History of Rocketry and Astronautics

Proceedings of the Thirty-Fourth History Symposium of the International Academy of Astronautics

Rio de Janeiro, Brazil, 2000

Otfrid G. Liepack, Volume Editor

Donald C. Elder, Series Editor

AAS History Series, Volume 30

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 20

AAS Publications Office
P.O. Box 28130
San Diego, California 92198

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 2009

ISSN 0730-3564

ISBN 978-0-87703-549-7 (Hard Cover)
ISBN 978-0-87703-550-3 (Soft Cover)

Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198
Web Site: http://www.univelt.com

Printed and Bound in the U.S.A.

Chapter 4

Indian Space Endeavors: A Historical Perspective*

K. Kasturirangan, K. R. Sridhara Murthi, Mukund Rao, M. Y. S. Prasad and G. Madhavan Nair†

Introduction

Indian space efforts had their modest beginnings in 1962, under the aegis of the Indian National Committee for Space Research, and subsequently, the Indian Space Research Organization (ISRO), which was formed as an autonomous body. The history of ISRO during the past three decades represents a saga of intense development in the areas of space systems design and engineering, integration of mission management, and ground segment development. One of the hallmarks of this program is its strong orientation toward societal applications. The drive for developing state-of-the-art space systems emerged from a judicious blend of international cooperation and the vision of leaders for the application of advanced technologies to solve the problems of society.

ISRO has established a vibrant applications program, with modest budgets, through its constellations of Indian Remote Sensing Satellites, which provide data to Indian and global users, and the multipurpose Indian National Satellite System (INSAT) serving communications, broadcasting, and meteorological ob-

* Presented at the Thirty-Fourth Symposium of the International Academy of Astronautics, Rio de Janeiro, Brazil, 2000.

† The authors are associated with the Indian Space Research Organisation (ISRO), Antariksh Bhavan, New BEL Road, Bangalore, India.

servation needs. The Polar Satellite Launch Vehicle (PSLV) launched several Indian Remote Sensing Satellites in addition to small satellites of foreign countries. This was enabled by a step-by-step process of learning, experimentation, and operational use of space systems and by establishing an institutional framework for closely involving users, industries, and academic institutions, leading to several beneficial spin-offs.

This article describes the evolution of the space program of India and the emergence of ISRO as an institution of excellence with state-of-the-art facilities for designing, developing, and testing satellites and launching them with significant indigenous efforts. The article also traces the lessons learned through various missions and approaches to human resources development.

Historical Background

Indian interest in astronomy and cosmology has deep roots in its ancient culture. The description of planets and phenomena in the sky are found in ancient Vedic texts of India. Even in the pre-telescope era, there were astronomical observatories that were built in five cities by Raja Sawai Jaisingh (1686–1743). Later periods saw establishment of astronomical observatories in Chennai (1792) and Kodaikanal (1898). There was a long tradition of meteorological studies initiated by Colaba Observatory, set up in Mumbai in 1823, later followed by the India Meteorological Department, which came into existence in 1875. During the early periods following the discovery of the ionosphere, studies were undertaken on it at Calcutta University (1926). Cultural and institutional ambience combined with the initiative of individual scientists contributed to the growth of research in the field of the physics of the upper atmosphere and astrophysics in the first half of the 20th century.

In post-independent (after 1947) India, scientific activities received new impetus with the government's stated policy of harnessing science and technology for national development. The establishment of a large number of institutions and research laboratories was supported by the government. Under this new environment, research activities in areas such as Earth's environment, interplanetary space, solar physics, astronomy, and studies of elementary particles gained further momentum. The main institutions involved in these fields were the Tata Institute of Fundamental Research, Mumbai; the Physical Research Laboratory, Ahmedabad; and the National Physical Laboratory, Delhi. These institutions provided the nucleus for subsequent space science endeavors. By the early 1950s, the ground-based techniques for studying the ionosphere and magnetosphere were well developed, and balloon-borne payloads for study of the atmosphere were proven. The new opportunities that opened for *in situ* studies of the upper atmosphere, with the advent elsewhere of rockets and satellites, by 1960, naturally kindled the interest of Indian space scientists toward the use of rockets.

A turning point in the history of Indian space endeavors was the constitution of the Indian National Committee for Space Research (INCOSPAR) in 1962 under the leadership of Vikram Sarabhai, the gifted architect of the Indian space program. Just prior to this development, in 1961 the government of India entrusted the subject of the exploration of outer space for peaceful purposes to the Department of Atomic Energy (DAE). INCOSPAR was given the mandate by DAE to advise and help organize the Indian space program. It was the vision and the extraordinary capability of Dr. Vikram Sarabhai to bring together people—scientists, engineers and others—that created the foundation for the subsequent progress. A major development that occurred was INCOSPAR's decision to establish a sounding rocket range on the geomagnetic equator at Thumba, a village near Thiruvananthapuram, on the southern coast of India. This would enable scientists to study the upper atmosphere, and particularly, the phenomena associated with "equatorial electrojet," which was of great interest to the international scientific community. The study of the atmosphere in this region had a direct bearing on the better understanding of meteorology, which is of practical significance to India.

The sounding rocket program was initiated by collaboration agreements with the National Aeronautics and Space Administration (NASA) of the United States, French Space Agency (CNES) of France, and Hydrometeorological Services of the then Soviet Union. There was also a parallel ongoing program for the licensed manufacture of Centaure sounding rockets in India, in agreement with Sud Aviation of France. The sounding rocket range, known as the Thumba Equatorial Rocket Launching Station (TERLS) was developed as a United Nations sponsored facility to enable scientists from different countries to bring and launch their sounding rockets to study the upper atmosphere in the region. Beginning in 1963, scientists from several countries (including the United States, the then Soviet Union, France, Japan, the then Federal Republic of Germany, and the United Kingdom) utilized the TERLS facility for conducting rocket-based experiments. The administrative charge for Thumba establishment was formally entrusted in October 1963 to the Physical Research Laboratory (PRL) at Ahmedabad, which was also directed at that time by Sarabhai. The PRL was an autonomous society, supported by private foundations in addition to the government. This structure for carrying out the activities at Thumba combined the advantages of the support of the government and the flexibility of an academic-type institution. The formal dedication ceremony of TERLS was held on 2 February 1968 at Thumba with the august presence of then Indian Prime Minister Indira Gandhi and several international personalities.

Along with TERLS and the sounding rocket program, Sarabhai initiated a few important developments that later grew into major branches of Indian space endeavors, including satellites, launch vehicles, and large-scale societal applications. It was the conviction of Sarabhai that uses of outer space could be of immense benefit to developing nations wishing to advance economically and socially. He advocated a judicious blend of endogenous capacity building and international cooperation in the development and applications of advanced technologies for accelerating the socioeconomic development.

The foremost initiative in this direction was the establishment of a Space Science and Technology Centre (SSTC) in the vicinity of TERLS as approved by the Atomic Energy Commission in 1966. The center was given the task of developing expertise in aerospace engineering, sounding rockets of superior performance, and a modest satellite launcher. The center was also to deal with construction of scientific payloads and ground-based experiments supporting space research. A large group of engineers have been inducted in different disciplines relevant to space technology. A rocket propellant plant and rocket fabrication facility were also established. The first in the series of Rohini sounding rockets (RH-75) that were indigenously developed in these facilities was successfully flight tested in November 1967.

Another major initiative energized by Dr. Sarabhai was the development of a satellite Earth station in the early period after the advent of satellite broadcasting in the world. A project was initiated in the mid-1960s to set up an Experimental Satellite Communications Earth Station at Ahmedabad with the assistance of the United Nations Development Fund and the International Telecommunication Union (ITU). This station was set up in 1967, and served as a training facility for both Indian and international personnel, particularly from other developing nations. Subsequently, Indian engineers successfully built a bigger station (29-meter dish) for overseas satellite communications through the Intelsat system. Two other major initiatives for collaboration with NASA were triggered by Dr. Sarabhai: the use of satellites for instructional television for Indian villages and for early detection of coconut wilt disease, which affected a large number of plantations in Kerala, using a camera carried on a helicopter.

Setting Up the Indian Space Research Organization

A major milestone in the history of Indian space endeavors was the setting up of the Indian Space Research Organization (ISRO), on 15 August 1969, under the leadership of Dr. Sarabhai, by bringing together the nuclei of trained personnel in addition to activities in laboratories that were part of INCOSPAR. The activities in ISRO continued under the overall direction of PRL in Ahmedabad until the sudden demise of Dr. Sarabhai in December 1971. By this time, the goals and plans of ISRO, for the decade 1970–1980, were already articulated and documented. A document titled "Atomic Energy and Space Research: A Profile for the Decade 1970–1980" set forth the principal objectives of the National Space Program as follows:

> The principal objectives of the Space Program of India are to develop indigenous competence in designing and building sophisticated hardware involved in Space technology including rockets and satellites for scientific research and practical applications, the use of these systems for providing point-to-point communications, and a National TV hook up through a direct broadcast synchronous satellites and the application of satellites for meteorology and for remote sensing of Earth resources.*

Following Dr. Sarabhai's demise, Professor M. G. K. Menon took charge as chair of ISRO, and guided space activities for a brief period until the government of India constituted the Space Commission and set up the Department of Space (DOS) in May 1972. ISRO and PRL came under the fold of DOS Professor S. Dhawan when he was appointed chair of the Space Commission, Secretary of DOS, and chair of ISRO. The DOS is under the charge of the prime minister of India.

Subsequent to this reorganization, a new phase of consolidation and growth began in the organization, whose strength was about 3,000 people. Several smaller units located around Thiruvananthapuram (including TERLS, SSTC, Rocket Propellant Plant, Rocket Fabrication Facility, and the Propellant Fuel Complex) were integrated in 1972 into a large center called Vikram Sarabhai Space Centre (VSSC). Professor Brahm Prakash, a renowned metallurgist, was appointed as its director. He led VSSC during the crucial years of the development of India's first satellite launch vehicle, SLV-3, which was realized under the leadership of Dr. A. P. J. Abdul Kalam. The similar integration of various units at Ahmedabad resulted in the creation of the Space Applications Centre

---

* ISRO, "Atomic Energy and Space Research: A Profile for the Decade 1970–1980," Government of India, Atomic Energy Commission, 1970.

(SAC). Two further major organizational entities were created for (1) the development of a scientific satellite (at Bangalore) as a sequel to the collaborative agreement with the then Soviet Union in 1972 and (2) establishment of a launch range for orbiting satellites. In order to put Indian satellites into orbits, a location was identified at Sriharikota, which is an island off the east coast. Facilities for casting solid propellant in rocket cases, their testing and assembly, and other facilities for launch were taken up. The Sriharikota range was designated as a center by ISRO in 1976. In the same year, a prime center for satellite development was created out of the nucleus established in Bangalore for undertaking the first Indian scientific satellite.

Several initiatives in management were also undertaken in the 1970s. The ISRO Council was created, comprised of the directors of the ISRO centers, in addition to the civil servants attached to the secretariat of the DOS, thus providing a forum for participative management. The concept of project management and matrix organizations, involving both research and development and project activities, was implemented in the ISRO centers. The zero-based budgeting approach was adopted in ISRO before it was adopted elsewhere in the government. A National Natural Resources Management System (NNRMS) was evolved, with participation of several user ministries, to prepare for the operational use of space-based remote sensing data. Dhawan, during his tenure as chair from 1972 to 1984, consolidated the organization and laid a sound institutional framework for dealing with diverse elements of space endeavors involving resources, infrastructure, and activities and strengthening linkages of the program with government, academia, industry, and user entities.

Learning Phase

Experience gained through major projects in the 1970s can aptly be termed as a learning phase for the organization. Highlights are as follows:

The First Indian Satellite Launch Vehicle (SLV)

SLV-3 was India's first SLV, originally conceived in 1969, its development was approved in 1973 with the objective of launching a 40 kilogram satellite into near Earth orbit. This launch vehicle was comprised of four stages, all using solid propellants. In view of the scant industrial base at Thiruvananthapuram, industries in different parts of India were used to support the fabrication. By the mid-1970s, ISRO management made a conscious decision to involve national industries extensively in the space endeavor and promote spin-offs. The first experimental launch of SLV-3 took place in July 1979. This was only partially successful because of a jammed valve in the second stage control system. Three more successful missions of SLV-3 were conducted in 1980, 1981, and 1983, orbiting small satellites in the Rohini series, carrying technological payloads. With the successful launch of SLV-3 in 1980, India joined a select group of countries with the capability to launch satellites with their own launch vehicles.

Establishing Satellite Technology

Following an agreement between India and the then Soviet Union, for collaboration in the development and launch of a scientific satellite, a project was started in 1972 involving setting up facilities in the refurbished industrial sheds of Peenya in the suburbs of Bangalore. The project started with a few personnel drawn from the satellite systems division of SSTC, Thiruvananthapuram, and PRL, Ahmedabad, and new graduates from Indian universities were inducted later. Under the leadership of Professor U. R. Rao, the project made rapid progress, culminating in the successful launch, by a Soviet launch vehicle on 19 April 1975, of the Indian-built satellite carrying scientific experiments for study of stellar X-rays, neutron and gamma radiation from solar flares and ionospheric particles, and radiation. The satellite was named for the Indian mathematician and astronomer of the 5th century, Aryabhata. The satellite was controlled and operated by the station built in India.

Satellite Instructional Television Experiment (SITE)

SITE, which was a project undertaken by ISRO in collaboration with NASA, had objectives of: (1) developing, testing, and managing a satellite-based instructional television system; and (2) demonstrating the utility of satellite television for mass communications and instruction to remote rural communities. The project involved the beaming of educational and instructional television programs to 2,400 villages in six states, using the U.S. Applications Technology Satellite (ATS)-6 satellite. The programs were directly received by low-cost terminals developed by ISRO. Social evaluation of the impact of SITE was conducted by a team of 100 social scientists. SITE was conducted during August 1975–July 1976 under the leadership of Professor Yashpal, who was then director of SAC. Professor Chitnis, a close associate of Dr. Sarabhai, guided the project. Another important experiment, which was conducted using the Franco–German satellite Symphony, in collaboration with CNES and Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR), was the Satellite Telecommunications Experiment Project (STEP), which provided valuable experience in testing a variety of satellite ground terminals and techniques in digital communications.

Application Experiments in Remote Sensing

With the assistance of NASA, Indian scientists used aerial photography for the early detection of coconut wilt disease. Extensive aerial surveys were undertaken in collaboration with the Indian Ministry of Agriculture to survey and map agricultural fields in Andhra Pradesh and Punjab. Following the launch of the American Land Remote-Sensing Satellites (Landsat) in 1972, the data from the satellites was procured and used for developing several applications relating to natural resources management. Building a station for directly receiving data from Landsat was undertaken in 1978, under the aegis of the National Remote Sensing Agency, an institution supported by the Department of Science and Technology. Later in 1980 this institution came under the purview of the DOS.

Experimental Phase

The missions that were conceived during the 1980s can be broadly termed as the experimental phase. During this phase, space missions were conceived involving the totality of their design, development, testing, launch, and applications to society.

Bhaskara Missions

Immediately following Aryabhata, two Bhaskara satellite missions were conceived, whose spacecraft designs were modifications of Aryabhata but incorporated remote sensing payloads relevant for practical applications. The payloads were comprised of a television camera system, which could picture a 341 kilometer x 341 kilometer of ground area in a single frame, and a microwave radiometer system, which could study the sea surface temperature, ocean wind velocity, and moisture content. The two satellites were launched with Soviet collaboration and provided an excellent training ground for conceiving future operational missions in remote sensing. Several experiments in practical applications involving users were undertaken to evaluate the efficacy of data generated from a space platform.

Ariane Passenger Payload Experiment (APPLE)

While SITE and STEP experiments provided insights into the use of satellite communications systems for practical applications, including the design and development of ground hardware, India had no experience to build satellites operating in geostationary orbit for telecommunications. An outside opportunity was utilized, when the European Space Agency (ESA) proposed to launch a satellite without fee to assist with the developmental flights of the Ariane launch vehicle. The Indian proposal for launching its experimental communications satellite was accepted by ESA, and the Indian-built Ariane Passenger Payload Experiment (APPLE) was launched in 1981. This satellite was provided with its own propulsion system, which used a modified stage of an Indian launch vehicle to transfer it from an orbit in which the launch vehicle delivers to a geostationary orbit. During its operational life span of about two years, APPLE provided excellent learning value for satellite operations in this orbit.

Augmentation of Satellite Launch Capability

The program that tested the mettle of ISRO engineers was the Augmented Satellite Launch Vehicle (ASLV). Even as the SLV-3 program was being implemented, the development of ASLV was undertaken to augment the payload capacity of SLV-3 to 150 kilograms by adding two solid rocket boosters as strapons. Two ASLV missions were approved in 1982. The first two ASLV missions did not succeed, but they provided a wealth of data for understanding the behavior of the vehicle. This was vindicated by successful flights in 1992 and 1994. The Stretched Rohini Satellite Series-C2, launched by ASLV in 1994, carried scientific instruments to detect and study transient gamma-ray bursts for celestial sources and electrical characteristics of the ionosphere and thermosphere in low latitude regions.

PSLV is the major endeavor of the experimental phase of the Indian space program. The PSLV was initiated in 1982 to develop the capability to launch a 1-ton class of Indian Remote Sensing Satellites in polar Sun-synchronous orbits. PSLV used liquid propulsion stages with engines derived from French Viking engines, whose technology was transferred to ISRO by the French. The Liquid Propulsion Systems Centre was formed in 1987 out of the infrastructure and resources in VSSC to provide focus for growth in the area of technology and to support ISRO's launch vehicle and satellite projects. Apart from implementing lessons learned from ASLV, the PSLV project successfully assimilated several new elements in launch vehicle design, including improvements in navigation and guidance systems and a larger fairing to accommodate bigger spacecraft.

PSLV uses one of the largest first stage boosters, with a 129-ton load of solid propellants. The 44-meter tall vehicle weighs about 280 tons at lift-off. The first development flight took place on 20 September 1993. It was not successful in putting the IRS-1E satellite into orbit, as the flight suffered a malfunction in its early phase because of a software error. This limitation was overcome during a second flight, which took place on 15 October 1995 and orbited the 804-kilogram IRS-P2 satellite. After one more successful mission of PSLV, which launched the IRS-P3 satellite on 21 March 1996, PSLV was declared as an operational vehicle.

Toward an Operational Phase

As a developing country with a large population, India has several needs that are to be met by space systems. Most important among them are the enhancement of the telecommunications infrastructure, generation of reliable meteorological information for agriculture in addition to disaster management applications, and timely information on the state of natural resources, such as land, soils, forests, water bodies, and minerals. Such systems for providing operational services on a reliable and continuous basis have to be robust in design and should be state-of-the-art in technical efficiency. The overall management system should ensure optimal utilization of those systems. Taking over from Dhawan in 1984, until the end of his tenure in 1994, Rao led the transition of the Indian space program to an operational phase, spreading widely the impact of space applications in national life.

Indian National Satellite Systems (INSAT)

INSAT was conceived to meet, at a national level, the operational services for telecommunications, television broadcasting, and meteorological observations. Even as the experimental phase was continuing after SITE through STEP and APPLE projects, there were urgent and mature demands for these services in the country. Hence a deliberate decision was taken to procure from abroad the first generation INSAT systems comprised of four satellites. The project for the first two satellites in this series was approved in 1977. It was also decided that the development of second-generation spacecraft would be undertaken in India, incorporating necessary upgrades, which would be relevant when they entered into service.

A unique management system was established for the INSAT program involving the user ministries/departments, such as telecommunications, information and broadcasting, and science and technology to plan and guide the program, at the same time ensuring the commitment of the users to the system. The design of the INSAT system was innovative in the sense that it combined multiple services including meteorological observations in the same spacecraft to achieve overall economy. These satellites also permitted warning of impending cyclones, by tracking their movement, to populations living on the coastal zones. The first generation satellites were built in the United States to ISRO specifications and were launched by the United States with European launchers. Beginning with INSAT-1A, which was launched in April 1982, this series continued services through INSAT-1D, which was launched in June 1990. A dedicated facility (Master Control Facility) was created at Hassan, a town 180 kilometers west of Bangalore, to control and maintain INSAT satellites in orbit. Only two of first generation INSAT satellites provided services through the entire intended operational life, thus demanding the earliest possible induction of the second-generation INSATs. A project for four satellites in the INSAT-2 series was approved in the mid-1980s and one more satellite, INSAT-2E, was approved later. These satellites have been built by ISRO and launched by Europe's Ariane launcher during the period 1992 through 1999. These satellites were designed to incorporate higher capacity and superior performance capabilities than those of the first generation. INSAT-2 satellites allowed further diversification of services through the use of new radio-frequency bands for communication, mobile services on an experimental basis, search-and-rescue warning, and coverage characteristics extending beyond Indian territories. Part of the capacity in the INSAT-2E satellite was also leased by the Intelsat organization for telecommunications services in the region.

As the capacity of the INSAT system was steadily augmented making it one of the largest domestic satellite systems in the world, the demands for services had also been growing rapidly. These are planned to be met through third-generation systems, which are currently under development. In addition, one of the satellites in the second generation, INSAT-2D, had a premature termination of services soon after its launch in June 1997, because of a massive power short in orbit. In the third generation, INSAT-3B was launched. The Indian government also announced a policy to promote private sector role in establishing Indian satellite systems for telecommunications.

Operational Remote Sensing Programs

Following the successful implementation of the experimental missions of the Bhaskara satellites, a bold step was taken to close the gap between those satellites and contemporary operational satellites in the world. This logically led to the realization of the Indian Remote Sensing Satellite, IRS-1A, in 1988. Compared to Bhaskara, considerable improvement was achieved in every aspect of the satellite mission, namely the orbit and attitude control, the spatial and spectral resolutions of payloads, in addition to reliability aspects needed for an operational mission. Subsequent to IRS-1A, more satellites, IRS-1B, IRS-P2, IRS-1C, IRS-P3, and IRS-1D, were launched in 1991, 1994, 1995, 1996, and 1997, respectively. These missions, together with those planned in the future, form the strong base of India's achievements in satellite remote sensing, in terms of providing continuity of services, integrating the advancements in technology in tune with the contemporary global developments, and establishing a leading position by virtue of operating a constellation of state-of-the-art remote sensing satellites serving the global community. India has also established a strong applications program, which took the technology of outer space to a grassroots level development.

A major dimension in the Indian remote sensing program was to add ocean-sensing capability through a dedicated mission, IRS-P4 (Oceansat), which was launched on the PSLV-C2 flight of 25 May 1999. It carried state-of-the-art sensors for the study of biological activity in oceans, for generating information on fisheries, and deriving information on wind speeds, sea state, and water vapor in air, which have relevance to weather forecasting.

The vibrant remote sensing satellite program is planned to grow further through more advanced satellites with improved capabilities for information generation. IRS-P5 (Cartosat) aims to provide data with a higher resolution for cartographic and precision applications, while IRS-P6 (Resourcesat) provides multispectral information on resources with higher resolution than present systems in IRS-1C and IRS-1D.

Commensurate with the developments in satellite technology and data availability, considerable progress has been made toward effective utilization of the data for various applications. Since the days of macro-level assessment of coconut wilt disease using a Hasselblad camera, remote sensing applications have come a long way in their efforts toward sustainable resources management. Today this technology has been operationalized to cover diverse themes/areas, such as forestry, agricultural crop acreage and yield estimation, drought monitoring and mitigation, flood monitoring and damage assessment, land use/cover studies, wasteland identification and reclamation, water resources development and management, groundwater targeting, marine resources survey, urban planning, mineral prospecting, environmental impact assessment, and so on, thus encompassing almost every facet of sustainable resource development and management.

The gradual transformation of the applications system, in pace with the capabilities provided by technological advances, is another facet of creating successful models for integrating high technology for the development process. This transformation process itself is a result of a whole gamut of initiatives involving creation of an institutional and management framework (which integrates user needs and inputs), establishment of an application infrastructure (which is well distributed), development of trained human resources at the user end, forging a strong linkage with academic institutions, and taking steps to promote private entrepreneurship in value-added services. The transformation process is also characterized by the efforts, on the one hand, to bring in synergy among technology generators, local administrators, the NGOs, and the ultimate beneficiaries and, on the other hand, integration of various aspects of information generated by remote sensing with conventional and collateral information through the use of modern computer-based tools, such as geographic information systems.

Operational Program for Launcher and Development of the Geosynchronous Satellite Launch Vehicle (GSLV)

Subsequent to two developmental flights of PSLV, which launched the IRS-P2 and IRS-P3 satellites, the first operational flight of the vehicle was used to launch IRS-1D, India's most advanced remote sensing satellite, on 28 September 1997 to continue and complement the services of its predecessor IRS-1C. The subsequent launch of PSLV, in addition to carrying Oceansat, successfully launched two small commercial satellites from Korea and Germany. PSLV's role for launching satellites, in low Earth inclined orbits and polar orbits, will continue because of the demands of Indian remote sensing and scientific satellite programs in addition to commercial launch demands from other countries.

The gap in launch capability to launch communications and weather satellites in geostationary orbits was addressed through the GSLV project, which was approved in fiscal year 1990–1991. While it could use several systems developed for PSLV effectively, it also needed an efficient upper stage working on cryogenic fuel. In order to reduce overall lead time for the vehicle, it was planned to import technology and a few stages for use in initial flights. An agreement was signed with Glavkosmos, Soviet Union, in 1991 for this purpose. However, it was modified in 1994 to exclude technology transfer aspects as Russia cited force majeure conditions. An indigenous project to develop cryogenic upper stage was initiated to sustain future GSLV flights. The first developmental flight of GSLV was envisaged for fiscal year 2000–2001.

International Cooperation

India actively pursued cooperation in exploration and peaceful uses of outer space with several advanced and developing countries. While the international cooperation has assisted in contributing to the building of Indian capacity, the partners have also benefited from the commercial opportunities created by expanding Indian space projects, their launch service needs, and a wide range of applications.

India has been actively participating in international forums related to space, including ITU, the United Nations Committee on the Peaceful Uses of Outer Space, the International Astronautical Federation, the Committee on Space Research, the Committee on Earth Observing Satellites, and others. Dr. Sarabhai was the vice president and scientific chair for the first United Nations Conference on Exploration and Peaceful Uses of Outer Space (UNISPACE) held in Vienna in 1968. Prof. Yashpal was secretary-general for UNISPACE-82, while U. R. Rao was elected president of UNISPACE-III, held in 1999. Subsequently, at UNISPACE-82, India implemented a program for sharing its experience in space applications, under which more than 50 persons from other developing countries were assisted to gain hands-on experience in Indian space centers. India also hosted a United Nations affiliated Centre for Space and Technology Education in Asia and in the Pacific regions. Through a collaborative arrangement between ISRO and the German agency, Deutsches Zentrum für Luft- und Raumfahrt (DLR), the Indian IRS-P3 satellite carried a German instrument, the Modular Electro-Optic Scanner, which is a hyperspectral camera for observation of the ocean surface.

Preparations for a joint Indo–French mission for the study of tropical climate parameters are underway. India also exchanges its meteorological satellite data with the United States and a few other countries. As the process of globalization is unfolding in several aspects of exploration and the use of outer space for peaceful purposes, India is constantly renewing its role to promote the beneficial aspects of space for humankind.

Enabling Commercialization

As the practical applications of space began to grow, the commercialization of several space activities has grown apace. Antrix Corporation was created in the early 1990s as a marketing arm of the Department of Space to promote the commercial sale of space products and services from ISRO and Indian industries. The major activities of Antrix include international marketing of data from Indian Remote Sensing Satellites in alliance with Space Imaging, Inc., of the United States. Antrix also marketed satellite components, launch and early orbit phase support (LEOP), and launch services for small satellites on PSLV. Several industries in India are encouraged to participate in space activities through technology transfer, long-term vendor relationships, and support for value-added services.

Conclusion

Modern space endeavors in India are more than four decades old. ISRO and the Department of Space now employ about 17,000 people, and their annual budget is in the range of $400–450 million. India has launched 30 Indian satellites, so far, and 13 of these with its own launchers. Two foreign satellites were also launched by Indian launch vehicles.

Starting on a modest scale in the early 1960s, the India space program has come a long way, maintaining its emphasis on indigenous capacity building and pursuing applications relevant for society. This focus for practical applications in the context of national needs, combined with political support, ensured the sustainability of the program. The history of this endeavor during the past four decades is full of exciting events representing a saga of committed efforts to realize the vision of the application of advanced space technologies for national development. This history is full of lessons and provides inspiration for building the future. It was not possible to mention in a short article like this the names of several people who made extraordinary contributions to the program. Similarly, a number of illustrious personalities in the international space community assisted in several ways. Their endeavor, however, has created a culture valuable for multidisciplinary interaction and team effort, which allows the continued development of space for the benefit of India and the global community.