CSIR GOLDEN JUBILEE SERIES

MAN IN SPACE

P. RADHAKRISHNAN

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Foreword

The Council of Scientific & Industrial Research (CSIR), established in 1942, is committed to the advancement of scientific knowledge, and economic and industrial development of the country. Over the years CSIR has created a base for scientific capability and excellence spanning a wide spectrum of areas enabling it to carry out research and development as well as provide national standards, testing and certification facilities. It has also been training researchers, popularizing science and helping in the inculcation of scientific temper in the country.

The CSIR today is a well knit and action oriented network of 41 laboratories spread throughout the country with activities ranging from molecular biology to mining, medicinal plants to mechanical engineering, mathematical modelling to metrology, chemicals to coal and so on.

While discharging its mandate, CSIR has not lost sight of the necessity to remain at the cutting edge of science in order to be in a position to acquire and generate expertise in frontier areas of technology. CSIR's contributions to high-tech and emerging areas of science and technology are recognised among others for precocious flowering of tissue cultured bamboo, DNA finger-printing, development of non-noble metal zeolite catalysts, mining of polymetallic nodules from the Indian Ocean bed, building an all-composite light research aircraft, high temperature superconductivity, to mention only a few.

Being acutely aware that the pace of scientific and technological development cannot be maintained without a steady influx of bright young scientists, CSIR has undertaken a vigorous programme of human resource development which includes, inter alia, collaborative efforts with the University Grants Commission aimed at nurturing the budding careers of fresh science and technology graduates.

However, all these would not yield the desired results in the absence of an atmosphere appreciative of advances in science and technology. If the people at large remain in awe of science and consider it as something which is far removed from their realms, scientific culture cannot take root.

CSIR has been alive to this problem and has been active in taking science to the people, particularly through the print medium. It has an active programme aimed at popularization of science, its concepts, achievements and utility, by bringing it to the doorsteps of the masses through both print and electronic media. This is expected to serve a dual purpose. First, it would create awareness and interest among the intelligent layman and, secondly, it would help youngsters at the point of choosing an academic career in getting a broad-based knowledge about science in general and its frontier areas in particular. Such familiarity would not only kindle in them deep and abiding interest in matters scientific but would also be instrumental in helping them to choose the scientific or technological education that is best suited to them according to their own interests and aptitudes. There would be no groping in the dark for them. However, this is one field where enough is never enough.

This was the driving consideration when it was decided to bring out in this 50th anniversary year of CSIR a series of profusely illustrated and specially written popular monographs on a judicious mix of scientific and technological subjects varying from the outer space to the inner space. Some of the important subjects covered are astronomy, meteorology, oceanography, new materials, immunology and biotechnology.

It is hoped that this series of monographs would be able to whet the varied appetites of a wide cross-section of the target readership and spur them on to gathering further knowledge on the subjects of their choice and liking. An exciting sojourn through the wonderland of science, we hope, awaits the reader. We can only wish him Bon voyage and say, happy hunting.

Preface

When the first artificial satellite went up in 1957, I was a schoolboy. Gagarin made his historic space trip in 1961, when I was in college. I had just started in my present career when Armstrong and Aldrin walked on the moon in 1969. What heady years those were !

Among the various fields of complex human endeavour, space technology stands out way ahead of others. The progress during the last few decades has been simply phenomenal. "Yesterday's dream; today's reality" — nowhere is this truer than in the realm of space. Expanding the frontiers of our knowledge of the near and remote environment of our planet earth, and using the technological advances to enhance the quality of life on earth constitute the mission of the space era. Space technology has changed our concept of distance and given us a new measure of ourselves in relation to the cosmos.

In the beginning, space activities were limited to the big powers. They were motivated by national pride and military advantage. But the situation today is hardly so. The applicability of space technology as a vital tool for growth of a developing nation is now recognised beyond doubt. In tune with this, the Indian space programme has the objective of building self-reliance in design and development of space systems, and using them to provide nation-wide communication and television coverage, meteorology and remote sensing of earth resources. In the words of late Dr. Vikram A. Sarabhai, the founder of space efforts in our country: "The question is not whether a developing country should adopt space technology. The question is whether it can afford to ignore it."

In this book I have made an attempt to present the elementary principles of space technology in a simple manner. It is my sincere hope that children will find this book understandable.

Acknowledgements

This book would not have come into existence but for the persuasion of Dr. G.P. Phondke, Director, Publications and Information Directorate of CSIR and Shri Biman Basu, Editor, *Science Reporter*. I am thankful to them.

I am also grateful to Shri P. Sankaran Kutty, who painstakingly helped to give the text a presentable form.

Most of all, I am indebted, beyond words, to Prof. U.R. Rao, Chairman, Indian Space Research Organisation from whom I received many valuable lessons in space technology.

P. Radhakrishnan

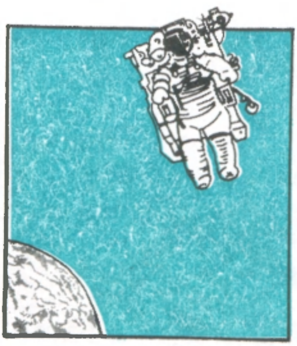
To

The school children of

my country

Contents

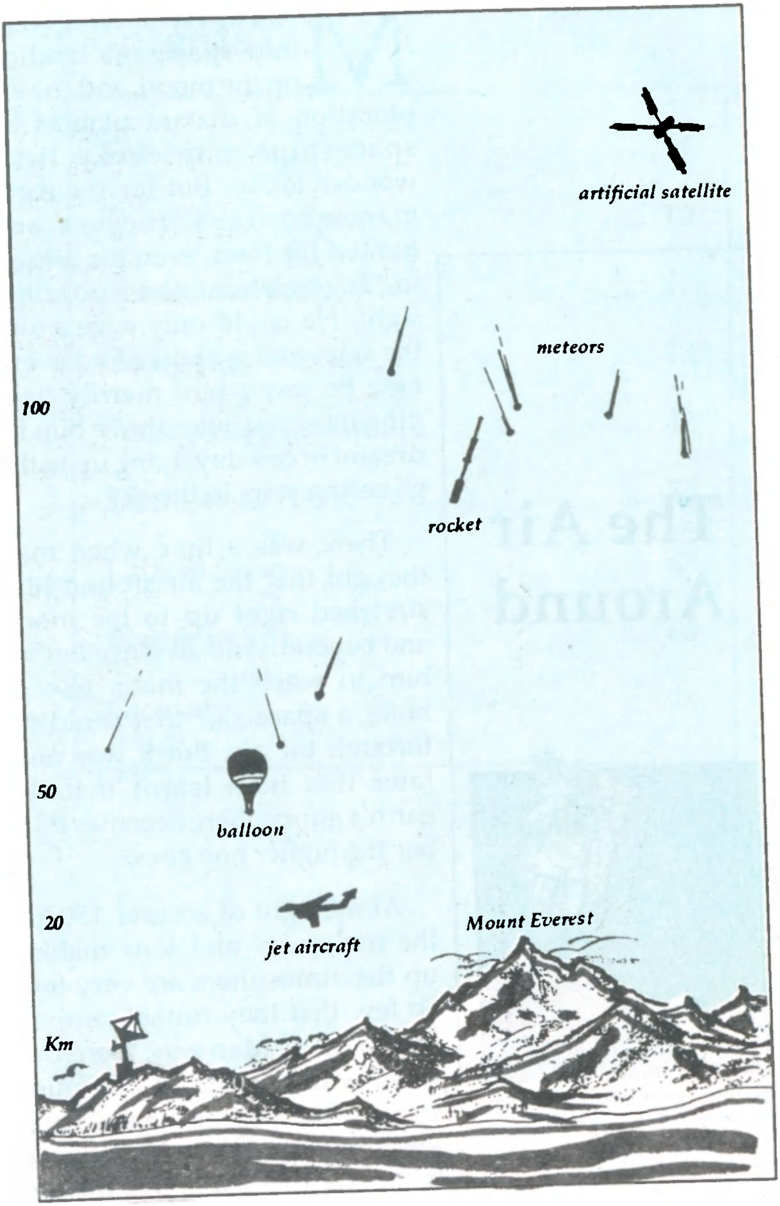
The Air Around



MAN's first faltering steps into space, his landing on the moon, and the exploration of distant planets by spaceships may evoke little wonder today. But for the early man who lived in caves and hunted his food, even the glittering sky overhead was a puzzling sight. He could only gaze up to the skies and wonder. And every time he saw a bird merrily flapping its wings way above him he dreamt of one day flying up to the glittering stars in the sky.

There was a time when man thought that the air around him stretched right up to the moon and beyond. And all it needed for him to reach the moon was to build a spacecraft that could fly through the air. But it was only later that man learnt that the earth's atmosphere becomes thinner the higher one goes.

At a height of around 150 km the molecules and ions making up the atmosphere are very few. So few that they cannot support life up there. Man was, therefore, faced with the task of designing space capsules that would carry their environment with them. It had to be independent of the surrounding regions where the gas pressure is so low that a man un-



This is how high you will get in the vehicle of your choice protected would perish suddenly and painfully. Of course, today man has come up with innumerable space vehicles that can carry him up to where there is no air. He has rockets that shoot through the atmosphere right up to the moon and now even planets much beyond it.

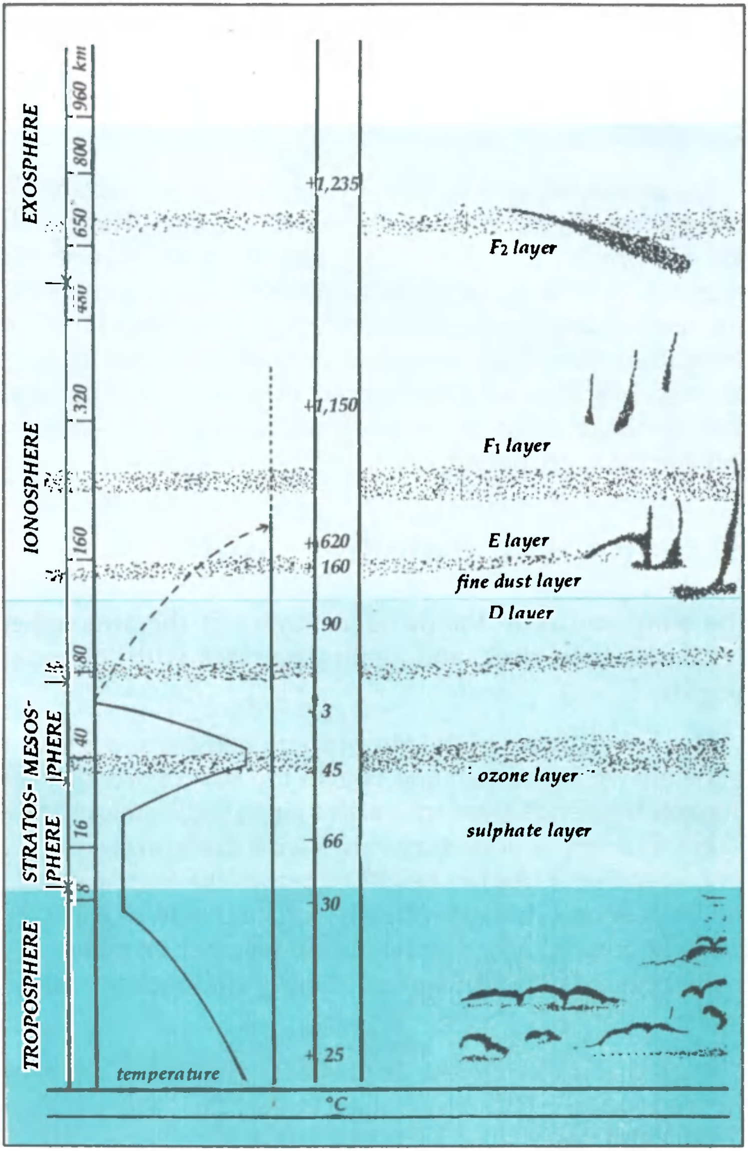
The atmosphere, as we know today, extends to a comparatively short distance above the earth's surface. The density and air pressure in the atmosphere drop with increasing height. At great heights the atmosphere blends imperceptibly into the low-density interplanetary medium. There is thus no sharp line where the atmosphere can be said to end. It can be conveniently divided into different regions depending upon characteristics such as temperature, composition, density, and electrical properties.

Blowing Hot, Blowing Cold

The temperature in the different layers of the atmosphere decreases, then rises, and again decreases with increasing height.

The lowest layer of the atmosphere is the troposphere. It is the air we breathe in and is also the seat of weather and climate. It extends from the earth's surface to a height of 8 to 16 km. The upper boundary varies with the latitude and also time of the year. As the height increases the temperature in the troposphere falls at a nearly constant rate of 6.5° C for every kilometre. Most of the visible weather changes occur in this region of the atmosphere. Nearly all clouds are formed here.

Immediately above the troposphere is a thin layer of air, the tropopause. The temperature in the tropopause is about –75° C. The tropopause leads to the next higher region of the atmosphere called the stratosphere. It extends to a height of about 50 km. In this region, the temperature increases gradually and is nearly 0° C at the top, which is known as the



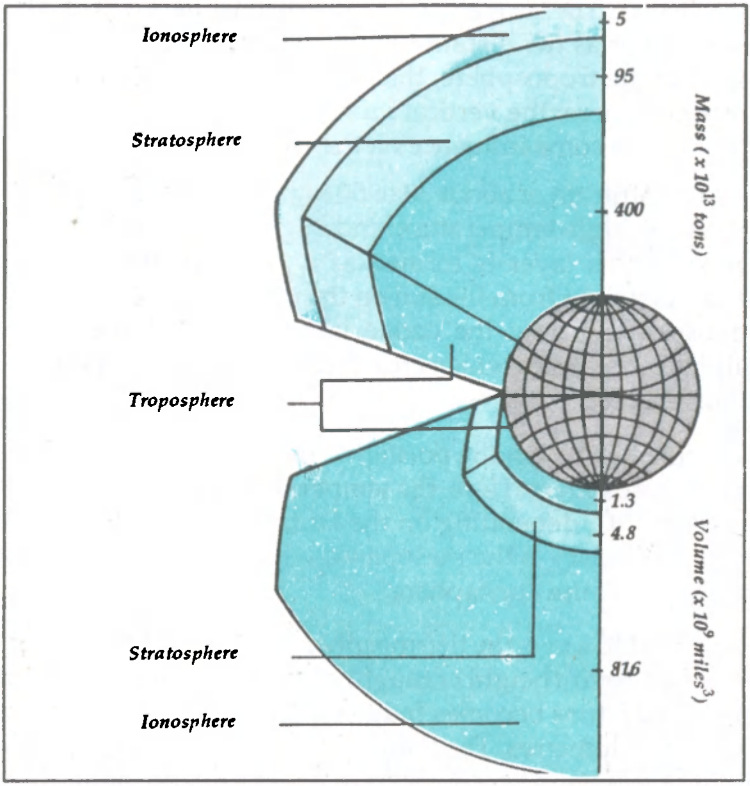
The temperature blows hot and cold in the different layers of the atmosphere stratopause. The temperature of the stratosphere increases in the summer as the distance from the poles decreases. Compared to the troposphere, the stratosphere is a quiet part of the atmosphere; the vertical mixing of air is very slight. But it does have some influence on the weather.

At an altitude of about 30 to 50 km there exists a region of relatively high temperature and high ozone content. The ozone in this layer is formed as a result of the action of ultraviolet light from the sun on the molecular oxygen in the atmosphere. Below the ozone layer is a layer containing sulphate molecules which are not found anywhere else in the atmosphere.

From 50 to 85 km the portion of the atmosphere is known as the mesosphere. Here, the temperature again decreases to about –90° C, depending on the latitude and the season. Its upper boundary is the mesopause where the temperature is the lowest in the atmosphere.

Beyond 85 km is the thermosphere where the temperature increases up to a height of roughly 300 km. Above this height, the temperature becomes independent of height for several hundred kilometres. The temperature in the thermosphere is highly variable with the time of the day latitude and the changing cycles of the sun. At the minimum of a **sunspot cycle**, the highest average temperature in the thermosphere at middle latitudes is about 750° C whereas at sunspot maximum, it is about 1,250° C.

The upper regions of the atmosphere have very low gas densities. Therefore, the temperatures described here are an indication of the average kinetic energy associated with motion of the gas molecules or atoms in the atmosphere. Because of the extremely low densities at high altitudes, the distance between molecules is very large. For example, at a height of 350 km, a gas molecule has to travel a distance of 1.5 km before it gets a chance to meet another molecule. In other words, its **mean free path** is 1.5 km. A spacecraft located in



With increase in height, volume of air increases but mass decreases

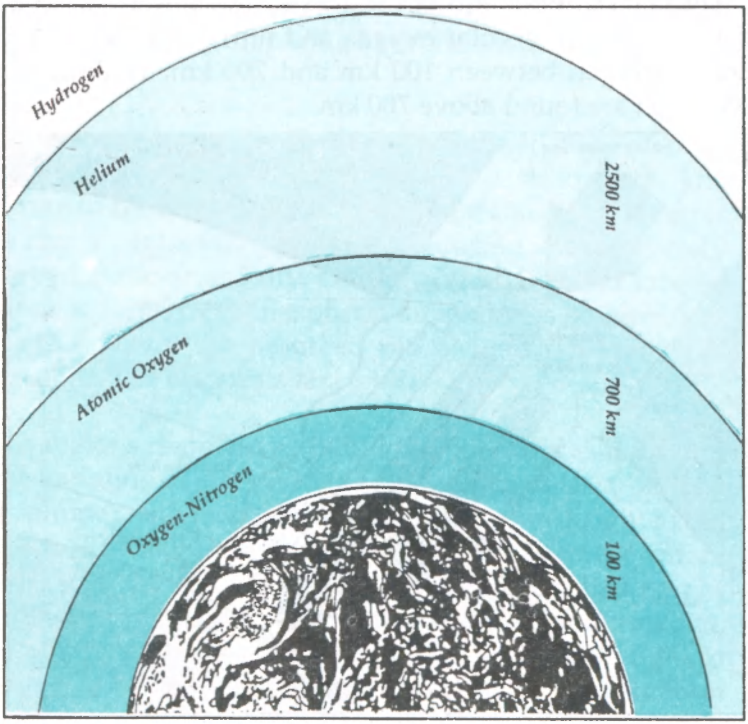
such an environment will not have a temperature as indicated by the movement of the molecules. The actual temperature of the spacecraft will be determined, on the other hand, by the amount of solar radiation it absorbs and reflects back; both of which depend on the shape, material and surface properties of the spacecraft.

Higher You Go, Thinner it Gets

From sea level upto 100 km, the atmosphere gets thinner the higher one goes. The atmospheric density decreases by a factor of 10 for every 15 km increase in height. Because of the continuous changes taking place in the upper atmosphere, the density and temperature above 100 km may not be the same at a given time of the day and season. With changing levels of solar activity the amount of solar radiation given out may vary, which in turn could affect the temperature of the upper layers of the atmosphere.

What's in the Air?

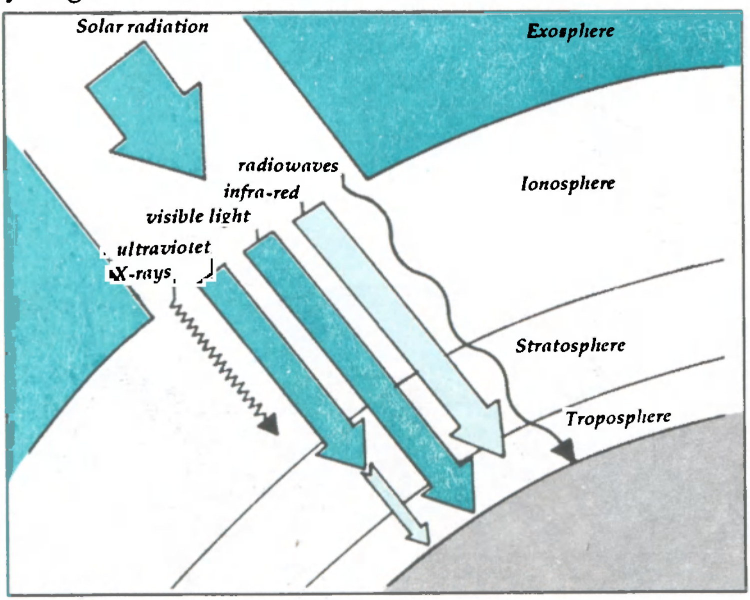
Up to a height of 100 km, because of a circulation of air, there is a continuous mixing of the gases in the air. The composition and the average molecular weight of the air in this region is



Lighter molecules lie above the heavier molecules thus essentially constant being the same as at sea level. Above 100 km where there is very little mixing, the composition changes with height.

The atoms and molecules are distributed vertically according to their weight with the heavier oxygen and nitrogen molecules at lower levels and the lighter atomic oxygen, helium, and hydrogen at higher levels. At heights above 600 km, gas molecules having high enough speed can escape the gravitational attraction by the earth. Light atoms and molecules, since they move faster, can escape more readily than the heavier ones. Because of this possibility of escape, the region above 600 km is called the exosphere.

The chief components of the atmosphere in the region up to 100 km are molecular oxygen and nitrogen whereas it is atomic oxygen between 100 km and 700 km. Helium and hydrogen are found above 700 km.



The atmosphere filters the harmful radiations

An Electrifying Atmosphere

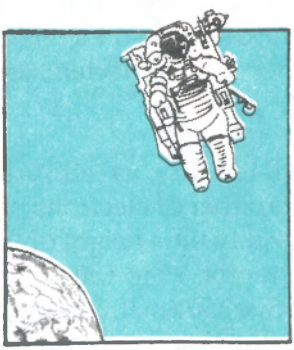
The atmosphere also shows variations in its electrical properties owing to the presence of electrically charged particles. Ordinarily an atom is electrically neutral because it contains positive and negative charges in equal number. When this balance is upset there will be positive ions and electrons. This process is known as ionization. The whole ionized region of the atmosphere is termed the ionosphere.

The ionization results from the absorption of radiations from the sun . The density of the air and its composition, and the intensity of the solar radiation intensity jointly lead to the formation of the ionosphere that extends upwards from a height of about 60 km. It plays a key role in radio communication.

The ionosphere can be divided into different layers like D, E, F_1 and F_2 which reflect radio waves back to earth. The structure of the ionosphere is continually changing. It varies from day to night, with season, latitude and is also severely disturbed by solar activity. During solar flares and intense sunspot activity, the atmospheric ionization is so increased that radio waves are absorbed rather than reflected, and communication blackouts take place.

The regions maintain an individual identity, as indicated by the variation of electron density (number of electrons per unit volume) with height. The average day time height of the D region is 60 to 90 km, that of the E region 90 to 150 km, F_1 region 150 to 250 km, and F_2 region above 250 km. In the night F_1 and F_2 regions, which are primarily due to solar ultraviolet, merge to form the F region. The F_2 region can be thought to end at about 1,000 km, because the amount of ionization taking place at that level is very low.

The Riddle of Space



MAN's conquest of space has not been easy. It has taken him ages. Since the dawn of consciousness, man had been enthralled by the changing patterns in the sky. Every day the sun rose in the east, travelled across the sky and set in the west to disappear from view for several hours before reappearing again. The moon, the brightest of all bodies in the sky, kept continuously changing its shape through a period of around 29 days. Then, there were the innumerable twinkling stars which apparently remained fixed in the night sky.

A young child seeing a starlit sky for the first time is truly re-enacting the wonder experienced by the early man watching the heavens. The celestial scene was awe-inspiring. And unable to make any meaning out of the mysterious movements in the sky the early man naturally imagined that the sky was the home of supernatural beings who ruled over the stars and the planets. Some even thought that the sun, moon, planets and the stars were all gods in their own right.

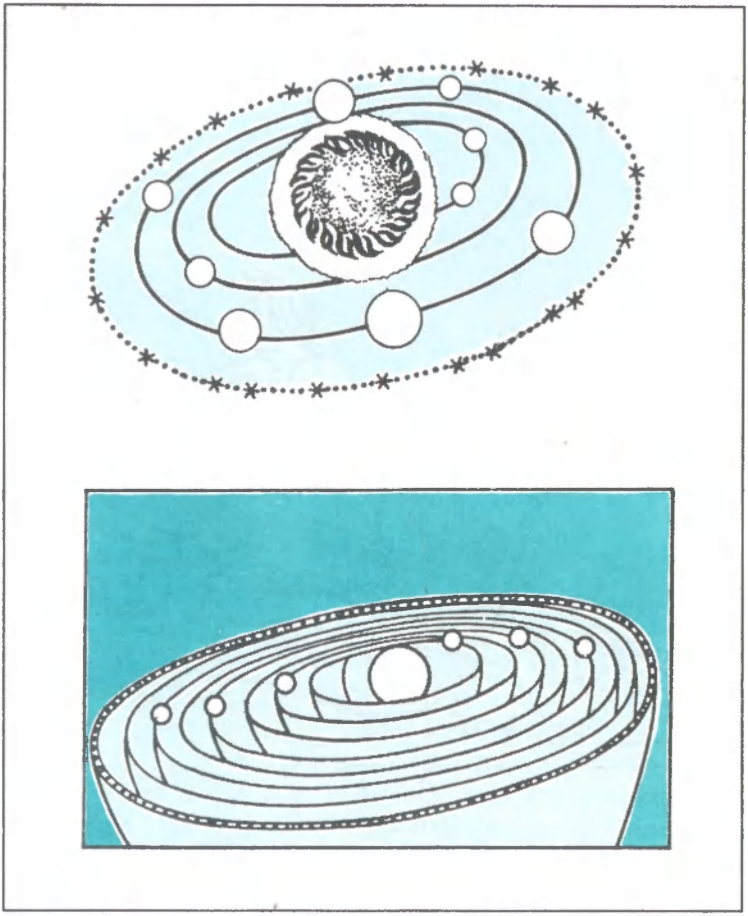
Then slowly putting two and two together man put the cycle of heavenly motions to use. He num-

Stars are guides

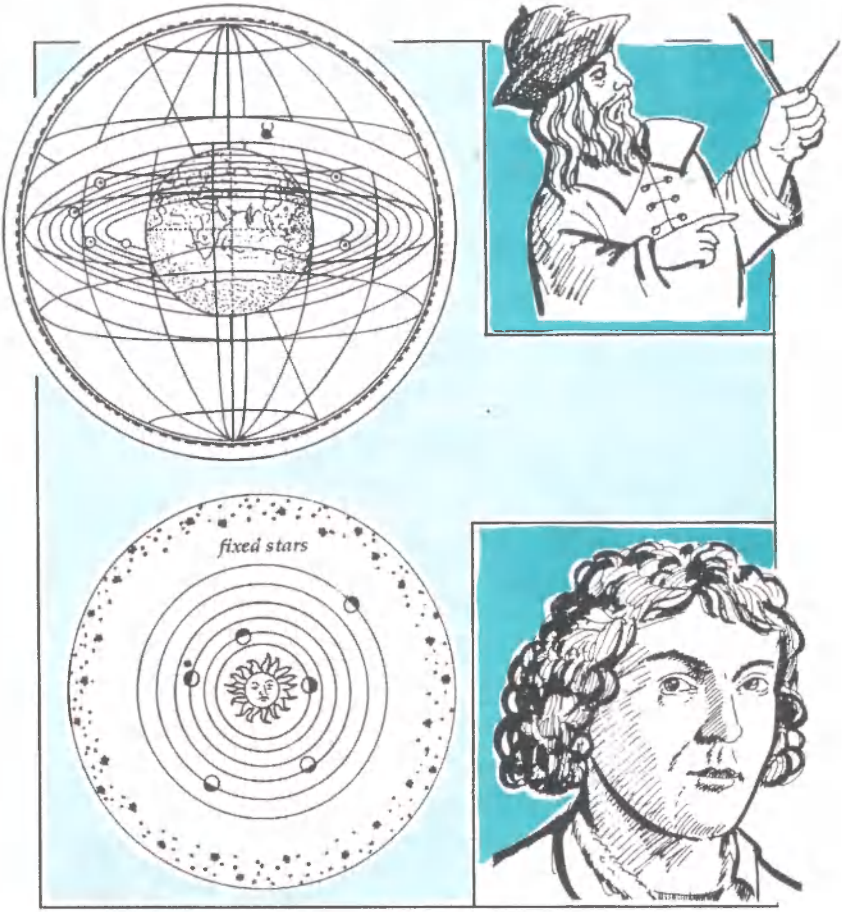
bered days, months, seasons and years, in other words constructed a calender for crucial events. To the farmer the heavenly motions foretold the times of planting and harvesting, and of rains as well. The position of the stars in the night sky served as a guide to navigation for the traveller.

Sun Circles Earth!

But, still, no clear concept of the solar system had emerged till then. What was the heavenly body around which other bodies revolved remained a topic of controversy for centuries. Man, in his arrogance, had naturally started with the



An early Greek theory — all bodies including the earth and sun circle an invisible 'Central Fire' (top) and Aristotle's concept of crystal spheres carrying all heavenly bodies around the earth (bottom)



(Top) Ptolemy's universe — all heavenly bodies go round a stationary earth; (inset) Ptolemy, and (bottom) Copernicus (inset) who said that all planets go round the sun; he, however, erred in assuming the stars to be fixed

notion that his position was at the centre of the universe, and so all bodies revolved round the earth. This is known as the geocentric (earth-centred) scheme of the solar system.

Slowly, as the understanding of the universe deepened, he realised, much to his anguish and against great resistance from prevailing institutions of power, that the earth was nowhere near the centre of the universe. It was merely a small planet of a minor star known as the sun, which is located at an insignificant corner of the **Milky Way** — only one among the uncounted billions of galaxies. This came to be called the heliocentric (sun-centred) scheme of the solar system which is accepted today.

Flights of Fancy

Man's vision of the universe was becoming clearer. He now wanted to fly free from the earth to get a closer and clearer

A dream come true

Flying atop a magic carpet

view of the heavens. Throughout the recorded history people have undertaken daring, often desperate, voyages of discovery. The thrust into uncharted seas and unknown lands represent man's irrepressible urge for exploration and conquest of his surroundings. Soon he realized that journeying over the lands and through waters would be just enough to establish his presence over the surface of the earth. But he would still be earth bound!

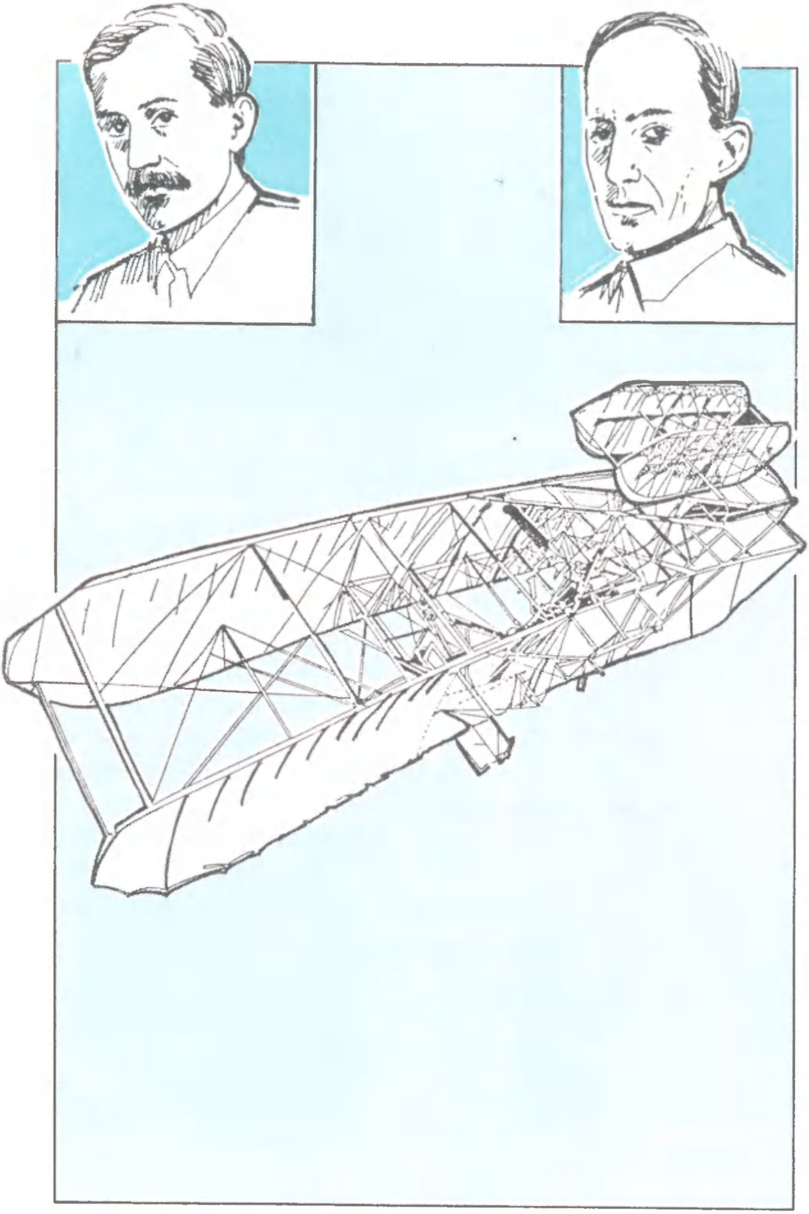
There was, therefore, the passionate craving to move in the only direction remaining — upward and outward to the skies. Birds flying high up in the sky fueled their urge all the more. Visions of flying machines in mythology and folklore, such as the *Pushpaka Vimana* and the Magic Carpet, stand testimony to this age-old desire. Outside the speculations in literature, numerous ludicrous attempts at flight were made by man in the style of the birds. The true breakthrough in flight, however, came when man thought along the lines of fixed wings as in modern planes in contrast to moving wings of the birds.

Up in the Air

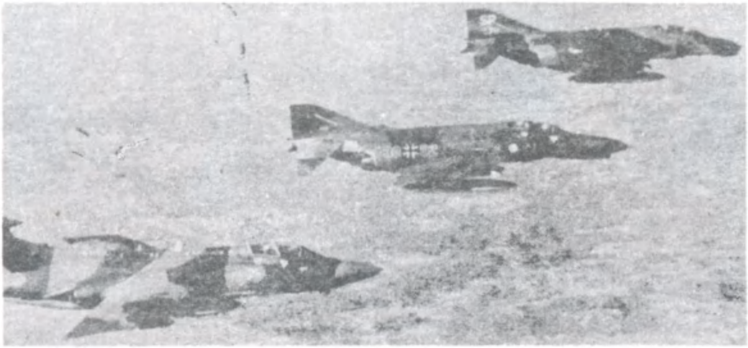
The first ever gasoline-powered plane bearing at least a remote resemblance to the present flying machines was the one flown on December 17, 1903 on the beach near Kitty Hawk, North Carolina, USA by Orville and Wilbur WRIGHT, the celebrated Wright brothers. It flew for a distance of 35 metres staying aloft for 12 seconds! This epoch-making event was achieved with a primitive plane that was a far cry from the powerful jet planes of today. It was a two-winged plane (biplane); its wings were made of fabric and were held together with struts and wires. The engine was set on the lower wing, to the right of the pilot; the propellers were at the back of the plane. Although not very successful, this was a great beginning, nonetheless.

When World War I broke out in 1914, airplanes were still a novelty. But, they did really come of age in the course of the war. During World War II, the importance of air power became a decisive factor. Towards the end of the war, jet planes made their appearance. These were based on an entirely different principle from that of the early propeller planes. When hot gases produced as a result of burning a fuel rushed out through an exit at the rear, the thrust of the gases created an equal and oppositely-directed force (exactly what Newton's third law of motion says) which pushed the plane forward.

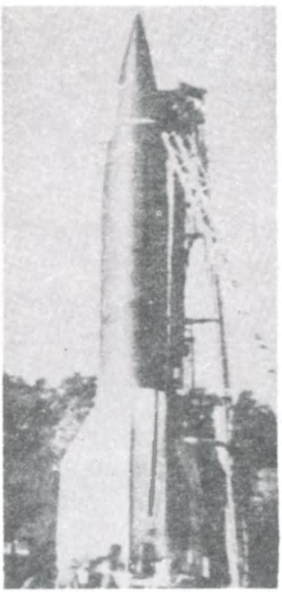
Today one would, perhaps, not pay much attention to the vast number of air transports, air freighters and private planes that make their way through the skies daily. But what seems commonplace today would have utterly amazed men just some decades ago.



Orville Wright (left) and Wilbur Wright (right), and the first airplane they flew



Harmless early airplanes gave way to deadly fighter planes



German V-1 rocket

The conquest of air was the first step towards the exploration of space. After the airplanes, man's next major achievement was the development of rockets. World War II witnessed the German V-1 and V-2 which were the forerunners of the modern rockets. In a rocket engine the fuel, either solid or liquid, is burned. The rocket also works on the jet principle. But unlike the jet engine, a rocket does not draw air from the atmosphere. It carries its own oxygen with it.

The deadly rockets that harassed enemies in World War II would later pave the way for powerful rockets that would one day send man into space.

The Rocket Era

THE making of the rocket saw man's dreams of breaking free from the earth's gravity and entering space coming closer to reality. The first glimmerings of the true basis of space travel began to emerge only towards the end of the 19th century.

But the idea of a rocket for space travel had evolved out of ages of imaginative and fanciful stories. Many stories had been written about journeys from the earth to the moon and the nearby planets like Mars and Venus.

The earliest known fictional account of man's venture into space was written about AD 160 by the Greek satirist LUCIAN. In his work, *True History*, intended as a parody of Homer's Odyssey, a ship in the Atlantic is lifted from the ocean and carried to the moon by a powerful whirlwind. There the passengers encounter fantastic beings who are preparing for a war against the sun. In another story, Lucian had his hero strap on wings and jump from a mountain to fly to the moon.

These stories came at a time when Greek scholars were beginning to accept the moon as a solid body, somewhat like the earth. No space fiction appeared for a

Lucian's ship blown to the moon by a storm

long time until the 17th century when the telescope was invented. In 1609 when the Italian scientist GALILEO turned his microscope to the skies he saw what no other man had ever seen before—mountains and waters on the moon's surface. This event sparked off a revival of interest in possible other worlds.

There was a rash of fictional accounts of moon-voyages by such writers as VOLTAIRE, Alexander DUMAS, Jules VERNE, Edgar Allan POE and H.G. WELLS to name only a few. Jules Verne's account of a voyage to the moon in a rocket was much closer to reality. His book *From the Earth to the Moon* published in 1865 still stands tall among the fictional accounts of those times. He realized quite correctly that for a spaceship to leave the earth, it should necessarily have an upward speed enough to overcome the earth's gravity. Later, *The Brick Moon* written by Edward Everett HALE in 1870

A bizarre idea for a spaceship

Jules Verne wrote of a ten-ton aluminium spaceship being blasted off towards the moon by a canon

first described the launching of an artificial satellite into orbit.

From Crackers to Deadly Weapons

When the first rocket was developed remains unknown. The earliest rockets were a Chinese invention. In AD 1232, the Chinese repelled attacking Mongols with the aid of "arrows of flying fire" which are believed to have been made of arrows attached to rockets propelled by gunpowder. The arrow, like the guiding stick of the common rocket used in

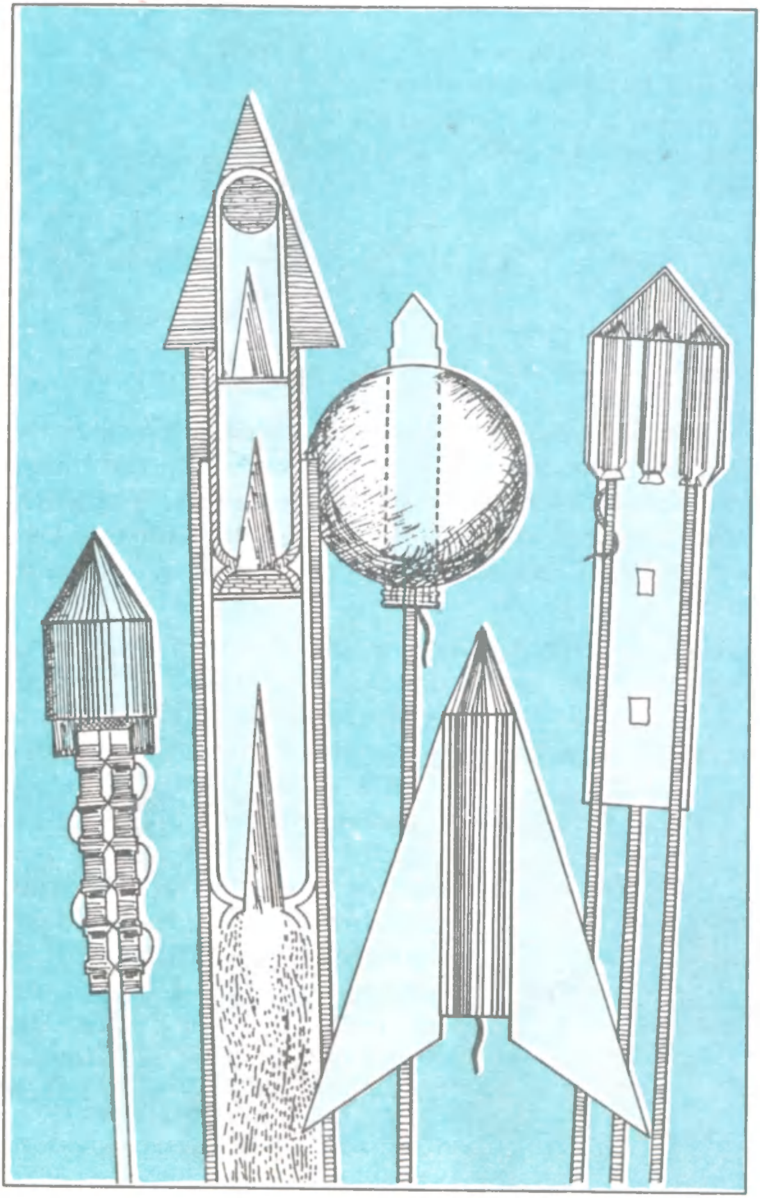
Shooting the most common form of rockets fireworks, served to stabilize the weapon in flight. These early rockets reached Europe by the middle of the 13th century.

The early 19th century witnessed an intense interest in military rockets. This was largely the result of their effective use against the British armies towards the end of the 18th century by Haidar ALI of Mysore, and particularly, by his son and successor, Tipu SULTAN. These rockets consisted of a thick metal tube attached to a 3-metre-long bamboo stick. Weighing 3.5 kg, it had an effective range of 1.5 km, an outstanding performance for those days.

Around 1801, William CONGREVE, a colonel in the British army heard about these weapons and from that time till his death in 1826 he worked on developing rockets for military purposes. Congreve developed a rocket that was propelled by a solid fuel. His rocket was extensively used in the Napoleonic wars. Incidentally, these rockets were also used for humanitarian purposes like throwing a line from shore to a stranded ship, enabling the distressed crew to be pulled back to the shore. In 1846, the British inventor William HALE found that the rocket could be stabilized in flight by spinning it, thus eliminating the guiding stick.

It was in 1903 that a truly scientific treatise on space travel advocating the use of liquid fuel rockets first appeared. The author was a deaf Russian school teacher, Konstantin TSIOLKOVSKY. He derived certain mathematical equations fundamental to rocketry. Although his theories were scientifically sound, their influence on the development of rocket technology and space exploration in Russia and elsewhere was delayed. The reason was that most scien-

Konstantin Tsiolkovsky



The earliest rockets

tists in the early part of the 20th century regarded space travel as anything but a fantastic dream. Tsiolkovsky's work consequently remained obscure for some time.

Hermann Oberth

The Take-Off

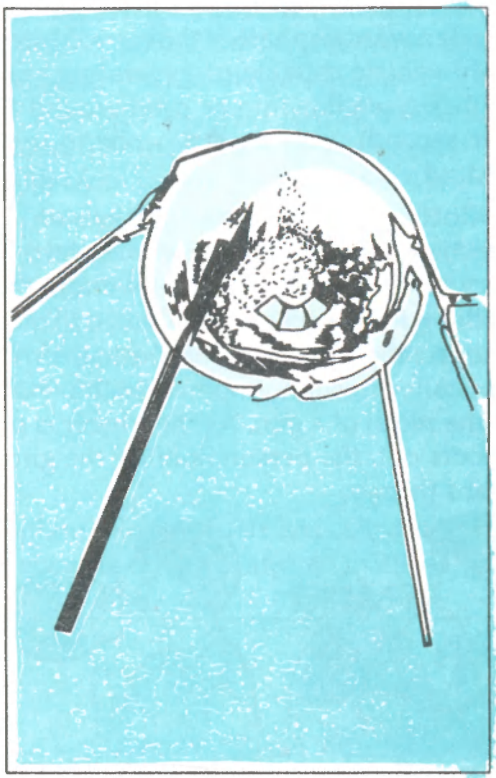
In the period between the two World Wars, two men working independently, laid the groundwork for the technology that ultimately took men and their instruments to the moon and beyond. In the United States, Robert GODDARD experimented with rockets fueled by liquid oxygen and liquid hydrogen. In Germany, Hermann OBERTH also pushed the development of liquid-fuel rockets.

March 16, 1926 is a monumental day in the history of rockets when the first liquid rocket was launched by Goddard. It covered a distance of 55 metres. The flight, while not spectacular in the distance it travelled did nevertheless prove that a rocket flight was indeed possible. By 1936, the range extended over 2,200 metres and speeds over 1,100 km per hour. On July 17, 1929, Goddard launched the first rocket with instruments on board. The instruments consisted of a barometer and a thermometer with a small camera focused to record their readings.

Robert Goddard with his rocket

World War II saw a tremendous development in military rocketry. The largest and longest-range rocket of the day was the German V-2, a liquid-fueled weapon that bombarded London after a flight of about 300 km from its GERMAN base. The present rockets used in space programmes have largely evolved from the V-2.

Finally, on October 4, 1957, Sputnik-1, the first man-made satellite was launched into orbit by what was then the Soviet Union. The first American satellite followed shortly after on January 31, 1958. The Space Age had begun !



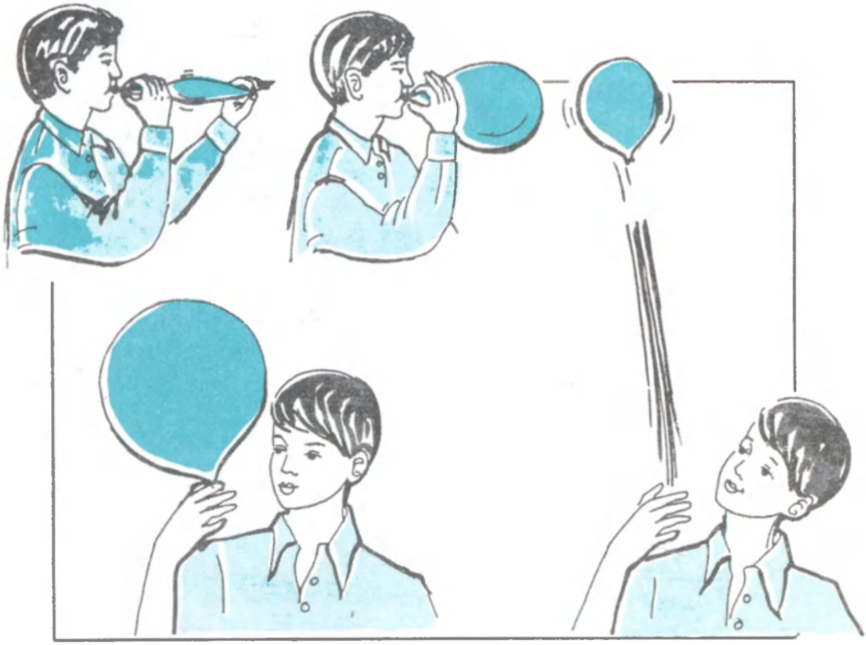
Sputnik-1, the world's first artificial satellite

Shooting through Space

The only practical method of driving about in the region beyond the earth's tangible atmosphere is by rockets. A rocket can move in any medium, be it air or vacuum or water. This is because the rocket is self-contained. It carries its fuel and also the oxygen required for burning the fuel. So it does not require the presence of air around it to draw oxygen from.

As it happens, the rocket is more efficient in vacuum than in the dense atmosphere of the earth. Moreover, the rocket is the only vehicle capable of generating speeds high enough to launch a satellite into an orbit around the earth (about 8 km per second) or to send a probe to the moon (11.2 km per second).

Rockets operate on the well-known principle of action and reaction contained in Newton's third law of motion. Most commonly the law is seen at work in the case of an air-filled balloon from which air is allowed to move out from the open end. As the air rushes out, the balloon shoots forward in the opposite direction. Another familiar example of this principle is the recoil of a gun. As the trigger is pressed and the bullet shoots out, the person holding the gun experiences a backward thrust.

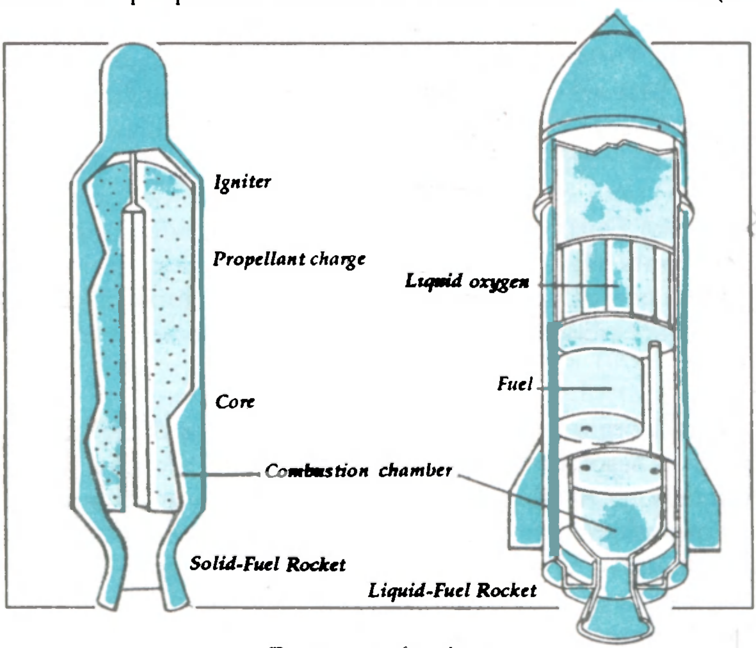


Action and reaction at work — as the air rushes out, the balloon shoots upward

In the same manner, rocket engines create thrust by burning large amounts of fuel. As the fuel burns, it becomes a hot gas. The high pressure inside pushes the gas out through an exit nozzle at the rear causing a steady, forward motion of the rocket due to reaction. The maximum speed that can be attained by a rocket is determined by the speed with which the hot gas is expelled through the exit. This speed in turn depends mainly on the temperature of the gas and average molecular weight of the gas. The interior shape of the exit nozzle also determines the speed. The choice of the propellant and the design of the rocket engine are, therefore, influenced by these considerations.

Rocket Fuels

Now, what is a propellant? Rocket fuels are called propellants. The propellant consists of a fuel and an oxidizer (the



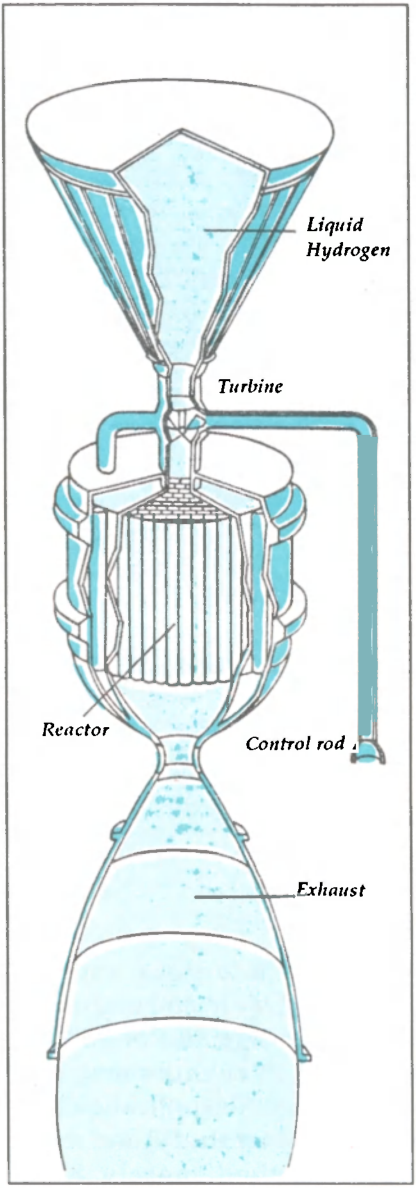
Two types of rockets

oxygen-containing substance required for combustion) that help to propel the rocket. The present day rockets used for launching spacecraft are of two types depending on the type of propellant used — solid or liquid.

Solid-propellant rockets are relatively simple. Besides, the propellant is ready for use any time on short notice. All the propellant is contained in the combustion chamber which also contains the oxidizer. An electrical or pyrotechnic igniter fires the propellant. The main disadvantage is their lower performance. The efficiency of propellants is expressed as the thrust that one pound (0.45 kg) of fuel can produce in one second. This is also known as the propellant's specific impulse. Solid propellants have a lower specific impulse than liquid propellants. Also, it is not controllable, once ignited.

Before 1940, black powder(gun-powder) was almost the only solid propellant employed in rockets. It was not until World War II that other successful solid propellants became available. Three important types of solid propellants are now in use. These are double-base (for example, nitrocellulose and nitroglycerine), composite type (an inorganic salt as oxidizer suspended in an organic fuel generally mixed with fine metal particles), and composite double-base (combination of the other two). During World War II, a number of new composite propellants were produced. Many of these contain ammonium perchlorate as the oxidizer. The fuels most commonly used are polyvinyl chloride, polyurethane and synthetic rubber.

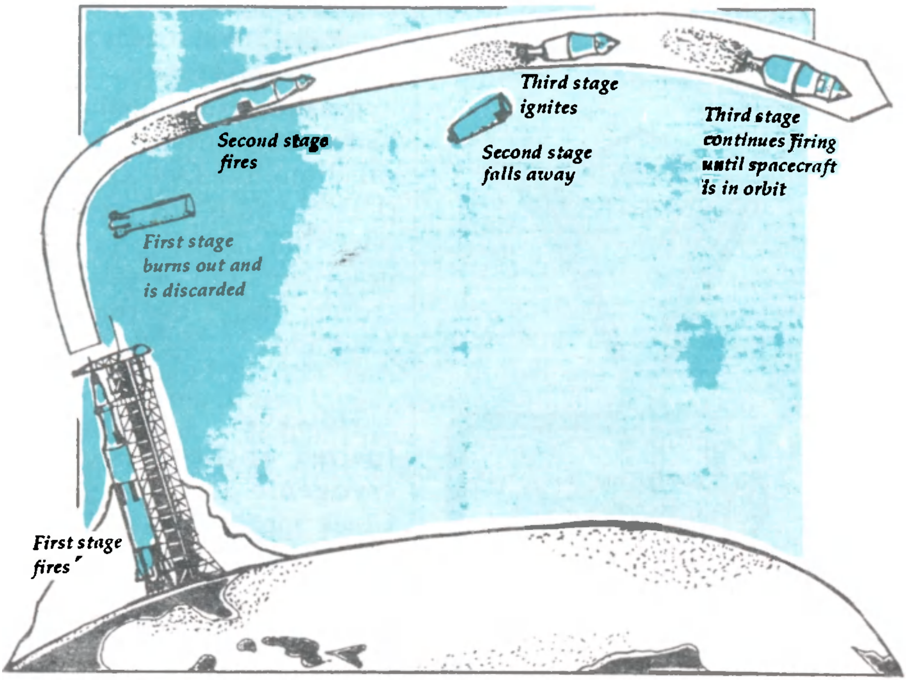
Liquid propellant rockets have fuel and oxidizer liquids stored in separate tanks. These liquids are brought to the combustion chamber at the required pressure by suitable pumps and ignited. This is why liquid propellant rockets are quite complex. These rockets have a number of moving parts whereas the solid variety has none. The liquid propellant rockets perform better and can be easily controlled — they are easy to stop and start as necessary.



Liquid hydrogen rocket

The propellants used generally are aerozene (a 50-50 mixture of hydrazine and dimethyl hydrazine), unsymmetrical dimethyl hydrazine (UDH) and nitrogen tetroxide. These liquid propellants can be easily stored under ordinary conditions.

However, liquid fuelled rockets using cryogenic ("kryos" in Greek means "ice-cold") propellants like liquid oxygen and liquid hydrogen show a still higher performance. In order for these propellants to remain liquid, the temperature has to be extremely low. For oxygen the boiling point is –183° C while for hydrogen it is –253° C. The cryogenic propellants have to be maintained in the liquid form because as gases they have very low density and hence would occupy a large volume and require impractically huge storage tanks. Elaborate arrangements have to be made to main-



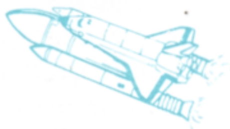
The staging principle

tain the necessary cryogenic temperature.

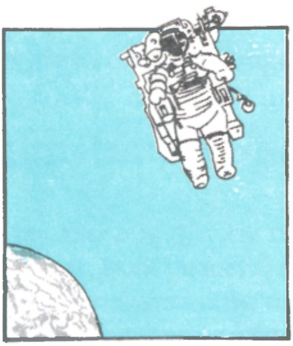
Launching a Spacecraft

Today there is a wide range of rockets to suit a variety of purposes, both peaceful and military. Day in and day out one hears of rockets being used to launch satellites of all kinds. Not only for studies of the earth and its environment, or for astronomy but also for more down-to-earth applications such as communication, meteorology (weather study) and remote sensing. Whereas Sputnik-1 weighed merely 83 kg, spacecrafts weighing several tens of tonnes are today being launched by modern rockets.

A satellite is lifted by a rocket high enough to be lauched into space with the right speed and direction. This is achieved with the help of multistage rockets known as launch vehicles. Usually, 3 to 4 stages are stacked one over the other. The lowest stage (first stage) operates first. When the fuel in the first stage has been used up it is discarded and the second stage is then ignited. The same process then continues with the third and the fourth stage. Each lower stage gives those above itself, a share of the speed the spacecraft should finally have to fall into an orbit or to escape the earth's gravity. This scheme of working is called staging.



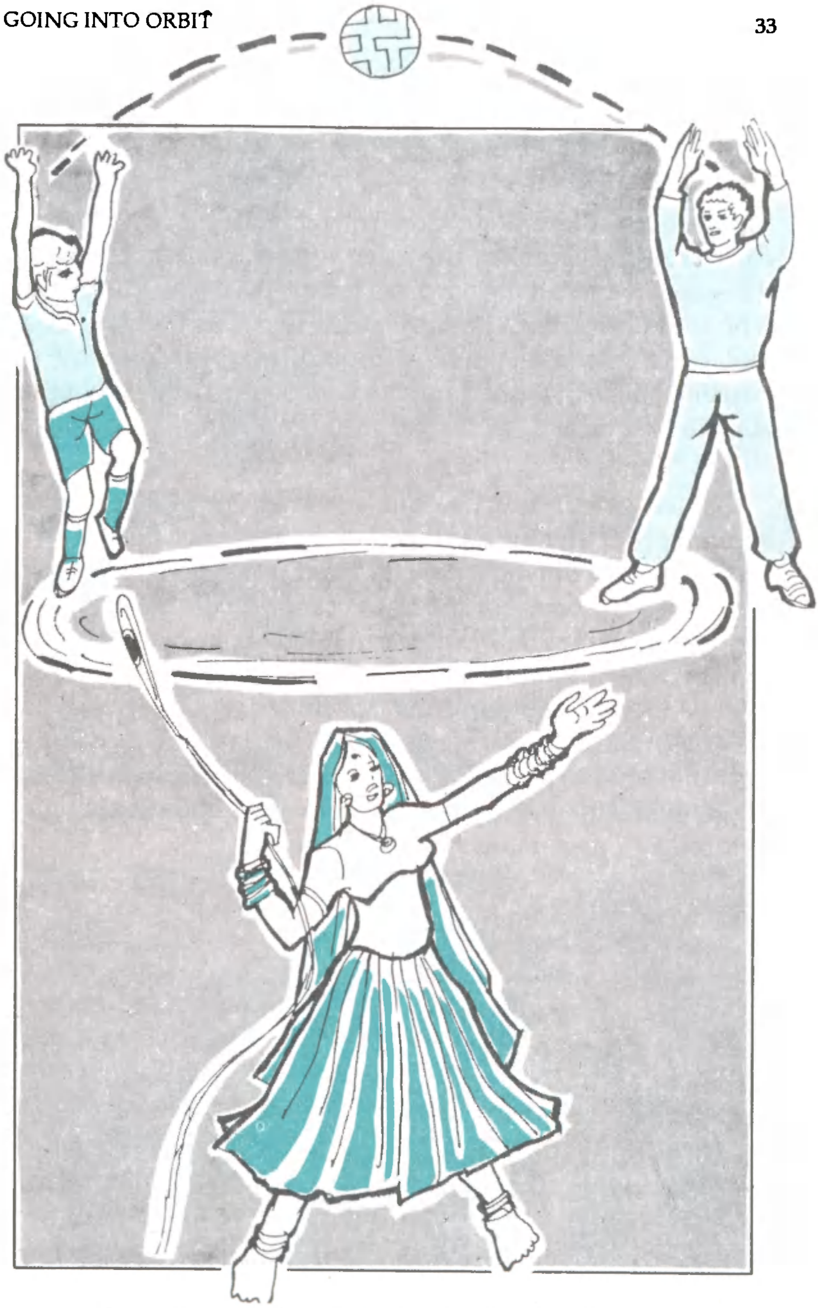
Going into Orbit



Once it is launched, the rocket carrying the spacecraft rises against the earth's pull to a suitable height. If the spacecraft is then injected into an orbit around the earth it becomes an artificial satellite. The moon that goes round the earth is a natural satellite. A spacecraft directed far out into space towards the moon or a planet is known as a space probe. A probe may eventually fall on the target, or it can get into an orbit around it, or even fly past the target, depending on the mission.

An orbit is a path that forms a closed and repetitive circuit around the earth (or any other heavy body, for that matter). Another word in frequent use is trajectory. Unlike an orbit, a trajectory is a path that leads directly from one point to another. The path of an airplane, or a bullet is thus called a trajectory. So is the path of a space vehicle travelling from the earth to the moon. But once the space vehicle starts going round the moon it is said to be in orbit.

An artificial satellite or space probe moving in space will observe the same laws that govern the motion of the planet or the moon.



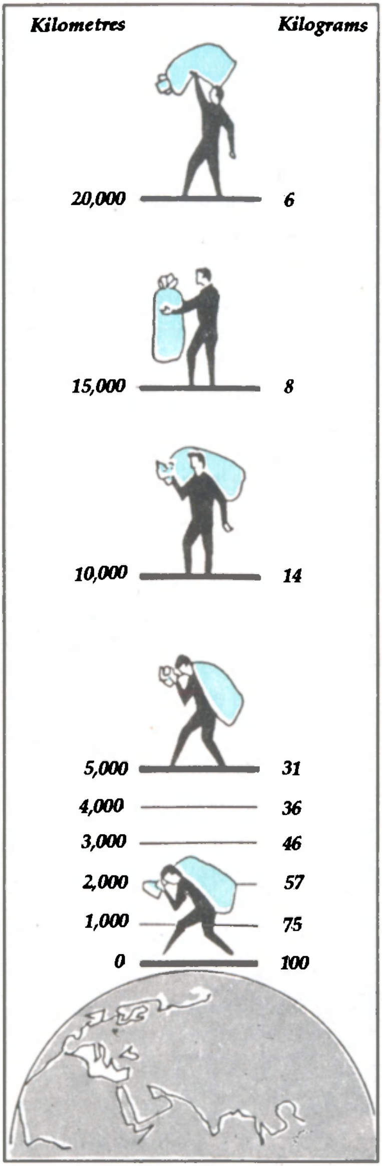
Every projectile has a trajectory (top); this is how an orbit looks like (bottom)

From Copernicus to Newton

Much before the time of Copernicus, man thought that the earth is at the centre of the solar system. For, surely everything seemed to revolve around the earth. It was Copernicus who first pointed out that it was the earth and other planets that went round the sun. Although pooh-poohed by the powers that be in those times, he was later proved right when Galileo first turned his telescope to the skies.

Galileo found four moons circling the planet Jupiter; enough proof that the earth with only one moon could not be a pre-eminent member of the solar system. Galileo later developed the basis for the laws of motion. In the early 17th century, Johannes KEPLER formulated the laws of planetary motion, one of which stated that the planets orbit the sun in oval paths called ellipses, and not circles, as Copernicus had believed. These laws together with the laws of gravitation formulated by Isaac NEWTON made it possible to deduce mathematically the motion of heavenly bodies and also, naturally, of man-made objects in space.

Newton and the famous falling apple



Away from the earth gravity becomes weaker and things weigh less

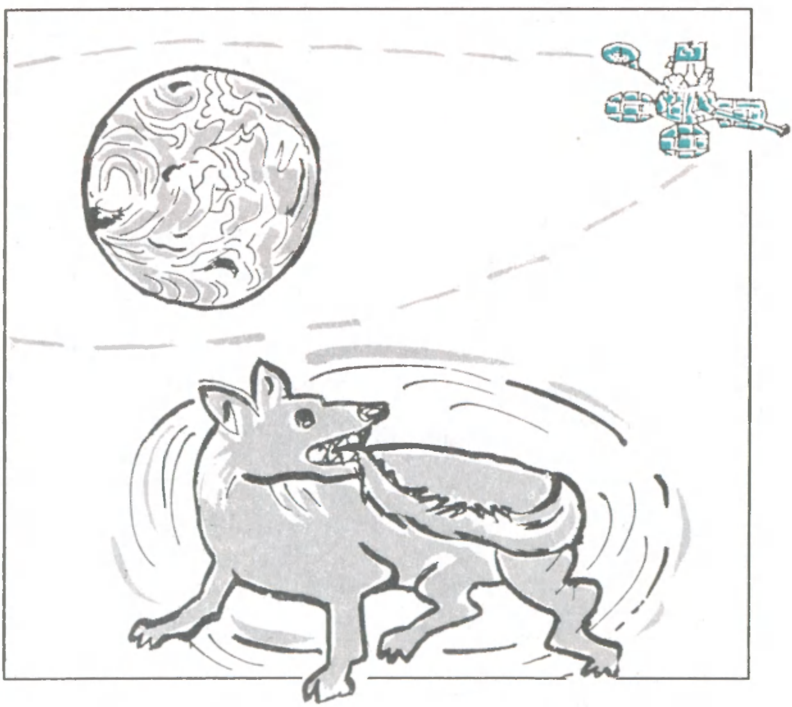
In his law of gravitation Newton said that two bodies attract each other with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. Thus, the earth also has a gravitational field which attracts every object towards the centre of the earth. The object, as a result, accelerates (moves with steadily increasing speed) towards the earth. The value of this acceleration due to gravity at the surface of the earth is often taken as a reference. It is known as 1g.

The strength of this pull weakens four times as the distance of the object from the centre of the earth is doubled. It decreases nine times if the distance is trebled, and so on. This is the well known inverse-square law. An object near the earth is subjected predominantly to earth's gravity; yet, strictly speaking, it is not completely free from the gravitational effects of the sun and the moon.

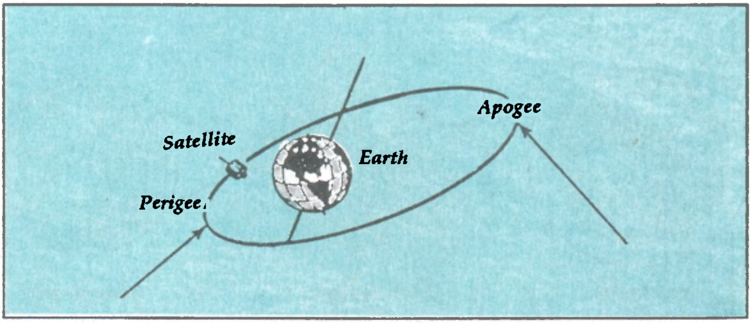
Falling into Orbit

Suppose an object is thrown with a certain speed parallel to the earth's surface at that place. For the sake of simplicity, it can be assumed that this event takes place at about 150 km above the surface of the earth. Then the resistance offered to the object by the atmosphere (aerodynamic drag) can be disregarded because at this height the atmosphere is very thin. Only the effect of gravity needs to be considered. The body will strike the earth some distance from where it was thrown.

As the speed of throw is increased, the body will return to the earth farther and farther away. If, however, the speed is increased to about 8 km per second, the object, instead of



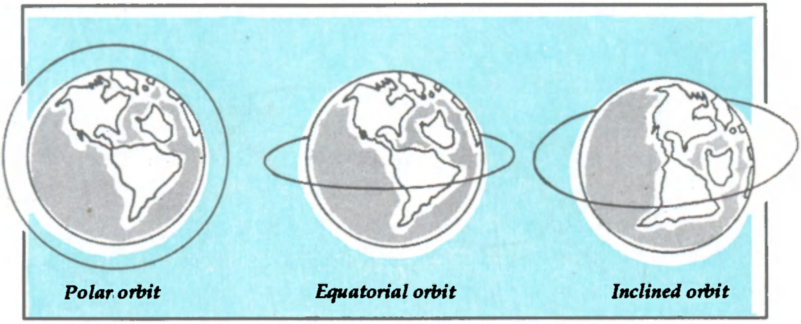
A satellite in orbit is like a dog chasing its tail



An elliptical orbit

falling back to the earth, settles into a circular orbit. The object moves forward horizontally at the rate of 8 km per second, falling at the same time a distance of 5 m towards the earth under the effect of gravity. This distance incidentally happens to be the same as the depth by which the earth's surface curves down over a horizontal distance of 8 km, the earth being nearly spherical in shape. Thus, figuratively, the object falls and falls and falls..., but the earth curves and curves and curves.... It is like a dog chasing its tail. The object is thus in an endless free fall. Such a free fall without any resistance results in weightlessness. In more familiar terms, the object has now become a satellite of the earth. Its inertia that would have taken it along a straight line is just curbed by gravity. Gravity pulls the spacecraft out of the straight path and causes it to circle round the earth.

If the object were to be thrown at speeds higher than that required for a circular orbit, it will settle into an elliptical orbit which is oval in shape. An elliptical orbit is generally easier to achieve than a circular orbit which requires more precise control of the direction and speed with which the satellite is put into orbit. An elliptical orbit has an apogee, the farthest point from the earth, and a perigee, the point nearest to the earth. For a circular orbit,since the distance from the earth is the same throughout the orbit, apogee and perigee are not



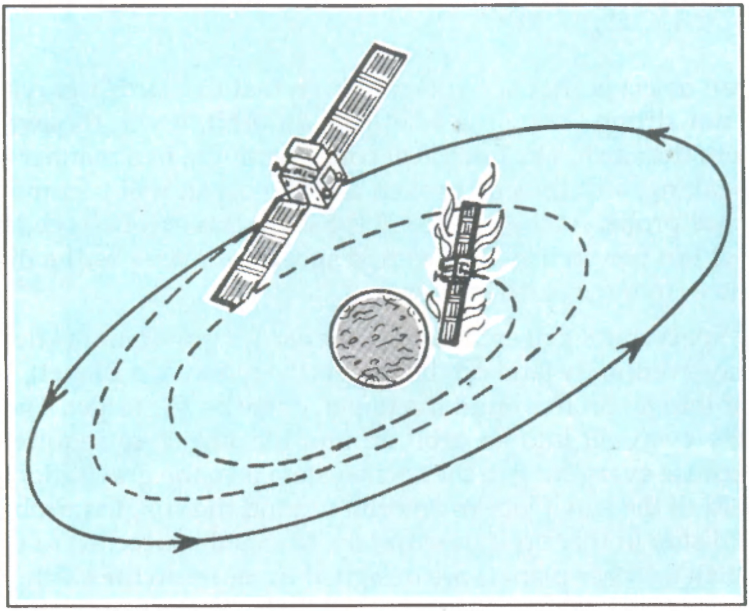
The type of orbit depends on the mission of the satellite

distinguishable. For the first man-made satellite, Sputnik-1, the apogee was 940 km and the perigee 225 km from the surface of the earth.

The plane of the orbit should necessarily pass through the centre of the earth; this is an important condition. But the orbit may be inclined towards the earth in any manner. The desired orbit will depend on the mission for which the satellite is intended. The orbit may pass over both the poles in which case it is called a polar orbit, preferred generally for remote sensing satellites. If the plane of the orbit lies along the earth's equator, it is an equatorial orbit. Most communication satellites are positioned in the **geostationary orbit** which is always equatorial.

Orbital Period

The time a satellite takes to go round the earth once is known as the orbital period. This period depends on the height of the orbit; higher the orbit, longer the period. Orbits which are a few hundred kilometres from the surface of the earth have periods about 90 minutes. Geostationary communication satellites which are at a height of about 36,000 km directly above the equator, take 24 hours to complete one full orbit.



A satellite very close to the earth eventually spirals downwards towards the earth

Satellites that are in orbits very close to the earth do not last long. The dense atmosphere causes resistance to the motion of the satellite. Even though the atmosphere is very thin above 150 km, it is not a complete vacuum; molecules and other particles exist there, nevertheless. When they strike the satellite, although the individual effect of the particles is insignificant, repeated bombarding of the satellite results in reduction of its speed in course of time. This reduction of speed is most severe at the perigee. The satellite will thus not be able to rise to the former apogee. As a result the next perigee will be still lower. Thus, the satellite will spiral its way into denser and denser atmosphere, getting increasingly closer to the earth. In a majority of cases, the heating caused by friction with the atmosphere is so much that the satellite burns out before reaching the earth; only very massive fragments may survive and fall on the earth.

Breaking Free

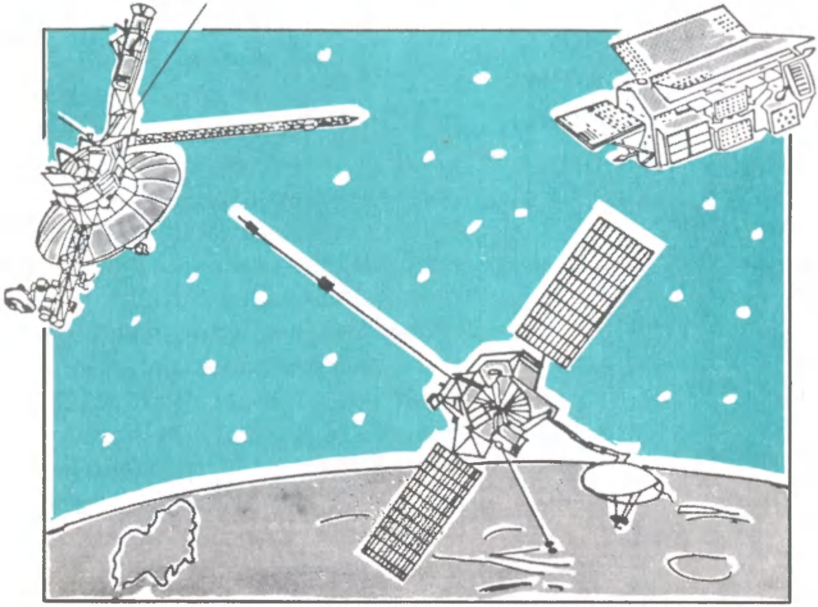
If an object is shot at a speed so high that the earth's gravity is not strong enough to hold it in an orbit, it will fly away from the earth. The umbilical cord of gravity, in a manner of speaking, will thus be broken and the object will become a space probe. At the surface of the earth this escape speed is 11.2 km per second. The escape speed decreases as the distance from the earth increases.

Spacecrafts that escape from the earth's gravitational field may eventually land on the target (the moon or a planet), or get into an orbit around the target, or fly by the target. They may even get into an orbit around the sun, if so required, because everything in the solar system is in the gravitational field of the sun. Once in an orbit around the sun, the probes will stay in that orbit indefinitely. Manned spacecraft to the moon or other planets are designed to return to the earth.

Celestial Spectacle

Among the most exciting events of space exploration have been close-up views of celestial bodies provided by space probes from time to time. The Luna programme, begun by Russia in 1959, included a series of moon probes. Some of them crashed on to the moon, others flew past it or went into orbit around the moon. Luna 3, launched in October 1959, was the first spacecraft to go completely round the moon. It photographed that 'other' side of the moon which is always hidden from our sight. This is because the moon turns once about its own axis in the same time as it takes to go around the earth.

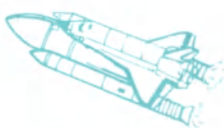
Several moon probes that followed, both Russian and American, soft-landed on the moon and conducted scientific studies on it. While the moon is about 400,000 km from the earth, the nearest planets, Venus and Mars are millions of kilometres away. But they too have been reached by the



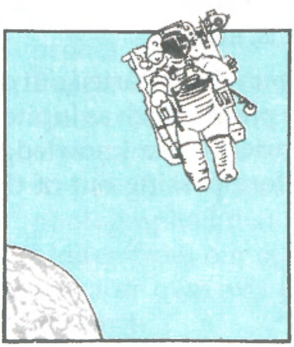
Voyager (top left), an astronomical satellite (top right) and Mariner (bottom)

Mariner spacecrafts of USA and Venera spacecrafts of the erstwhile Soviet Union. The probes to Mars and Venus revealed many useful facts about the surface temperature, magnetic fields, ionosphere, radiations, etc.

Worthy of special note is the Voyager which started out on its one-way journey in 1977. It flew by planets such as Jupiter, Saturn, Uranus and Neptune, and enriched our knowledge of the planets and their satellites before passing out of the limits of the solar system.



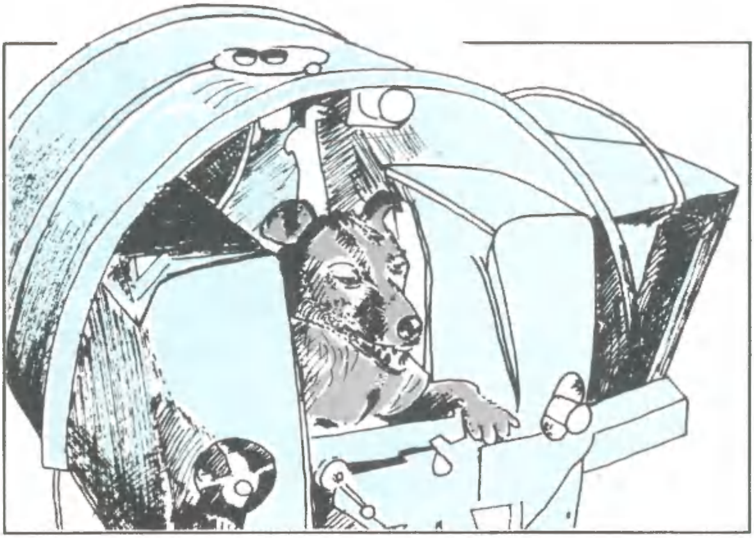
Perils of Space Flight



Man has defied the elements ever since he stepped on the earth. Driven by the necessity for survival, by his love of adventure, and by an insatiable curiosity about the unknown, he plunged deep into the oceans, climbed up mountains, waded through scorching deserts, conquered the skies, and has now even gone up high into space. Just as the dangers of the unknown always appear threatening, space too had seemed filled with many terrors before men finally ventured beyond the screen of the atmosphere.

Space is, no doubt, a hostile environment. There is no air. In the sun one fries; in the shade one freezes. Water evaporates very rapidly. Beyond the protective shield of the earth's atmosphere, radiation in space could kill an unprotected human being. Besides, the atmosphere also shields us from the incessant downpour of meteors which bombard our planet daily. It had seemed unlikely in those times that either men or vehicles could survive for long outside the protective blanket of the atmosphere.

Yet another worry that plagued those contemplating space flight



Laika — the first living being in space

was weightlessness. Because weightlessness had never been experienced by human beings for more than a fraction of a minute, there was fear it might produce uncontrollable nausea, lack of muscular coordination, rapid heart beats and many other dangerous changes in the body. But the Russian dog Laika — the first living being to go into space — set these fears at rest. Its week-long flight aboard Sputnik II in November 1957 gave invaluable information on the condition and behaviour of living organisms in space.

A monkey ready to go into space

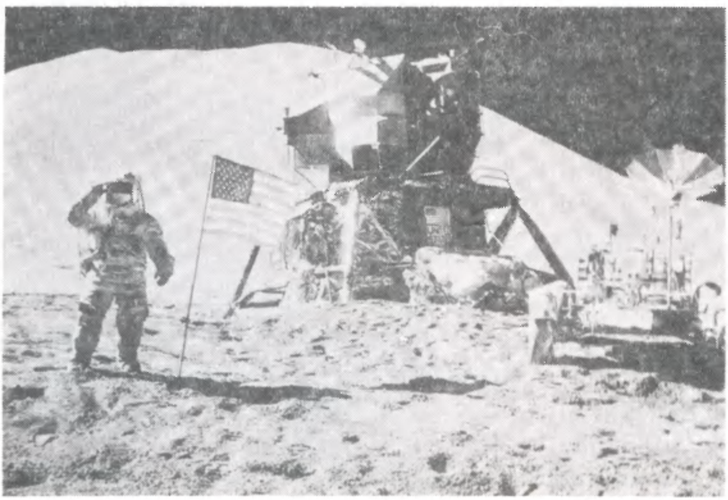
Man Steps into Space

After man had launched quite a few unmanned space probes and explored the conditions by sending animals, it was time he launched himself into space.

Yuri Gagarin
with his daughters

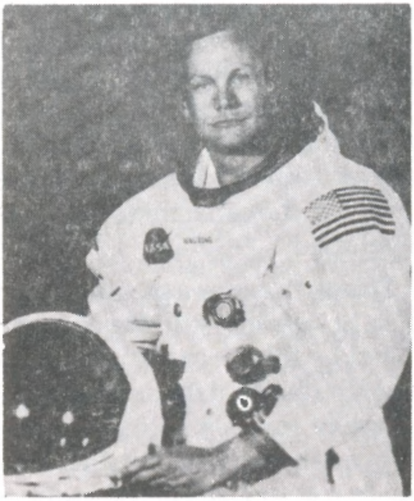
On April 12, 1961 the Russian cosmonaut Yuri GAGARIN made the first spectacular flight around the earth. His flight lasted merely 108 minutes; yet it made history! There were several others who circled the globe after Gagarin.

The next most spectacular event in the history of mankind occurred on the moon. On July 20, 1969 American astronaut



A giant step for mankind

Neil ARMSTRONG became the first man to step on to the moon. "One small step for a man, one giant leap for mankind," were his memorable words when he stepped down from the last rung of the ladder to the lunar surface.



Neil Armstrong

Another astronaut, Edwin ALDRIN, got down on the moon with Armstrong, while the third member in the crew, Michael COLLINS, remained inside the command ship Apollo 11 which kept going round the moon. For more than two hours, the two astronauts walked on the moon, collecting rocks, photographing the area and setting up experiments. Four days later Apollo 11 with its three-man crew splashed down safely in the Pacific Ocean.

Once it became clear that the moon was after all within reach, the interest of both the Americans and Russians turned to building space vehicles for longer stays in orbits near the earth. While the Russians developed the Soyuz and Salyut space stations, the Americans came up with Skylab. The latest in line is Mir, the Russian space station. Russian cosmonauts hold the record for the longest stay in space — about one year.

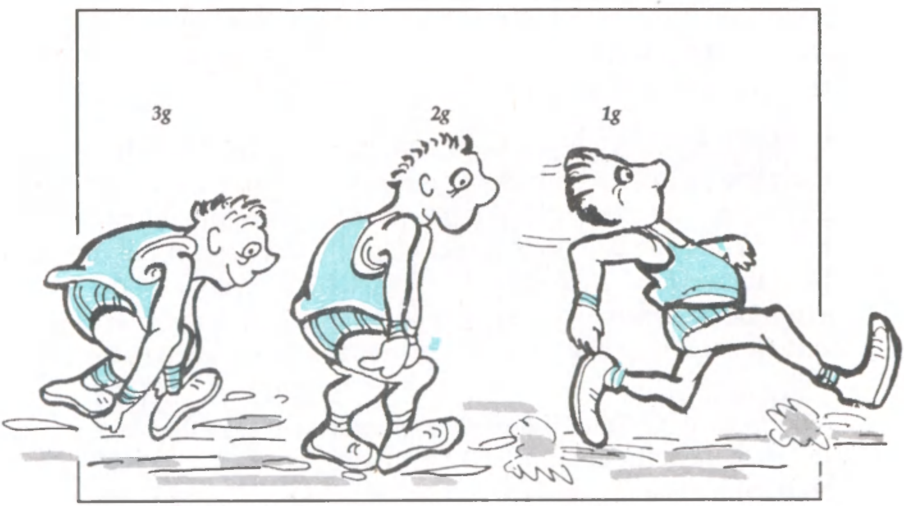
From time to time, the design of space vehicles has been altered to meet the needs of the astronauts. There is now more room to move about, greater comfort and more facilities. But, still, the inherent discomforts of weightlessness and the psychological pressures of being alone and far away from the earth are always there.

Too much Weight

Once in orbit, the astronauts are suddenly deprived of the force which had always held them down while on the earth and which they had got used to. This imposes certain strange conditions on the astronauts. By proper training, however, the capacity to withstand these conditions can be developed.

The earth exerts a gravitational pull or force which we refer to as 1g. For millions of years we have been so much conditioned by this force that we are no more aware of it than we are of the fact that the atmosphere weighs down upon us with a force of roughly 1 kg over every square centimetre. But if we are subjected to any different value of gravity, say 2g, we will feel a very curious sensation — as if we have suddenly become twice as heavy; three times as heavy for 3g and so on.

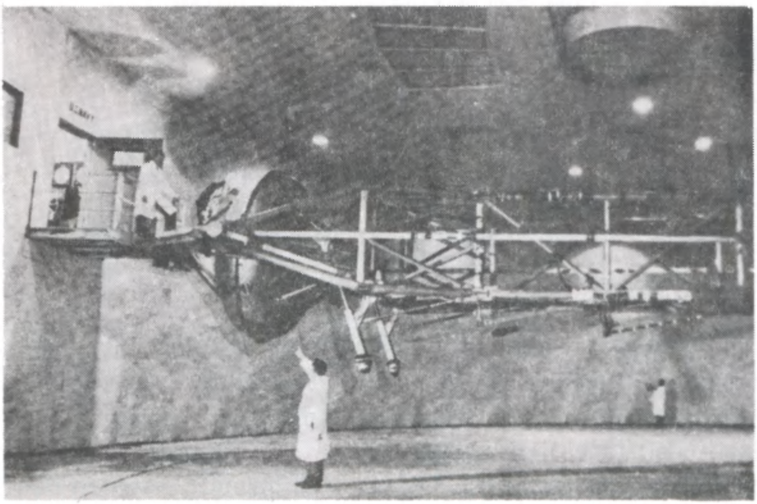
Much the same effect is induced when a rocket achieves extraordinary acceleration that is necessary to overcome the



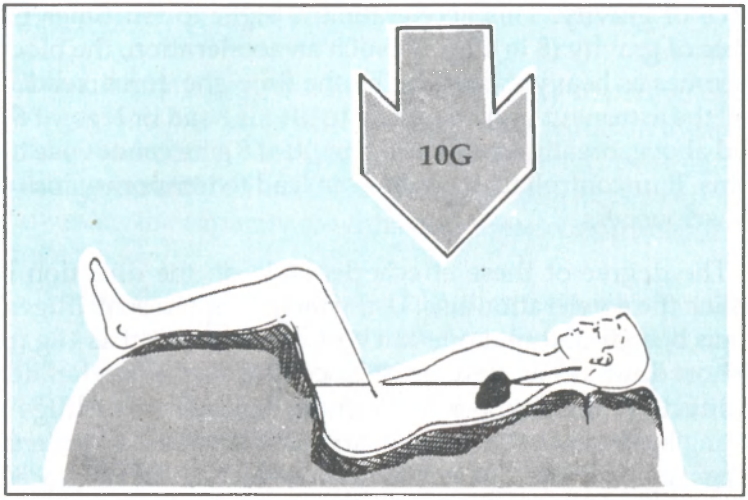
Higher the value of gravity, the heavier we feel force of gravity. This acceleration is eight to ten times the force of gravity (8 to 10g). At such an acceleration, the blood becomes as heavy as iron. So by the time the force reaches 4 g, the astronaut will be unable to lift his head or legs; at 6 g and above, breathing will be difficult; at 8 g he cannot use his arms. If uncontrolled, it could even lead to temporary loss of consciousness.

The degree of these effects depends on the direction in which the acceleration acts. Using large 'human centrifuges', it has been found that one can withstand as much as 10g for a short duration without great discomfort if the acceleration is directed from the back to the chest. A human centrifuge is a long beam, about 15 m long, and able to rotate at one end. It has a chamber at the other end in which a man is placed. By rotating the beam at appropriate speeds, the man is subjected to varying values of g.

A couch which keeps the knees slightly bent and the heart about the same level as the head has been found appropriate to protect the astronaut from the large acceleration. When one



The human centrifuge



For an astronaut the supine position is the best

lies in a supine position, the acceleration acts along the back-to-chest direction. In the present day flights, the acceleration rarely exceeds 5g.

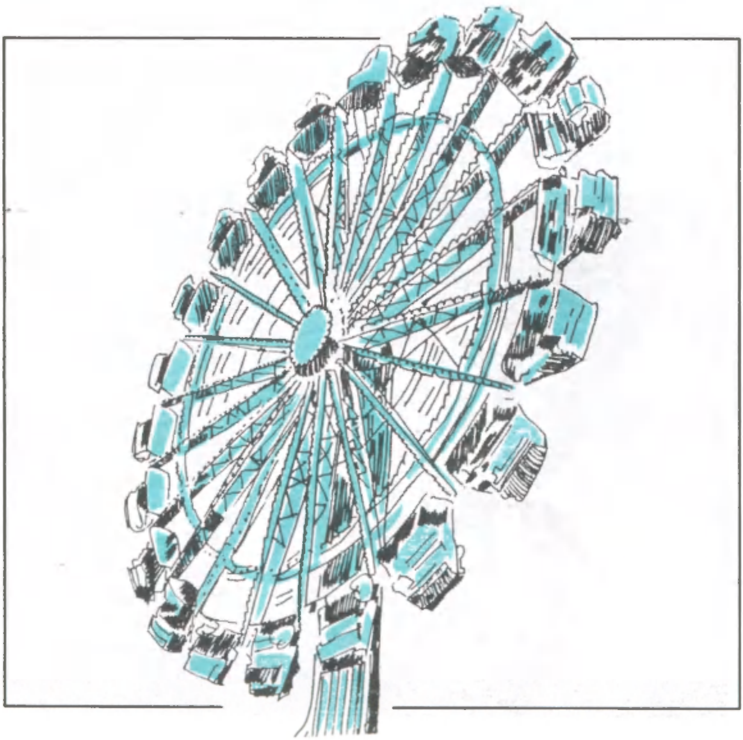
Worries of Weightlessness

The phase of feeling increased weight lasts only for a few minutes. Once the spacecraft gets into an orbit around the earth, the situation just about reverses. The sensation of being weighed down by the g force gives way to complete weightlessness.

Incidentally, this weightlessness is not due to the absence of gravity though the effect is often described as being due to "zero gravity". In fact, even at a height of 300 km from the earth's surface, the force of gravity is still more than 90 per cent of that at sea level. There is a difference between being under a gravitational influence and feeling the sensation of weight.

"Now I have got you"

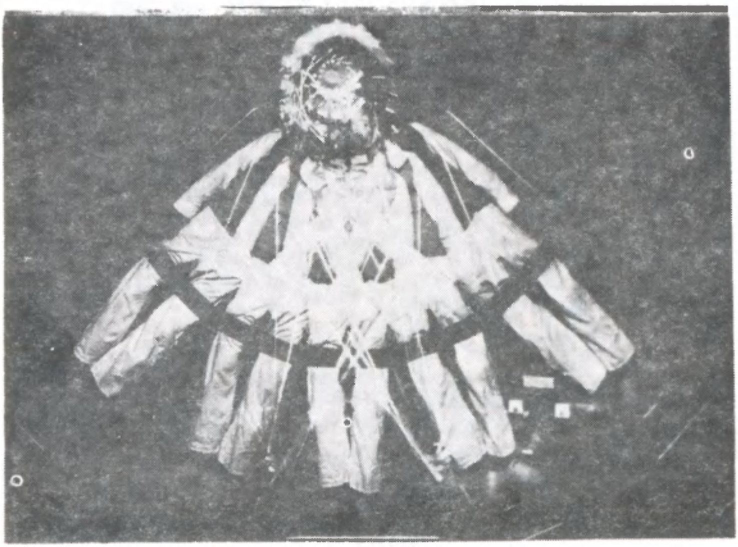
Weight is felt only when the pull of gravity is resisted. If an object simply yields to the pull of gravity without resisting it in any way, it is said to be in a state of free fall and feels weightless. A spacecraft in an orbit around the earth keeps falling freely without resisting the gravitational pull. In other words, the spacecraft floats weightless in orbit. Likewise, all objects within it float freely. A familiar example is the feeling of lightness one experiences in a giant wheel at a carnival.



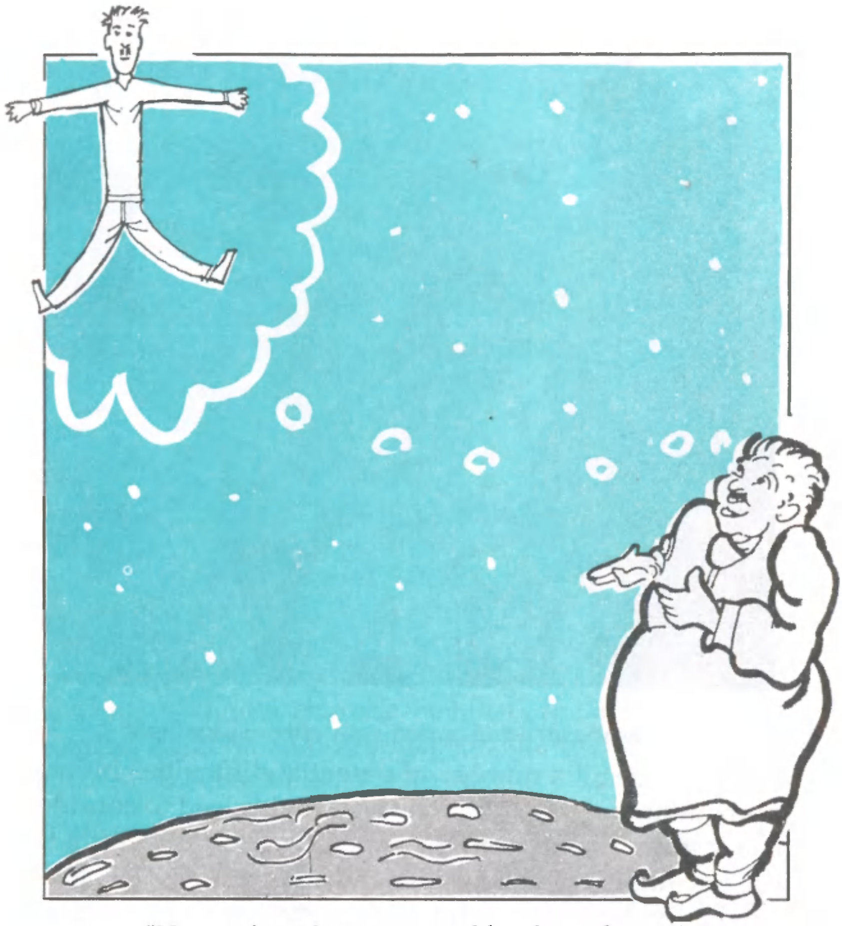
There is no difference between a falling body and an orbiting one. Both are unrestrained and are yielding completely to the gravitational pull. Both are weightless. Such is not the case when we hold an object against the pull of gravity. We feel a force which we call its weight. Similarly, a man standing or seated in a chair does not feel weightless because he is prevented from freely yielding to the earth's pull by the ground in the former case and the chair in the latter.

Likewise, weightlessness is felt in the space vehicle only when it is not being driven by the driving force of its rockets or opposed by any other force. Weightlessness begins only when the propelling rocket is cut off and the spacecraft starts falling in reaction to the pull of gravity. But a feeling of weight again comes on when the spacecraft is opposed by the earth's atmosphere when it re-enters it to reach the earth.

Weightlessness causes several physiological effects on human beings. It brings about a sense of disorientation



An astronaut undergoing strenuous tests on a tilt machine



"Now, only a trip to space could make me leaner."

(losing one's bearings or sense of direction), dizziness and erratic control of one's movements. The degree of these effects varies widely in different individuals. The rigours of weightlessness are not very bad in the short run; there are only minor inconveniences like space sickness. Gravity no longer drains the body fluid (including blood) to the feet, so the astronaut's face and eyes get puffy, distorting facial expressions. Similarly, people in space get about one centimetre taller, and also leaner by losing a little weight in flights lasting up to two weeks. But none of these is truly debilitating.

An astronaut being carried away after a space flight

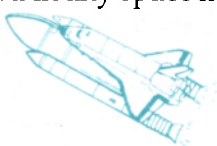
There are still a number of potential difficulties in long-term missions. Long duration space flights lead to considerable loss of calcium from the bones. On return to earth, the lost calcium is regained, rather slowly, though. The loss of weight continues throughout the flight. There is deterioration in the condition of the muscles because they do not have to hold the body straight in space. Here on the earth, the muscles have to constantly work against gravity to keep the body upright or to enable movement. Exercise onboard the spacecraft is necessary to counteract these effects of weightlessness. Pedalling a stationary bicycle or walking on a treadmill are the common exercises to keep muscles in tone. Astronauts, immediately on return to the earth after a long space flight, find it hard to hold themselves properly; they need some reconditioning before they regain their muscle strength.

Emotions in Distress

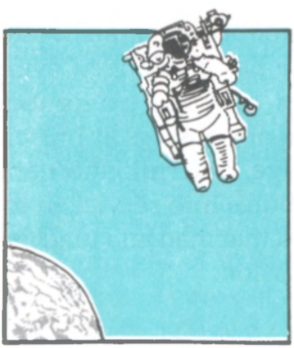
Psychological effects of space travel are no less serious. They are caused by isolation and confinement. The astronauts find it difficult to escape the thought that they are far away from anyone and anything dear to them; that any serious malfunction or mishap would cut them away permanently from their home planet. The limited living area in the space vehicle, stereotyped and monotonous setting, relative lack of privacy and recreation, and unchanging company can evoke undesirable emotional responses like impaired judgements, decline in alertness, irritability and indecision.

As far as rigid requirements of space travel are concerned, man is not the most efficient mechanism. He requires an environment very closely resembling that in which he lives on the earth. To survive, he needs about 1 kg of oxygen a day, a certain amount of atmospheric pressure, a definite range of temperature, and a way to eliminate waste. He requires rest, food and relaxation. In space, he must cope up with weightlessness, isolation and confinement, and radiation hazards. Unlike a machine, he is not expendable.

In spite of all this, there is no doubt that man would challenge the dangers of space as he has challenged every other unknown danger. Man brings to space exploration certain attributes which machines do not possess at present such as creativity, judgement, courage, determination and intelligence. He can press these attributes into service in the face of dangers. None can deny the fact that man and machine can together succeed in any space mission.



Satellites at Work



SPACE, today, is considered man's fourth environment. The other three — the land, the oceans and the air — have already been put to great use. Space can, in this sense, be regarded as a natural resource that is yet to yield its bounties. Judicious harnessing of space could be the answer to the overbearing demands of increasing populations in a world that is facing a resource crunch.

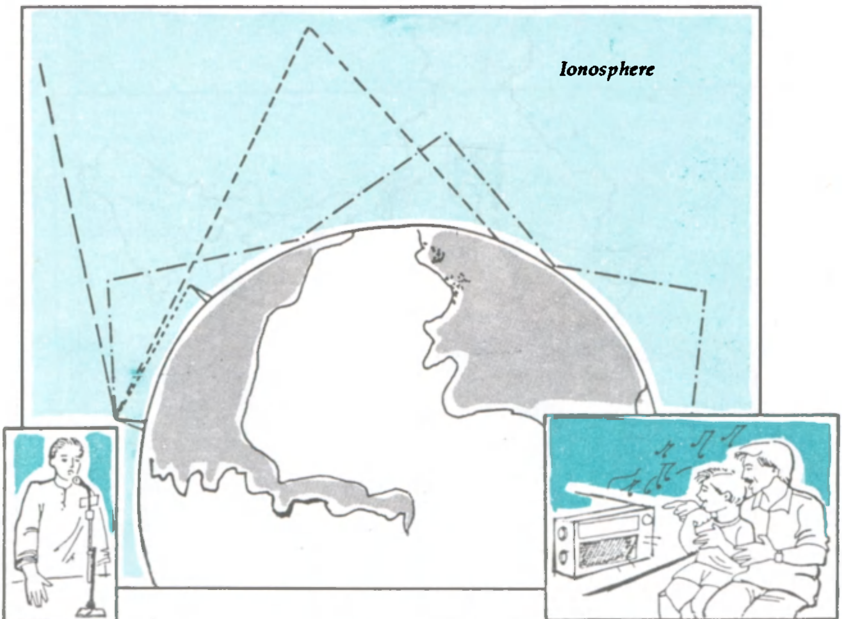
The space age that began with the launch of Sputnik-1 in 1957 is now beginning to pay dividends. The recent years have witnessed an impressive array of orbiting satellites doing invaluable service to mankind. Never before have we had such complete knowledge of the weather conditions — the location of storm centers or the progress of hurricanes.

With the launching of communication satellites, you can hear and see both local and international events at the press of a button. You can even talk to your friend in the remotest corner of the world. And what is more, with the much wider view they command, satellites are helping man locate the resources of the earth.

Linking the Continents

Communication has been closely linked with the progress of human civilization. Today, thanks to the satellites, communication has gone global. With the ever-expanding news coverage and global telecommunications facilities, the communication satellites have linked up continents. But how do these satellites score over the conventional channels of communication ?

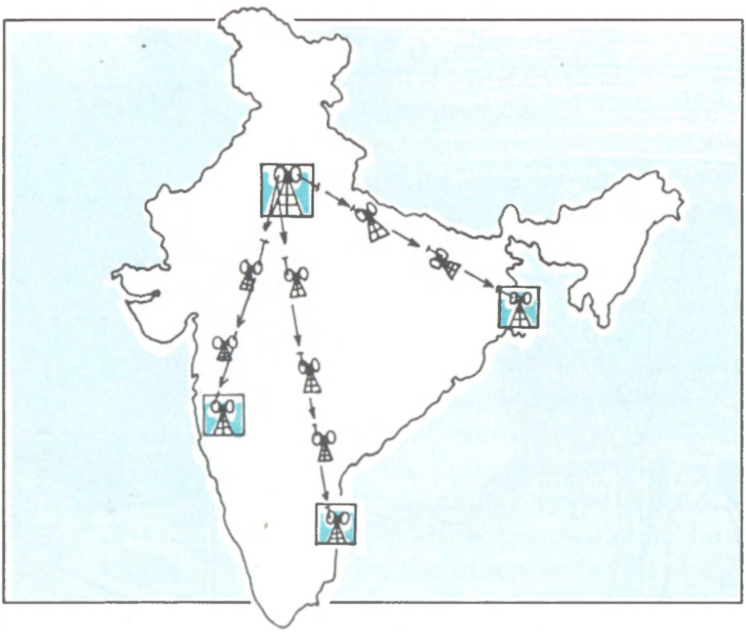
The conventional communication links use land and submarine (under-sea) cables, high frequency radio waves and microwaves. Cables, particularly submarine cables, are very expensive, difficult to maintain and also have limited bandwidth. Bandwidth is an attribute which expresses the amount of information that a communication system can carry at any one time. Larger the bandwidth, greater is the



Radio waves are reflected by the ionosphere number of communication channels, for example, telephone conversations, that can be handled simultaneously.

High frequency radio communication depends for its functioning on the ionosphere enveloping the earth. The ionosphere reflects the radio waves making communication possible between distant locations not in direct line-of-sight, in other words, not visible to one another. But the ionosphere is always subject to a variety of disturbances causing havoc to communications. Since the ionosphere varies in height and intensity, depending on the position of the earth, magnetic field, night and day, and the sun's disturbances, high frequency radio communication is not very reliable.

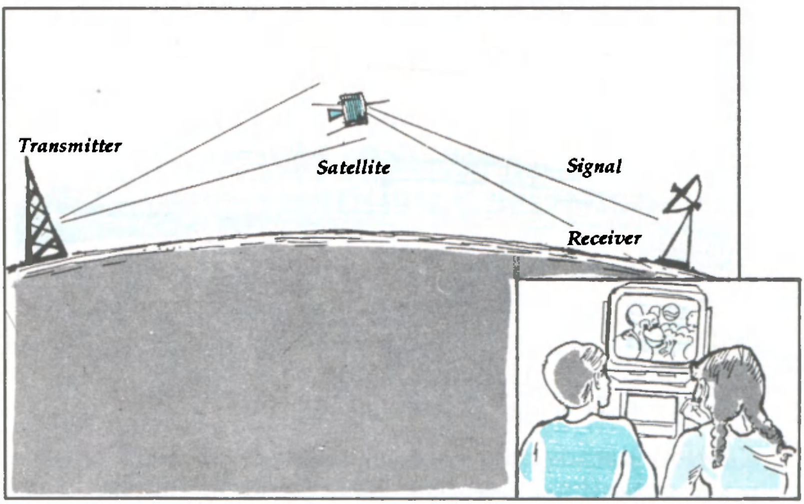
Microwaves, in spite of their ability to carry several television channels or thousands of telephone channels, can connect only points in line-of-sight. This is because microwaves travel only in straight lines, as does light. So,



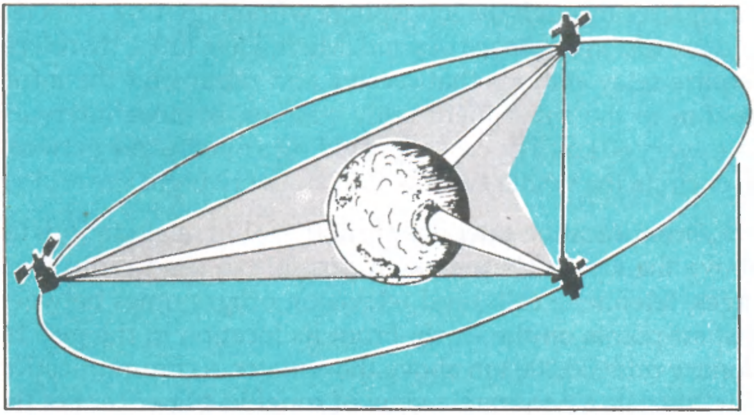
Microwave systems require repeater stations
which receive and retransmit the information to the next relay point

they pierce through the ionosphere without getting reflected and are lost in the space beyond. Microwave links, therefore, require relay stations that receive and retransmit the information to the subsequent relay stations, at close intervals, say, every 60 km. The cost of providing a microwave network to encircle the whole earth would run very high.

Communication satellites are nothing but relay stations far above the earth. They make it possible to send radio messages, telephone calls, and television programmes between distant points on the earth. From its location in the geostationary orbit 36,000 km above the equator, a communication satellite gets a panoramic view of roughly 40 per cent of the total surface area of the earth. Thus, three satellites placed 120° apart from each other in the geostationary orbit can together "see" every part on the globe except the polar regions where communication requirements are negligible. A satellite in such an orbit will take exactly one day to make a revolution around the earth — the same time the earth takes



Communication satellites are relay stations far above the earth



Three satellites placed 120° apart from each other can see every part on the globe

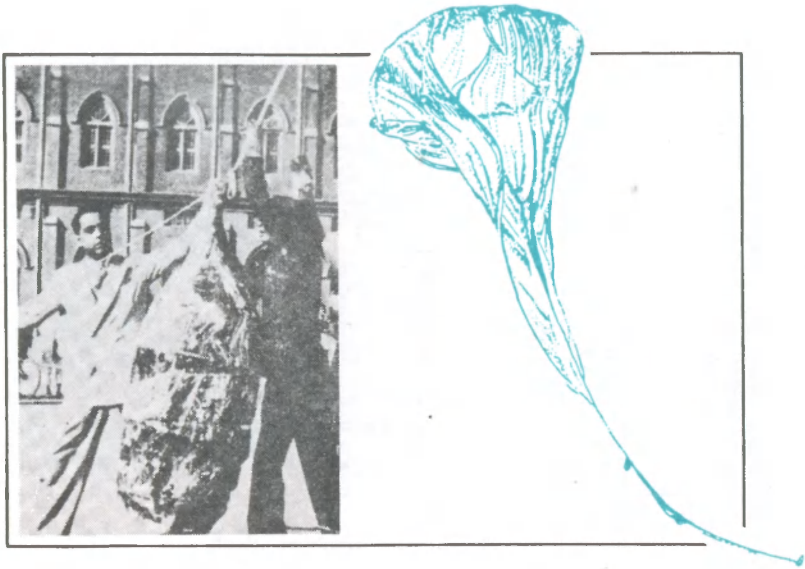
to turn once. So, the satellite will appear to stand still relative to the earth. It will thus give round-the-clock service.

In communication by satellites the cost is not determined by the distance between the end-points so long as the satellite is visible from these points. Besides, the performance of the communication link is not affected by the terrain in between. Since satellites permit the use of high frequency microwaves, larger bandwidths become available. Larger bandwidth affords larger number of telephone and television channels.

Weather-wise Satellites

Most of man's activities are still inescapably influenced by weather. Be it farming, transportation, construction or sports, nothing can escape the vagaries of weather. Forecasts, accurate and well in advance, could be a great help. It is here that the meteorological satellite steps in.

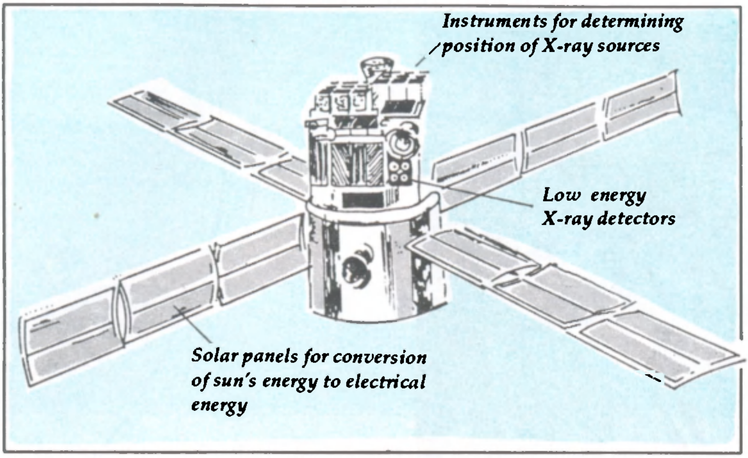
Before the advent of weather satellites weathermen had to work under the severe disadvantage of knowing the state of the atmosphere only in bits and pieces. Instruments located on the ground or carried up in the air by balloons used to be



Homi Bhabha launching a balloon for studying cosmic rays (left); and a balloon in flight (right)

the only source of weather data. Later, airplanes came to be used for meteorological survey, particularly for locating hurricanes. These conventional methods, of course, still continue to supplement the information provided by meteorological satellites.

But ground observations can never be pieced together with the same thoroughness and speed as from a satellite in orbit which gets a wider view. The satellite not only has a view of the most populated areas, but it is also able to look at the vast expanses of land and sea where no weather-monitoring stations can be set up. To predict weather with any degree of accuracy, extensive data from all over the earth on temperature, pressure, density, composition, winds, rainfall, and heat transfer in the atmosphere, are required. The satellites carry television cameras that take pictures of the earth's surface. The pictures show how clouds move. They also show snow and ice on the earth's surface. The information sent down to earth is processed by weather forecasters who can



Satellite for X-ray determination

discover the movement of storms. They can then warn people to prepare for the storms.

World weather has been monitored daily from space since 1966 and several hundred typhoons and hurricanes have been tracked and early warning given to people to take adequate precautionary measures and thus minimize loss of life and property.

In the years that followed the transmission of the first visible cloud picture from space in 1959, much progress has been made. Weather satellites now carry infrared detectors also. These instruments measure the heat coming from the earth and the clouds.

Eye in the Sky

With resources running out fast and demands spiralling upwards, a better knowledge of the earth's resources is needed. Satellites can help here, too. The technique to study the resources from space is known as remote sensing, because data is obtained without physical contact with the object under observation. An orbiting satellite is equipped with sensors capable of making a variety of observations on soil conditions, forests, water resources, mineral resources, terrain of the land, oceans and marine resources. Observations by such remote sensing satellites are also used to make maps.

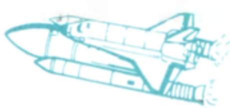
Aerial photography from airplanes was earlier the only form of remote sensing. It is still in extensive use. However, observation of the earth from a high point in space helps collect information over a wide range of radiations in the electromagnetic spectrum. Every object, in its own special way, absorbs, reflects or emits radiations ranging from ultraviolet to microwaves. These are the "spectral signatures" which reveal the nature and condition of the objects. Just as human beings can be identified by fingerprints, the different features on the earth can be identified by their signatures in the electromagnetic spectrum.

For agriculture and forestry visible light (the familiar VIBGYOR) and the near-infrared (heat waves) are used; for studying oceans slightly longer infrared waves associated with the heat radiations from water bodies are used. In the microwave region having still longer wavelengths, radiometers measure quantities like soil temperature. Microwave radars are used to make land and ocean surface measurements.

The remote sensing satellites collect large volumes of information in a fraction of the time required for conventional, land-based observations. Satellites usually carry different sensing devices such as cameras, radars and radiometers, each effective in different parts of the electromagnetic spectrum and useful for various purposes. Choice of proper orbits further makes it possible to make observations under constant and favourable illumination conditions. This makes it easier to join together small pictures to form a large one for detailed and accurate analysis. Regular observations every two to three weeks can give a lot of information about a place like its vegetation, deserts, snow cover and so on.

Remote sensing satellites help in mapping and management of floods

In the near future, the satellites of today performing specific tasks would be replaced by huge space platforms that would single-handedly perform a variety of tasks including communications, weather-monitoring and remote sensing. These platforms would weigh several hundred tonnes and measure kilometres in size. The platforms would be built in stages. The turn of the next century is likely to witness massive benefits from harnessing space using these platforms.



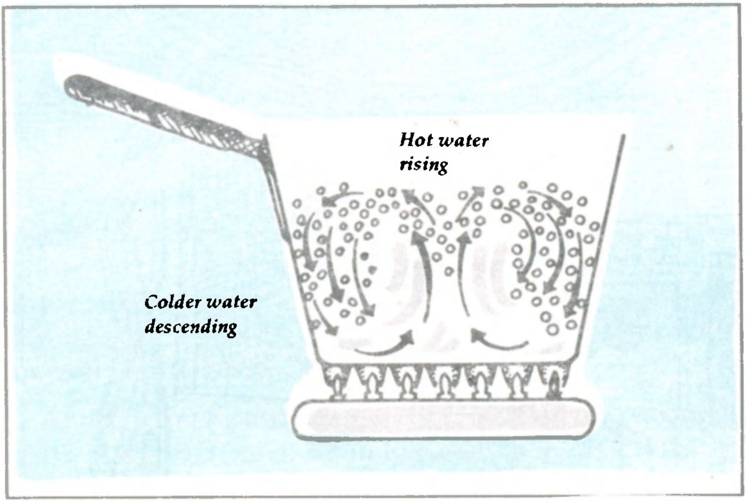
Labs in Space

WEIGHTLESSNESS in space can be an overwhelming experience. But not only that. The **microgravity** conditions that prevail inside an orbiting spacecraft could provide an ideal environment for making advanced studies in the science of processing and manufacturing materials, and in several other areas. These laboratories in the sky could well turn out to be a boon for mankind.

In an orbiting spacecraft the pull of gravity is only a few millionths of 1 g encountered on the surface of the earth. This low gravity combined with the high vacuum of space offers unique opportunities for investigating various processes that cannot be duplicated on the earth. Phenomena like convection, sedimentation and hydrostatic pressure, which are unavoidable on the earth, are virtually absent in a spacecraft. This offers altogether new possibilities and adds a totally new dimension to the processing of materials.

Materials can be melted, shaped and solidified in the absence of a container! Processes that require extremely high vacuum and involve large

The magic of space — solidifying materials without containers



When a liquid is heated convection currents are set up in it

amounts of heat can be performed inside a spacecraft without much bother. This is because there is an almost perfect vacuum and any amount of heat can be drawn away on account of the extremely low temperatures in space — roughly –269° Celsius or 4 Kelvin.

Once considered a nuisance to the comfort and health of astronauts, microgravity is now accepted as a desirable environmental condition for a new field known as Space Processing of Materials. This area of activity has, by now, successfully passed through the preliminary experimental stages in a number of spacecrafts like Soyuz, Salyut, Apollo, Skylab and most recently Mir.

When we heat a liquid, the part closest to the source of heat expands and becomes lighter. As a result it rises to the top. The cold liquid from above, in turn, moves to the bottom. This cycle goes on repeating setting up what are known as convective currents. In some applications, such as separation of a mixture of materials into the ingredients, convection can disrupt uniform liquid flow patterns, making the process less

While on earth liquid drops are not round, under microgravity they acquire perfect spherical shape efficient. Many of the space experiments use the microgravity environment as a convenient way of eliminating convection.

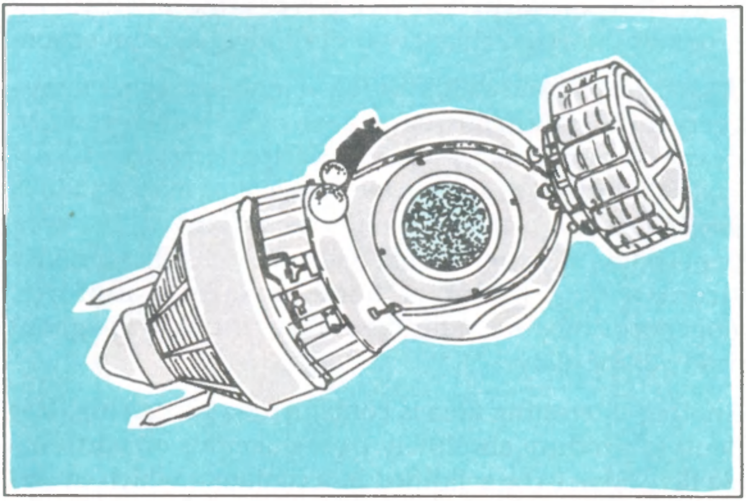
Crystal growth and solidification of molten materials happen very differently in microgravity. Large crystals grown in space can be used to make superior electronic devices. Closely related to crystal growth is the problem of making alloys in large quantities; under conditions of gravity the constituents of the alloy are not likely to mix well. Microgravity environment on the other hand, ensures a uniform, homogeneous mixture of the constituent metals throughout the body of the alloy.

Another interesting area is containerless processing. It is difficult to produce absolutely pure materials on earth because they have to be solidified in a container which causes its own contamination. In the microgravity environment of space, however, materials can be solidified without a container !

Another interesting application of material processing in space is making a perfect sphere by solidifying a liquid drop of molten material. Under microgravity, liquid drops acquire a perfect spherical shape because of uniform surface tension. On the earth such perfection in sphericity is difficult if not impossible. Since surface tension and gravity compete with each other in deciding the shape of the drop, very accurate spherical shape is possible only for relatively small sizes.

Yet another area is the study of fluid flow and chemical processes under microgravity; this essentially has the nature of basic research. Study of bubbles and thin films also is ideally possible in space.

Processing of biological materials has been the subject of keen interest. Microgravity makes it possible to purify medically useful proteins to a far better degree than could be accomplished here on earth. A biological or chemical process produces a mixture of proteins, fats, fatty acids, carbohydrates and so on. The chemical industry has its ways of

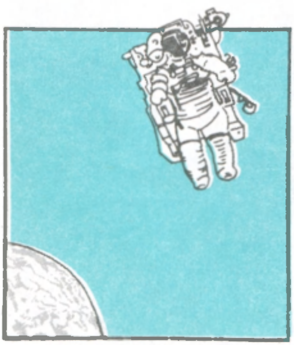


The Photon spacecraft built for processing materials

separating the required substance for use in a medicine. **Electrophoresis** is a technique extensively used for this purpose. While dealing with large quantities the separation techniques generally do not produce as pure substances as are ideally desired in medicines. Electrophoresis under conditions of microgravity in space can guarantee far greater purity because of the absence of convection and sedimentation.

Among the areas on which studies have been carried out in space, crystal growth and separation of biological molecules have shown a good deal of progress. Containerless processing has led to production of microminiature latex spheres, a few thousandths of a millimetre in diameter, which can be used for calibration purposes in certain special contexts like microphotography.

Living in Space



THE rapid advances that man has made in the field of space flight are breathtaking. Starting from simple rockets that shot through space and then plunged down towards the earth, man moved on to space capsules that could carry a few passengers on board.

In the early days, there was not, perhaps, even a window in the space capsule to look out. The astronaut could not climb out of the spacecraft unassisted. But this is no longer true now.

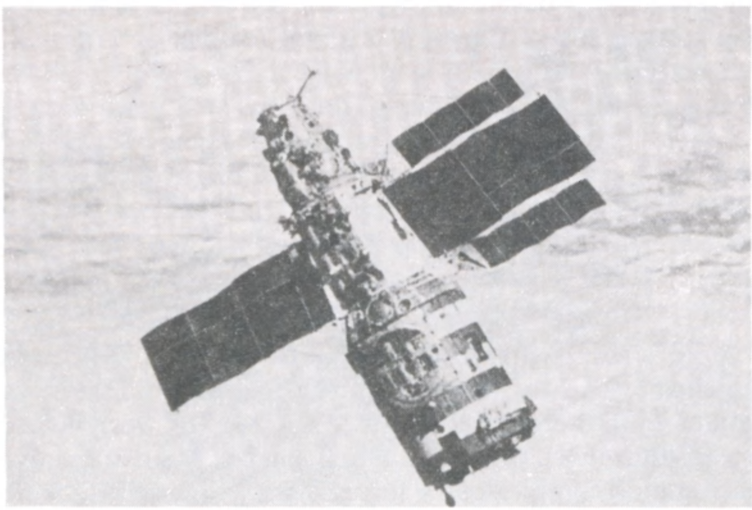
In today's gigantic spacecrafts the astronauts have greater freedom of movement, scope for work, and even recreation. A modern space cabin is not very different in facilities from the interior of a modern passenger plane though comparatively small. The role of astronauts has also steadily increased with time. Besides the normal routine, astronauts today have to retrieve malfunctioning spacecraft, repair faults in the spacecraft, and launch satellites from low earth orbiting platforms like the Space Shuttle. They can even go to an orbiting space vehicle, work and live inside for a certain period, and return to the earth.

Sleep, take a shower and enjoy music — all inside the spacecraft; and if it gets boring just take a walk in space

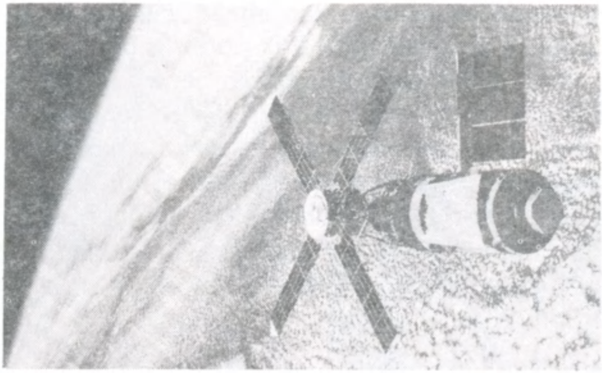
Today, man has taken a step ahead. He has established space stations. A space station is nothing but a spacecraft orbiting around the earth or some other body, such as the moon. But it is much larger. It is designed to accommodate besides the astronauts some non-astronaut passengers like scientists, engineers, and others. There are living quarters for the crew and laboratories where experiments of varied nature can be performed. Necessary supplies can be replenished at required intervals by cargo carriers sent to the space station.

Space Stations

The idea of a space station has been around for a long time. However, the first space station could be put into orbit only in 1971. It was the Russian Salyut-1. The cylindrical spacecraft was 13 m long and 4.2 m in diameter. Astronauts were carried to and from the Salyut in a Soyuz spacecraft. Since then, a number of Salyut space stations have been launched at inter-



Salyut-1 — the first space station

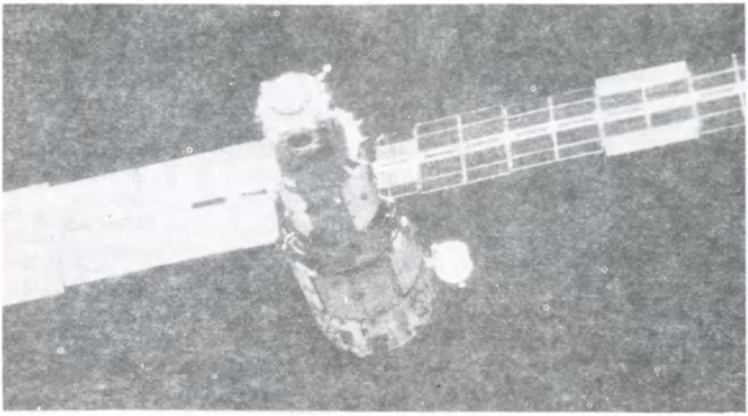


Skylab gave a wealth of data on solar activity

vals. Astronauts onboard Salyut carried out various experiments in space sciences and material processing. Most important is the great amount of information on long-duration space flight extending to nearly one year derived from these missions.

The American space station Skylab was launched in 1973. It was built from parts of the Apollo space vehicle which took men to the moon. A wealth of data on solar activity was returned from the space station. Skylab was occupied by three separate crews at different times for a total duration of 171 days. The first crew had to repair the Skylab because one set of solar cell panels used to convert sunlight to electricity had developed a snag. The dramatic and successful repair was a breathtaking event that showed what men could do in space.

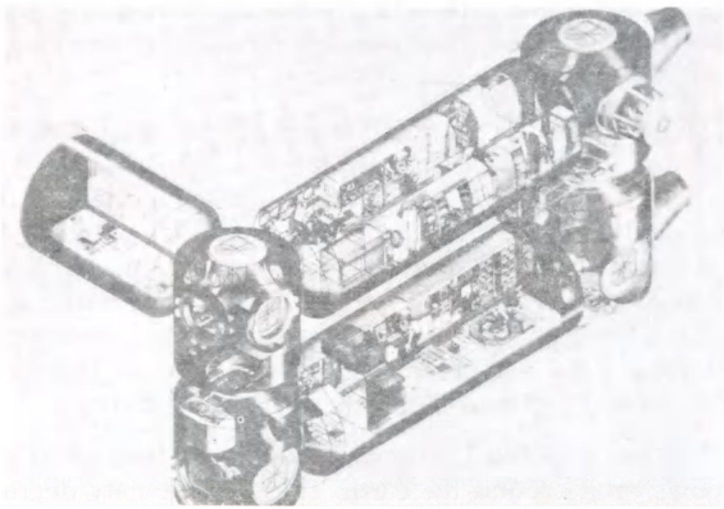
A very sophisticated space station called Mir was launched by Russia in early 1986. Mir differed from the other stations in the sense that it was conceived and designed to serve as the nucleus of a substantially larger, and expandable space station complex of the future. Mir, with its six docking ports, can permit attachment of a variety of modules for living and working. Astronauts built a 15m tower as an



Mir — a sophisticated space station

experimental step towards building large space structures of the future.

An American space station called Freedom is also in the making. The basic concept behind this is to carry parts of this space station in a number of rockets (or Space Shuttle) and



Freedom — a space station in the making

assemble them in space into the final shape. Operating in a low-earth orbit, about 400 km high, the space station will be initially composed of two primary modules — the living quarters, and a laboratory module for scientific work. Later other modules will be attached as needed.

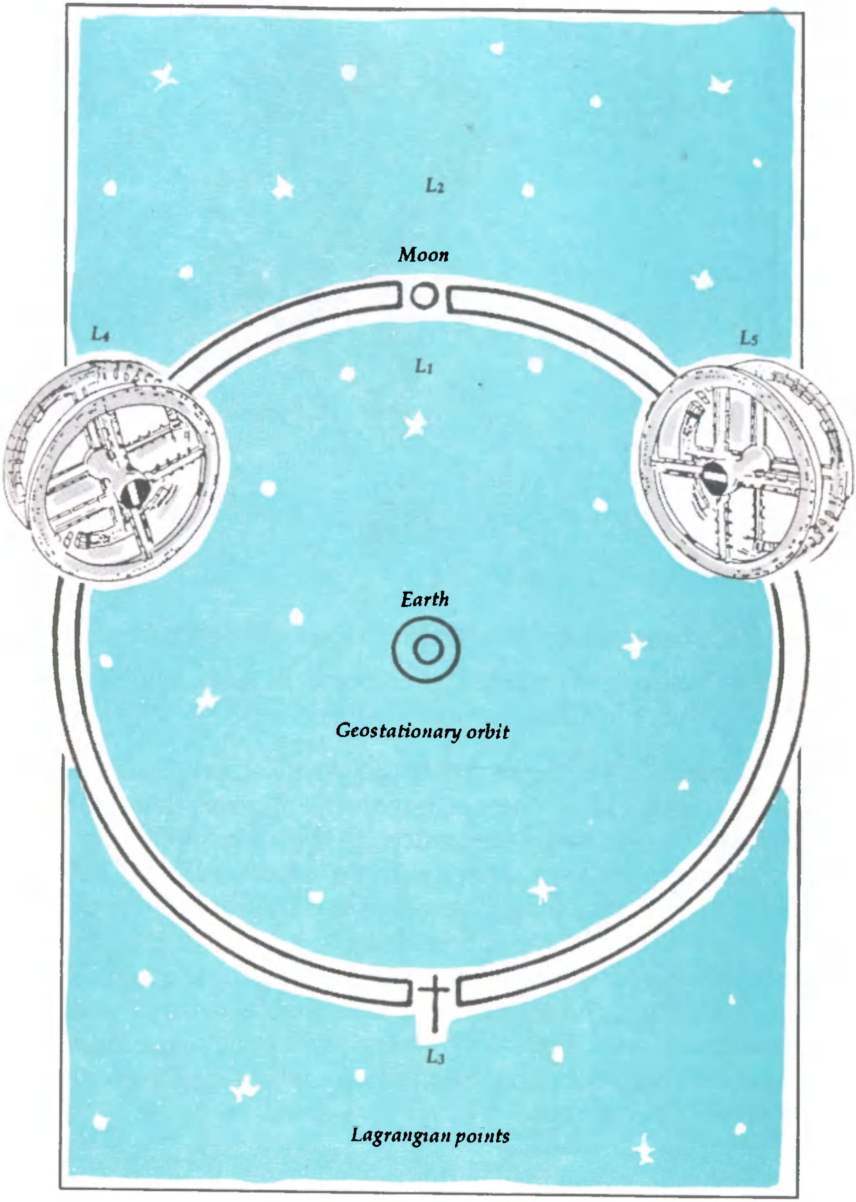
A Colony in Space !

The most speculative role for man is building space colonies where he could live for a much longer time, or perhaps, forever. Such colonies would have their own ecosystem and a host of facilities. At a time when the earth is bursting at its seams due to the ever-increasing population, such an idea deserves greater attention.

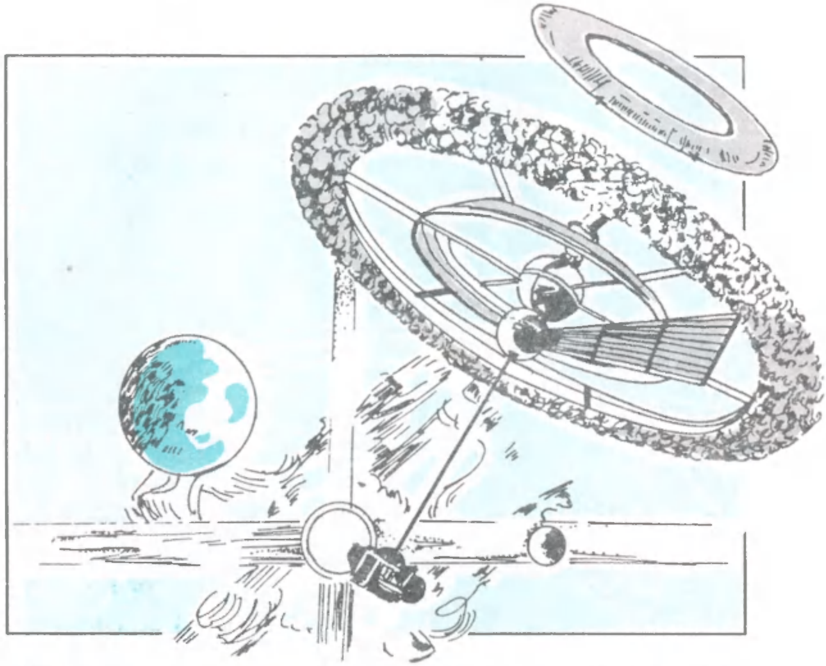
Joseph Louis LAGRANGE proposed a suitable location for a space colony in the moon's orbit. Lagrange, who was an 18th century French mathematician, had calculated that there were five special points in a system consisting of two bodies — say, the earth and the moon — where the gravitational effects of the two bodies neutralize each other. An object placed at these points does not experience any force trying to push it away.

These points in the earth-moon system are called the Lagrangian points and are named L-1, L-2, L-3, L-4 and L-5. Of these L-1, L- 2 and L-3 lie along the line connecting the earth and the moon. An object placed at these points will be in an unstable equilibrium, in the same way that a pencil balanced on its point is in unstable equilibrium. In other words, a colony at these points would remain in position only as long as it is exactly there; but any slight disturbance from that precise location will dislodge it from its position.

The L-4 and L-5 Lagrangian points are located in the moon's orbit around the earth. These are at sixty degrees ahead of and behind the moon. Each forms an equilateral triangle with the earth and the moon. L-4 and L-5 are both



Fitting locations for future space colonies



The wheel-shaped colony that would accommodate 10,000 people

stable Lagrangian points and an object in their vicinity tends to stay there in spite of minor disturbances.

Gerard O'NEILL, an American physicst, proposed building a colony at L-5. There is, however, still some debate about whether L-5 is the best location. O'Neill's giant colony was to be shaped like a wheel with an outer radius of 800 m. Artificial gravity would be generated by rotating the wheel because living in weightlessness for a long time would be undesirable. It was intended that 10,000 people could live in such a colony giving each resident about 50 square metres of residential area. The colony would have to be surrounded by a relatively massive radiation shield, which could simply be a layer of lunar rock.

The most novel idea in this proposal was to use the moon as a source of much of the bulky material that would be needed to build the colony. Lifting materials from the earth

Lifting a rock on the moon is much easier than on the earth would require a great deal of rocket power; much smaller energy would be enough to lift rocks from the moon to L-5 because the moon's gravity is only a sixth of that of the earth. Besides, it was further felt that most of the **asteroids** which keep approaching the earth are much closer to L-5 than the surface of the moon, and that they might be even better sources of raw materials.

Much on the same lines a base on the moon itself could be a massive step beyond the space stations. Exploration of the moon is evidently one possible purpose. It is a firm place to mount a telescope unlike a satellite orbiting the earth which will require complex stabilizing and pointing mechanisms. Radio telescopes on the other side of the moon would be free from terrestrial interferences.

A more likely role for a moon base could be that of a mining outpost. A wide variety of future space activities like interplanetary space travel may well require bulky materials. It is much easier for the rocket to lift such materials from the moon than the earth because of its lower gravity.

Activities such as a base on the moon entail enormous costs and a single reason alone for constructing it can not justify the cost. The idea for colonizing space is a thing of the future. It still remains a vision. But some day it might turn out to be a reality.

No one could describe the situation better than Robert Goddard, a pioneer in rocketry and space travel, who said: "It is impossible to say what is impossible; yesterday's dreams are today's hopes and tomorrow's reality."

Glossary

Asteroids: Small planetary bodies that orbit the sun. Most of these are found between the orbits of Mars and Jupiter. These bodies are also known as minor planets or planetoids.

Electrophoresis: A method of separating and purifying large biological molecules, such as proteins and DNA, through the use of an electric field.

Geostationary orbit: A circular orbit above the equator. An artificial satellite in this orbit takes the same time to go round the earth as the earth takes to rotate once. Therefore, it appears to remain always above the same point on the earth's surface.

Mean free path: Average distance travelled by gas molecules between collisions.

Microgravity: Greatly reduced gravity, of the order of about one millionth of 1g, which is encountered on the earth's surface.

Milky Way: The galaxy to which our sun, the earth and the rest of the solar system belong. It is composed of millions of stars in the form of a flattened spiral. Since the earth and the solar system lie near one edge of this spiral, from the earth, seen edge-on, the galaxy appears as a white band of light.

Sunspot Cycle : A cycle which lasts about 11 years during which the number of sunspots increases and decreases periodically. Sunspots are irregularly shaped dark patches on the surface of the sun.

MYSTERIOUS is the emptiness of space, immense its vastness and breathtaking the celestial spectacle it offers. Outer space has overawed man since time immemorial. Although there are still light-years to go before space reveals itself completely, if it ever does, man's ingenuity has helped unravel at least some of its secrets.

This lavishly illustrated book, written in a popular language and targeted at the nonspecialist, plunges headlong into the murky 'depths' of outer space. Starting with man's urge to fly like a bird and his eternal quest for the unknown, which has always drawn him off the beaten path, the book delves deep into the knowledge gained about space to date. It traces the development of rockets and spacecrafts and goes on to describe the troubles, traumas and delights of man's flight into space. In a fitting denouement, the book takes its readers into the distant future of space stations and colonization which will literally put man in space.

About the Author

P. Radhakrishnan (b. 1943) did his M.Sc. in Physics from Kerala University. He joined the Indian Space Research Organisation as a trainee in 1966 and became a regular employee of the organisation next year. He was a member of the team that built the first Indian satellite, Aryabhata. In 1985, he was selected to fly in a US space shuttle. But the programme was cancelled following the Challenger disaster in January 1986. He has worked in a variety of disciplines like Electronics, Programme Planning, Reliability and Quality Assurance.

Mr. Radhakrishnan is at present working as the Deputy Project Director of the Geosynchronous Launch Vehicle Project at the Vikram Sarabhai Space Centre, Trivandrum. *Man in Space* is his first popular science book.

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