

## FOUR DECADES OF INDIAN LAUNCH VEHICLE TECHNOLOGY

G Madhavan Nair\*

### Introduction

I am extremely happy to be with you this evening and feel proud and honoured to have the opportunity to deliver the Neelakantan Memorial lecture organized by the Aeronautical Society of India on the occasion of the Centennial celebration of the 'First engine-powered heavier-than-air aircraft flight by the Wright Brothers'.

Dr Neelakantan, the founder Director of the National Aerospace Laboratory was a great visionary. He built institutions and facilities far ahead of their time whose relevance and importance grew more and more as the future unfolded. It is the vision of such great scientists like Dr Neelakantan and Prof Satish Dhawan, which led to formulation of the aeronautical and the aerospace agenda for our nation. The Aeronautical Society itself was largely the result of Neelakantan's untiring efforts and sound organizational skills, which has emerged instrumental in invigorating the aeronautics community.

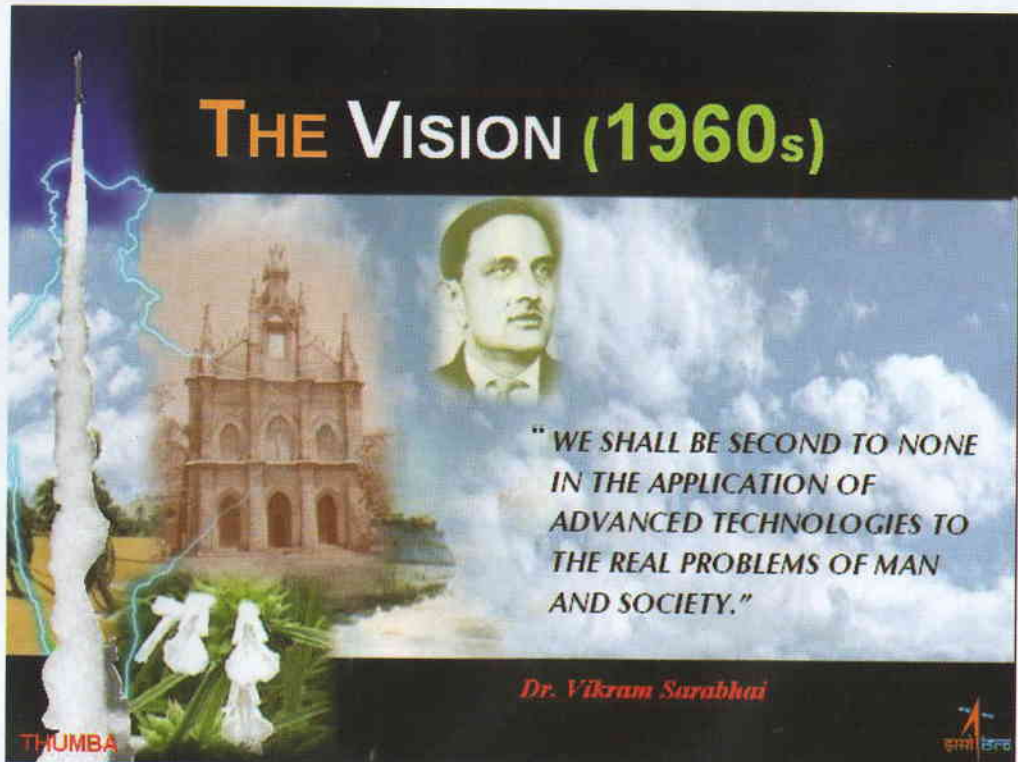
In the last forty years, as the progress in the area of aeronautics was flowering by way of a setting up of various institutions, our country also nurtured its space programme. It all started when sounding rocket experiments were initiated by Dr Vikram Sarabhai, the founding father of our space programme, in the Southern tip of India, Thumba near Thiruvananthapuram for investigation of the upper atmospheric and

ionospheric phenomena associated with electro jet over the geomagnetic equator. He also formulated a vision statement that :

**"we shall be second to none in the application of advanced technologies to the real problems of man and society"**

This vision is the driving force for the Indian space programme and has translated into vision - mission - project mode of functioning leading to development of cutting edge technologies, creation of Centres of excellence, harnessing of human resources and development of institutional framework. Present day ISRO is the result of all these.

Though the sounding rocket program began with the launching of foreign Nike-Apache and Centaur rockets



\* Chairman, Indian Space Research Organisation / Secretary, Department of Space  
Text of the Neelakantan Memorial Lecture delivered at the 55<sup>th</sup> Annual General Meeting of the Aeronautical Society of India, on 17<sup>th</sup> December 2003, Bangalore, India

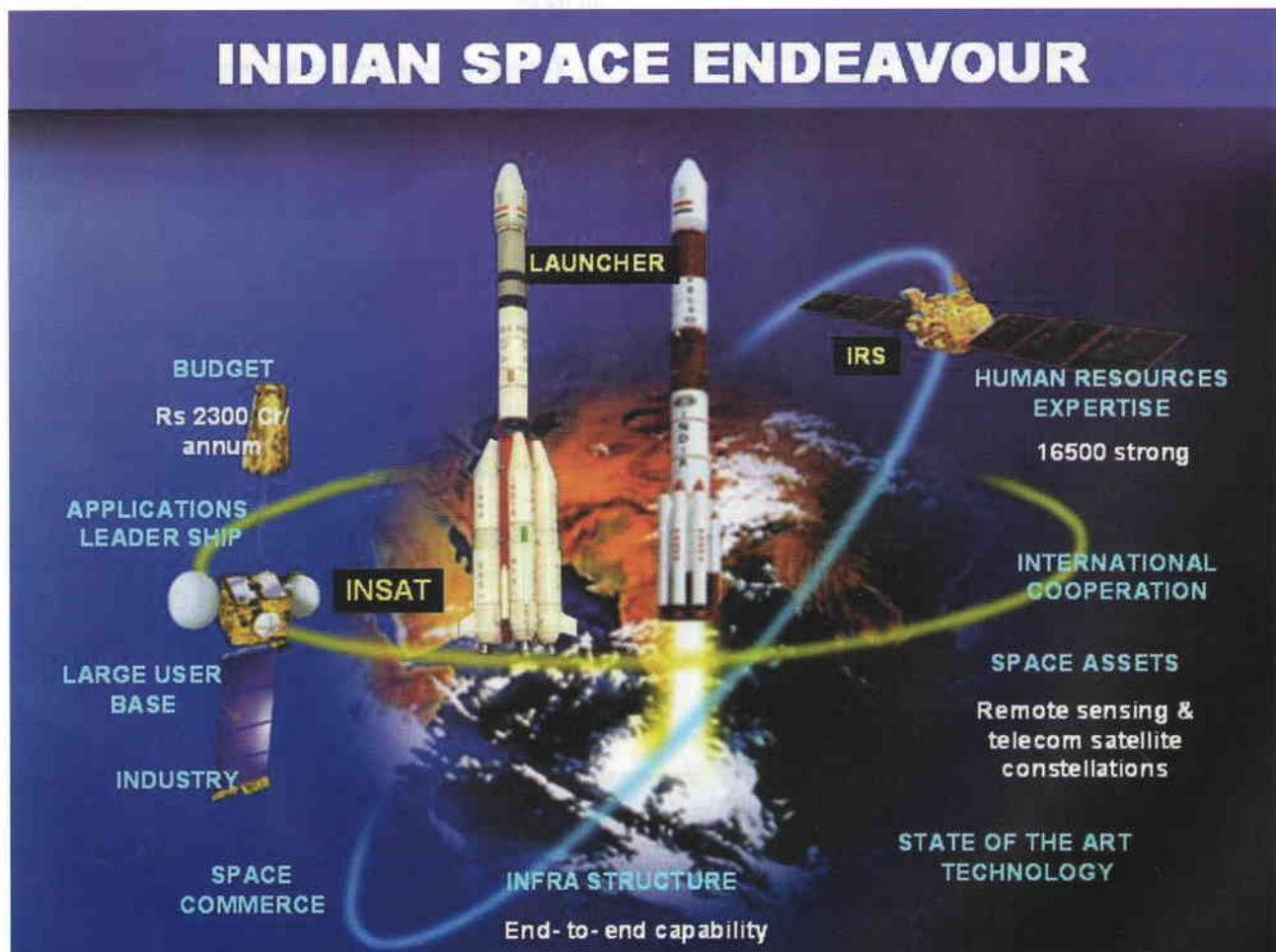
with international participants under the aegis of the United Nations, the Indian Space Research Organisation (ISRO) also in parallel started development of indigenous sounding rockets. Today, we are proud to have a range of Rohini rockets from 75 mm to 560 mm diameter with capability to loft from 10 to 100 kg payload to an altitude up to 550 km. Till date, more than 4000 sounding rockets have been launched including those from US, the erstwhile Soviet Union, France and others. Recently, our rocket, RH-300 has also been flown by the Norwegian Space Agency for conducting scientific investigation of upper atmosphere in the North Pole region.

### Indian Space Programme - A Glimpse

Indian Space programme is unique and one of the largest of its kind today providing end-to-end solution to our national development. It comprises of three segments i.e. INSAT and IRS series of spacecraft catering to communication/TV Broadcasting, Remote sensing, applica-

tion programme based on space based systems as well as multi stage rockets to access space.

The Indian National Satellite system, INSAT is one of the largest domestic communication satellite systems with a present complement of 6 satellites providing services through nearly 130 transponders. The exclusive meteorological satellite KALPANA-1, has enhanced the INSAT system for meteorology. While INSAT system continues to provide regular services in the areas of telecommunications, business communication, broadcasting and meteorological services, several initiatives have been taken to expand the application of INSAT to new areas. An important initiative is in the field of Tele Medicine, which enables expert consultancy of specialised doctors from cities to patients in remote areas. In the field of education, a dedicated EDUSAT will be launched during 2004 for providing virtual classrooms in remote areas. Use of INSAT for e-governance and developmental commu-





nication is also fast expanding. The INSAT system has extended the outreach to less accessible areas like North-East and far flung islands.

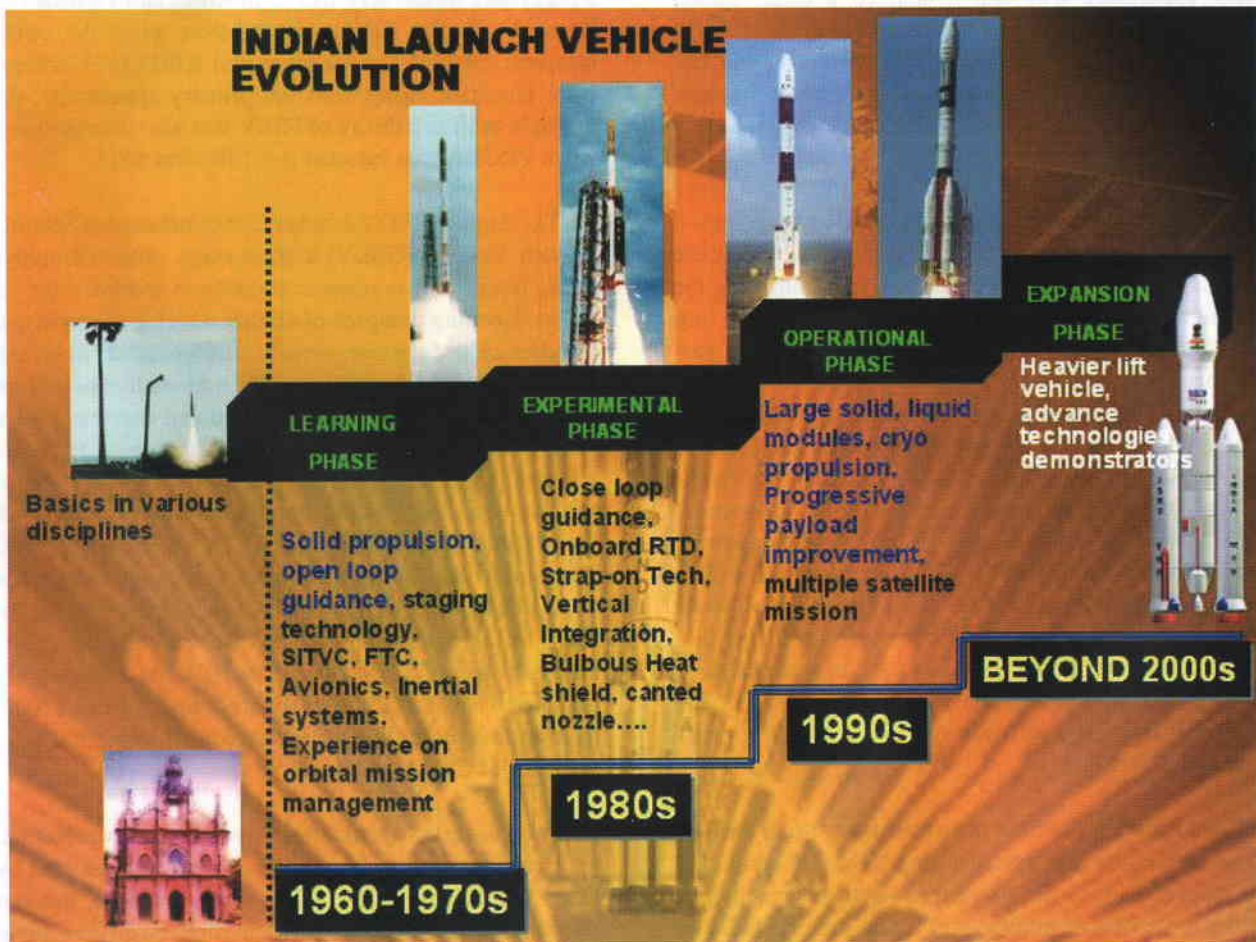
The Indian Remote Sensing Satellite system, IRS has the largest civilian constellation of earth observation satellites today providing data in variety of spatial resolutions and spectral bands. The data is used for various applications in the fields of agriculture, forestry, ground and surface water, drought assessment and monitoring, flood mapping, land use and coastal studies. The data from the Indian Remote Sensing Satellites are also utilized by worldwide ground stations providing commercial benefits.

Initial launches of IRS and INSAT were carried out with procured launch vehicles. Considering the need for achieving self-reliance and possibility of launch denials in case of critical applications, ISRO has initiated a programme for development of rocket systems. Such tech-

nologies were not available from any quarter and thus it demanded setting up of laboratories and putting our own efforts in developing solid propellant and liquid propellant rockets integrating them with control, guidance and navigation systems as well as well as evolving the launch sequence and mission management plan. I am happy to say that, today, we have totally realized them and have a set of launch vehicles, which has enabled India to achieve self-reliance in launching IRS and INSAT class of spacecrafts.

**Evolution of Launch Vehicles**

Sounding rockets provided the necessary technological capability in solid propellants. Applying this to larger multi stage rocket systems led to the development of India's first launch vehicle in SLV-3 (Satellite Launch Vehicle) with 40 kg in low earth orbit. SLV-3 programme resulted in significant developments in multiple disciplines of rocketry and gave the confidence to take up



projects of greater complexities. The intricacies of launch vehicle technology were learnt through three successful launches of SLV-3 during 1980-83. Though the very first flight conducted in the year 1979 was not successful, it provided the required insight into design and development of multidisciplinary launch vehicle systems, various interfaces like launcher to spacecraft, launcher and launch complex operations, establishing tracking, telemetry and command networks etc.

Considering the need for higher payload capability for scientific experiments and to achieve such a mission within the shortest possible time, a configuration of Augmented Satellite Launch Vehicle (ASLV) was evolved. It served as the low cost flying test bed for new technologies. Despite two failures, the extensive analysis brought out improvements in the better characterisation of vehicle, new technologies and simulations. With two consecutive successful launches of ASLV, all the objectives of this programme were achieved. The major contribution of ASLV experience was that it enabled a better understanding of the difficult atmospheric regime of flight (control-structure interaction), implementation of on-board real-time based decision-making for event management, closed loop guidance for better tolerance in injection conditions.

Even while the development of ASLV was going on in 1982, ISRO took the challenging task of developing the Polar Satellite Launch Vehicle (PSLV) for launching the 1 tonne class operational remote sensing satellites into Polar Sun-Synchronous Orbit (SSO). Aiming at a performance increase by a factor of 20 times over its predecessor, ASLV and employing new technologies like liquid propulsion and three-axes guided injection, the gigantic PSLV required development efforts, generation of facilities and industrial support of much larger proportion. PSLV for the first time adopted liquid stages in addition to solid rockets. All the PSLV systems functioned well in the first flight conducted in 1993 but still the mission could not succeed in injecting the satellite into orbit due to a software implementation error. This led to strengthening further the ground simulations, additional testing of the vehicle hardware and software systems to its fullest capabilities prior to flight.

Eight launches of PSLV have been taken up so far. The last seven missions conducted during 1994-2003 provided a string of successes. Starting with a payload capability of 800 kg in its first developmental flight, the capability of PSLV has been systematically improved to 1400 kg in its

eight mission. These improvements have been made possible by incorporating improved propellant loading for solid as well as liquid stages, improved efficiency of the upper stages, overall inert mass reduction by adopting composite structures wherever feasible, optimization in strapon firing sequence, miniaturization of avionics packages etc. PSLV is under production to launch all national remote-sensing satellites and to respond to potential commercial opportunities. The capability of PSLV to carry 1000 kg to Geo-synchronous Transfer Orbit (GTO) has also been established with the launch of KALPANA -1.

In order to utilize the spare capacity whenever available, various payload accommodation strategies have been evolved over the years. These include provision for carrying up to two micro satellites on the vehicle equipment bay, or two spacecrafts of around 500 -600 kg using the dual launch adaptor or a possible mix of micro & mini satellites. The first one has been accomplished in the fifth mission of PSLV wherein it carried two micro satellites in a piggyback mode- KITSAT- 3 of Korea and TUBSAT of Germany. In the subsequent mission, when the micro satellites PROBA for Belgium and BIRD for Germany were launched along with the primary spacecrafts, the multiple orbit capability of PSLV was also demonstrated when PROBA was injected into Elliptical SSO.

The 2 tonne GTO Launcher Geo-synchronous Satellite Launch Vehicle (GSLV) a three-stage vehicle employs solid, liquid and cryogenic propulsion modules for its stages. Keeping pedigree of already developed stages and in order to reduce the overall developmental cost and schedule, the PSLV modules were maximally utilized for the first two stages of GSLV. A procured cryogenic stage from Russia was used for the upper stage. Cryogenic propulsion is selected as it delivers more energetics measured in terms of specific impulse, which is almost 1.5 times that of liquid and about 1.75 times that of solid propellants. Especially when used as the upper stage, the payload capability of the launcher improves by 15 kg for every 1 s increase in specific impulse, which speaks, of its necessity for GTO launchers. GSLV has successfully completed two development flights during 2001 and 2003, making it ready for launching operational communication satellites of 2 tonne class.

Though the cryogenic stage was procured from Russia, total avionics system for cryogenic stage was realised by ISRO. Definition of the mechanical, electrical, thermal interfaces with ISRO subsystems and qualifying them through a series of joint hardware tests and software



checks posed a major challenge. A number of interface checks were done at the level of engine, and through a series of cold and hot tests of stage using ISRO electronics. The realisation of the cryogenic umbilical arms for feeding the propellants and the safe retraction of these just prior to take off was a critical development.

For the initial launches of GSLV the bought out cryogenic stages from Russia will be used. In the mean time, efforts are on to develop indigenous cryogenic stages. A cryogenic engine of indigenous design using liquid oxygen and liquid hydrogen has been fully qualified through a series of ground tests. Efforts are also on to complete the development of cryogenic stages for GSLV within 2 years.

### Launch Vehicle Design - Criticalities

The design cycle for a launch vehicle starts with the definition of the mission requirements for a given payload mass and envelope. The major steps involved during the

course of design are sizing of the vehicle in terms of external configuration, number of stages, size of each stage, design of nominal flight sequence, consideration of aerodynamic and propulsion parameters, atmospheric conditions etc. These are used for carrying out the optimal trajectory design. The design during the atmospheric phase is more critical as the vehicle has to withstand the severe aerodynamic loads thereby making the structural integrity the prime concern. However, during the exo-atmospheric phase, the steering of the vehicle using closed loop guidance to the intended target is of prime importance. In addition to this, the overall mission design is very closely interlinked with other broader problems associated with aerodynamics, structure, thermal, navigation, guidance, control, propulsion etc.

Aerodynamic design of a launch vehicle is a complex activity that requires a synthesis of experimental aerodynamics (wind tunnel tests), use of available aerodynamic

# Launch Vehicle Design

## Aerodynamics/ Thermal

- Configuration design/ Pressure-load distribution
- Multi body flow field analysis
- Aerodynamic heating
- Acoustics
- Thermal Protection Systems

## Structures/ Materials

- Structural design, analysis, testing
- Evaluation of dynamic loads & responses
- Dynamic interaction studies – Pogo, slosh, Aeroelastic interactions etc.
- Ground wind response
- Managing steel Composition
- Composite Motor case

## Propulsion

- Solid/ Liquid/ Cryogenic
- Solid – Propellant casting, HTPB
- Liquid – Carbon Phenolic throat, Bell, contour nozzle
- Cryogenic – Propellant storage, handling

## Navigation, Guidance & Control

- Accurate sensors, Navigation software
- On-board computers, sequencing
- Optimal Guidance algorithms
- Robust Digital Autopilot Design
- Mission salvage
- Redundant & Fault tolerant designs
- Simulation test beds

## Integration & Checkout

- Vehicle Integration
- Sub-system, system, vehicle level checkout
- Launch campaign

data banks, analytical and empirical methods, and increasingly use of CFD tools. The detailed load distribution along the length of the vehicle is carried out as a pre requisite to do the structural design, control system design and vehicle flexibility analysis. Detailed pressure distributions on the various components of the vehicle structure are needed for structural design. Aero acoustic characterization of the launch vehicle is another very important and challenging task. Multi-jet interactions as in the case of simultaneously burning strap-ons and core are very complex as at some conditions in the flight the jets can expand so much that their interactions lead to reverse flow of jets and consequent base heating. The aerodynamic noise due to shock oscillations in the transonic region and boundary layer noise also are very difficult to characterize, and one relies predominantly on experimental and flight measurements.

The vehicle needs to be thermally protected to counter the aerodynamic heating and this requires accurate design inputs on the aerodynamic heating pattern. The time or altitude of ejection of the heat shield is also determined by aero-thermal considerations. Other important thermal protection considerations are for the protection of protrusions, components exposed directly to exhausting hot plumes etc.

Vehicle electronics, another important component of launch vehicle caters to Navigation Guidance and Control system (NGC), which is equivalent to the brain of a launch vehicle. It enables to steer the launch vehicle towards the desired path and deliver the payload in the intended orbit. The other is the Telemetry Tracking and Command (TTC) system, which enables monitoring of health and performance of launch vehicle systems. Modern NGC system is realized using inertial sensors, sophisticated computer, electronics and fault tolerant software. In addition control Electronics & Power Plants, and sequencing electronics play a significant role.

The validation of NGC system for varying vehicle environments is a time consuming task. This calls for the realisation of simulation test beds with multiple computers and real-time operating software. Simulation test beds for Autonomous simulation, on board computer simulation, Hardware in loop simulation and Actuator in loop simulation have been developed over a period of time. In autonomous simulation thousands of runs are taken to validate the design algorithms and overall system design. This is done using standard digital computers. Once the system design is validated the next phase starts with the

testing of on board software and hardware. In onboard computer simulation, actual processing elements with software are tested. Around thousand simulations are carried out in various environments of mission before the software gets validated. The software is also tested for nominal and failure conditions.

### Decade Plan - Launch Vehicles

There has been a significant growth in the payload capability of PSLV from 800 kg to nearly 1400kg. This is being further improved by another 100-150 kg in the coming years with the induction of the improved solid strapon stages. Similarly, though the payload capability of GSLV presently stands at 2000 kg, various improvement schemes such as increased propellant loading and thrust augmentation of the upper cryogenic stage and induction of the indigenous cryogenic stage etc will take it up to 2500kg.

PSLV and GSLV together can cater to spacecraft requirements up to 2 tonne in GTO. The development of GSLV-Mk-III is a next step in enhancing the payload capability towards meeting national requirements for launching heavier payloads of 4 tonne class as well as to offer cost effective Launch Services for international customers.

GSLV-Mk III is a three-stage vehicle with two Solid strapon motors of 200 tonne propellant loading (S-200) and liquid core of 110 tonne propellant loading with the clustering of two Vikas engines (L110). The upper stage with a cryo engine has a propellant loading of 25 tonne (C25). The core vehicle has a diameter of 4 m. The overall length of the vehicle is 42 m and the gross lift-off weight is 629 tonne. The strapons are 3.2 m in diameter and 25 m tall. The Heat Shield is 5 m in diameter, with a payload volume of 100 m<sup>3</sup>. The first development flight of GSLV MkIII is scheduled for 2007 -2008.

### Space Industry Interface

ISRO views industry participation as an essential requirement for the success and growth of the programme. About 500 industries are participating in the space programme in a variety of fields. Currently, more than 30% of the budget of ISRO is spent in industries and in case of launch vehicles; industry contribution is as high as 70% of product value. Space and industry have had a symbiotic relationship - space has drawn upon the potentials of the industries and in turn has enriched the industrial force with new technologies and opportunities.



**Space Projects in Academic Institutions**

Since nearly three decades, ISRO has established a strong linkage with academic institutions for carrying out research in developmental, educational and promotional activities of important to the Indian space programme. The institutions covered under the Sponsored Research (RESPOND) programme spread across the Indian subcontinent. ISRO has established a number of Space Technology Cells in some of the premier institutions to further research in this hi-tech area. Nearly 500 research projects in 50 research areas involving 1200 researchers have been accomplished so far. International dimensions

International co-operation has always been an integral part of Indian Space programme. While the international co-operation has been the essence of our Indian space programme since its inception, the partners have also benefited from commercial opportunities created from expanding Indian space projects, their launch service needs and a wide range of applications. Over the years, ISRO has matured in experience and technological capabilities and has been working with developed countries as

equal partners and also offering assistance to developing countries.

**Commercialization**

Antrix Corporation serves as a marketing arm of Department of Space to market the space products and services from ISRO and Indian industries. The major activities of Antrix include international marketing of data from IRS satellites in alliance with international partners and leasing of the communication transponders. Antrix also markets satellite components, launch services and TTC support for LEOP and in-orbit support and space related training programmes.

**Future Technology Drivers**

Indian launch vehicle programme constantly strives to improve capability in a cost-effective manner. In tune with this, studies have been taken up on various concepts such as large cryogenic boosters and semi-cryogenic boosters. Studies also have been initiated in the rocket based combined cycle engine development including air-breathing propulsion. Newer propulsion technologies such as super-

**TECHNOLOGY DRIVERS**

**NEXT 10 YEARS**

**HIGH ENERGY PROPULSION SYSTEM**

- ADVANCED CRYOGENIC SYSTEM
- TRI-PROPELLANT ENGINES
- AIR-BREATHING
- ION

**ADVANCED MATERIALS**

- METAL MATRIX
- CARBON-CARBON MATRIX
- SUPER ALLOYS

**AVIONICS**

- HIGH ACCURACY SENSORS
- ENHANCED FAULT TOLERANCE
- MINIATURISATION

**COMPUTATIONAL FLUID DYNAMICS**

- CONCURRENT ENGINEERING

**NEXT 25-30 YEARS**

- ADVANCED DESIGN OF RLV/SSTO/TSTO LIFTING BODY VEHICLE
- TECHNOLOGY DEMONSTRATORS

**PAYLOAD RECOVERY/RE-ENTRY**

- SPACE DOCKING

**REDUCTION IN GLOW**

- IMPROVED RELIABILITY
- IMPROVED PAYLOAD FRACTION
- REDUCED COST/KG
- PROVIDING FOR INCREASED FLIGHTS

sonic combustion required in the design of air-breathing propulsion are being experimented in the sub-scale programme. Satellite Recovery Experiment involving reentry/recovery have also been planned in the near future. A demonstrator towards developing newer technologies for the Reusable Launch Vehicle is in the initial phase of design making use of concurrent engineering practices and inter-disciplinary design approach. High specific impulse propellants, high strength materials like Al-Li alloy, metal matrix composites, supersonic and hypersonic aerodynamics, CFD tools for internal and external flow field analysis, smart actuation system, robotics, fault tolerant on-board computers and advanced navigation sensors are some of the areas of R & D efforts.

**Conclusion**

Over the last four decades, the Indian space transportation capability has been systematically developed and improved through SLV-3, ASLV, PSLV and GSLV missions. PSLV will routinely launch national satellites and

is also available for commercial launch services. GSLV is ready for carrying operational spacecraft. The Chandrayaan mission will form one major stepping stone in the efforts of ISRO and the nation as a whole towards launching a probe into a 100 km polar orbit around the moon in about five years from now using PSLV. This mission could provide an opportunity to explore the lunar surface and throw light on some of the aspects related to the origin of earth and kindle scientific temperament in the younger generation. GSLV-Mk III the new vehicle under development is designed to meet the growing requirements of INSAT in the heavier payload class of 4 tonne and with the aim of lowering the cost of access to space. Long term R&D is pursued on more advanced concepts of launch vehicle for performance enhancement as well as further reducing cost. Reusability and recovery will become the norm for next generation vehicles. This could also call for integration of launch vehicles and aircraft technologies paving the way for achieving excellence and international competitiveness.

