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# A glimpse of the Indian space programme

S. DHAWAN
Space Commission, Bangalore 560 009
Indian Institute of Science, Bangalore 560 012

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**Abstract.** This paper, based on the Presidential Address delivered at the 43rd Annual Meeting of the Indian Academy of Sciences held at Calcutta during 26–29 November 1977, is a brief survey of recent developments in the Indian space programme and of the plans for the near future.

**Keywords.** Space technology; Indian space programme; rockets; satellites.

## 1. Introduction

The twentieth anniversary of the launching of the first artificial earth satellite was observed just over a month ago. Since 4 October 1957, when the USSR placed a sputnik in orbit, nearly 2000 satellite launches have taken place—about 80% of them successful. Currently about 150 launches take place every year—i.e. almost one every other day; several countries contribute to this number, but most are from the USSR and USA. Satellites are thus now common place, although only 30 years ago the idea of a man-made satellite orbiting in space was beyond the imagination of most people; even the scientific community, with a few exceptions, did not consider it a serious possibility. In the history of science it is not uncommon that ideas far ahead of their time are often first scorned and later acclaimed.

Space flight has long fired the imagination of mankind. Writers and poets kept the dream alive and sustained the pioneers of rocketry and spaceflight like Tsiolkovsky, Oberth, Goddard, Korolov and Wernher von Braun. By the time the second World War was over both the science and the technology necessary were virtually already in existence. Newtonian dynamics and the Keplerian laws of celestial mechanics had of course been well known for centuries. Jet engines and rockets had been used in the second World War. Radio telemetry and radar were reasonably well understood. It only took a few more years for the birth of the first electronic computers and solar cells, and these completed the basic ingredients required for undertaking space flights. With the knowledge and experience thus available, mankind was in a position to develop the technologies required for spaceflight. These were principally:

—a sufficiently powerful source of energy in the rocket motor using chemical propellants,

—suitable control and guidance systems,

—radar and telemetry for tracking and for maintaining real time contact and communication with the vehicle and

—a compact source of power onboard through chemical batteries and solar cells.

Even though the time was ripe from the viewpoint of basic knowledge regarding the elements of space flight, it needed government money and scientific respectability for space flight to become a reality. In the 1950s these elements were provided by the cold-war atmosphere and the International Geophysical Year (IGY) programme.

## 2. Objectives of the Indian space programme

In India, activity relating to space started some six years after the world's first satellite went into orbit, with the establishment of the Thumba Equatorial Rocket Launching Station in 1963. The Indian space programme has now two main objectives, derived from a matching of the inherent capabilities of satellites in orbit around the earth with two major national needs. These needs are:

—rapid development of mass communication and education, especially in the widely dispersed rural communities, and

—timely survey and management of the country's natural resources.

Thus the main thrust of the Indian space programme is towards the development of communication and earth observation satellite systems suited to Indian needs.

Of course, satellites by themselves cannot achieve anything. Benefits become possible only when human beings utilise the unique capabilities of satellites to synoptically survey vast regions of the earth and use them to take radio and TV to the whole country. It is worth pointing out that the greatest social benefits from space research and technology occur through large scale applications rather than through those which have limited scope.

## 3. Development of satellites and rocket launchers

Since the attainment of the objectives of the space programme depends upon satellites and rockets, I propose to devote the rest of this paper to providing a glimpse of the activities relating to rockets and satellites underway in the Indian Space Research Organisation during the last five years or so. Achievement of space flight is primarily a matter of technology rather than science. Having said that, let me hasten to add that in the design and construction of space-worthy satellites and their launchers, the technology utilised is often such that the state of knowledge is pushed to extreme limits and very often in this process positive gains accrue to science. The design and development process of satellites and rockets is essentially a multi-disciplinary activity. The process is highly complex and combines science, engineering, and—very importantly—the management of large teams of people and of large quantities of information.

In this paper it will not be possible to go in any depth into the design and development processes. I will briefly sketch the general approach and then illustrate it from the satellite and rocket projects currently underway.

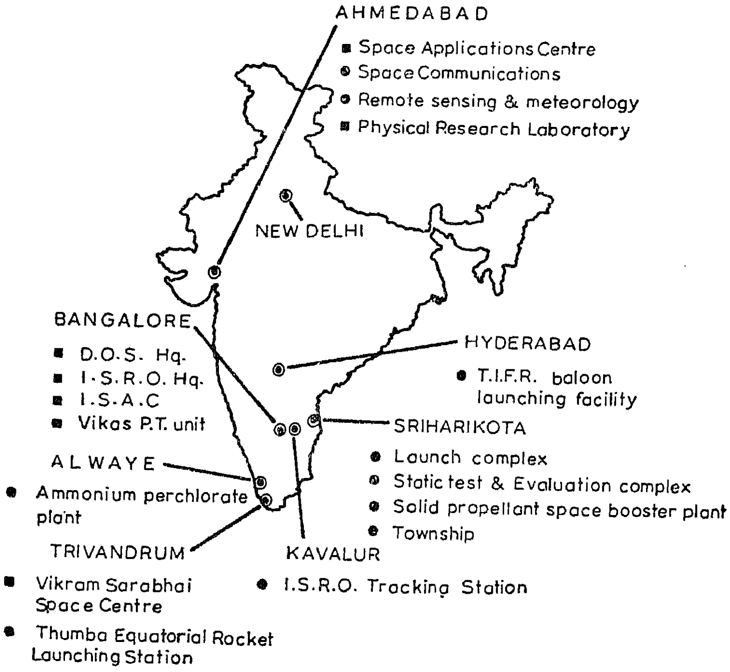

**Figure 1.** Centres of space activity in India

## 4. Indian space centres and activities

Figure 1 shows the location of various ISRO units and space-related facilities in the country. The major technology centre is situated at Trivandrum. The Satellite Centre in Bangalore deals with the research and development related to design of satellites and takes also the responsibility for execution of satellite projects. The Space Applications Centre (SAC) at Ahmedabad mainly concerns itself with payloads for and the utilisation of the space segment, and also the development of the ground segment. The Sriharikota Range (SHAR) is the primary national facility to test large rockets and to launch and track satellites.

Figure 2 describes the broad profile of the Indian space programme as it has developed in the past and as now planned for the near future (say, the coming few years). Broadly speaking, the programme includes selective development and application of both rockets and satellites. On the right hand side of figure 2, one sees the initiation of application experiments beginning with the establishment of the Experimental Satellite Communication Earth Station (ESCES), Satellite Instructional Television Experiment (SITE), Satellite Telecommunication Experiment Projects (STEP) and remote sensing experiments, culminating in operational remote sensing satellite systems and the multipurpose Indian National Satellite System (INSAT) for telecommunication, TV broadcasting and meteorological services. The first step on the road to achieve self-reliance in the satellites required for such applications was taken with the launching of *Aryabhata*; future spacecraft will be sharply oriented towards experimental application missions. The left hand side of figure 2 shows the developmental steps in acquiring a launch capability for remote sensing satellites.

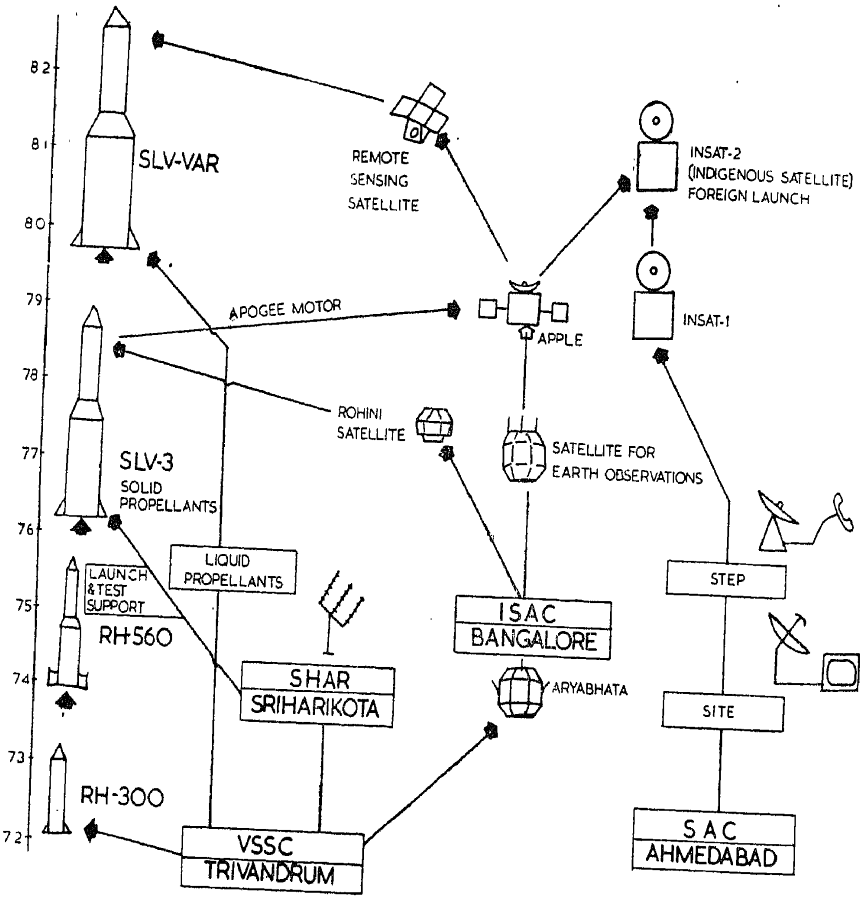

Figure 2. Profile of the Indian space programme

I now propose to sketch very briefly the important steps in developing satellites and rockets with illustrations from current ISRO projects.

## 5. Satellites

Satellites in orbit obey the laws of celestial mechanics. To remain in orbit, a satellite has to move sufficiently fast so that the centrifugal force balances the gravitational pull.

For near-earth orbits—say, a few hundred kilometres above the earth—the required satellite velocities are of the order of 8 km. This is several times faster than the speed of any macroscopic object on the earth. In order to have a reasonably long life, satellites have to operate above the earth's atmosphere—otherwise atmospheric drag will bring the satellite closer to earth, and the temperatures generated through frictional heating would be so high that the structure would burn up. There are however penalties in leaving the atmosphere. First, there is virtual vacuum in deep space, causing corona problems in the high voltage and power circuits, and also making the convective cooling of the components difficult. Second, the sun's radiant

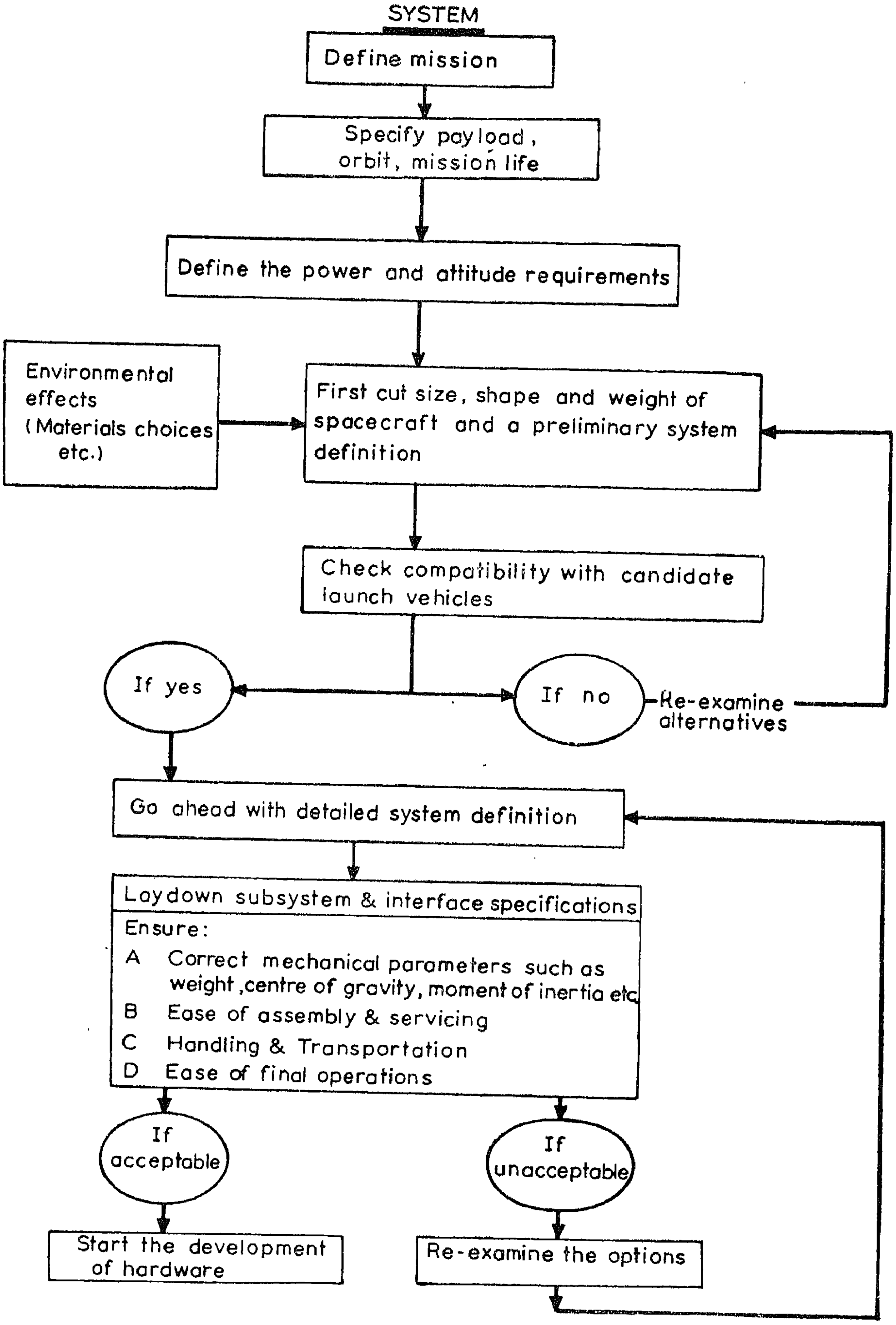

**Figure 3.** Sequence leading to the definition of a spacecraft

energy flux can cause radiation damage, and furthermore produces temperatures of several hundred degrees on the sun-side while there exist extremely low temperatures on the leeward side. Thus all instruments and materials that go to make up the satellite function in a most hostile environment. The spacecraft designer has to take account of this in every single component of the satellite—from metals, wires, insulation, to the electronic/electrical and mechanical components he uses. He has to deal with probabilities that a given piece of equipment will operate at the design level for a specified period in such an environment. *Reliability* is thus of the utmost importance in everything that a satellite designer does. He thus avoids, if he can, moving parts with metal-to-metal contact lest they get cold-welded, designs his circuits with built-in redundancy, avoids high voltages if possible for fear of corona problems, tries to achieve extreme cleanliness for fear of contamination of the optical and thermal control surfaces, etc. Every component and subsystem is tested on the ground in simulated conditions over and over again.

The process of satellite definition and design, illustrated in figure 3, begins from the definition of a mission and its requirements. In the actual design process one does not of course go through each step *ab initio*, but instead the designer starts with a few optional configurations selected on the basis of experience. Then the rigours of detailed design calculations are applied to these optional configurations to choose an optimal design. Figure 4 illustrates the major spacecraft subsystems which need to be clearly defined for each mission. It should be noted that all these subsystems are interdependent and closely interact with each other. A major effort in finalising a spacecraft design is to strike a balance between the often-contradictory requirements in optimising each subsystem. Figure 5 illustrates some salient interfaces between the subsystems.

The sequence leading to the development of flight hardware starting from the initial design is shown in figure 6. An important feature worth noting again is the multipli-

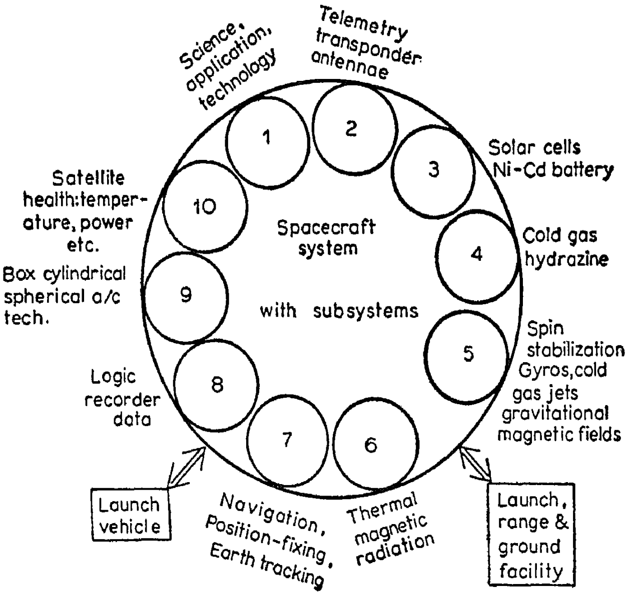

Figure 4. Spacecraft system

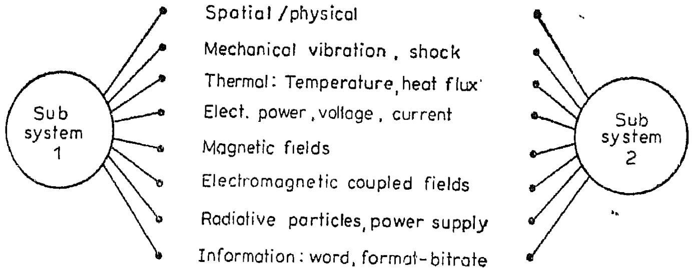

**Figure 5.** Interfaces between subsystems of a satellite

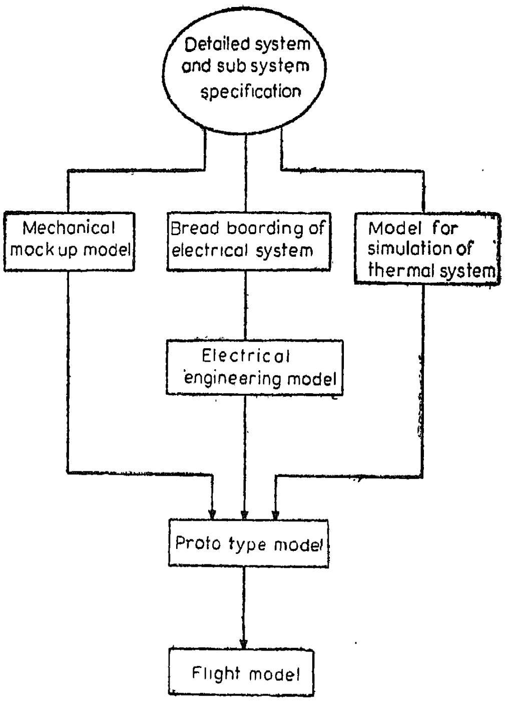

**Figure 6.** Typical development sequence for spacecraft

city of tests and simulations that are carried out on spacecraft models and subsystems to verify design concepts and fabrication standards.

## 6. Examples of satellite development

Now for a few examples of satellite development in India. Figure 7 shows the *Aryabhata* injection sequence. The *Aryabhata* project was undertaken essentially to master the technology elements involved in spacecraft development and fabrication. Besides the primary technological subsystems, *Aryabhata* carries three scientific experiments, which unfortunately malfunctioned after five days of operation due to a problem in one of the power supply systems. The orbit of *Aryabhata* is near-circular, with an altitude of about 590 km and inclination (to equator) of 51°. The satellite weighs about 360 kg and is spin-stabilised.

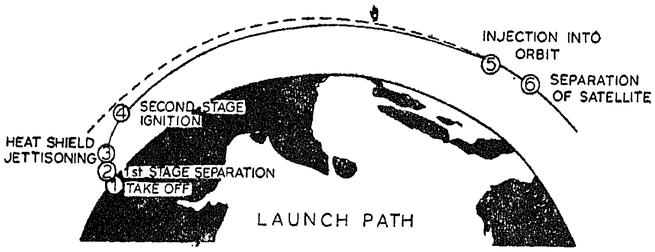

**Figure 7.** *Aryabhata* injection sequence

Figure 8 (plate 1) shows an exploded view of *Aryabhata*—the top shell, bottom shell, solar cells, the gas bottle, electronics etc., are identified in this figure. The layout takes into account electromagnetic compatibility, accessibility, moment of inertia considerations, etc.

The Satellite for Earth Observations (SEO) is a follow-up on *Aryabhata* and is planned to be launched in 1978. SEO would weigh about 425 kg and would be launched in a 525 km circular orbit with an inclination of 51°. The primary payloads are two slow scan TV cameras, one operating in the 0·54 to 0·66 $\mu$m band and the other in the 0·75 to 0·85 $\mu$m band, and a two-frequency (19 GHz and 22 GHz) passive microwave radiometer. The ground resolution of the TV payload is about 1 km in a swath of about 325 km × 325 km. The spacecraft is spin-stabilised with attitude control and the spin rate is maintained by a cold gas system. The attitude sensors are sun sensors (photodiodes in an array with suitable slits to define the sun-direction), horizon sensors (thermistor bolometer with germanium lens, the detection of horizon being the identification of space-earth discontinuity from $CO_2$ emissions), magnetometer and (sun) albedo sensor.

Figure 9 (plate 2) shows a picture of the *Rohini* satellite RS-1 now under construction; this is scheduled to be launched in 1979 with the Indian launcher SLV-3.

Figure 10 shows a cutaway view of the configuration of the APPLE spacecraft, which, when launched around 1980 by the European launcher *Ariane*, will be the first Indian geosynchronous communication satellite.

Figure 11 illustrates the INSAT-1 system concept, a project recently approved by the government. INSAT is a multipurpose satellite system designed to meet telecommunications, television and meteorology needs. To achieve high reliability and long life for this operational national system, it has been considered necessary to have the spacecraft with proven components; for this reason, in the first phase these will be procured from abroad. From the experience being gained through *Aryabhata*, SEO, *Rohini* and APPLE, the later versions of the INSAT system will be indigenised.

As a sequel to SEO an Indian Remote Sensing Satellite is planned; ISRO has done some preliminary systems studies to define this satellite. There has to be intensive interaction for a couple of years with users from agriculture, hydrology and other sectors to define more sharply the mission requirements so as to maximise the utility of the satellite in the Indian context. Present plans are to launch the satellite in about five years from now.

Many interesting and often troublesome scientific and technical problems were encountered during the development of *Aryabhata* and I shall illustrate these with two examples. Figure 12 compares the predicted thermal performance with actual in-orbit

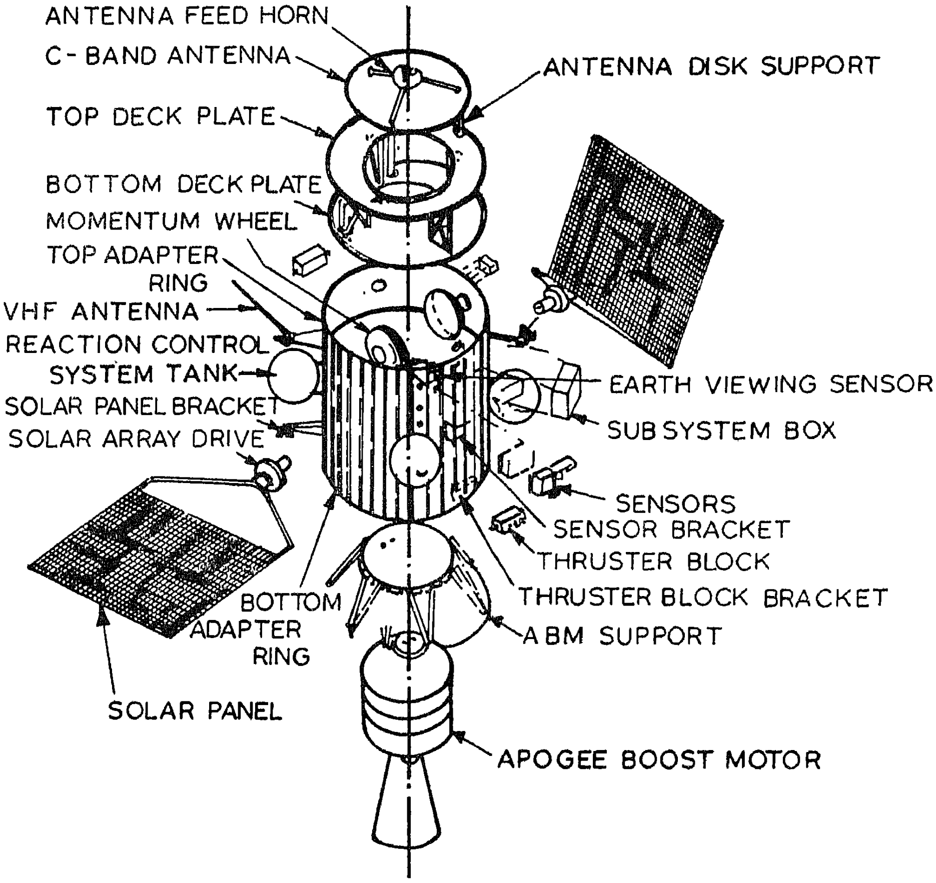

**Figure 10.** Exploded view of APPLE spacecraft

measurement in the case of one subsystem on the satellite. There was an anomaly noticed which was later resolved—the problem simply was that in the design calculations a mode in which one subsystem will be OFF and thus thermally colder was overlooked. Figure 13 compares the spin rate decay calculated with pessimistic and optimistic assumptions and the observed performance. The spin decays predominantly due to the interaction of the earth's magnetic field with the magnetic moment of the satellite. During the design phase of *Aryabhata* rather conservative values were assumed for the magnetic moment, even while taking care to ensure magnetic cleanliness. The in-orbit experience of *Aryabhata* enables us to make better estimates of some design parameters for SEO not only on spin decay but also on satellite dynamics at low spin rates.

## 7. Rockets

Now let us briefly dwell on some design principles and examples of rocket systems.

The four main elements of a satellite launch vehicle are the following.

(i) A chemical *rocket engine* which burns a fuel with an oxidizer to produce large quantities of hot gases which are accelerated through a convergent-divergent

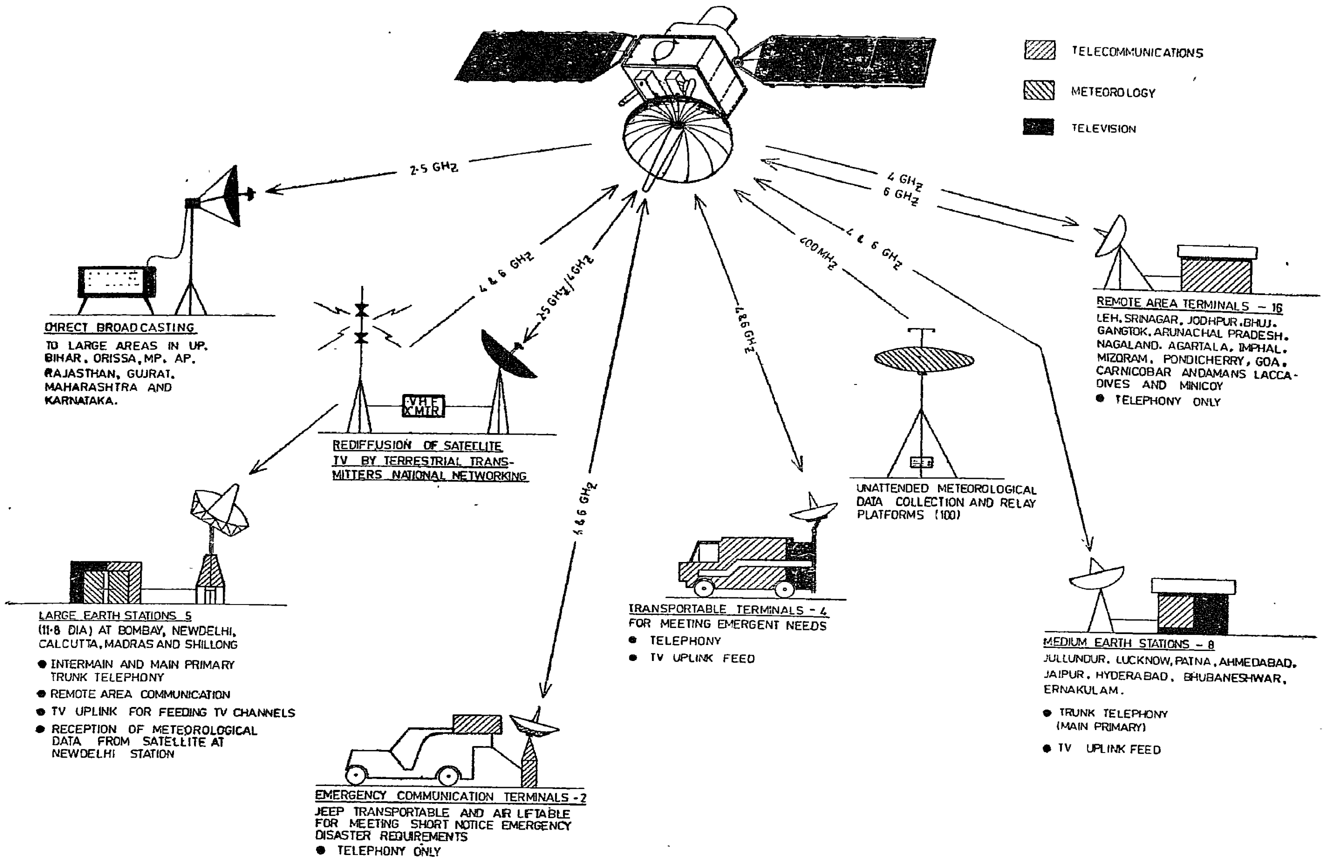

**Figure 11.** INSAT system concept

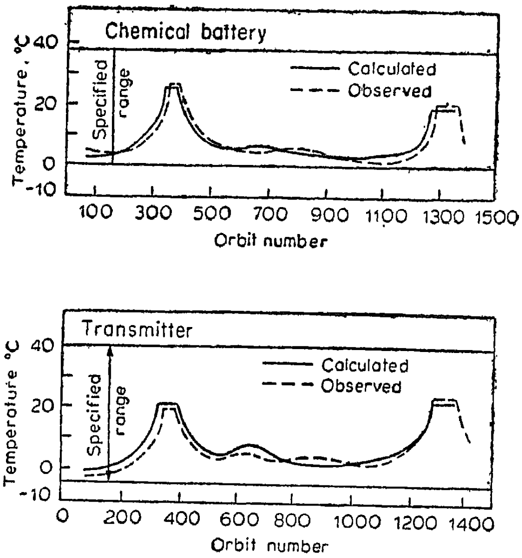

**Figure 12.** In-flight thermal performance of *Aryabhata*

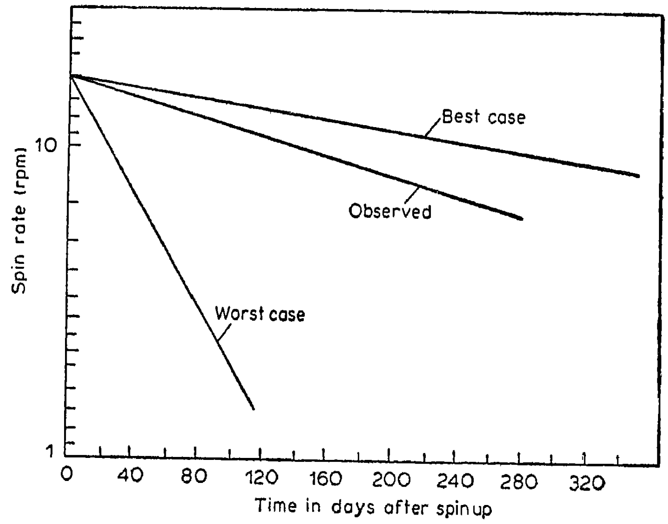

**Figure 13.** Spin decay characteristics of *Aryabhata*

nozzle to produce propulsive thrust. A rocket works on the familiar Newtonian principle of a change in momentum producing a force or thrust.

(ii) The *fuel and oxidiser*, carried by the vehicle, in solid rockets as integral solid propellant grains, and in liquid rockets in tanks, from where they are fed to the engine by pumps or by a pressure feed system.

(iii) A *streamlined structure* that offers the least possible resistance in the atmosphere, supports the rocket motor, the fuel and oxidizer and the instrument on the launch pad and in flight.

(iv) A *guidance and control system* that orients and stabilizes the launch vehicle and makes it follow the calculated trajectory from ground to orbit.

Both solid and liquid rockets are used. An important performance parameter or figure of merit is the specific impulse $I_{sp}$ of a propellant system, defined as thrust produced per unit weight flow (usually expressed in seconds). Some typical propellants are:

| | *Fuel* | *Oxidizer* | $I_{sp}$ |
|---|---|---|---|
| *Solid* | Synthetic rubber, (polymers) polyurethane | Ammonium perchlorate | 280 s |
| *Liquid* | Kerosene, unsymmetrical dimethyl hydrazine, aniline | $N_2O_4$, red fuming. nitric acid, liquid oxygen | 320 s |

Solid propellants need to be carefully 'tailored' by rocket engineers through complex chemistry, and chemical and physical engineering to produce:

(i) the desired thrust-time relationship during burn,

(ii) reliability and repeatability, and

(iii) good mechanical handling properties, which include ability to withstand vibration shock, thermal shock and gradients, etc.

The rocket casing is usually lined with protective coatings and the propellant cast with the grain is shaped to a pre-determined cross-section through the use of suitable mandrels or post-cast machining—'star' shaped cross-sections are often used to increase burning area with time and produce uniform burning characteristics.

ISRO has now established within the country all the chemical and processing technology for rocket motors—inclusive of the chemical processing plants to produce the propellants.

## 8. Satellite launcher design problems

In taking the satellite safely through the atmosphere from zero velocity on the earth to about 8 km in the appropriate direction at the specified orbital altitude, the rocket vehicle encounters complex problems. Some of these are:

(i) the vibration and shocks imposed by high accelerations,

(ii) severe aerodynamic heating, leading to temperatures of 500–600°C, caused by the high speeds of flight through the dense layers of the atmosphere,

(iii) severe control problems produced by ground winds and gusts at lift-off,

(iv) base heating caused by rocket exhaust gases, and

(v) the complex and delicate sensors, gyros and electronics, all subjected to vibration, heating and acceleration (upto 10 g), required to achieve the necessary accuracies in control and guidance in flight and at orbital injection.

It is usual to use three or four stages for satellite launchers since it is obviously efficient to drop the burnt out stage hardware at successive intervals and proceed with only the weight of the upper stages and the payload. Staging however introduces the additional complexity of achieving stage separation without disorientation of the vehicle in flight.

Finally the launcher-satellite interface has to be carefully designed, the satellite protected by a heat shield which must be jettisoned before orbital injection, and a spin-up/stabilisation and separation system has to be provided to allow orbital injection angles to be kept within specified limits (these can vary from 0·1 to 0·01° depending on the mission).

The design and development of a satellite launcher thus becomes a complex undertaking.

Figure 14 illustrates a typical launch vehicle development sequence starting from the mission requirements to hardware development.

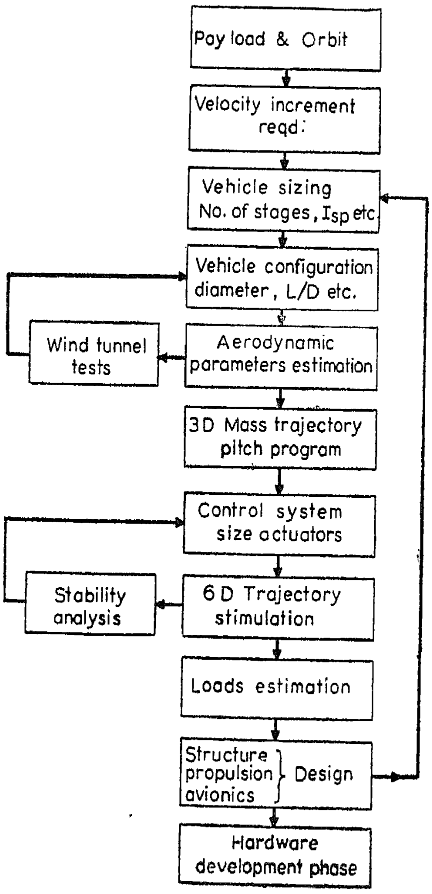

**Figure 14.** Launch vehicle development sequence

Figure 15 shows the main elements of the launch vehicle hardware development after designs of the main systems and subsystems have been worked out.

The development process is an iterative one; often obstacles crop up, in materials availability, performance of subsystems, design modifications, reliability etc. These require separate investigations, and solutions when found have to be fed back into the main system. Often new test facilities—which are complex entities in themselves—require to be designed and built along with the system to be tested.

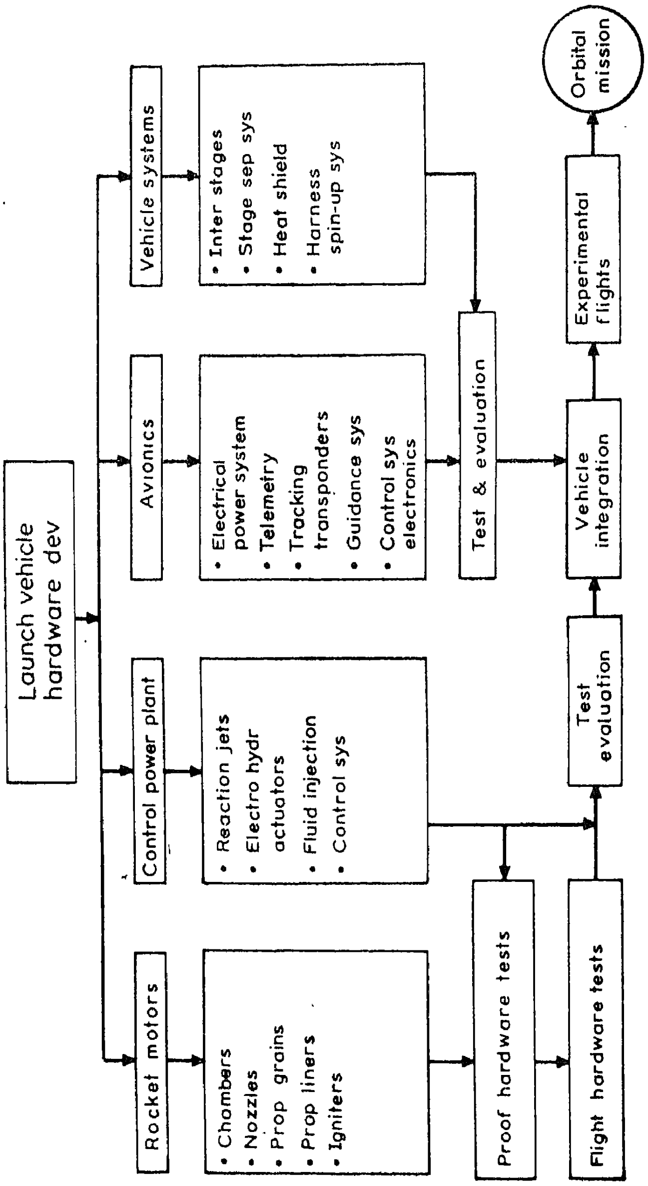

**Figure 15.** Main elements of launch vehicle hardware development

## 9. Example of SLV-3

Rather than discuss the general problems of launcher design in any detail, I propose to illustrate the process from the four-stage satellite launcher currently under development by ISRO and expected to place a 40 kg satellite—the RS-1—into low earth orbit in 1979. Some salient design features of the SLV-3 are listed in table 1.

Table 1. The SLV-3 Project

| | First stage | Second stage | Third stage | Fourth stage |
|---|---|---|---|---|
| Propellant weight (tonnes) | 9 | 3·2 | 1 | 0·267 |
| Thrust (tonnes) | 43 | 20 | 9 | 2·4 |
| Thrust/weight ratio | 5 | 6 | 9 | 10 |
| Burn time (s) | 53 | 44 | 46 | 32 |
| Rocket casing materials | steel | steel | fibre reinforced plastic | fibre reinforced plastic |

Vehicle weight ≈ 17 tonnes

Total propellant weight ≈13·5 tonnes
≈80% of vehicle weight

Vehicle length 23 m

Booster diameter ≈1 m

Project organised in October 1973

Launch scheduled for 1979

Apart from the major effort by ISRO, about 40 other industries and research and development institutions including the aircraft industry have been involved in SLV-3 development

The project team consists of about 300 engineers/scientists backed by the VSSC and SHAR centres

The launch vehicle trajectory consists of:

vertical ascent for a few seconds,
gravity turn till the vehicle clears the atmosphere at about 80 km,
pitch programme executed above the atmosphere to obtain the terminal orbital altitude and attitude,
coasting and firing of final stage to reach orbital velocity, and
final stage separation and satellite injection by an on-board sequencer.

Figure 16 illustrates the SLV-3 launch sequence. The launch corridor is planned taking into account the maximum utilisation of the velocity advantage available from a launch due east and the need to avoid flight over populated land masses for reasons of safety.

Figure 17 (plate 3) illustrates the SLV-3 in the full-scale mock-up and figure 18 illustrates the control system concepts; it may be noted that a fin tip control system using aerodynamic forces, as well as mass injection and expulsion systems, are used to control the vehicle.

It is impossible in this brief paper to discuss or even to enumerate all the tests conducted on SLV-3 but I will show a few examples to illustrate this aspect.

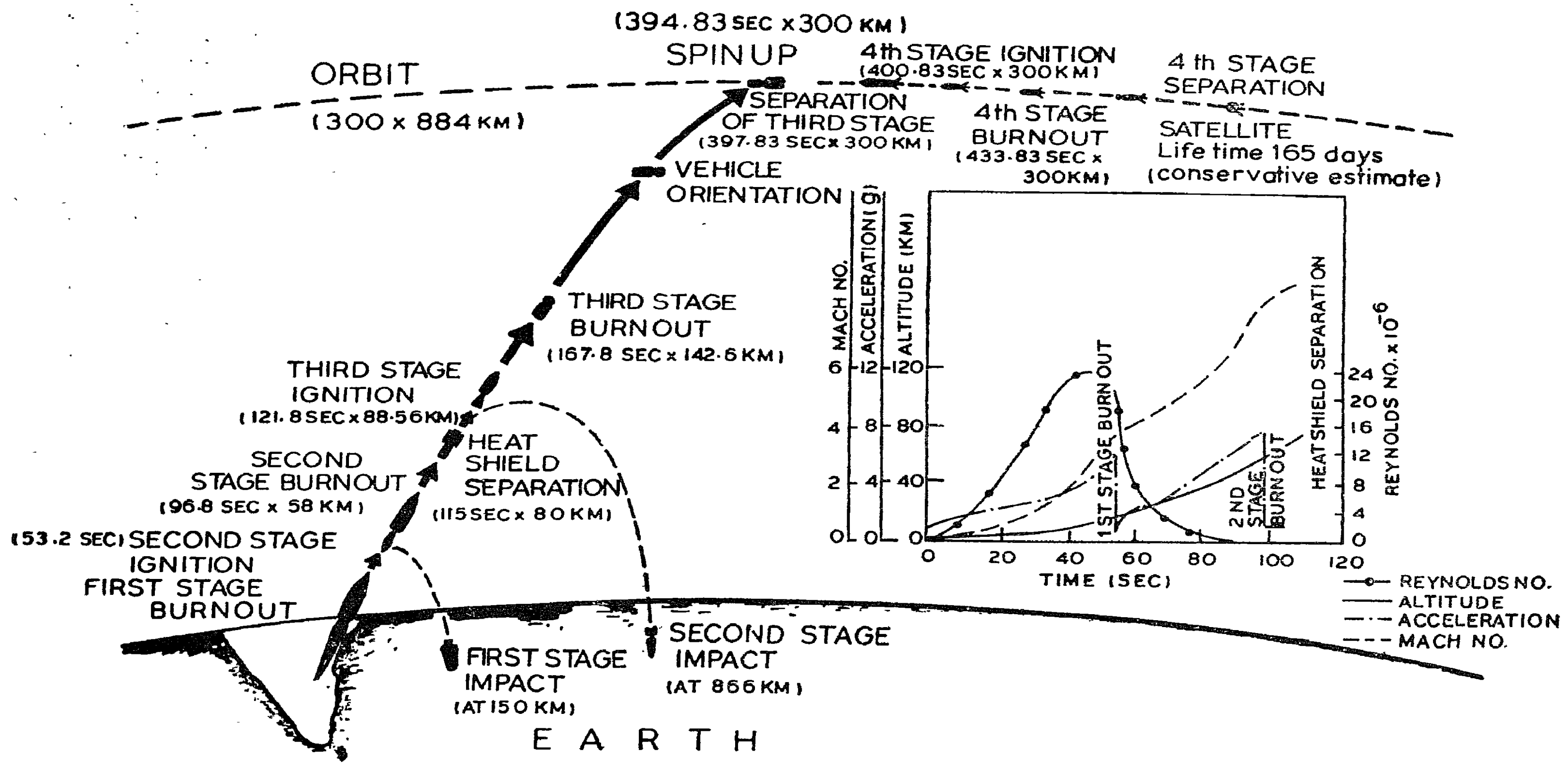

Figure 16. SLV-3 flight sequence and trajectory parameters (for EP-1 trajectory)

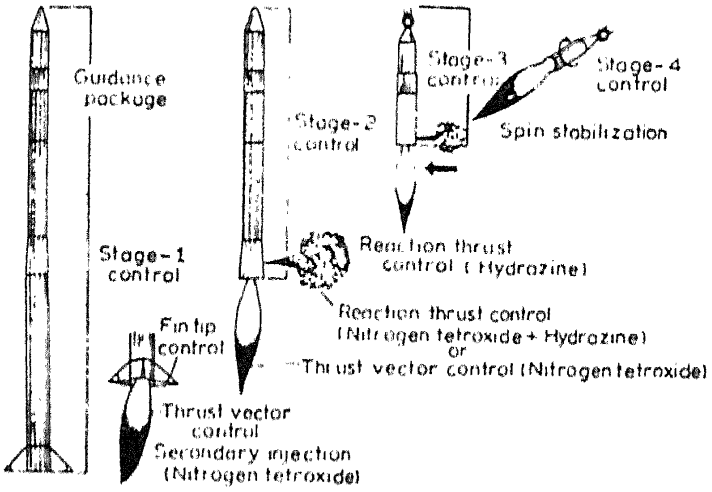

Figure 18. SLV-3 control and guidance system

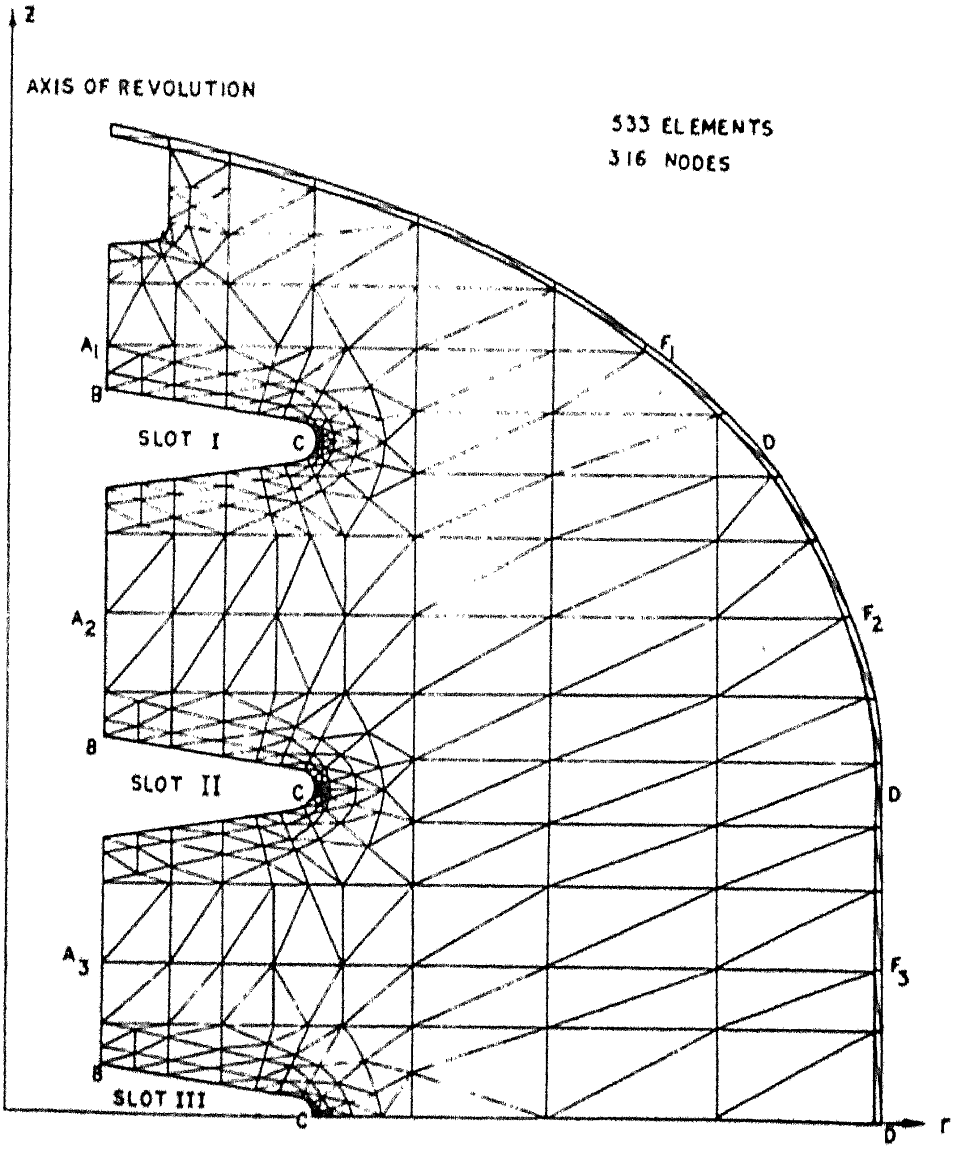

Figure 21. Finite element idealization of the grain

Figures 19 and 20 (plates 4 and 5) illustrate high and low Mach number wind tunnel tests. Figure 19 (plate 4) is a schlieren photograph of the flow taken in a supersonic tunnel, to study the aerodynamic performance of the vehicle at high speeds. Figure 20 (plate 5) is about an altogether different problem, namely that of the combined aerodynamic performance of the launch pad and vehicle; the winds in the launch range can not only cause structural damage to the vehicle but may also affect the control of the vehicle during the initial lift-off. The low speed wind tunnel tests provide the basic data regarding the tolerable wind condition during which the launch can take place.

Figures 21, 22 and 23 illustrate a propellant grain configuration and the results of a viscoelastic analysis of the grain. The important point to be noted is the steep

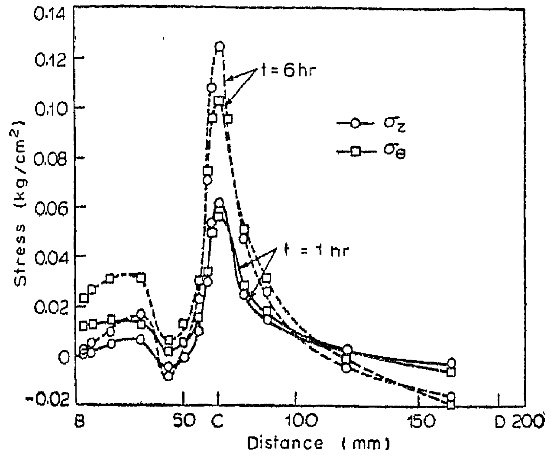

**Figure 22.** Variation of axial and hoop stresses along BCD of slot I

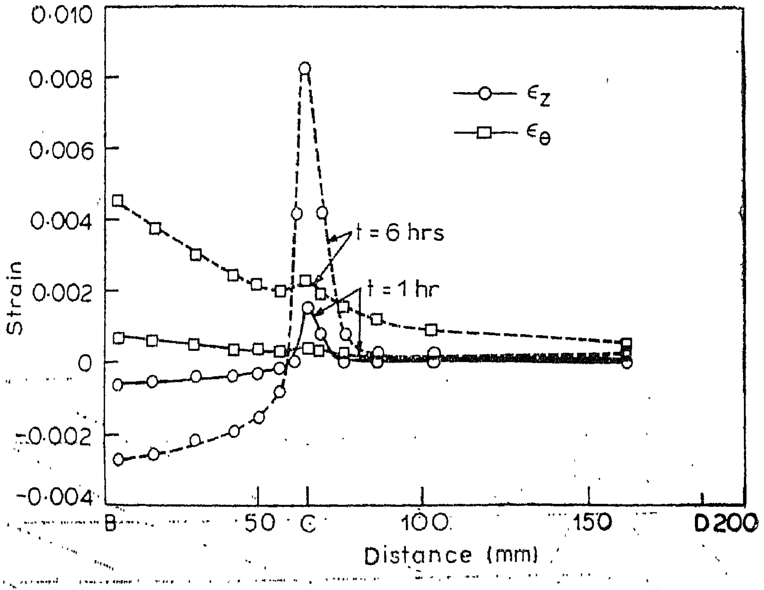

**Figure 23.** Variation of axial and hoop strains along BCD of slot I

increase in the strain with additional hours of curing (figure 23). This necessitates careful planning of the curing cycle, mechanical design of motor cases, propellant grain configuration, etc.

Figure 24 (plate 6) shows the first stage proof motor being readied for test in the Static Test Evaluation Complex at SHAR. It illustrates the assembled proof motor fully instrumented for remote monitoring of performance on a test bed. If there are deviations in propellant grain formation, cracks in the nozzle material, ablation rate etc., the pressure build-up in the motor can increase beyond the allowable levels and lead to an explosion. One such explosion took place during early stage proof motor tests. The problems have since been identified and resolved; subsequently successful static tests on the proof motor and flight motors have been conducted.

I have mentioned the wind tunnel tests, the static test beds, etc. Another important element of the launch vehicle project is the ground tracking, telemetry and command (TTC) facilities required at the range to acquire real time information on the position and performance of the launcher and the satellite carried by it. These launch vehicle and satellite TTC equipment are available at SHAR. The major elements of such systems are tracking radar, VHF/S-band antennas, high power transmitters, receivers, quick-look displays, real-time computer systems and communication/data lines.

## 10. Conclusion

I hope this broad-brush treatment of a complex subject, with a few examples from the Indian scene, has given some idea to readers about the various technological and scientific challenges that are posed by the Indian space programme.

## Acknowledgements

The facilities extended by Hindustan Aeronautics Limited, National Aeronautical Laboratory, Bharat Electronics Ltd., Controllerate of Inspection Electronics, and many other institutions and agencies in executing the ISRO programmes are gratefully acknowledged.

Plate 1

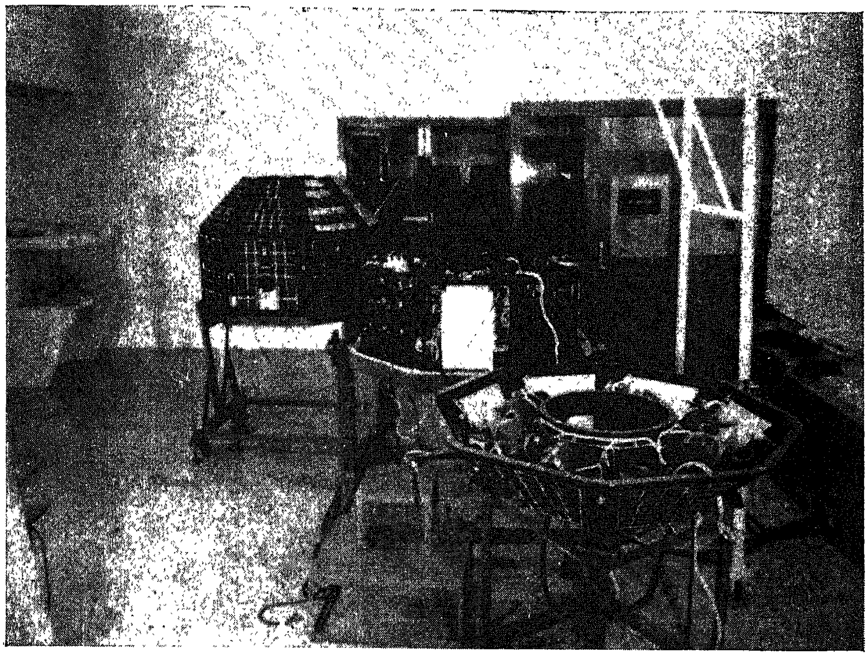

**Figure 8.** Exploded view of *Aryabhata*

Plate 2

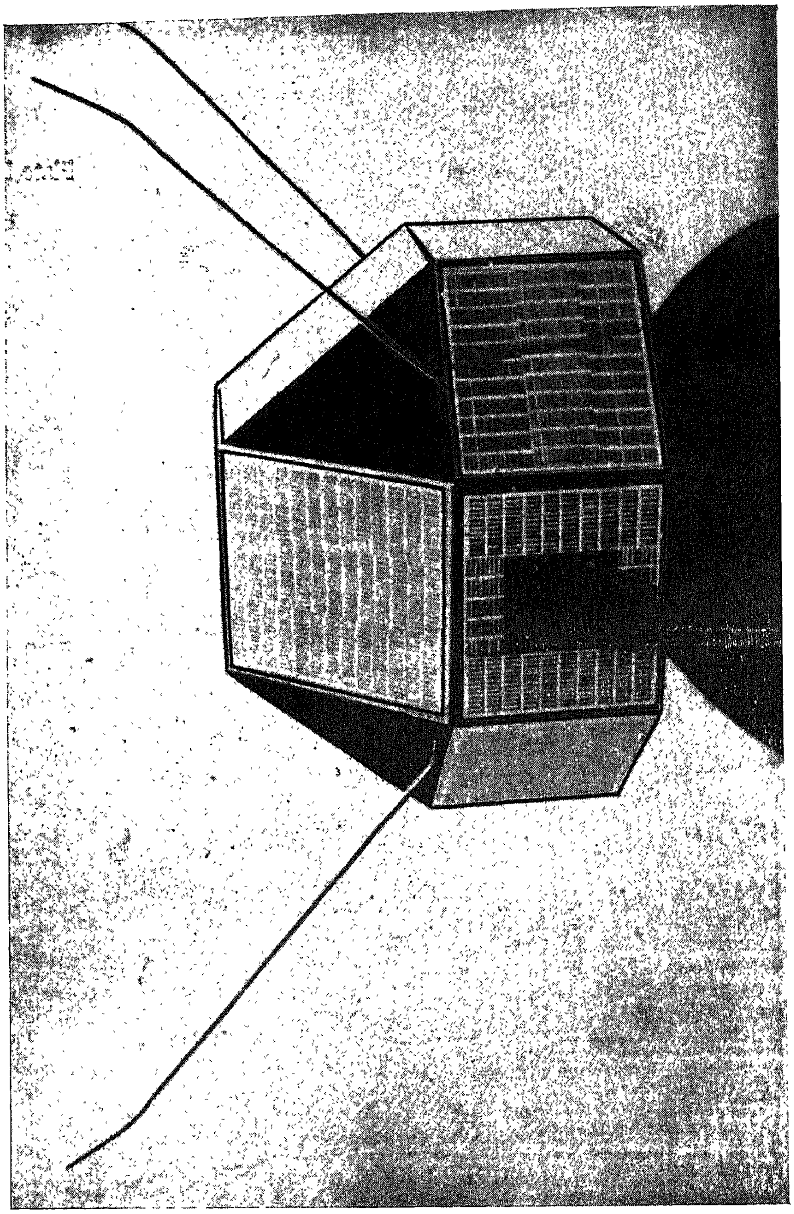

**Figure 9.** *Rohini* satellite RS-1

Plate 3

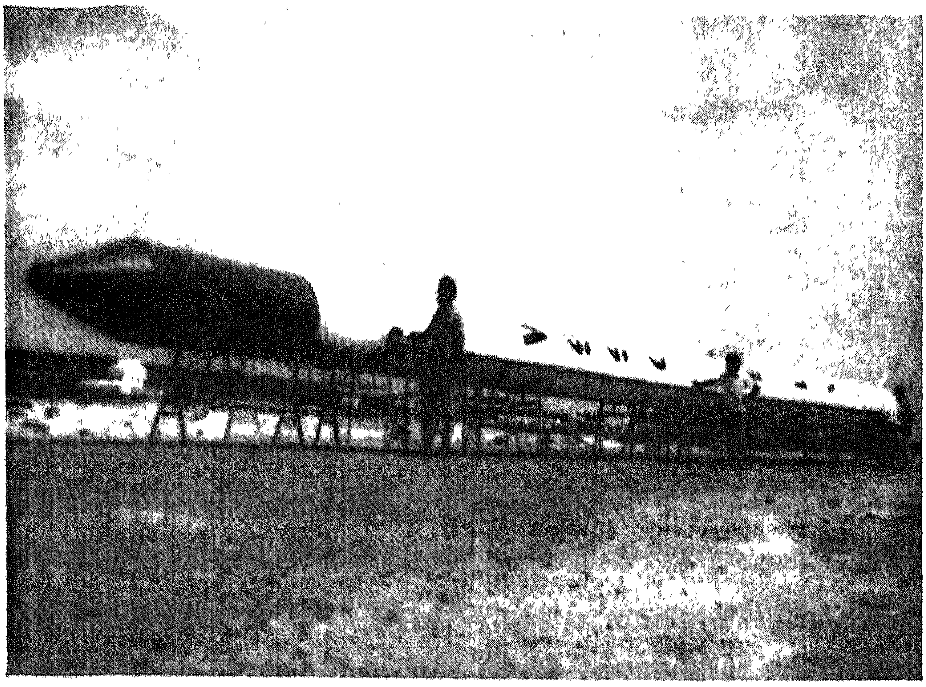

**Figure 17.** Full scale mock-up of SLV-3

Plate 4

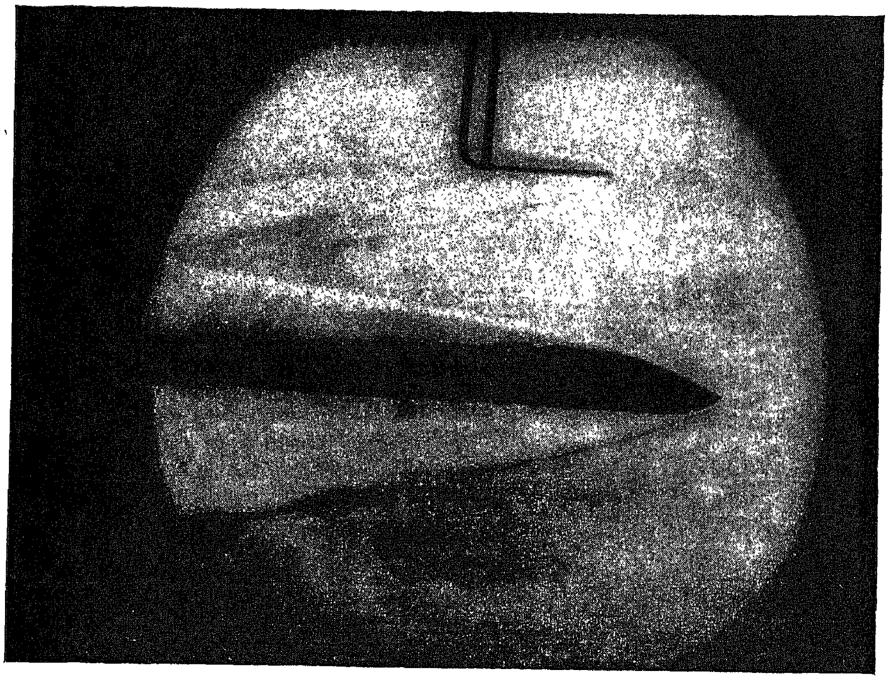

**Figure 19.** Wind tunnel test of SLV-3

Plate 5

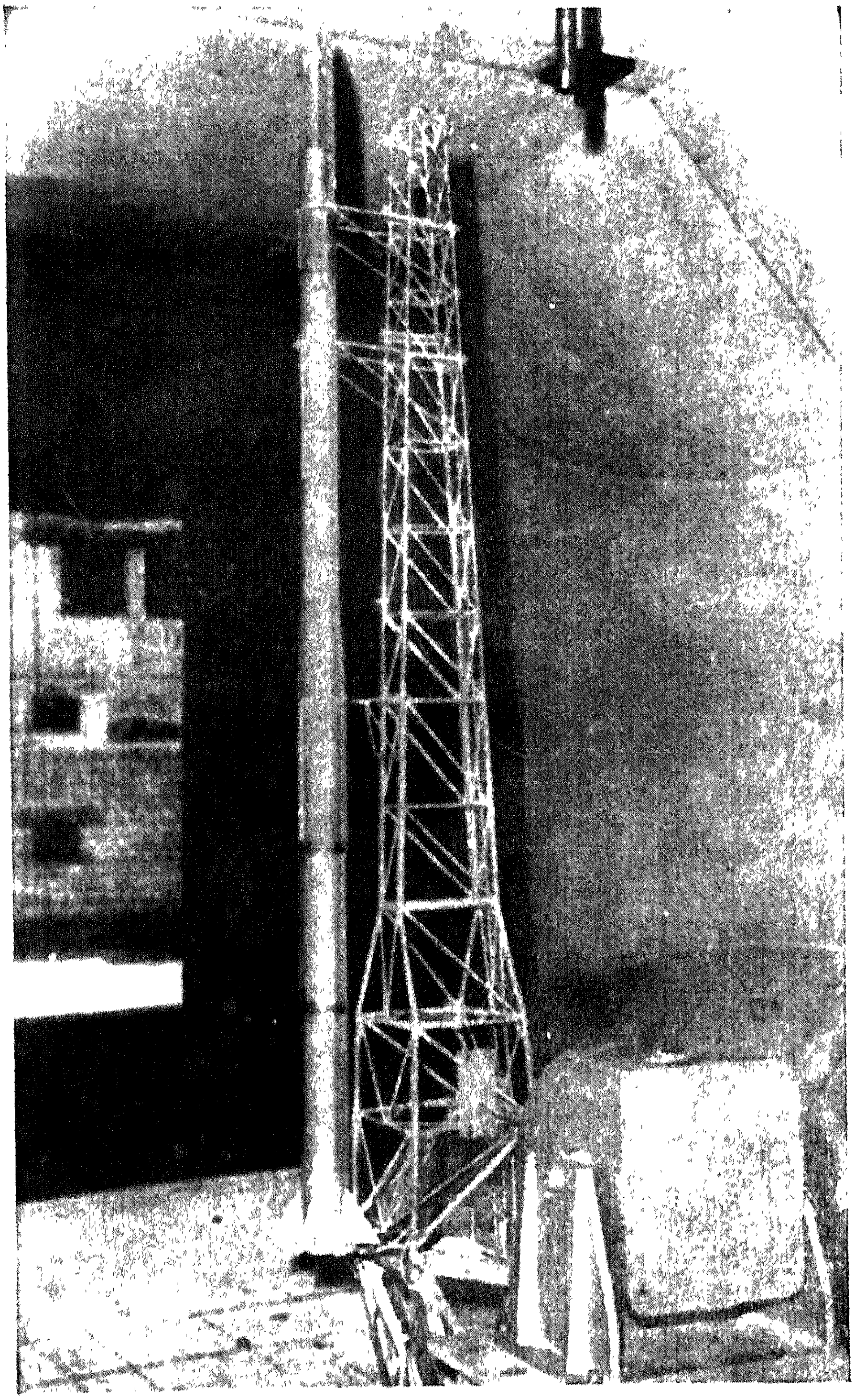

**Figure 20.** SLV-3 launcher in a low speed wind tunnel

Plate 6

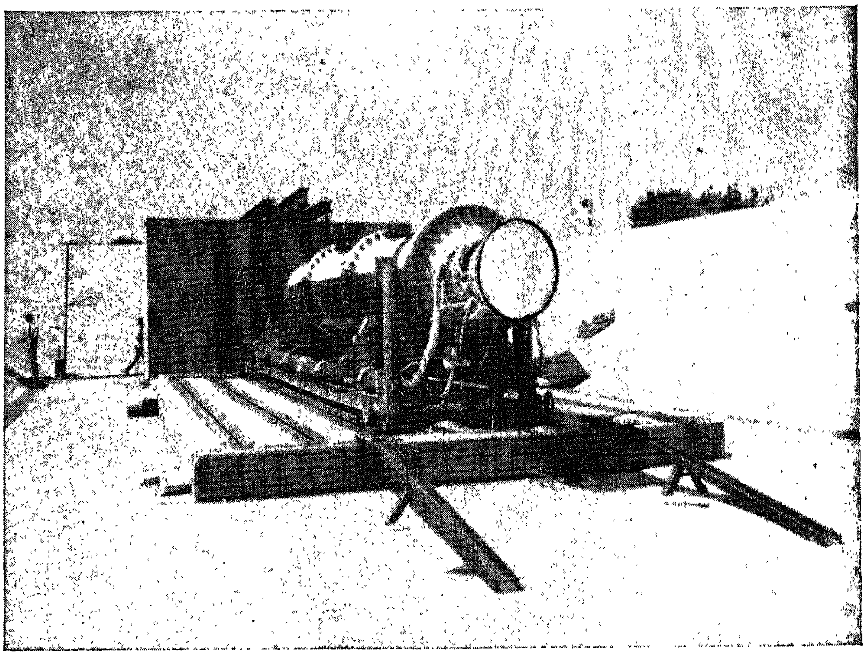

**Figure 24.** First stage proof motor on static test stand