapping using RS data	~ 11,000

C.	*Economic Benefits*		Rs. Millions	
	Program	Nature of Benefit	Estimate from Case Studies	Potential Benefit to the country in the Long-run
1.	National Drinking Water Technology Mission	Cost saving due to increase in success rate	2,560 (5 States)	5,000 – 8,000
2.	Urban Area Perspective / Development / Zonal / Amenities Plan for Cities / Towns	Cost saving in mapping	50.4 (6 Cities)	16,000 – 20,000
3.	Forest Working Plan	Cost saving in mapping	2,000 (200 Divisions)	11,860
4.	Potential Fishing Zone Advisories	Cost saving due to avoidance of trips in non-PFZ advisories	5,450	16,350
5.	Wasteland Mapping: Solid Land Reclamation	Productivity gain	990 (UP)	24,690
6.	Integrated Mission for Sustainable Development: Horticultural Development in Land With and Without Shrub	Gross income	Rs.0.20 to 0.40 (per hectare)	13,000 – 26,000
7.	Bio-prospecting for Medicinal Herbs	Value of Indian life saving drugs		800

Note: 1US $ = Rs. 45.

Turning the spotlight again on India and her dreams to transform herself into a developed nation in the very early part of 21st century, it is pertinent to note that the mix of strategies and planned approaches evolved so far by Indian space program have the potency to fire a powerful vision of future space endeavours. In its core part, this vision will continue to orient space activities towards societal needs such as education, health services, sustainable management of resources and environment, disaster management support and so on, possibly with new generations of thematic satellite constellations.

Further, it could embrace new steps for expanding the horizons of knowledge through front ranking missions for space exploration in a way that strengthens international cooperation. Future space missions will also be strong instruments for new advances in technology bringing in new synergies such as those between air and space, energy and matter, and living and nonliving objects. Our vision has to cater to younger generation, whose population will be over one half of a billion, for technological leadership, environmental stewardship and economic prosperity (Kasturirangan 2004c). While the strategic framework of the Indian space endeavour will evolve further in response to the changing environment India could even leverage space capabilities in bringing greater global integration in many other human endeavours. It is important to recognize the values that gave those strategies potency and vitality. Striving always to keep Space relevant to the public, transparency, accountability, drive for excellence, cost-effectiveness and team culture are the backbones of the strategy. They are responsible for the success of the Indian Space Enterprise and indeed for effectiveness of its strategic thinking and planning.

Before I conclude, it is appropriate to recall the extraordinary directions provided by the successive leaderships of the organization; M.G.K. Menon, Satish Dhawan and U.R. Rao; scientists with vision and deep understanding of the role of technology in national development. The culture of team spirit is a special attribute of the space program. We recall with pride the yeoman contributions made by our present President H.E. Dr A.P.J. Abdul Kalam in creating and nurturing this culture when he headed the India's prestigious first launch vehicle project SLV3. The success story of space program is also a tribute to the sustained enthusiasm, dedication and hard work of men and women of ISRO/DOS and other cooperating agencies.

To all of them and to the political system symbolized by the late Shri K.R.Narayanan, we owe the credit for touching the lives of millions of people towards a sustainable improved quality of life.

References

Dhawan, S., 1983, "Space and Industry", Shri Ram Memorial Lecture, New Delhi, February 7.

Dhawan, S., 1985, "Application of Space Technology in India", Aryabhatta Lecture, Indian National Science Academy, August 2.

Dhawan, S., 1988, "Prospects for a Space Industry in India", Lala Karamchand Thapar Memorial Lecture, New Delhi, February 26.

Gupta, S.C., 2006, "Growing rocket Systems and the Team", Prism Books Private Limited, Bangalore.

ISRO Report, 1972, Seminar on "Indian Program for Space Research and Applications", August 7–12.

Kale, P.P., and William, F., Sarlez (Jr), Cochairs, 1971, "INSAT Satellite Systems" study by MIT and ISRO, published by ISRO.

Kasturirangan, K., 2001, "Space: An Innovative Route to Development", 4th JRD Tata Memorial Lecture, Assocham, August 31.

Kasturirangan, K., 2004b, "Environment from Vantage Point of Space", Third Darbari Seth Memorial Lecture, New Delhi, August 19.

Kasturirangan, K., 2004c, "Space — A Vision for the Next 25 years", 40th Founder Memorial Lecture, Sriram Institute for Industrial Research, New Delhi.

Kasturirangan, K., 2004a, “Space Science in India — Two Recent Initiatives”, Sir Jagdish Chandra Bose Memorial Lecture, delivered at the Royal Society, London, December 14.

Kasturirangan, K., and Fracois Becker, Cochairs, 2004, “Space to Promote Peace”, IAA Commission — V Study’ Group Report, Paris, September.

Logsdon, John M. (ed.), 2001, “Exploring the Unknown”, selected Documents in the History of US Civil Space Program Vol. V: Exploring the Cosmos, the NASA History Series.

Narasimha, R., and Kalam A.P.J., (eds) 1988, “Developments in Fluid Mechanics and Space Technology”, Dedicated to Satish Dhawan, Indian Academy of Sciences, Bangalore.

Rao, U.R., 1995, “Space Technology for Sustainable Development”, Tata McGraw Hill Co., New Delhi.

Sankar, U., 2006b, “The Indian Space Program: An Exploratory Analysis”, to be published by Oxford University Press”, New Delhi.

Sankar, U., 2006a, Private Communication.

Sankar, U., et al., 2003, “Economic Analysis of Indian Space Program: An exploratory study”, Madras School of Economics, Chennai, November.

Sarabhai, V.A., 1966, Sources of Mans Knowledge, National Program of Talks Series, “Exploration in Space”.

Sarabhai, V.A., 1979, “Sarabhai on Space”, A collection of writings and speeches, ISRO, Bangalore.

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