

Popular Science & Technology Series

SATELLITES



Defence Scientific Information & Documentation
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Popular Science & Technology (PST) series is being published by DESIDOC to promote the knowledge and understanding of the applications of science and technology in Defence among Defence personnel, students and general public. Since the aim is to create awareness of current developments in frontier areas of science and technology among these groups, the presentation of material in the PST publications is lucid and generally in non-technical language. The text is supported by illustrations. Each issue of PST is devoted to a particular subject/discipline of current interest. PST is a half-yearly publication.

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Editor	Anuradha Ravi
Production	Ashok Kumar S.B. Gupta
Sales	G.P. Uniyal R. Kohli
Cover Design	S.K. Saxena

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Satellites

M. Krishnamurthi
Chief Controller Research & Development (Retd.)
DRDO



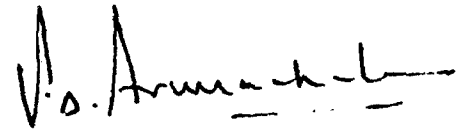
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Foreword

Satellites have become an integral part of the Nation's infrastructure in the last decade or so. The common man and woman in the country are deriving many benefits by the use of satellites. The farmer in the field, the worker in the factory, the student in the educational institution, the housewife at home and everyone else is being entertained, informed and educated through a wide network of TV stations rendered possible only because of satellites. Weather forecasting and warning, telecommunications, resources survey and surveillance have all improved enormously with the advent of satellites. This small volume presents satellites in a nutshell: their construction, launching systems, orbits, and the ground support systems that go with it. All these areas are described in a language understood by a layman. The description is supported by diagrams and photographs.

India is still a young member of the space club. Even though we have many achievements to our credit, we still have some distance to go. Soon we shall be launching satellites into geo- synchronous orbits.

This will provide us with a competence that will take the country far ahead in space science & technology.

A handwritten signature in black ink, appearing to read 'V. S. Arunachalam'. The signature is fluid and cursive, with a prominent initial 'V' and 'S'.

(V S ARUNACHALAM)
Scientific Adviser to the Defence Minister

Preface

This little book is about man-made satellites of the earth and their uses. A deliberate attempt has been made to eschew too many references to the exciting developments in space exploration and astronomy so that the size of the book remains within limits. An effort has, however, been made to explain in simple terms the principles of orbital motion, the laws governing motion of satellites under the sole action of gravity and the principles of rockets and satellite launch vehicles. An understanding of these subjects is necessary if one is to appreciate the potentialities and limitations of satellite technology. However those readers who would like to postpone dealing with such considerations to a later stage may skip the first three chapters and start from the fourth one. They may return to these chapters after reading the later three chapters.

Any book of this type on a rapidly developing technology is unlikely to be upto date when it is published. As the book was being written new developments were taking place. It is therefore likely that the reader might feel that some important development has been missed. In such a case, it should be examined whether the development is a recent one or alternately whether it concerns space rather than earth satellites.

The book has been divided into six chapters followed by an epilogue. The first chapter describes the motion of natural satellites like the planets going round the sun. The three laws governing such motion as derived by Johannes Kepler and Newton's extension of them to derive the universal law of gravitation are explained. It is the gravitational force of attraction between the sun and the planets that keeps the latter going round the sun and a similar force keeps artificial earth satellites going round the earth once they are put in orbit. In the second chapter it is mentioned that the satellite orbit is determined solely by the energy, altitude and direction of the satellite at the point where it is set free from the launching system. From then on the motion of the satellite is wholly determined by the gravitational attraction of the earth. The orbit is subjected to changes due to the earth not being a perfect sphere, due to its rotation and due to earth's atmosphere. Other minor influences are due to the sun, the moon, earth's magnetic field, etc. The choice of orbit for a satellite depends on its use. The third chapter deals with the principles of rockets and their use as satellite launch vehicles (SLVs). The need for a multistage rocket system to launch the satellite is explained. Some characteristics of SLVs already made or proposed to be made in India are presented. In chapter IV, the uses of satellite for scientific research, commercial activities, industrial applications and intelligence gathering have been described. The types of orbits used for different applications and their inter-relationship with the life expectancy of the satellites are discussed. The types of instrumentation

needed for different applications are also mentioned. But all satellites use certain common instruments which keep a watch on the health of the satellite and its various components.

India is one of the few countries to realise quite early the great potential of satellite technology for development of the country. It has therefore embarked on a wide-ranging programme for using this technology for various developmental purposes. Chapter V describes the facilities created by the Indian Space Research Organisation (ISRO) and also highlights its successes and failures in the design, fabrication and use of various experimental as well as operational satellites. ISRO's efforts at launching satellites on its own without going abroad are dealt with in this chapter. In the sixth chapter, the space programmes and future directions of space technology applications in some of the advanced nations like USA, USSR and Europe are described briefly.

A number of diagrams and pictures have been added to help in understanding the subject. An illustration quite often serves to elucidate a point more easily than a lot of words.

If this book excites the reader to look for more detailed information on any aspect of satellite technology and its applications, the author would feel that his purpose in writing this book has been served. Reading this book should not be an end in itself.

Hyderabad

M. KRISHNAMURTHI

30 Nov 1988

Acknowledgements

I have been greatly helped by ISRO and NRSA in writing this book. They not only supplied a lot of material and reports but also provided many of the illustrations in this book. I am particularly thankful to Shri Y.S. Rajan, Col. N. Pant and Prof. B.L. Deekshatulu of these organisations for all their help given so readily and unstintingly. It is also a pleasure acknowledging the help given by Shri S.S. Murthy, Director, Shri P.G. Krishnamurty and Smt Anuradha Ravi of DESIDOC in preparing this book. The staff of DESIDOC Unit at Hyderabad were very helpful in getting the manuscript typed. While writing this book, I am afraid I had neglected my wife and left her almost alone in the house. She bore it all with patience and cheerfully and looked after me. I am grateful to her.

*Dedicated
in memory of my teacher
late Prof. S Bhagawantham*

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SATELLITES

1. Planets and Satellites

The sky, with thousands of stars, the milky way, the sun and the moon have been a constant source of attraction and curiosity for humanity from time immemorial. Even thousands of years ago, it was noticed by keen observers that while almost all stars seemed to be fixed relative to each other on the firmament, a very small number of star-like objects and the sun and the moon were moving across the general stellar background from day to day. To these few bodies, the name given in Sanskrit is *grahas* and in English the planets. The *grahas* are the Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn and Rahu & Ketu, the last two being imaginary points in the sky.

In the West, visible planets including the sun and the moon were postulated to be moving round the earth and this theory was propounded by Ptolemy as early as the second century after christ. The geocentric concept of the universe held sway for nearly fourteen centuries until Copernicus questioned its validity and propounded a heliocentric concept in which earth as well as Mercury, Venus, Mars, Jupiter and Saturn were described as planets going round the sun, while the moon was going round the earth. These were the only planets that could be seen with the naked eye. After the invention of the telescope, the planets, Uranus, Pluto and Neptune were discovered; in addition, it was also observed that many of the planets had their own moons and Saturn had material rings round itself.

Although Copernicus postulated his heliocentric theory as early as 1547, it did not find acceptance for many decades. In fact, the Christian Church seemed to have reservations on the matter. To resolve this conflict of views, Tycho Brahe, a Danish astronomer in undertook very systematic and prolonged observations of the positions of planets using the best astronomical instruments available for his time. He even improved some of them to make them more accurate. He had the patronage of the king of Denmark Fredrick II for 12 years for this work.

Unfortunately, Fredrick's successor was not interested in Tycho Brahe's work. Still, Brahe persisted for eight more years in Denmark and in 1597, he moved to the court of Rudolf II of Germany to continue this work. Here he acquired a very able assistant by name Johannes Kepler and the two worked together for a short time until Brahe's death. Kepler inherited the very valuable data collected by Tycho Brahe for more than two decades and he started analyzing the data. On the basis of this analysis, he enunciated three laws known as Kepler's laws of planetary motion. The first and third were announced in 1609 and the second one a decade later in 1619. Before these laws are explained, it would be interesting to have a look at the data regarding various planets as we know them today. These are given in Table 1.1.

As already mentioned, at the time of Kepler and Tycho Brahe, the existence of three planets in the above table were not known. Kepler's three laws of planetary motion may be stated as follows:

1. Every planet goes round the sun in an elliptic orbit with the sun at one focus.
2. The straight line joining the planet and the sun (radius vector) describes equal areas in equal intervals of time or the areal velocity of the radius vector is a constant for each planet.
3. The cube of the semi-major axis (R) of a planet's orbit is directly proportional to the square of the period (T) of revolution of the planet round the sun or R^3/T^2 is a constant for the solar planetary system

These laws apply not only to the solar planetary system but also to the moons going round the different planets. The planets going round the sun could be considered as satellites of the sun. Similarly, the moons going round the planets are satellites of the concerned planets. While these are natural objects, the laws of planetary motion apply even to man made artificial satellites going round the earth or the moon or other planets. Hence it is necessary to understand Kepler's laws well to be able to understand the orbital motion of satellites round the earth or other heavenly bodies.

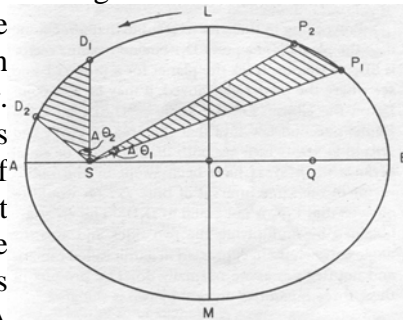
Table 1.1 Data on solar planets

SI. No.	Planet	Rotation period	Revolution (around sun) T(days)	Max. the distance from sun (million km)	Min. distance from sun (million km)	Mean sun distance R(million km)	R^3/T^3
1	Mercury	58.65 days	87.97	69.7	45.9	57.9	25.08
2	Venus	243.16 days	224.70	109.0	107.4	108.2	25.09
3	Earth	1 day	365.26	152.0	147.0	149.6	25.09
4	Mars	1.03 day	686.98	249.1	206.7	227.9	25.08
5	Jupiter	9 h 50 m to 9 h 55 m	4332.59	815.7	740.9	778.3	25.12
6	Saturn	10 h 39.4 m	10759.20	1507	1347	1427	25.10
7	Uranus	16 h 18 m	30684.9	3004	2735	2869.6	25.10
8	Neptune	18 h 12 m	60190.3	4537	4456	4496.7	25.10
9	Pluto	6 d 9 h 17m	90465	7375	4425	5900	25.10

In Fig. 1, the orbit of a planet round the sun is shown. The orbit is in the shape of an ellipse with two foci S and Q. The sun is assumed to be located at S while Q is not occupied. ASQB is called the major axis and LOM is the minor axis.

O is the mid point of AB and LM is perpendicular to AB. OA and OL are called semi major axis and semi minor axis of the ellipse respectively. Incidentally O is also mid point of LM.

Let us assume that the planet is at a point P_1 on the ellipse at a given moment. The line joining S and P_1 is called the radius vector R. After a little time DT let the planet move to a point P_2 in the direction shown by the arrow; SP_2 will be the new radius vector. Let the angle P_2SP_1 be θ_1 . (In mathematics, small quantities are indicated by using D . Thus DT is a small interval of time and θ_1 is a small angle. Kepler's first law says that every planet goes round the sun in an orbit having the shape of an ellipse; it also says that the sun is at one focus of the ellipse. We have drawn the diagram accordingly. A very important thing to note is that ellipse is a plane figure. Every point on the ellipse is in the same plane. In our case, all points of the ellipse are in the plane of the paper. Further two foci and the center are also in the same plane along with the point O. This should be understood and remembered when we talk of orbits of man-made satellites. It should also be realized that the distance between the sun and the planet keeps on changing, the minimum distance being SA and the maximum SB.



Proceeding in time, let us assume that after some days the planet is at a point D_1 . The new radius vector is SD_1 . If we now track the planet for a time DT and see where the planet has moved, it may be at a point D_2 on the ellipse. Let the angle D_2SD_1 be θ_2 . Kepler's second law says that the area of P_1SP_2 and area of D_1SD_2 [which are both shaded] must be equal because these areas have been swept by the radius vector in the same interval of time DT . It would be obvious that P_1P_2 is not equal to D_1D_2 . The areas are obtained by multiplying the two sides and also the angle between them expressed in a unit, called radians and not degrees as we normally do. The product of these three quantities divided by two is the area.

$$\text{Area of } P_1SP_2 = 1/2(SP_1 \times SP_2 \times \text{angle } P_2SP_1)$$

$$\text{Area of } D_1SD_2 = 1/2(SD_1 \times SD_2 \times \text{angle } D_2SD_1)$$

Kepler's second law says that these two areas are equal. As SP_1 and SP_2 are larger than SD_1 and SD_2 the angle P_2SP_1 must therefore be smaller than angle D_2SD_1 . This leads to the result that D_2D_1 is longer than P_2P_1 . Therefore, the planet has moved a longer distance when it was closer to the sun than when it was farther from the sun in the same interval of time DT . This means that the planet does not move with constant speed round the sun but moves slowly when it is farther away and moves faster when it is closer to the sun. The variation in speed will be more marked if the ellipse is more elongated. This also is an

important result. Earth satellites move faster when they are closer to the earth than when they are farther away in the orbit.

The third law of Kepler says that the cube of the semi major axis is directly proportional to the square of the time (T) taken for the planet to go round the sun once. In our figure OA^3 by T^2 is a constant for us all planets going round the sun. Thus if we observe how long it takes for a planet to go round the sun, we should be able to calculate the mean distance between the sun and the planet as we know both these values for earth.

Table 1.1 gives the values for R^3/T^2 and other data for all the solar planets. We can now apply this to earth satellites. We know that the moon which is at a mean distance of 400,000 km from the earth takes about 29 days to go round the earth. The value of R^3/T^2 for this is $400,000^3/29^2$. We would like to calculate the mean distance at which a satellite should be to go round the earth in one day. We equate $400,000^3/29^2 = X^3/T^2$ and we get $X = 42,376$ km

This is the distance from the centre of the earth to the satellite and from the surface of the earth it will be approximately 36,000 km. These satellites are known as geosynchronous satellites and take the same time to go round the earth as the earth takes to go round itself, i.e., one day.

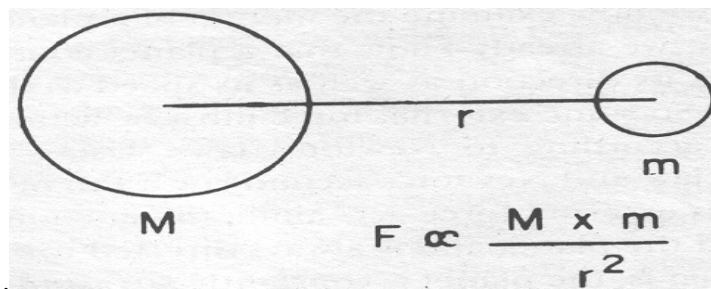
After Kepler announced his laws, Newton applied his own laws of motion to them and derived a very important result. Newton's laws of motion are three in number. The first one says that a body will continue to be at rest or travel along a straight line with uniform velocity unless acted upon by an external force. The second one says that the force is proportional to the rate of change of momentum of the body and the change takes place in the direction in which the force acts. The third law states that action and reaction are equal and opposite. For the purpose of our present discussion, we will briefly explain the first two laws.

The first law describes the effect of applying an external force on a body. If the body is at rest, application of a force makes it to move. If it is already going along a straight line, the application of a force can either change its speed or direction or both. If no force is applied, the body cannot by itself change its direction or speed.

The second law gives a measure of the effect of applying the force. Whether a body moves from rest or moves with a different speed or in a different direction on the application of a force, the body is said to be having an acceleration or a change in its velocity. The second law leads to a conclusion that acceleration takes place in the direction in which the force acts and to is equal to the force divided by the mass of the body. Thus, according to Newton's laws, a change in direction of motion or in the speed of a body can be lame brought about only by application of a force. The larger the force, the greater the rate of change. It should be remembered that we are dealing here with rate of change and not merely change. To obtain a given change in speed one can apply a smaller force very for a longer time or a

larger force for a shorter time. In the first case the speed will increase slowly and in the second, rapidly.

If we now examine the motion of a planet round to the the sun, we already know that a planet continuously Id the changes its direction as well as its speed as described earlier. So some external force must be acting on the planet according to Newton's laws, Using Kepler's second law and Newton's second law it can be derived that this external force acts along the line joining the sun and the planet and is always directed towards the sun. That is, the planet is constantly attracted towards the sun, It can also be sown that this force is directly proportional to the mass of the sun and the mass of planet and is Inversely proportional to the square of the distance between the sun and the planet is, greater is this force of attraction. If the distance is more, the force goes down. For example, if the distance between the sun and planet is doubled, the force goes down to a fourth or quarter. If the distance is tripled, the force goes down to a ninth. Newton propounded his universal law of gravitation based on the above conclusions. This states that if there are two particles of mass M and m separated by a distance r , then they attract each other with a force F which is proportional to $M \times m$ and inversely proportional to r^2 . Expressed as an equation. It can be written as $F = GMm/r^2$ Where G is called universal constant of gravitation. Although this law was derived for solar planetary system, it is applicable to any two bodies from the size of atoms



This illustrated in Fig. 2

A close look at this law shows that not only does the sun attract the planets, but the planets also attract the sun. However, the sun is so much more massive compared to any of the planets that this force of attraction by the planet is not able to move the sun and hence the planets go round the sun. It should be noted that the planets also attract each other with some force which keeps varying as distances between planets do not remain constant. The result is that the planets are very slightly disturbed in their orbits. As a matter of fact, it was on the basis of such disturbances that the existence of the outer planets was first postulated. Careful search through telescopes later revealed their presence.

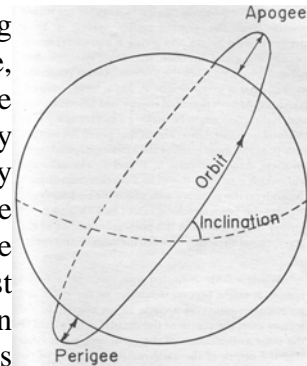
This force of attraction is what keeps the moon going round the earth and the other moons round other planets. This force is known as gravitational attraction. This force is what makes bodies close to earth fall on the earth. It always acts along the line joining the two bodies. For purposes of calculation of this force, we have to assume that each body is located at a point called its centre of gravity and that its entire mass is concentrated at this point. Thus the centre of gravity of the earth is the centre of the earth itself. Similarly for any other body it would be a point inside the body. For a body on the surface of the earth, the distance between the body and the earth for calculating gravitational attraction would be the radius of the earth. All bodies on the surface or above the surface of the earth are attracted toward the centre of the earth along the line joining the centre of the earth and the body. This direction is what we call the act vertically downward direction. When a body falls to the earth due to earth's attraction, it is actually trying to move towards the centre of the earth but once it hits the surface of the earth it stops. The force of attraction is still there but unable to move it due to the solid barrier of the earth. This force is what gives the body its weight. The weight of the body is the mass of the body multiplied by the acceleration due to gravity caused by the action of this force. It can be shown that for all bodies near the surface of the earth, the acceleration due to gravity is the same and is denoted by the small letter g opposed to the universal constant which is written as capital G . The significance of g is that if a body is falling freely towards the earth from a height, its velocity in the vertically downward direction will increase by 9.8 metres per second, every second of fall, g being equal to 9.8 metres per second per second. This increase is the same whatever be the mass of the body, be it a heavy iron ball or light tennis ball for instance. Similarly when any body is thrown vertically up, its upward velocity keeps decreasing by 9.8 metres per second every second as it ascends. After its velocity upward is reduced to zero, it starts falling back to the earth with increasing velocity.

The value of g is on an average taken as 9.8 metres per second per second but actually at different places on earth its value changes due to (a) altitude, (b) latitude, (c) presence of heavy minerals, (d) water, (e) oil, etc. It also is different on top of a mountain compared to a point at the same height above a plain. All these features influence the value of g , even when a body is tens to hundreds of kilometers above the earth. These can be measured by sensitive instruments placed in an aircraft or a spacecraft thus enabling one to detect the presence of minerals, water, oil, etc. In some cases this method yields very reliable results but in other cases, there are better methods. Changes in value of g could also lead to slight perturbations in satellite orbits. From time to time during a satellite's life in orbit, it may therefore become necessary to make slight corrections to bring it back to the predetermined orbit round the earth.

2. Orbital Motion

In the previous chapter, we have seen how planets are kept moving in fixed elliptical orbits round the sun by the gravitational attraction between the sun and the planets directed towards the sun. We have however not touched on the circumstances leading to the planets being put in their orbits billions of years ago. This aspect is dealt with in the subject of the origin of solar planetary system. It is not our intention to deal with this subject but it should be realized that putting a satellite in a given orbit is an entirely separate activity from maintaining its motion in the orbit. In this chapter, we shall cover some aspects of how to induct a satellite into a given orbit and the factors that influence the motion of a satellite in orbit.

To define the orbit of satellite round the earth the following characteristics of the orbit are usually given. They are the apogee, perigee and inclination. Apogee is the farthest distance from the earth and perigee the farthest distance from the earth, usually given in kilometers from the surface of the earth. For any calculation using Kepler's laws, one has to add the radius of the earth to these distances. The inclination is the angle between the plane of orbit and the equatorial plane measured from east to west when the satellite crosses the equator from south to north. In addition to these, one can also give the orbital period but this is fixed by the other parameters already given.



A satellite is usually carried by a multistage rocket system from the ground. After taking it to a predetermined height and giving it a predetermined even a velocity in a given direction, the rocket system is shut off and separated from the satellite. At this point, the satellite is at a given height h , has a total energy E consisting of both potential energy and kinetic energy and its direction might be making a given angle β with the local horizontal direction at that point. All further history of the movement of the satellite depends only on these three quantities h , E and β . The accuracy with which a satellite moves in a predetermined path depends on the accuracy with which the rocket system imparts the predetermined values to E , h and β . All further movement from this point is controlled by the gravitational attraction between the satellite and earth.

When a body is hurled into space by a rocket system, it might become a satellite of the earth and go round it either in a circle or an ellipse. In the former case, the centre of the circular orbit would be the same as the centre of the earth and in the latter case the centre of the earth would be at one of the two foci of the elliptic orbit. But there are two other possibilities which should be mentioned. If the body, the time of separation from the rocket system, has an equal amount of potential energy and kinetic energy (in such a case total energy would be zero as potential energy is always considered negative the body will take a parabolic path and move away from the earth. It would come to rest at infinity. If the kinetic energy is larger than the potential energy, the body will travel along hyperbola upto infinity and lined even at infinity it would still have a velocity.

For a given height from the ground, the velocity which will make a body escape to infinity along a parabolic path is called the escape velocity V_e . This velocity is solely dependent on the height of the point and not on the body itself and the velocity would be in the local horizontal direction. As an example, a body thrown horizontally with a velocity of 11.2 km per second from the surface of the earth will travel along a parabola to infinity and come to rest. As we go higher, this escape velocity becomes smaller. A body at the distance of the moon if thrown horizontally with a velocity of only 1.38 km per second would escape from the gravitational attraction of the earth. If a body is to go round the earth either in a circle or an ellipse, it must have a minimum velocity V_e at a given height. This is approximately 70 percent of the escape velocity for that height. To be exact $V_e = 2$ times V_c . Thus at the surface of the earth $V_e = 7.92$ km per second.

Actually we cannot make a body go round the earth right at the surface; so, a body has to be taken to some height and then made to go round the earth either in a circle or ellipse. If the horizontal velocity at that height is exactly 1/2 of the escape velocity, V_e , then the body will go round in a circle. If it is more than that but less than the escape velocity, the body will go round in an ellipse; the higher the velocity the more elongated or eccentric would the ellipse be. If the height of the point is h , then its distance from the centre of the earth is $R+h$ where R is the radius of the earth, V_e can be calculated for any value of h by the equation

$$V_e = \sqrt{2GM/(R+h)} = 893/\sqrt{6400+h} \text{ km/sec.}$$

where G is the universal constant of gravitation explained in the previous chapter, and M is the mass of the earth. Similarly, the velocity of a body to be put in circular orbit at a height of h is given by

$$V_c = \sqrt{GM/(R+h)} = 632/\sqrt{6400+h} \text{ km/sec.}$$

We use the above two equations to get values of V_e and V_c at different heights, h , where h is expressed in kilometres.

In deriving the above equations and in arriving at the conclusions mentioned earlier, we have ignored three factors, Firstly' that the earth is not a perfect sphere but a spheroid; It is slightly larger in diameter at the equator than along the poles. It also has a slight bulge south of the equator and a slight depression north of it. Secondly, we ignored that the earth is rotating round itself from west to east with a period of 24 hours. Thirdly we have also not taken into account the existence of a fairly dense atmosphere above the surface of the earth through which the satellite has to move especially at lower altitudes. All these three factors affect the path of a satellite.

Because of the spheroidal shape of the earth, the orbital plane of the satellite itself will rotate in a direction opposite to the satellite motion while maintaining the same inclination to the equator. Usually satellites are launched eastwards to take advantage of the eastward motion of the earth. This motion gives all bodies on the earth and taking off from it an eastward velocity and to that extent makes the task of giving a higher velocity

eastward easier. As satellites are launched eastward, the motion of the orbital plane will be westward. The effect of this can be explained as follows. Suppose the path of the satellite crosses the equator over a point A while going from south to north. In the ideal case where the earth is a non-rotating perfect sphere with no atmosphere, the next time the satellite crosses the equator from south to north, in fact, every time it does so, it should go over point A. However, because of the spheroidal shape of earth and the consequent rotation of the plane of the orbit, the satellite crosses the equator not over A but over a point west of A. This phenomenon is called nodal regression.

The amount by which the satellite moves westwards with each orbit depends on the angle of inclination of the orbit the equator. Thus if the orbit is a polar one -i.e., the satellite is traveling over the two poles and its orbit is perpendicular to the equator-the nodal regression is zero. If the orbit is parallel to the equator it will be a maximum. Further, the nodal regression depends on the altitude of the satellite. The higher the altitude, lower is the value of the nodal regression. Thus, if a satellite is going round the earth in an orbit at an inclination of 10° and at an average altitude of 320 km, the nodal regression will be approximately 8° per day.

Another effect of the spheroidal shape of the earth is that the satellite will be nearer to the earth at the equator. This causes the satellite to be slightly speeded up or accelerated every time the satellite crosses the equator. This results in a rotation of the axes of the elliptical orbit in the plane of the orbit. This rotation of the axes is in same direction as the satellite at low inclinations and in the opposite direction at high inclinations. At an inclination of 63.4 the degrees, there is no rotation of the axes i.e., the shape of the earth does not affect the orbit of the satellite in so far as the axes of the ellipse are concerned. The Soviet Union which is situated far north of the equator usually prefers this orbit with the apogee in the northern hemisphere for its communication satellites. The rotation of the axes reduces as the height of the satellite increases.

The above two effects, i.e., nodal regression and rotation of axes, are due to the deviation of the shape of the earth from being a perfect sphere. These are deviations which can be accurately calculated for all types of orbits and are taken into account even before launching the satellites. In the ideal case, a satellite's path when plotted on the ground should pass over the same set of places on earth forming a closed curve. But, due to the two perturbations mentioned above, the line joining the places over which the satellite passes forms a sort of open curve. The northern most and southern most points of the curves lie on the latitudes which have the same value as the inclination of the orbits. Thus if the inclination of the orbit to the equator is 10° , the satellite will go over places between 10° North latitude and 10° South latitude. It will not go beyond this latitude. If more places on earth are to be covered, the inclination should be increased. All places on earth could be covered over number of orbits, if the inclination is 90° and the satellite goes over the poles.

Apart from the above two causes for perturbation, the following also are some of the other causes.

- The gravitational attraction of Sun and Moon
- The earth's magnetic field and its fluctuations;
- Solar radiation pressure; and
- The inertia of moving parts in the satellite.

These effects are much more complicated and difficult to calculate. However, they are small in magnitude. In addition to the four factors mentioned above, satellites in low earth orbits are also subjected to friction due to the atmosphere of the earth. This friction is directly proportional to the density of the air and inversely proportional to the square of the speed of the satellite. The effect of this friction is to slow down the satellite, bring it down and finally burn it up. For this reason, satellites are rarely allowed to come nearer than 200 km above ground. For such satellites, this life time would be very short. The life times of some types of satellites are given in Table 2.1.

Many of the satellites may become useless much before their life-time due to failure of the instruments and equipment installed in them.

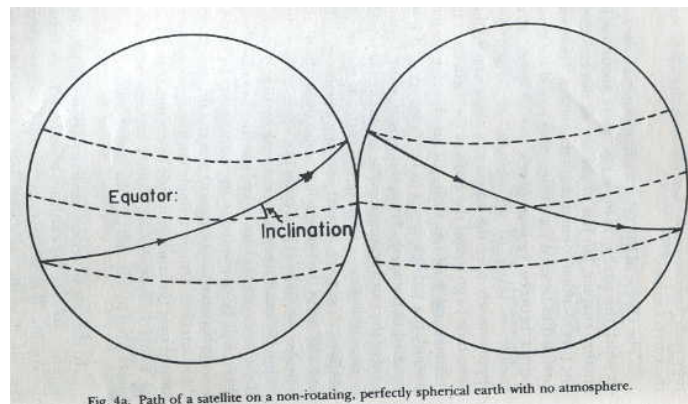
Table 2.1 Life expectancy of some satellites

Satellite	Perigee (km)	Apogee (km)	Life expectancy
Spy Satellites	118	430	15 days
Sputnik-1	225	946	3 months
Explorer-1	361	2550	12 years
Transit (Navigationary satellite)	1090	1110	1000 years*
Geostationary	36000 (approx)	36000 (approx)	1 million years*

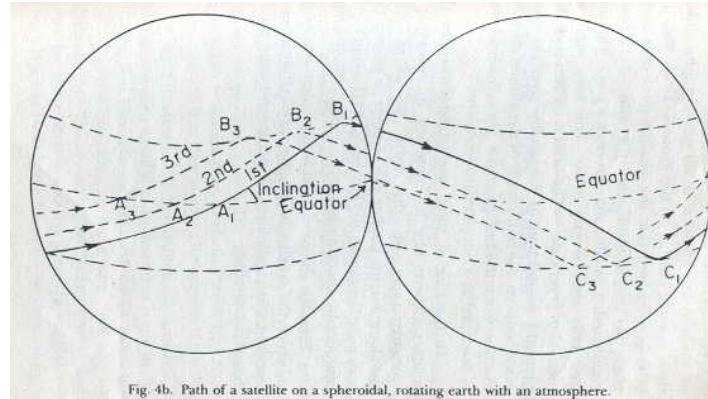
The other factor which influences the satellite orbit is the rotation of the earth. It is well known that the earth rotates round itself once every twenty-four hours. In one hour it rotates through 15 degrees. When the path of a satellite is plotted on the surface of the earth, it describes a wavy curve and not a circle as we would expect. If the satellite crosses the equator at point A, in the first orbit, it will cross the equator at a point A₂ which will be west of A, in the next orbit. However, after several orbits, the satellite may again go over A. These are illustrated in Fig. 4. (a) and (b) there, and include effects like nodal regression and rotation of axes.

We have thus seen how the path of a satellite is influenced by the various factors. Some of these can be calculated before hand and taken care of while others, which are usually not very significant, cannot be accurately predicted. In such cases, the satellites are provided with correcting mechanisms which could be commanded from ground to operate from time to time such that the satellites might be brought back into the correct orbit.

The choice of the orbit itself depends on the use to which the satellite is to be put. More about this in another chapter, but just to cite one or two examples one may mention communication satellites. These are intended to be used for maintaining round the clock contact between various places on the earth. If a satellite is taken to an altitude of 36,000 km approximately over the equator, it takes exactly the same time to go round the earth as the earth takes to rotate round itself. As such, for an observer on the ground, the satellite seems to be stationary as if it is attached to the earth. From this height, more than a third of the earth becomes visible or the satellite would be accessible to one third of the earth. If two other satellites were to be located over the equator at 120° or 240° from the first satellite respectively, the three together would be able to cover the whole of the earth except for small areas in the extreme north and south. If the three satellites are linked together by radio, then there will be a possibility of maintaining 24 hours contact between any two points on earth through these three satellites. Usually a single satellite appropriately located over the equator should be enough to provide 24 hours communication facility between any two places even in a country of the size of India.



In the case of remote sensing satellites, Images of different areas of the earth are repeatedly taken from the satellite. It is necessary to take such images when the Sun is at the same elevation over the place of interest each time. This ensures that any shadows cast by sunlight are identical in all photographs, unless there is some change on the ground. To do this, the orbit is so chosen that the satellite goes over every place in synchronism with the sun. As already mentioned, a satellite may go over a place a second time only after several orbits" This may mean an interval of several



days. The orbit is chosen such that when the second pass of the satellite over the given place happens, the Sun's angle of elevation is the same as it was when the first pass took place. Such an orbit is described as a Sun synchronous orbit.

In the case of some spy satellites used by the military, where one is interested in observing a particular spot on the earth to assess some development, the satellite can be made to go over that spot quite low (about 100 km) but quickly rise to higher altitudes by choosing a fairly eccentric elliptic orbit.

Thus the choice of orbit is dependent on the use to which the satellite is put, the expected duration of use and the capabilities of the instruments put on board the satellite.

3. Rockets and Satellite Launch Vehicles

It was mentioned in the previous chapter that, to induct a satellite into a predetermined orbit, the satellite should be taken to a precisely determined height and given a precise velocity in the right direction. It is these three parameters which ensure that the satellite travels in a particular orbit round the earth under the sole influence of the earth's gravitational attraction. It was also briefly mentioned that a rocket system is used to carry the satellite to the given height and give it the necessary energy and direction. In this chapter, we shall describe how rockets function and how they are used for satellite launching.

Rockets are used both to launch satellites and also to control their motion to some extent while in orbit. In the first case, the rockets used will be large, use a lot of propellant burning for a long time and have large thrusts. The second type of rockets is small, burns fuel for short periods and has small thrust. However, both types of rockets are based on Newton's third law of motion mentioned in the first chapter. The principle of operation is simply stated.

A fuel is burnt with the aid of an oxidiser in a chamber and very hot gases are produced. These gases occupy the vacant space in the chamber and as more and more gas is generated, the pressure in the chamber builds up. At the back of the chamber is fitted a nozzle which prevents the pressure from building up too much by allowing the hot gases to escape in a controlled manner. As long as there burning fuel, hot gases keep escaping through the nozzle. Depending on the pressure inside the chamber and the shape of the nozzle, the gas escapes as a jet. The important characteristics of this jet are the mass of gas escaping per unit time and its velocity. As the gas escapes, the rocket is pushed forward. According to Newton's third law, the momentum (i.e. mass multiplied by velocity) of the gas jet will be equal and opposite to the momentum of the rocket. The faster a rocket must move, the higher should be the momentum of the gas jet. As the fuel and oxidiser are both provided in the combustion chamber, a rocket can operate even above the earth's atmosphere where there is no oxygen.

Thus the important constituents of a rocket are a combustion chamber, fuel, oxidiser, an igniter to start combustion on command and a properly shaped nozzle. The fuel and oxidiser could be a single chemical or two different chemicals. They could be both solid or both liquid or one may be solid and the other liquid. Whether single or composite, if the chemicals are in the solid state the rocket is called a solid propellant rocket. If the propellant chemicals are in the liquid state, the rocket is described as liquid propellant rocket. In the third case of a combination of a solid fuel and liquid oxidiser or vice versa, the rocket is described as a hybrid rocket. It is the state of the fuel and oxidiser which is reflected in the description solid, liquid and hybrid rockets.

A solid rocket (Fig. 5) would be made up of a metal or glass fibre reinforced plastic chamber in which the properly shaped solid propellant is placed. The propellant

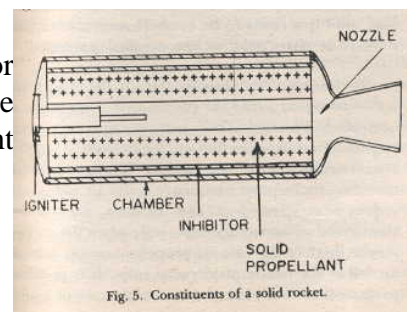
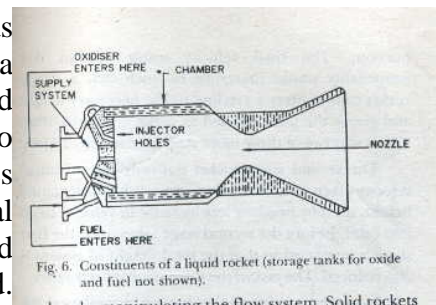


Fig. 5. Constituents of a solid rocket.

would be a long cylinder tightly fitted into the chamber which would be lined with an inhibitor to prevent the combustion of the propellant from spreading to the walls of the chamber. The cylindrical propellant will be hollow in the middle along the axis. At one end of the chamber will be an igniter which simply generates an electric spark to start ignition. At the other end would be the nozzle which is actually a pipe which is narrow in the middle but wider at both ends. The combustion starts in the hollow of the propellant and spreads outward until the whole propellant is burnt out.

The total time taken for the propellant to burn is called burnout time and the completion of combustion is called burnout. In large rockets, burnout time may be as much as 100 to 120 seconds and pressures in the chamber may be of the order of 30 to 50 times the atmospheric pressure. Temperatures inside the chamber may reach 2400 to 4400 Kelvin. Thus very special materials have to be used in constructing the rocket to withstand high temperatures and pressures. The nozzle also needs to be made of similar materials and its shape is crucial to the performance of the rocket. In the case of solid rockets, the propellant could be in the rocket all the time until it is ready to be used. However, once the combustion starts, it cannot be controlled or stopped.

In the case of liquid rocket (Fig. 6), the propellant has to be injected into the combustion chamber in a controlled manner. Thus two storage tanks are required for storing the fuel and the oxidiser. A supply system to introduce the fuel and oxidiser in controlled quantities in the proper sequence is also an additional requirement. The fuel and oxidiser are to be transferred to the storage tanks only when the rocket is to be fired. In this case the propellant supply system as well as the nozzle play crucial roles. It is possible to shut off or control combustion in the case of liquid rockets by manipulating the flow system. Solid rockets are however considered to be simpler and more reliable.



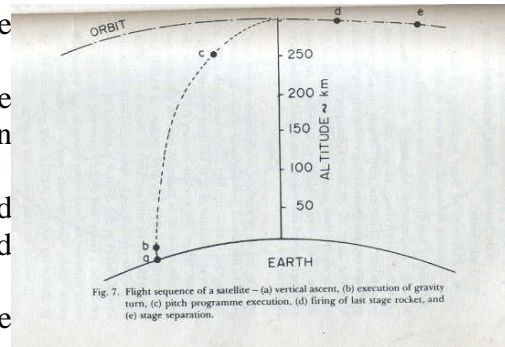
Whether solid or liquid rocket, the motion of the rocket is governed by the escaping jet of hot gases. At sea level the gases may escape with a velocity of 1800 to 4500 metres/second. As the fuel burns, the rocket, which is initially at rest, will start moving up picking up speed with time. The weight of the rocket will continuously decrease as the fuel burns and hot gas escapes. Thus velocity increases more rapidly with time. The final velocity will depend not only on the burnout time but also on the final weight of the rocket. The ratio of initial weight to final weight should be as high as possible to attain high velocities. However, because the combustion chamber, nozzle and other parts remain till the end and some fuel also would be left unburnt, it is not possible to make this ratio more than four or five; i.e., the initial weight of the rocket would be about 4-5 times the final weight after burnout. The final velocity using present day propellants would therefore be such that a single rocket cannot carry a satellite to the necessary height and give it the push needed to make it go into orbit. This is why two or three more stages are usually added.

The second stage rocket not only has an initial velocity given to it by the first stage, it has also gained height, thereby needing less increase in velocity to go into orbit. Before the second stage takes over, the first stage is separated so that the total weight of system is also reduced. The task of the third stage is even easier.

However, it is found that having more than three or four stages does not make the task of launching a satellite into orbit significantly easier. Having too many stages might also make the system less reliable. Hence, the usual practice is to have not more than a four-stage system for launching satellites. The first stage is usually called the booster stage and the subsequent ones as sustainer stages.

The various events leading to the injection of a satellite into orbit are given in Fig. 7. The trajectory of the satellite launch vehicle would be generally as follows :

- Vertical ascent for a few seconds.
- Execution of a gravity turn till the vehicle clears the atmosphere.
- Pitch programme execution above the atmosphere to obtain the terminal injection conditions, especially the orbital altitude.
- Coasting up to the orbital altitude and firing of the last stage to inject the required velocity increment.
- Execution of stage separation so that the satellite is now all on its own in orbit.



Satellite launch vehicles are equipped with very accurate instruments on board to continuously provide the correct orientation, position, velocity and acceleration. These are continuously measured and guidance computations are carried out using this data with the help of on board computers. Steering commands are then passed onto the autopilot in the vehicle. For some satellite launches, however, preprogrammed commands are stored and issued to the autopilot.

The above procedure is applicable to low earth orbits. In the case of geostationary or very high orbits, the satellite is first injected into a low earth orbit at an average altitude of 200 km and inclined to the equator. When the satellite crosses the equator the first time, its orbit is changed into an elliptical one with perigee of 200 km and apogee of 36,000 km. The orbit will be still inclined to the equator. When the satellite reaches the apogee at 36,000 km altitude, a small rocket in the satellite is ignited to change the orbit into a circle and also to turn the plane of the orbit from an inclination to being in the equatorial plane itself. The various stages of launching the geostationary satellite APPLE are given in Fig. 8.

It would be interesting to look at some of the characteristics of satellite launch vehicles used and proposed for the Indian space programme and also to compare them with other means of transport

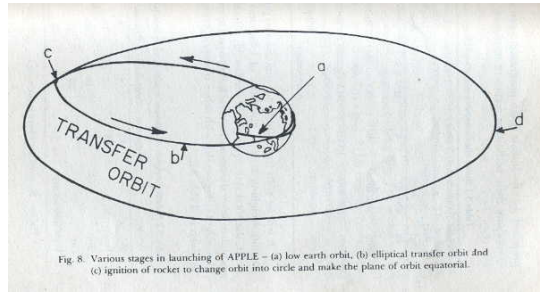


Fig. 8. Various stages in launching of APPLE - (a) low earth orbit, (b) elliptical transfer orbit and (c) ignition of rocket to change orbit into circle and make the plane of orbit equatorial.

Table 3.1 Some characteristics of Indian SLVs

Pay load of (kg)	Wt. of Satellite (kg)	Altitude (km)	Inclination (deg)	Velocity (km/sec)	ISRO system	rocket Total weight (tonnes)	initial weight (tonnes)
40		400	40°	9	SLV-3 IV stage	17	
600		500	40°	9	SLV variant III stage	80-100	
600		550-900	97°-105°	10.5-11.0	SLV variant IV stage	150-170	
600		36,000	0°	13.7	SLV synchronous	400-450	

It will be seen from Table 3.1 that even to put a satellite weighing tens to hundreds of kilograms in orbit, the total system weight of the launch vehicle is as high as several tonnes to several hundreds of tonnes. One might compare this with other transport systems as given in Table 3.2.

The last column in Table 3.2 is the useful load to be transported. The sum of the other two columns gives the corresponding load of fuel and other associated systems required.

Table 3.2 Relative weights of different constituents in vehicles

Vehicle*	Properiant	Propulsion	Payload
SLV	88	4	6
Jet aircraft	43	7	10
Ship	15	10	25
Car	3	22	25
Train (75 wagons)	1	3	77

* The best achieved anywhere is presented.

It would be realized that in a satellite both volume and weight have to be kept minimum. The materials and mechanical fittings used should be able to withstand high accelerations, the extreme conditions in space and must have long life. The rocket system and every component in it must also function with very high reliability. This calls for new materials, better fabrication practices and sophisticated testing procedures. India has developed expertise in all these areas.

4. Earth Satellites and Their Uses

In the previous chapters, we have seen how, with the help of a multistage rocket system, a body can be injected into any predetermined orbit round the earth. We have discussed some principles of orbital motion and the operation of rockets. It will therefore be realized that it is now possible to put in orbit objects as small as a few kilograms to as heavy as several tonnes. The altitude could range from about 100 km for a low earth orbit to the geostationary orbit at 36,000 km above the earth in circular or elliptic orbits with orbital periods varying from about 90 minutes to 24 hours. The only restriction is that the plane of the orbit must pass through the centre of the earth. We shall see in this chapter how these satellites can be used.

Satellites are essentially platforms protected from the severe environment existing in space. In the enclosed and controlled environment of a satellite it is possible to place instruments and equipment or even human beings to make observations of the earth and of the environment surrounding the satellite as well as of deep space. Depending on the altitude of the satellite, large areas of earth can be observed simultaneously; the higher the satellite, larger being the area. As the satellite platform keeps going round the earth, it would pass over the same area on earth repeatedly, enabling the observation of that area repeatedly. If there are changes taking place in the area, such as crops growing or getting diseased, these will be revealed clearly in such observations. If there are movements of people, construction activity, etc., progress of such activities can be monitored as is usually done by military spy satellites. By having satellites with elliptic orbits, it is possible to make direct observations and measurements on the environment at different altitudes above the earth's surface.

The earth's atmosphere consisting of air, water vapour, dust, smoke and other particles greatly modify the radiation that we receive from stars and interstellar space. The earth's near environment does not allow gamma rays, X-rays, ultraviolet rays, infra-red and radio waves of certain wavelengths to reach the surface of the earth. It also prevents most of the meteorites and cosmic ray particles from reaching the earth. The earth's magnetic field also plays apart in this. Thus, observations from the earth's surface will not give us a full picture of all types of radiation and particle's constantly arriving near the earth from all directions of the cosmos. By using appropriately instrumented satellites placed above the atmosphere of the earth, we could collect accurate data on these aspects.

The satellite also provides a zero gravity environment. The earth's attraction due to gravity is neutralised by the centrifugal forces caused by the satellite's orbital motion. Such a zero gravity environment will be very useful in fabricating perfect geometrical shapes, in growing perfect crystals and such other mechanical operations. For example, liquid drops tend to be more perfect spheres than on earth due to zero gravity. When such drops happen to be molten solids, when they solidify we get perfectly spherical particles.

The use of satellites could be classified broadly into four categories. The first one relates to scientific research. Important areas of scientific research are:

- Atmospheric and ionospheric measurements are directly at different altitudes.
- Magnetospheric research.
- Looking at cosmic rays and meteorites.
- Gamma ray, X-ray, ultraviolet, infra-red and radio astronomical observations. The universe looks different at these different wavelengths and all of them are different from the universe we see at optical wavelengths. Several new branches of astronomy have now come up like X-ray, astronomy, infra-red astronomy, etc.

The second category of uses relates to commercial and human activities. Among these we may mention the following three important uses:

- Remote sensing and surveying natural resources including crops, forests, minerals, water, oceanography, environmental pollution.
- Meteorological studies both on national and global scale.
- Communications within a country and round the globe. In this category one might also mention navigational satellites.

The third category of applications relates to industrial uses. In the satellite environment, there are physical conditions like almost total vacuum, zero gravity, exposure to all types of radiation from all over the universe, extremes of temperature depending on whether the satellite is sun-lit or in the shadow of the earth, etc. Some of these conditions are almost impossible to create on earth. As already mentioned, satellites therefore provide an environment where certain types of materials and shapes could be fabricated. Satellites are also used for testing live and inanimate objects under the conditions mentioned above, to see whether the objects remain as they are, or undergo changes. If there are changes, their nature, extent and duration is studied. By these studies, one can choose proper materials and fabrication techniques and also set safe limits to human, animal and plant usage in such vehicles. Satellites are also used to test new equipment, instruments and components before they are incorporated in future satellites.

A fourth category of uses of satellites is in the field of intelligence gathering. Such satellites are popularly called spy satellites. While there are restrictions on civil and military aircraft flying over other countries due to their relatively low altitude, satellites have no such restrictions. Their orbits can be so devised that they can approach any place on earth fairly close (90 to 100 km) and make observations of great military value. These spy satellites are used to detect new installations on earth, weapons testing, military movements and concentrations and to monitor progress of local wars. The two superpowers are constantly and continuously engaged in this activity.

We have seen that satellites can be used in many different ways. When a country decides to launch a satellite it first determines the use to which the satellite is to be put. This will enable the satellite to be designed, i.e., its size, its complement of instruments, sensors, power supplies, etc. On the specific use also depends the satellite's orbit and its life. These two are somewhat interdependent. A long life would require the satellite to move at higher altitudes. Higher altitudes in many applications may not give good and clear observations of the earth. Thus there has to be a compromise between choice of orbit and

life expectancy. The main criterion for the choice of an orbit is that the satellite should pass over the places and areas of interest to the user. Further, the life of the satellite should be at least as much as the life of the instruments and equipment installed in the satellite.

In the case of remote sensing satellites there is an additional requirement. The satellite carries instruments to take clear images of the areas of interest on earth. Such images come out best when taken while the area of interest is lit by sunshine. It will also be an advantage if such images are taken when the shadows cast by sunlight are fairly short. Usually, satellite orbits are so chosen that the satellite goes over the area of interest between 1000 hrs and 1400 hrs local time (i.e., approximately within two hours of local noon time). To do this the satellite is injected into a sunsynchronous orbit. As is well known, the earth takes about 364 days to go round the sun or the angle swept by the line joining the sun and earth per day is approximately one degree. If the plane of the orbit of the satellite moves by this same angle in the opposite direction and the orbital period is properly adjusted, then the satellite goes over different places within the local time limits mentioned above. We may recall that the nodal regression is different for different angles of inclination of the orbital plane to the equator, being zero for 63.4 degrees. It also varies with altitude. At the same time, the earth's rotation from west to east makes the satellite go westwards by several degrees with every orbit. By adjusting the inclination and altitude of the orbit, one can arrive at a suitable orbit to ensure synchronism with the sun. In the case of IRS-I launched on 18 March 1988, the inclination is between 91-103° and altitude approximately 904 km. This ensures that all areas of India are imaged between 1000 hrs and 1400 hrs local time and when the satellite goes over the same place after 15 or 16 days the local time is approximately the same. The shadows cast by the sunlight are approximately the same and hence are not likely to cause confusion while determining changes in the images taken at intervals of 15-or 16 days.

For communication satellites, geostationary orbits are used by countries low latitudes like India. The orbit will be at an altitude of 36,000 km in the plane of the equator, the satellite going round the earth once from west to east in 24 hrs. The satellite therefore appears to be fixed in space so far as an observer on earth is concerned. The satellite appears to be overhead of a point on the equator. The longitude of the point is so chosen that the satellite is visible from all the places in the country using the satellite. Usually the only detail given about the position of a geostationary satellite is its longitude. The rest, namely, that its orbit is in the equatorial plane and its altitude is 36,000 km, is understood. From this altitude, one-third of the earth can be seen by the satellite. However, areas far north or south of the equator beyond about 75° latitude would not be able to see the satellite.

For countries like Soviet Union, Sweden, Norway, etc., the geostationary orbit is not of much use. The Soviet Union uses an orbit at an inclination of 63.4° with an orbital period of several hours and apogee (40,000 km high) being in the northern hemisphere and perigee (500 km high) in the southern hemisphere. Such an orbit allows the satellite to move rather slowly over the northern hemisphere. A series of two or three satellites moving in the same orbit but at regular intervals ensures that there are always one or two

satellites available to the whole country for global communication. Because of their high altitude, they survive for many years, in fact, longer than the equipment placed in the satellite.

These are some examples of how orbits are chosen depending on use, area to be covered and life expectancy. We shall now see what sort of instruments are installed in satellites. There are two types of instruments normally used in satellites. One set is somewhat common to all satellites while the other set depends on the usage of the satellite.

The first set is intended to monitor satellite's functioning and the physical conditions inside it. Measurement of temperatures, pressures, accelerations, spin, positions, altitudes, voltages, currents, etc. are made routinely and signals sent back to earth. These indicate whether the satellite is functioning properly and whether various parameters are within the prescribed limits. If any of these shows unusual deviations, either self-correcting mechanisms or mechanisms commanded by radio from the ground become operational and bring back the parameter to acceptable values. These are called health monitoring and housekeeping activities and are required in all satellites. It should be noted that a satellite is made to spin 6-12 times a minute round itself so that no part of it is exposed to the sun too long and gets heated up. Rather the spin will ensure that all sides are fairly uniformly exposed to sun. It should also be noted that the only way heat can be lost to the surroundings is by radiation. Conduction and convection do not play a role because there are no significant material particles in the satellite environment. Heating is controlled to some extent by making the outer surface of the satellite highly reflecting.

The other types of instruments are those that do the job that the satellite is actually intended for. In the case of remote sensing there are return beam vidicon cameras (RBVC), multispectral scanners (MSS), microwave radiometers, etc. We are able to see any object because light incident on it is scattered in all directions and some of the scattered light enters our eyes. In the case of a camera the scattered light enters the camera lens. The nature and amount of scattered light depends on the object. The incident light may have different colours in a certain proportion but the scattered light will not have the different colours or wavelengths in the same proportion. This is what gives colour or colours to different parts of the object.

In a large landscape, we would be looking at not one object but many such as trees, buildings, roads, hills, water, etc. Each of these has its own characteristic way of scattering the different wavelengths of light. Instead of looking at all wavelengths or recording them all together, if we record them in different colours or bands of wavelength we find that the different records bring out prominently different features in the landscape. If one record shows green vegetation prominently, another may show up water with greater emphasis. A third record may show buildings and roads very clearly. Thus there is an advantage in looking at a given scene through different colour filters and recording the images. This is what both RBVC and MSS do. The RBVC looks at a large area and records the entire area in three or four different bands of the spectrum. The MSS on the other hand looks at a narrow strip and scans it from one end to the other and then passes on to next strip and so on. As an analogy, one may think of taking

photograph of this page. That photograph at one stroke records all that is on the page - text, figures, etc. On the other hand, when you read you read one line at a time from left to right and then pass on to the next line. The RBVC does the first type of job and the MSS does the second type.

In both cases, however, the recording is done in a number of bands. The records themselves might be black and white pictures with different shades of grey. In the case of scanners, each strip is made up of a number of cells and corresponding to each cell a number could be recorded giving the average value of the greyishness. There may be as many as 125 shades of grey from black to white. These numbers are recorded on magnetic tape. When the tape is replayed, a computer is used to reconstruct the full image consisting of a number of strips. One can also give various colours artificially corresponding to these numbers and get an artificial colour image. The images thus obtained in different bands can be again combined to give a single coloured composite. It should be remembered that these colours in the composite picture are not the same as the natural colours on the ground. It is like a translation from one language to another. The words in the original and the translation are different but hopefully, the meaning and substance is the same. At the time of printing the translation, one could also employ different types of letters like italics, capitals, etc., to bring out or emphasise certain aspects and statements. Similarly, the computer can be programmed to do this while reconstructing the images from the magnetic tapes. A set of four pictures taken by IRS-I in four bands and the colour composite made by the computer at NRSA are reproduced elsewhere in this book.

In the case of satellites used for scientific research, the orbit of the satellite is basically arranged to be outside the atmosphere of the earth to avoid the effects of the atmosphere on the radiation or particle streams. The instrumentation essentially consists of sensors and transducers which are sensitive to the type of radiation or particles involved. The particles could be neutral or electrically charged. The sensors or transducers react to the incident radiation or particles produce electrical signals which are then amplified, processed and either recorded on tape or transmitted back to earth stations.

In the case of meteorological satellites, both low earth orbits and geostationary orbits have been used. for example, in the INSAT satellite, the orbit is geostationary and one of the objectives of the satellite is to study and forecast weather. The Very High Resolution Radiometer (VHRR) installed in the satellite collects data which is later converted into pictures of earth's cloud cover over India and adjoining land and sea areas.

So far as communication satellites are concerned, they are conveniently located in geostationary orbits. They carry transponders which receive signals from ground and retransmit them back to earth. While the ground systems have highly directional antennas pointed towards the satellite, the signals from the satellite are beamed to the entire area of coverage. The upward link from earth to the satellite and the downward link for the opposite direction are usually in the microwave region and two different frequencies are used for the two links.

For all types of uses, it is obvious that satellites need electric power. Much of it is usually obtained by using large solar cell panels which are deployed after the satellite is injected into the orbit. Some special, light-weight, long-life batteries for space applications have also been developed. Space and weight both being at a premium, miniaturisation and weight reduction have been developed into a fine art not only for electronic components and circuits but also for all mechanical parts. Specially designed tape recorders for space use may be mentioned in this connection. Many new materials, fabrication techniques and sub-systems have been developed for space use which are now spilling over into terrestrial systems.

5. Indian Space Programme

The end of World War II saw the entry of rockets in scientific research and about two decades later artificial satellites became a part of human existence. India was one of the few developing countries of the world which realized quite early the vast potential of satellites in helping the development process. This was true of both the government and the scientific community in India. The country is vast and it has also a very large population. A large part of this population lives in villages many of which are poorly connected by roads and are quite inaccessible. Many of these villages do not have proper facilities for education, health, information, communication, etc. A large part of the country has never been surveyed for minerals, ground water and other resources. Even with regard to our animal and plant resources, our knowledge is not quite adequate. The main reason for this is that conventional methods of surveying for natural resources are very time consuming and expensive. The requirements of skilled manpower are also very large. Satellites can play an important role in surveying for natural resources and also in providing communication and other facilities to villages. Realizing this, India started an active space research programme. Although the programme is named space research, in reality, the main aims of the programme are to learn more about the country, its resources, its environment and to help the development of the people.

In 1972, the Government of India established the Space Commission and under it Department of Space (DOS). The Indian Space Research Organisation (ISRO) is the actual body which carries out and implements the space programme under the overall guidance and control of the Space Commission and with the administrative supervision of the Department of Space. The Head Quarters of all the three bodies is at Bangalore. The main objective of the Indian Space Programme is the harnessing of space technology in a self-reliant manner for the socio-economic development of the country. In pursuance of this objective the programmer's main thrusts are

- satellite based communications for various applications;
- satellite based resources survey and management, environmental monitoring and meteorological applications; and
- development and operationalisation, on a self-reliant basis, of indigenous satellites, launch vehicles and associated ground segment for providing these space-based services

Even a decade before the Space Commission came into existence, space research made a humble beginning in this country. In 1963, the Thumba Equatorial Rocket Launching Station (TERLS) was established close to Trivandrum near the magnetic equator. Rockets fired vertically from this location carried instruments for studying the atmosphere and the near-earth environment. Established with international cooperation, this facility was formally dedicated to the UN in 1968 and it continues to function even now as an international facility. The importance of this location is its proximity to the geomagnetic equator as at these latitudes many peculiar phenomena occur above the surface of the earth. These phenomena cannot be properly observed from higher latitudes.

Working at this station in collaboration with other advanced countries, Indians, acquired expertise in rocket launching, instrumentation, telemetry, and collection, analysis and distribution of data. This experience gave the necessary confidence to undertake the more ambitious space programme.

By 1987, seven centres were set up by the ISRO round the country .More than 14,000 persons are working in these centres. The centres and their charter are briefly described in the following paragraphs:

a) The Vikram Sarabhai Space Centre (VSSC) at Trivandrum is named after the father of the Indian Space Programme and first Chairman of the Space Commission, Dr. Vikram Sarabhai. It is engaged in developing the Menaka and Rohini series of sounding rockets and is the lead centre for the development of satellite launch vehicles and the related technologies. At present the Augmented Satellite Launch Vehicles (ASLVs) for launching satellites in the 150 kg weight class and Polar Satellite Launch Vehicles (PSLVs) for launching remote sensing satellites for resources survey are under development here. VSSC also looks after the TERLS international facility.

b) The ISAC at Bangalore is the ISRO Satellite Centre. It conducts research and development in satellite technology. All the satellites like Aryabhata, Bhaskara, Rohini, etc. built in India have been designed and fabricated here. Very recently, IRS-1 (India's first remote sensing satellite) was designed and fabricated here and launched from the Soviet Union in March 1988. At present work is in progress on the Stretched Rohini Satellite Series (SROSS) satellites.

c) The Sriharikota Centre (SHAR) in the Nellore district of Andhra Pradesh on the east coast based on the Sriharikota Island has facilities for launching large multistage sounding rockets and for launching satellites. It also has facilities for static testing of such vehicles and for solid propellant production. There are facilities for controlling and monitoring satellite launch vehicles (SLVs) and receiving data from satellites at SHAR.

d) The Space Applications Centre (SAC) at Ahmedabad is the main centre for activities related to application of Space Science and Technology for practical purposes such as telecommunication, TV broadcasting and reception, survey of earth resources from space and studies of space meteorology and satellite geodesy (geodesy is the study of the shape of the earth). All instrumentation for the applications mentioned are developed here.

e) The Auxiliary Propulsion System Unit (APSU) is co-located at Bangalore and Trivandrum. Between them, they are concerned with the development of liquid propellants, cryogenic (low temperature) propellants (such as liquid oxygen and liquid hydrogen), propulsion control and regulation systems, pressure transducers, etc,

f) The Development and Educational Communication Unit (DECU) at Ahmedabad deals with all communications 'software' such as television programmes and socio-economic research on the impact of technology, especially communications technology. Training programmes in these areas are also undertaken at DECU.

g) The five ground-based stations at Sriharikota (AP), Ahmedabad (Gujarat), Trivandrum (Kerala), Car Nicobar Island (Andamans) and Kavalur (TN) form the ISTRAC network extending telemetry, tracking and command support to various launch vehicles and satellite missions. The first three stations have all the necessary facilities for tracking commands and data reception and recording. The Car Nicobar Station is particularly intended to monitor the fourth stage of the launch vehicle and to ensure that the satellite has the characteristics for the intended orbit. It is also referred to as a down range station. Kavalur is used for visual tracking and laser ranging. All the five stations are controlled, monitored and coordinated from the Satellite Control Centre at Sriharikota.

All the above stations are directly managed by the DOS and ISRO. There are two other autonomous institutions operating under this Department. They are the National Remote Sensing Agency (NRSA) at Hyderabad and the Physical Research Laboratory (PRL) at Ahmedabad. The NRSA collects data by remote sensing based on both aircraft and satellites and analyses the data for natural resources survey. NRSA has its own aircraft fully equipped for carrying out such surveys. It also has equipment installed at Shadnagar near Hyderabad for receiving signals from remote sensing satellites of USA such as Landsat I, II, III and IV. These signals are further processed, analysed and edited for various user requirements by NRSA at Hyderabad. The NRSA is also managing the Photo Interpretation Institute at Dehradun. The Physical Research Laboratory carries out research in various fields related to Space Science. The PRL also manages the Solar Observatory at Udaipur in Rajasthan.

Mention may also be made of two other major facilities set up by ISRO in connection with the Indian National Satellite (INSAT) Programme. These are the Master Control Facility at Hasan in Karnataka and the INSAT Space Programme Office at Bangalore. More about these when the INSAT is discussed. The ISRO and DOS also support financially and otherwise, a number of space related research projects at various Universities, Institutes of Higher Learning and National Laboratories.

We have till now dealt with the many facilities created by the ISRO for fostering and utilising Space Science and Technology in the country. In what follows, we shall look at some of the major successes and failures of the space programme in India. The Indian space programme has pursued two parallel objectives. On the one hand, the programme aims at developing all the necessary technologies, facilities and skills for injecting satellites into predetermined orbits ranging from low earth orbits to geostationary orbits. Parallely, the programme is also developing the necessary technologies, facilities and skills for designing and fabricating satellites for different purposes such as scientific, remote sensing and communication. The first aim is not allowed to delay the second one. If satellite fabrication is achieved, its launching is carried out with the help of one of the other advanced nations without waiting for India itself to develop this skill. The experimental satellites Aryabhata, Bhaskara I and II and Apple satellites were designed and made in India but launched from other countries.

The Aryabhata satellite which was the very first one to be designed and fabricated in India was launched on 19th April 1975 from the Soviet Union. The orbit had an apogee of 619 km and perigee of 562 km and was inclined to the equator at an angle of 50.7° . This satellite enabled ISRO Scientists to develop the skills and facilities for fabricating satellites and monitoring its performance in orbit. Establishment of ground facilities for communicating with the satellite, tracking it and passing commands to it to carry out various tasks are some of the other achievements of this programme. The satellite also carried pay loads for X-ray astronomy, solar and meteorological studies.

The Bhaskara-I satellite was essentially intended to develop expertise in observing the earth from a satellite by means of remote sensing equipment. Collection of data, their analysis and dissemination of the results were the tasks undertaken in this programme. Observations concerned ground water for surveys, forestry and geological surveys. For this purpose, two television cameras and two microwave radiometers were installed in the satellite. The satellite weighing 444 kg was launched on 7 June 1979 from the Soviet Union with a nearly circular orbit at an altitude of about 500 km and inclination to equator of about 51° . After making several observations on forests, geology, sea state, sea surface, water vapour in the atmosphere above sea and snow cover on land surface by remote sensing techniques, the satellite was closed down in March 1981. Bhaskara-2 was similar to Bhaskara-I but with some improvements. It was launched from the Soviet Union on 20 November 1981. It functioned till late 1983.

The experience gained with these two experimental remote sensing earth observation satellites gave the Indian scientists the necessary competence and confidence to undertake the design and fabrication of a series of fully operational Indian Remote Sensing Satellites. The first one in this series the IRS-1 has been launched with the help of the Soviet Union on 17th March 1988. It became fully operational a few weeks later. It carries two TV cameras for taking pictures in four bands, three in the visible region and one in the near infra red. It is expected to yield valuable data on agriculture, hydrology, geology and forestry. It is in a polar sun-synchronous orbit at a height of 904 km, weighs 950 kg and repeats coverage of the same area once every 22 days. Its expected life is three years and ISRO hopes to launch such satellites regularly every three years or so. Pictures taken by IRS-I are reproduced in Fig. 9.

The APPLE (Ariane Passenger Pay Load Experiment) satellite is the third type of experimental satellites intended to provide experience in the use of satellites for communication. Fabricated in India, the satellite was launched with European Space Agency (ESA) help from the Kourou launching facility in French Guyana (South America) on 19th June 1981 and it was put into a geostationary orbit. A joint programme of the Department of Space and Department of Communications, this experiment gave the Indian Scientists and Engineers a lot of knowledge and experience in using satellites for communications. They were able to gain experience both with regard to the space segment and ground segment of the communication network using most modern techniques and technologies. The satellite functioned well for about two years and was shut down on 19 September 1983 due to exhaustion of fuel in the satellite.

All the above experimental (Aryabhata, Bhaskara and Apple) as well as operational (IRS-1) satellites were launched with foreign help. However, simultaneously ISRO was also working on its own Satellite Launch Vehicles (SLVs). After the failure of the first SLV - 3 launch in August 1979. India launched its first satellite from Indian soil successfully on 18 July 1980. The 35 kg satellite named Rohini was launched into an orbit with an apogee of 900 km and perigee of 300 km using a four stage SLV-3 vehicle. The launch was primarily intended to test the performance of the fourth stage. A second Rohini was launched on 30th May 1981 with a camera on board. The orbit was much lower than intended and hence the satellite got burnt out after only nine days of launching. The third Rohini went into orbit on 17 April 1983. The camera on board took nearly 2500 photographs in five months of operation both in the visible and near infra red regions. These images were used to get information on water, trees, soil, cloud cover, snow, etc. The satellite was shut down on 24 September 1984. All the Rohini launches were carried out from Sriharikota.

After completing the Rohini series of launches, the stretched Rohini series of satellites weighing about 150 kg were planned to be launched. The first attempt to launch this satellite using an Augmented Satellite Launch Vehicle ASLV failed on 24 March 1987. A second attempt with an ASLV also failed in 1988. All the satellites mentioned above, except IRS-1, are experimental ones intended to gain competence in various aspects of space technology.

The first operational satellite intended to be used on a commercial basis was conceived in 1977. Named the Indian National Satellite (INSAT) programme, this satellite was intended to be put in a geostationary orbit to carry out three independent tasks simultaneously. The tasks are (i) communication, (ii) television and radio broadcasting and (iii) meteorological observations. The satellite was to carry equipment to handle all three tasks and was to be fully supported and exploited by an elaborate network of ground facilities. There was much argument and hesitation in implementing this as some feared that combining three tasks in one satellite might lead to mutual interference. However, the concept was finally accepted and specifications drawn up by Indian scientists for all systems and sub-systems.

The actual construction, testing and launching of the satellite was entrusted to the Ford Aerospace Corporation of USA. The entire ground support system was developed and fabricated in India. The first satellite of the INSAT series, INSAT-1A, was launched on 10 April 1982. After 147 days of satisfactory operation the satellite developed some technical faults and had to be closed down.

The second satellite in the series, INSAT-I B, was launched with the help of the US Space Shuttle on 30th August 1983. For more than five years this satellite has functioned extremely well and might be said to have opened an entirely new chapter in Indian Communications, TV and Radio broadcasts and meteorological studies. Its estimated life is till mid-1989.

A third satellite, INSAT-IC was to have been launched in 1987 but this could not be done due to a disastrous accident to the American space shuttle Challenger and consequent postponement of all further shuttle operations. IC was later launched with the help of the European Space Agency's Ariane Space Launch Vehicle. Unfortunately the power supply is not functioning properly and hence it is not being utilised fully.

INSAT-ID is also on order. With this, the INSAT -I programme would be completed. The aim is to have atleast two satellites in orbit at a given time such that one would be a standby for the other. The country has got so used to the INSAT-I B that should anything happen to it, there will be a serious dislocation in many services in the country.

While the satellite itself was made elsewhere, the entire ground segment was designed and fabricated in India. These include the Master Control Facility at Hasan, 28 static and three mobile telecommunication stations, one primary and twenty secondary centres for receiving and studying meteorological data, 100 land based and ten sea surface based Data Collection Platforms (DCPs) which are unmanned. There is also a disaster warning centre. The TV and Radio broadcasts are taken care of from the four comprehensive stations at Delhi, Bombay, Calcutta and Madras as well as 94 radio receiving stations. There are 8000 direct receiving TV sets installed in 18 districts in six states. In addition, 13 high power and 112 low power TV transmitters and 125 TV receiving stations have been set up to cover nearly 70 per cent of the country for TV programmes. A sum of Rs. 250 crores has been spent on the ground facilities other than the MCF at Hasan which along with the two satellites cost Rs. 125 crores.

In the next phase, the improved INSAT -II series of satellites are expected to be made and launched from India itself. As a preliminary to this, two or three small satellites are expected to be launched from India in the next few years to be injected into a geostationary orbit. While our launching capabilities are still not upto the mark, our programme for designing and fabricating satellites has progressed well. We have also been able to create all the ground facilities for tracking, controlling satellites and receive analyse and disseminate the data collected by the satellite sensors. We may expect many new applications of satellites for development of the country in the future.

A somewhat different type of activity which still concerned the utilisation of satellite technology for development purposes was the SITE programme. SITE stands for Satellite Instructional Television Experiment. This experiment was carried out during August 1975-July 76, using the American satellite ATS-6. This experiment provided experience in hardware, management of satellite-based instructional television especially for the rural population and allowed the scientists to gain expertise in producing software (i.e., TV programmes) and assuring its effectiveness. More than 160 programmes of ten-minute duration for popularisation of science were produced in very small studies using a single video tape recorder. The experience gained and expertise and facilities developed during this experiment have enabled the better utilisation of satellite TV programmes for disseminating information and knowledge to large sections of the populace through the INSAT facilities.

6. Space Programme in Other Countries

While the Indian space programme is essentially civilian in character and oriented towards the developmental needs of the nation, space programmes of some of the other countries have kept both civilian and military potentialities of using satellites in view. Such countries include USA, Soviet Union and China. While in USA there are both civilian (NASA) and military agencies independently developing the satellite technology for their different purposes, Soviet Union and China are believed to be developing their programmes through their military organisations. In other countries like Britain and France also the space programmes have both civilian and military components. Countries like West Germany and Japan which are prevented by a treaty after World War II from indulging in certain military activities, are pursuing a purely civilian space program. The other countries active in this field include Australia, Brazil, Canada, Italy, Spain, Mexico and Sweden. The European Space Agency (ESA) is a collaborative effort among a number of European countries including Britain, France and West Germany which are also having their own national programmes. It is believed that Comecon countries allied with the Soviet Union have some collaboration with the Soviet Union. Other countries round the world like Saudi Arabia, Indonesia, Pakistan also have their space programmes mainly towards using satellites for their national needs. They have, however, not yet developed their own capabilities like building their satellites or launching them as India has done, although some of them are well on the way to do so.

It is not possible to deal with all these countries nor is it necessary to describe the advances made in each country separately. However, certain aspects of the programmes of USA, USSR and one or two others would be highlighted just to indicate the directions in which space technology and its utilization are proceeding in the advanced nations.

The very first satellite designated Sputnik I (meaning fellow traveller) was launched by Soviet Union as a part of its commitment to International Geophysical Year programme on 4th October 1957. The satellite weighed slightly less than 84 kg and moved in an orbit with an apogee of 941 km and perigee of 227 km. The first US satellite called Explorer was launched, again as a part of the IGY programme, a few months later and weighed only a few kilos. From then on satellite technology made rapid strides. The second satellite Sputnik II launched by USSR a few weeks after the first Sputnik, weighed about 500 kg carried into space the first living being, a dog named Laika whose heart beats, temperature and other conditions were monitored continuously from earth for eight days. As satellite recovery technology was not yet available at that time, the dog was put to death painlessly after eight days. Sputnik III launched on 15 May 1958 weighed as much as 1300 kg. Comparatively, the US satellites of those days were very much lighter. Within 4 years of launching their first satellites both US and USSR put men into orbit. The first man to go into space was Yuri Gagarin of the Soviet Union who made a single orbit round the earth on 12 April 1961. Although Alan Shepard of USA followed suit on 5 May 1961, he did not make a complete orbit round the earth.

One of the very first startling discoveries made by the first US Explorer satellite was the existence of two radiation belts round the earth called the Van Allen Radiation Belts. The

belts are thickest near the equator and thinnest near the poles. The lower limit of the belts is at an altitude of 600 km and peak intensities occur at 3200 and 17,500 km approximately. Exposure to this radiation can cause death.

After the initial successes of 1958, USA and USSR followed somewhat different paths in space technology and space research. Both countries have developed various technologies to use satellites for communications, resources survey, meteorology, scientific experiments particularly with reference to astronomy as well as study of near space environment and finally for military reconnaissance, surveillance and spying. The Americans named the different satellites by the purpose for which they were intended. Thus Explorer and Vanguard series of satellites collected data on space radiation, meteors, magnetic fields, temperatures, etc. Other satellites like Pioneer (interplanetary studies), Project Score, Echo, Courier and Advent (communication), Transit (navigational aids), Tiros (meteorology) have all been great successes into of the USA. The Soviet Union also has launched satellites for all these purposes. They have, however been somewhat secretive and named most of their satellites Cosmos and numbered them serially as each satellite was launched. Thus from 1958 till date more than 2000 Cosmos satellites have been launched and each of them served any one or more of the purposes for which satellites are used; A series of satellites named Luna have been launched to orbit round the moon and to transmit pictures and data. One of these satellites landed a vehicle, lunakhod, on the first satellite ever to photograph the far side of the moon which people on earth cannot see.

In the sixties, the USA launched the programme of landing a man on the moon by the end of the decade. For this they concentrated on the Gemini programme to develop long duration manned flight and rendezvous capabilities. A number of manned Gemini flights were undertaken and the astronauts gained space flight experience, extra-vehicular capability (i.e. going outside the satellite and moving short distances away from it, otherwise known as space walk) and experience in carrying out scientific experiments in space. The Gemini programme was followed by the Apollo programme which actually took men to the moon and landed them there.

Apollo 8 and 10 orbited men round the moon and brought them back to earth. Apollo 11 -also named Columbia -with three persons as crew approached the moon and then launched a lunar module named Eagle with two men on board. Eagle landed on the moon on 20 July 1969 with Neil Armstrong and Edwin Aldrin who were the first men ever to set foot on the moon. The third member of the team Michael Collins kept orbiting the moon until Eagle returned from the surface of the moon. The whole programme involved very high precision timing and manoeuvring as well as solving the many problems of docking and re-entry into earth's atmosphere. In all twelve men have so far landed on the moon.

The decade of the seventies and early eighties saw a new programme of the USA taking shape. It was the space shuttle programme. The shuttle is launched by means of rockets like any other satellite but it returns to earth like an aeroplane. While in space, it carries a number of persons on board, has enough space for carrying out experiments, for carrying

other smaller satellites which can be launched from space and it also has several facilities for manoeuvring and reaching other satellites needing repair and recovery. This programme also has been a tremendous success. Each shuttle is good for about 20 to 30 space flights. Unfortunately a space shuttle 'Challenger' with seven persons on board blew up soon after launch on 28 January 1986 killing all of them. The programme has been suspended temporarily until all the possible causes for the disaster are identified and eliminated.

Other important programmes of US included sending satellites to Venus and Mars and also to fly past other planets such as Jupiter, Saturn, etc. Many new facts very different from what earth-based observations led us to believe, about all the planets and their moons, have emerged from these explorations. It has been possible to get fairly close views and images of the planets and moons upto Uranus. At present the space vehicle Voyager 2 is approaching Neptune after having coasted by Jupiter, Saturn and Uranus. It was launched on August 20 1977, reached Jupiter in July 1979, Saturn in August 1981 and Uranus in January 1986. The encounter with Neptune is expected in August 1989.

A number of scientific experiments planned for the late 1980's have been postponed due to the Challenger shuttle disaster. These include a shuttle mission to the Halley's Comet, launch of the 'Hubble' space telescope and the 'Galileo' mission to the asteroid Amphitrite and planet Jupiter. The USA which was relying on the reusable space shuttle for launching all its future satellites has now reconsidered its decision. It will have a mixture of shuttles as well as non-recoverable (or expendable) rockets such as Titan and Saturn to launch satellites.

Apart from the above mentioned experiments which will be delayed by about three years, the USA also plans to set up manned space stations circling the earth to carry out earth observations, experiments and industrial activities in a microgravity environment and for outer space observations. A very important and highly controversial military programme is named the Strategic Defence Initiative (SDI) or popularly known as 'Star Wars' programme. It involves development of satellite-based weapons for destroying enemy missiles and satellites. Already considerable progress has been made in this programme. The general objection to this programme by many in USA and also by many other nations is that this programme extends future wars into space also and it would lead to a great escalation in the armament race among super powers as well thus reducing the availability of funds for other constructive activities.

The Soviet Union also has sent instrumented space vehicles to the Moon, Venus and Mars but not beyond. In the seventies it had concentrate on sending large satellites round the earth with as many as three persons and some times more staying in them and working for several months at a time. These were the famous Salyut spacecraft. On an average, every year they launch 100 satellites most of them being named Cosmos and numbered serially. There are used for remote sensing, meteorology, photo reconnaissance, surveillance, etc. Some of them are recovered after a few days in orbit. So far as communications are concerned, they use the Molniya series of satellites although they do have a few geostationary satellites. Among their latest satellites is the Mir, first launched

in February 1986, which is a huge satellite intended to be built up into a large space station. This satellite can receive and dock upto six satellites which together would form a big space station. By 1991 such a complex weighing 100 to 135 tonnes is expected to be assembled in space and used for large-scale industrial activities in space.

Both for Salyut and Mir, the Soviets use Soyuz spacecraft to ferry supplies and men from earth to the space station and back. They also use the 'Progress' spacecraft when only supplies are to be ferried. The Soviet efforts are generally characterized by steady progress using functional, relatively less sophisticated, production line spacecraft and launch vehicles that have been around for years.

So far as the future is concerned, the Soviets also are likely to develop their own reusable shuttle and are likely to cooperate with other nations in manned flights to other planets. An unmanned space shuttle was recently launched and recovered by the Soviet Union. The Soviets have always been able to put much heavier bodies in orbit than the others. Their latest launch vehicles Proton and Energia are in a class by themselves. It is believed that Energia (weighing 2000 tonnes) would be used to carry huge mirrors into space in due course to reflect sunlight into the northern regions of USSR during the long winter nights. It is also believed that Energia would be used to launch huge satellites into a geostationary orbit wherein power would be generated and beamed to ground stations for distribution.

If the first fifteen years of the space age saw a close rivalry between the two superpowers based on military considerations, the last ten years has seen a new phenomenon of economic competition between US on the one hand and European Space Agency as well as individual European nations and Japan on the other. Both with regard to launch facilities and use of satellites, various nations are now offering competitive facilities to users. Thus on commercial terms the European Space Agency undertakes to launch satellites fabricated by other nations. India has made use of this facility to launch INSAT-I C. In addition, in competition to the Landsat series of remote sensing satellites, France has launched the 'SPOT' satellite which provides images of the earth in various bands of the spectrum having a better resolution. Ambitious programmes are taking shape both in the European Space Agency and individual countries for the future. Thus USA is likely to face stiff competition in the utilisation of satellites for remote sensing, meteorology, communication, etc. This is likely to lead to more rapid progress and also to facilities being available at relatively cheaper rates to user nations. In view of the independent advances being made in various countries, scope for international cooperation in exploiting space technology is increasing.

International cooperation already exists in the use of satellites. In the case of geostationary satellites used for communication, there is an international regulatory organisation known as the International Telecommunications Satellite Organisation (Intelsat) which controls and allots slots in the geostationary orbit to various nations. The need for this regulatory body arises because the geostationary orbit can accommodate at any given time around 125 satellites located at 3° intervals round the equator. By spacing them like that, mutual interference is avoided. Particularly, the antenna beam from the

earth to the satellite should not spill over to the nearby satellites. At the same time, the antenna itself should not become too large to be manageable. The 3° spacing is a compromise between these two conflicting requirements. Thus, the geostationary orbit becomes a limited resource to be distributed equitably among nations. Intelsat does this job. With great difficulty, India has got two slots. In future, new nations entering this field may find it very difficult to get a slot allotted.

Another international organisation is the International Maritime Satellite. Organisation (INMARSAT). This organisation provides navigational satellite services to member countries. These satellites enable ships to navigate in all weather conditions unlike in the case of navigation depending on stars. INMARSAT also standardizes and approves equipment to be used by the customer nations. Another activity in which this organisation is involved is satellite-aided search and rescue.

There are other area of cooperation such as International Space Frequency Coordination Group, Consultative Committee for Space Data Systems, etc. An important area involves exchange of meteorological data collected by satellites through the World Meteorological Organisation (WMO). This enables nations to give more precise weather forecasts for their own regions. Apart from these multinational organizations, there are also a number of agreements between two or more states for collaboration and cooperation. India has such individual agreements with USA, USSR, Sweden, The Netherlands, Mauritius, France, Federal Republic of Germany, Australia and European Space Agency. As a part of the agreement between India and USSR, the latter trained two Indians to travel in space and actually helped one of them, Sqd. Ldr. Rakesh Sharma, to orbit round the earth in April 1984 for about seven days along with two other Soviet cosmonauts. The space programmes of various nations have led to the development of new technologies and new materials and also helped other areas and industries to improve. Very high precision and very fast real-time computations especially in the case of rendezvous operations, new materials to provide light weight miniaturized equipment and for such special applications as heat shields, microminiaturized electronic circuitry, special monitoring equipment to keep a close and continuous watch on the functioning of human and other living beings in space and even various instruments on board space vehicles have all led to new materials, processes, techniques and technologies which are now finding use in other areas. It is interesting to note how a relatively small problem defying solution could delay a major programme. For example, the American space shuttle programme was reportedly delayed by about two years because a proper tile which could serve as a heat insulator could not be developed for quite some time. At the time of re-entry of a space vehicle into earth's atmosphere from outside, it will be traveling at such speeds that friction with the atmosphere produces very high temperatures. It is necessary that these temperatures are confined to the outer surface of the spacecraft and are not allowed to be conducted to the inside of the spacecraft. It is also necessary that the material used on the outer surface does not distort, disintegrate or melt away at these temperatures. The Americans finally developed a ceramic tile and an adhesive both of which are stable and effective at these temperatures. The tiles are stuck with the help of the adhesive on the outer surface of the space shuttle to provide it necessary protection during re-entry. Thus

an entirely new material for the tile and a very high temperature adhesive have been developed which are now finding other uses.

It is clear that space technology and science have made rapid strides in the three decades since the first Sputnik was put in a low earth orbit. It is also obvious that many countries are taking to use of satellites for various national purposes. With this sort of active and widespread interest the subject promises to have a very bright future.

7. Epilogue

Every age in human civilisation has been named after an important technological advance. Thus we had the Industrial Revolution and the period covered by it named after the steam engine. More recently when nuclear powers come into its own, that period has been named the nuclear age. By the same token we are now in the space age. The advent of the satellite has made a significant difference to the process of development. The low earth orbit satellite has provided a convenient platform for rapid resources survey—mineral, water, agriculture, forest, etc. covering large areas and in sufficient detail. This has greatly enhanced our appreciation of the resources that this country holds and potential for future development. The geosynchronous satellite has enabled the remotest and most inaccessible parts of the country to be brought together and covered by telephone, radio and television. It is now possible to keep the population of the entire country informed, educated, entertained and bringing them closer through audio visual means. This satellite has also made it possible to keep a close watch on our weather, climate an pollution and give advance warnings in case of impending disasters.

Already, the country has come to depend vitally on satellite technology for various purposes. The important aspect of this achievement is the amount of self-reliance that has been built into the entire programme. As time goes by, the country will become more self-reliant in this area, and launch bigger satellites to provide better means of communication over wider areas, to survey all parts of the country in greater detail and to bring together and unify this country culturally and otherwise in a manner not possible without satellites.

Internationally, spectacular results have been obtained using satellites and space vehicles. A much better understanding of the earth's near environment as well as of the planets has been made possible. We know much more about the universe, having been able to observe it from satellites without obstruction or modification by earth's atmosphere. Man has already landed on the moon. It is likely that man will land at least on Mars in the next fifteen years and probably observe other planets from close quarters. Huge manned stations orbiting the earth are likely to become operational in the next few years. These should accelerate the many uses to which satellites could be put. Man with his intelligence and intuition can always outperform any sort of sophisticated instrument he himself has designed and built. Manned platforms are therefore likely to produce even more spectacular results than heretofore.

All in all, we are on the threshold of a great and revolutionary epoch and everything that the fertile human brain has conceived even as a wild fantasy is likely to become reality sooner than we expect.