a technical introduction to space

THE CHALLENGE OF SPACE EXPLORATION

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PREPARED BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION · UNITED STATES OF AMERICA–1959

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. – Price 25 cents

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I

INTRODUCTION

For as long as he has had the intelligence to think about it, man has dreamed of penetrating the rind of atmosphere which surrounds his planet and of exploring the vastnesses of the universe which lie beyond. It is a magnificent dream, compounded of his inherent spirit of adventure and his insatiable thirst for knowledge.

Full realization of the dream remains for future generations, but those now living in this era of explosive technology are privileged to witness the early steps toward the goal. Man-made objects are this moment orbiting about Earth, companions to the natural moon which has been circling the planet for millions of years. Others have been thrust away from the Earth to roam the solar system forever, mute testimony to human capabilities for fulfillment of the Great Dream.

And even as these objects course silently through space, their creators are preparing to send man himself outside of the Earth to which he has been bound since the beginning of life.

These fantastic accomplishments of contemporary science challenge the imagination, but they pale to feeble ventures in contemplation of the enormous task which lies ahead.

Among the nine planets which revolve about our sun, Earth ranks only fifth in size. Pluto, a "neighbor" in our solar system, is more than three and a half *billion* miles distant, yet it is held in its orbit by the massive gravitational attraction of the sun, which is 100 times as massive as the largest planet in its family.

Yet this sun itself is only a minor star. Its nearest neighboring star is so far away that even billions of miles are too puny a measure of distance. We must use instead the "light year," the distance traveled in one year at the speed of light, which is 186,300 miles per *second*. Proxima Centauri, the star nearest our sun, is four and one-third light years distant.

These two stars are members of a galaxy we call the "Milky Way," a grouping of an estimated 200 billion stars so immense it would take 100,000 years at the speed of light to traverse its length. And this galaxy is but one of uncountable galaxies moving through the universe.

Viewed in man-terms of time and distance, the challenge might seem insuperable. Yet one has only to review the technological accomplishments of mankind in the twentieth century and the "impossible" becomes merely "difficult."

Space will not submit readily to conquest. The exploration of space will follow the pattern by which man mastered flight within the atmosphere, each new development providing a platform from which to take the next step and each step adding an increment of scientific knowledge and technological skill. The first goal will be the exploration of our own solar system, in itself an assignment of awesome dimensions, but one which few in a position to evaluate doubt can be accomplished.

There is more involved in space exploration than satisfaction of man's natural curiosity. The scientific data to be gained can be translated into benefits to man's peaceful existence on his own planet. There are specific applications which already are obvious: expanded world communications through the use of extra-terrestrial satellite relays; intercontinental television; advances in meteorological science; navigation, geodesy, mapping.

The long term benefits are less tangible. They lie in knowledge. The modern world in which we live is the product of the accumulated knowledge of centuries. Solution of the mysteries of the universe cannot fail to elevate man's status on Earth and bring a world standard of existence beyond anything we can now imagine.

To quote the President of the United States:

"The opportunities which a developing space technology can provide to extend man's knowledge of the earth, the solar system and the universe . . . reinforce my conviction that we and other nations have a great responsibility to promote the peaceful use of space and to utilize the new knowledge obtainable from space science and technology for the benefit of all mankind."

DEFINITION OF SPACE

The question of just where outer space begins permits no simple resolution. It depends on what we use as a basis.

First, one might argue that space begins at the point where man can no longer obtain enough oxygen by breathing air. In that case, the dividing line is about six kilometers (between three and a half and four miles) above the Earth's surface.

Another point of view might feel that space begins at the level below which 99 per cent of the atmosphere lies. This would be at an altitude of 30 kilometers (20 miles).

We might also use the point at which aerodynamic vehicles can no longer be supported by the atmosphere, a non-specific, because it varies with the type of vehicle. We could use the level at which meteors first appear; about 120 kilometers (75 miles). Or it might be logical to take the point at which Earth's ionosphere terminates, an unknown level tens of thousands of kilometers above the surface.

For purposes of this introduction to space, it is necessary to be arbitrary in definition. Therefore, the term "space research" will embrace research of the Earth's upper atmosphere and the regions beyond, upper atmosphere being the portion above the 30 kilometer level, or the outer one per cent.

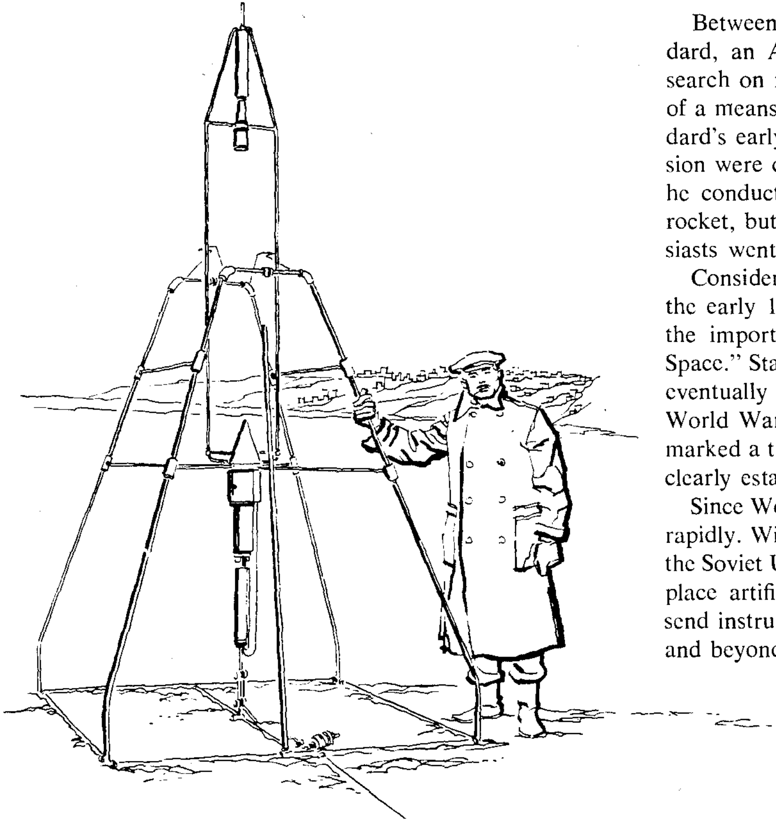
Space flight will include flight that reaches beyond the altitude of 100 kilometers (60 miles), below which lies all but one one-millionth of Earth's atmosphere.

ACCESS TO OUTER SPACE

Until recently, our access to outer space lay entirely through light and other radiations that penetrated Earth's atmosphere from the vastnesses of the universe. With the advent of the modern rocket, great new vistas opened before us, because it became possible to send observing equipment above the obscuring and distorting atmosphere to observe the universe in all the wavelengths that reach the *top* of our atmosphere. As technology advances, more and more of the solar system will become accessible to direct observation by means of instruments carried in rocket-powered vehicles.

The rocket makes all this possible, not only because of its ability to hurl objects away from Earth, but also because it can operate in a vacuum. As long ago as 1865, these abilities of the rocket were recognized by French author Jules Verne, who included in his fictional account of a "Trip to the Moon" rockets for steering the space ship, although, oddly, he elected to launch his vehicle from a cannon rather than by rocket.

At the turn of the 20th century, Constantine Ziolkowsky, a Russian mathematics teacher, wrote of the possibility of traveling in space by means of rocket vehicles.



Between 1914 and World War II, Dr. Robert H. Goddard, an American physicist, conducted extensive research on rockets, his principal motive being provision of a means of exploring Earth's high atmosphere. Goddard's early analyses of the problems of rocket propulsion were complete and remarkably accurate. In 1926, he conducted the first successful test of a liquid fuel rocket, but his efforts and those of other rocket enthusiasts went largely unheeded.

Considerable interest in rocketry arose in Germany in the early 1920's. In 1928, Hermann Oberth published the important work "The Rocket into Interplanetary Space." Starting on an amateur basis, the German effort eventually secured Government support and during World War II brought forth the V-2 missile. The V-2 marked a tremendous advance in rocket technology and clearly established the possibility of future space flight.

Since World War II, rocket engineering has advanced rapidly. With greatly improved launching vehicles, both the Soviet Union and the United States have been able to place artificial satellites in orbit above the Earth and send instrumented packages to the vicinity of the moon and beyond.

II

THE SPACE EXPLORATION VEHICLE

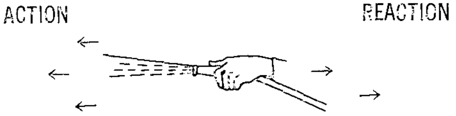
A space exploration vehicle, whether manned or unmanned, consists of a propulsion system, a guidance and control system, a payload and a frame which unites these components. The rocket is the only power system currently capable of propelling vehicles through space, because it can function outside Earth's atmosphere, it can produce the necessary very high velocities and it can develop great power in a small package.

The rocket engine is a form of jet propulsion. In the 17th century, Sir Isaac Newton expressed three laws of motion which are fundamental to any discussion of jet propulsion:

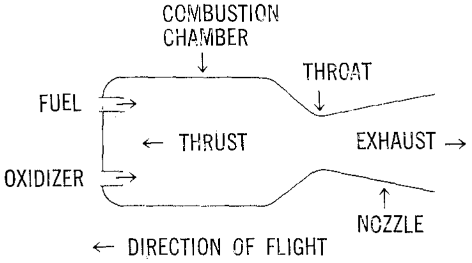
1. A body remains at rest or in a state of motion in a straight line unless acted upon by an external force.
2. A force acting upon a body causes it to accelerate in the direction of the force, the acceleration being directly proportional to the force and inversely proportional to the mass of the body.
3. To every action, there is an equal and opposite reaction.

The *third* Newtonian law contains the basic principle of jet propulsion. In any type of jet, the *action* is a stream of mass escaping through an exhaust nozzle. In the process of escaping, it creates a *reaction* in the opposite direction, that is, in the direction in which the vehicle is flying. The degree of force provided by this reaction is measured in pounds of thrust.

In a turbojet engine such as those now powering commercial airliners, the escaping mass is a stream of gas created by burning a mixture of fuel and air, the air serving as the "oxidizer," or the substance which provides the oxygen needed to burn the fuel.



Third Law of Motion



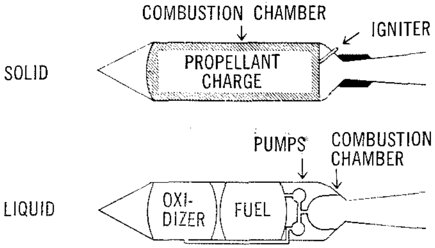
Rocket Action

The rocket engine differs in that it needs no outside air for combustion. Instead, it carries its own fuel and oxidizer, which are burned in a combustion chamber, producing hot gases which are exhausted through a nozzle at temperatures of several thousands of degrees Centigrade. In thus expelling the mass as a "jet," the rocket recoils in the opposite direction in exactly the same way that a gun recoils when a bullet is fired from it. In the case of the gun, however, the recoil is due to the sudden single impulse caused by the ejection of the bullet. In the rocket engine, the recoil is spread out over the period of burning of the rocket's propellants. This continuing thrust provided by the rocket jet is balanced by an equal and opposite thrust on the rocket itself, causing the rocket to move in the direction opposite to that of the jet and accelerating it in accordance with the *second* of Newton's laws.

ROCKET PROPELLANTS

The rocket propulsion system is usually based on the use of chemical propellants, which may be either liquid or solid.

In a liquid propellant rocket, the propellants are stored in tanks and fed into the burning chamber either under the driving force of a high pressure gas or by means of high speed pumps. Ordinarily, liquid propellant rockets are "bipropellant" vehicles; that is, they use two different liquids, one (such as gasoline or alcohol) as a fuel, the other (such as nitric acid or liquid oxygen) as the oxidizer. There are, however, monopropellant liquid rockets, in which a single propellant is decomposed to produce the jet.



Solid and Liquid Propellant Rockets

A solid propellant rocket is one in which the fuel and oxidizer are mixed in solid form, usually as a powdery or rubbery mixture known as the "grain" or "charge." The grain is packed in the rocket casing, which serves as both storage and burning chambers.

In general, liquid propellant rockets are considerably more complex than solid propellant rockets. However, it is possible to control the combustion in liquid propellant rockets with the simple closing or opening of a valve.

Liquid rocket engines are easier to keep cool, since one of the liquid propellants can be circulated through the engine walls to protect the metal of the walls from the high combustion temperatures. Such a process is known as "regenerative cooling."

It is also possible to allow some of one of the propellants to run into the combustion chamber through small orifices around the sides of the chamber, thus forming a thin cooling film over the surface of the chamber and nozzle. This is known as film cooling.

Solid rockets are simple in construction, requiring no pumps or valves. They can be loaded with propellant and stored for long periods of time, but it is difficult to terminate the burning of the solid rocket without resorting to drastic steps such as destroying the rocket burning chamber.

Operationally, liquid propellant rockets are the more difficult to handle. They require long periods of servicing in which the propellants are loaded into the vehicle and the propellant feed systems are readied for operation. This operation requires the handling of chemically active and sometimes dangerous liquids.

In general, it is desirable to launch a liquid propellant rocket as soon as possible after servicing. The solid propellant rocket may be set up on its launcher and held in readiness over a long period.

ROCKET ENGINE PERFORMANCE

There are a number of measures of rocket performance which need definition here. They include:

Thrust. This is the reaction force exerted on the vehicle by the rocket jet, or the "push." Two major factors determine the amount of thrust: the rate at which the propellants are burned and the velocity at which the resulting gases are exhausted. Thrust is measured in pounds.

The thrust of a rocket vehicle launched from the ground must be greater than the loaded weight of the vehicle. Thus, if large masses are to be lifted from the ground into an orbit about the Earth or ejected farther into space, correspondingly large thrusts are required. When a specific job permits a small payload, a low thrust will suffice to accomplish the mission.

Thrust-to-weight ratio is a comparison of the engine thrust with the vehicle's total weight. The German V-2, for instance, weighed about 28,000 pounds and had a thrust of 56,000 pounds. Thus, its ratio was two to one.

Total impulse of a rocket engine is the product of its thrust multiplied by the time of propellant burning.

Specific impulse is the amount of thrust derived from each pound of propellant in one second of engine operation. It is expressed in units of time, to date in seconds. Specific impulse means to the rocket engineer much the same as does miles per gallon to the motorist; it is a measure of the efficiency with which the rocket propellants are being used to generate thrust. To use the V-2 as an example again, its specific impulse was about 200 seconds at sea level, which means that it obtained one pound of thrust for each pound of propellant over an operating period of 200 seconds. This is not particularly good performance today; sea level specific impulses of about 250 seconds are the current norm. With chemical propellants, specific impulses up to 400 seconds are theoretically possible.

Exhaust velocity of a rocket denotes the speed at which the jet gases are expelled from the nozzle. This exit speed depends upon propellant burning characteristics and overall engine efficiency. The V-2's exhaust velocity was about 6,000 feet per second; present engines are capable of 7,500 feet per second and higher at sea level, about half the theoretical maximum for chemical propellants.

Mass ratio is the relationship between a rocket vehicle and the propellant it can carry, obtained by dividing the total mass at take-off by the total mass remaining after all propellants are consumed. High mass ratio, and high exhaust velocity or specific impulse, are the most important factors in determining the velocity and range of a vehicle, hence the most important goals of rocket research.

Excluding the effects of gravity and air resistance, a rocket vehicle with a mass ratio of 2.72 to 1 will achieve a speed equal to its exhaust velocity. A 7.4 to 1 mass ratio, considered feasible for single stage rockets, will produce vehicle speeds of twice the exhaust velocity. A 20 to 1 ratio would produce speeds three times the exhaust velocity, but this would require a structure, including payload, amounting to no more than five per cent of the total take-off weight and it is not likely that such a structure could stand up under the stresses of vehicle operation.

Inasmuch as the improvement of mass ratio improves the total rocket vehicle performance, then any device by which useless mass can be gotten rid of as soon as it is no longer needed should improve the performance of a rocket. This is the idea behind the so-called "step" or multistaged rocket.

In such a vehicle a series of rockets are joined in tandem. The first rocket fires, carrying the remaining rockets up to its terminal velocity. At the end of its burning, the first rocket is discarded, thereby reducing the overall mass of the combination, and the second rocket is ignited. After the end of the burning of the second rocket, it is discarded in turn, and the third rocket is ignited.

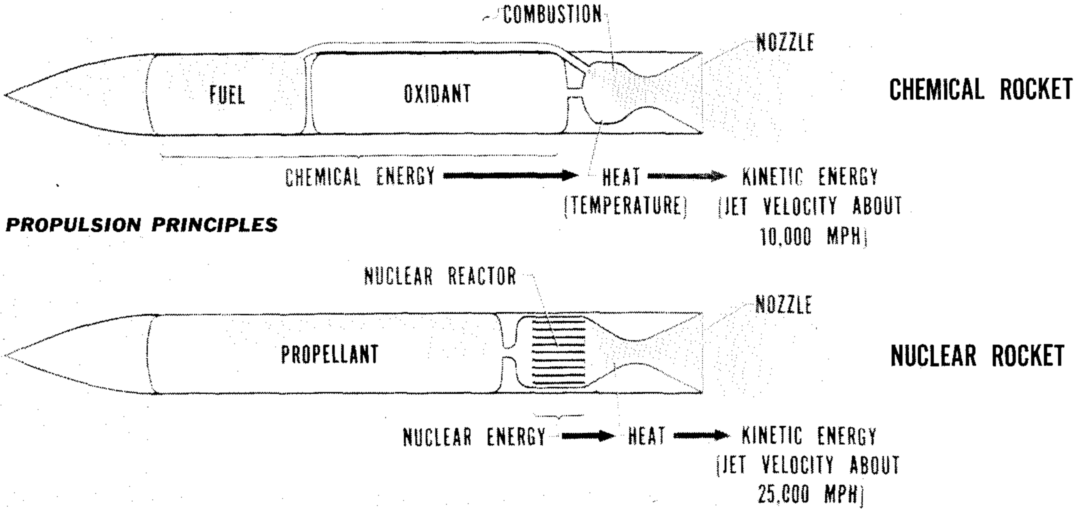
This is continued for as many stages as are used in the combination. By this device the overall mass ratio of the combined system is improved far beyond that obtainable in single stage vehicles. Roughly, the mass ratio of the combination is equal to the product of the mass ratios of the individual stages.

It is obvious from the foregoing that design of a vehicle for space exploration is an extraordinarily complex task. The designer must take into consideration the weight, volume and energy potential of a propellant; the weight, shape and volume of the vehicle structure; the weight and volume of the payload; the weight and power potential of the engine or engines; and the effects of atmospheric resistance and gravity.

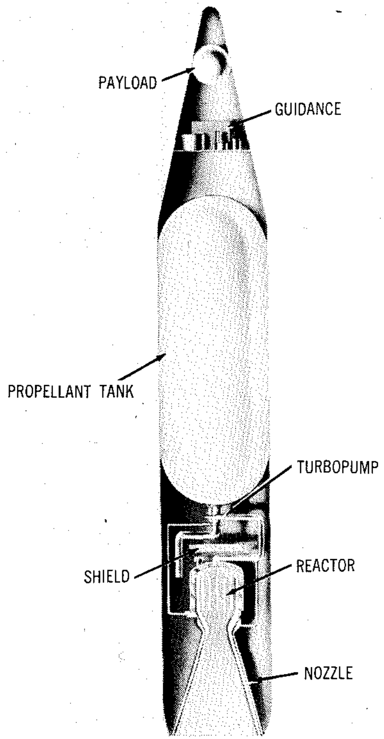
Most of these considerations are contained in a basic equation, the most important elements of which are exhaust velocity and mass ratio. An increase in either one automatically increases the speed of the vehicle.

FUTURE PROPULSION

The performance available to chemical rockets is clearly limited by the roughly 400 seconds specific impulse that constitutes the theoretical maximum and by the mass ratios obtainable with best engineering practice. In order to obtain vehicles with performance great enough to carry out long term and extreme distance space missions, it will become necessary to develop new propulsion systems with performance capabilities superior to those of the chemical rocket. The most promising new systems, now under study, include:



COMPARISON OF PROPULSION PRINCIPLES



NUCLEAR ROCKET COMPONENTS

Nuclear fission, a power plant which uses a nuclear reactor to heat a "working fluid," which might be hydrogen, helium or ammonia in liquid form. This heated fluid would then be channeled through a nozzle in the conventional rocket fashion. It is estimated that specific impulses ranging from 600 to 1,500 seconds can be obtained with this system.

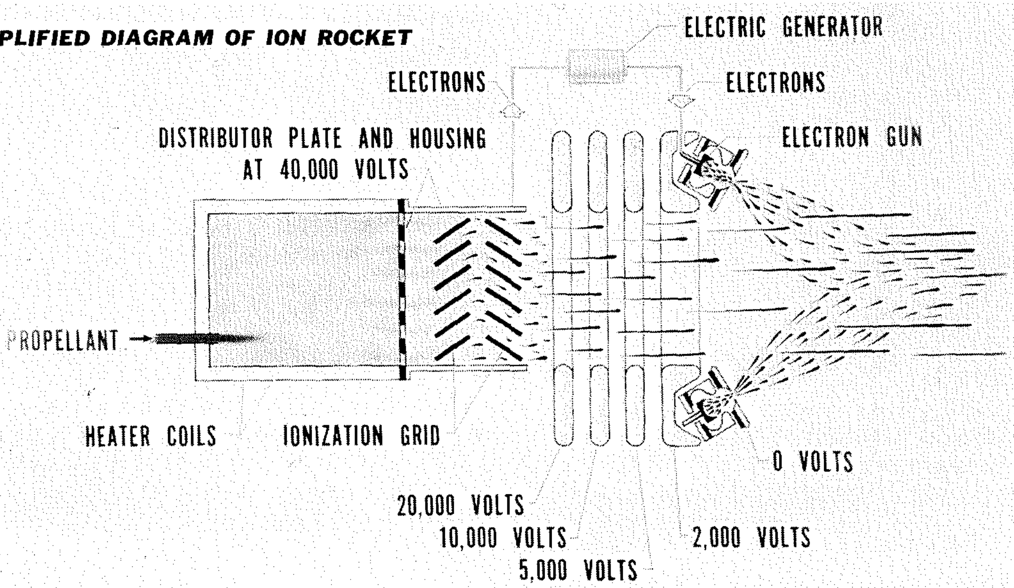
Nuclear fusion, a type of rocket in which light atomic nuclei are fused or united to form heavier nuclei. Very high specific impulses measured in millions of seconds should be obtainable, but the system presents a massive problem of containing the incredibly hot gases which would result. For example, to fuse deuterium (a form of hydrogen), temperatures of hundreds of millions of degrees would be needed, and no known solid materials could contain such a gas. One possibility is channeling the jet by means of appropriately shaped magnetic fields, a technique which requires a great deal more laboratory study.

Ion power, in which ions (atoms unbalanced electrically by the removal of one or more electrons) would form the rocket jet. The ions would be formed by passing a propellant through an ionizing device and accelerated to high speeds by electrical fields. The ions would derive their energy from either a nuclear reactor, batteries, or a solar radiation system.

Exhaust velocities obtainable would be very high, but it would not be practicable to eject large quantities of ions. Thrust would of necessity be very low, not adequate for launching vehicles from rest at the surface of the Earth, which would have to combat both the retarding pull of the Earth and the resistance of Earth's atmosphere. Ion systems would be most useful for operations in space after chemical or nuclear rockets had provided the initial boost from the ground.

A more remote possibility is the *photon rocket,* wherein photons, or light particles, would provide the thrust. Such rockets would be capable of extremely high specific impulses, but would require radiation of tremendously intense beams of light. It is not known how such intense beams could be generated, so for the time being such rockets must be considered only speculative.

SIMPLIFIED DIAGRAM OF ION ROCKET



III

CELESTIAL MECHANICS

Celestial mechanics is the study of motion in space, whether the object in motion is natural or man made. For purposes of this discussion, it will be confined to our own solar system.

GRAVITY

In addition to his laws of motion, Sir Isaac Newton formulated the law of gravitation, which is concerned with the mutual attraction, or "pull," that exists between all particles of matter. In its most simple form, Newton's law says this:

- All bodies, from the largest star in the universe to the smallest particle of matter, attract each other with what is called a gravitational pull.
- The strength of their gravitational pull is dependent upon their masses.
- The closer two bodies are to each other, the greater their mutual attraction. Specifically, the attraction varies inversely as the square of the distance between the two bodies.

Earth, a body moving in space, has a gravitational pull. It pulls anything within its sphere of influence toward the center of the Earth at increasing speed. This acceleration of gravity on Earth at its surface is used as a basic measurement. It is known as one gravity, or 1 "G."

Earth's gravitational influence is believed to extend throughout the universe, although the force weakens with distance and becomes virtually impossible to measure.

Any vehicle moving in space is subject to gravity. The vehicle, having mass, is itself a space body, therefore it attracts and is attracted by all other space bodies, although the degree of attraction of distant bodies is too small to require consideration. A vehicle moving between the Earth and the moon would be influenced by both bodies, and also by the sun.

ESCAPE VELOCITY

To leave the Earth on space exploration missions, a vehicle must overcome the pull of Earth's gravity. This can be done by accelerating the vehicle to a given speed. Since the force of Earth's gravity declines with distance from the center of Earth, the minimum speed required to overcome gravity varies. At or near the Earth's surface, the speed required to overcome gravity is slightly more than seven miles a second, or 25,000 miles per hour. At an altitude of 500 miles from the surface, the requirement drops to 23,600 miles per hour and at 5,000 miles altitude it is only 16,630 miles per hour.

The minimum speed at which an object overcomes gravity is known as *escape velocity*. "Escape," however, does not mean that the object is forever free from Earth's gravitational influence; it means only that the object or vehicle will not be pulled back to the surface, even when its power is exhausted.

A vehicle having achieved escape velocity does not continue moving at that speed after power exhaustion. Gravity will exert a braking influence and the vehicle will gradually lose speed. It will, however, always have enough momentum to continue moving away from Earth —until the control of the sun's gravity predominates over that of the Earth.

ORBITAL VELOCITY

At a speed lower than that of escape velocity, a vehicle can counterbalance Earth's gravity. For instance, assume that a vehicle is launched into a horizontal path at an altitude of 300 miles. Since it is above the restraining effect of atmosphere, it will continue to move at its original speed. It will be subject to two forces: 1) the centrifugal, or outward force generated by its speed, and, 2) the downward pull of Earth's gravity. If, at 300 miles altitude, the original speed is 18,000 miles per hour, the net effect of these two pulls would be zero—one would counterbalance the other. The vehicle or object would be in "continuous fall," its path of movement exactly matching the curve of the Earth. It would remain in that state indefinitely if it did not encounter other resistance and would continue to move about the Earth at the same speed and altitude. It would then be "in orbit."

Orbital velocity is the speed required to achieve such an orbit. Like escape velocity, the required speed varies with distance from Earth's center of gravity; the more distant the orbit, the lower the speed requirement. The moon is a satellite of Earth; it maintains its orbit at a speed of only 2,268 miles per hour.

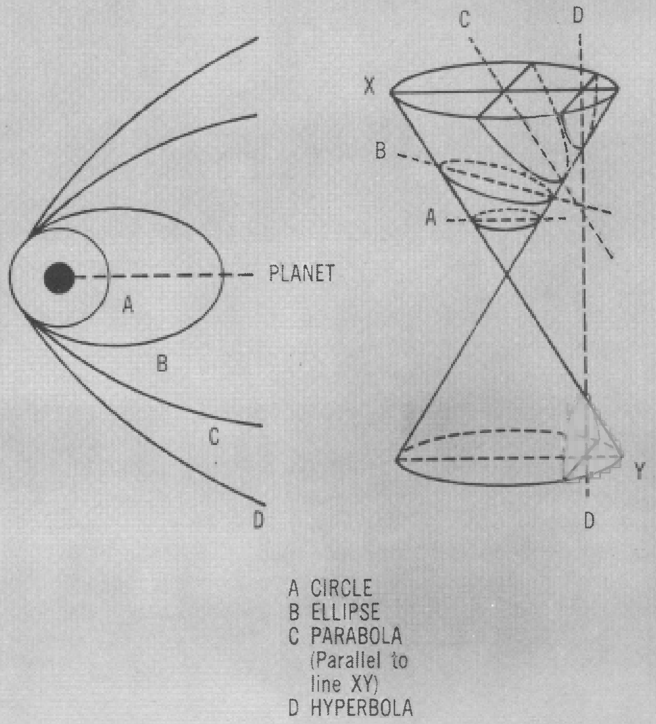
ORBITS

An orbit, then, is the path in which a body moves relative to a source of gravity. In the example described above, we were assuming that this path was circular, but it need not be. There are four types of orbits:

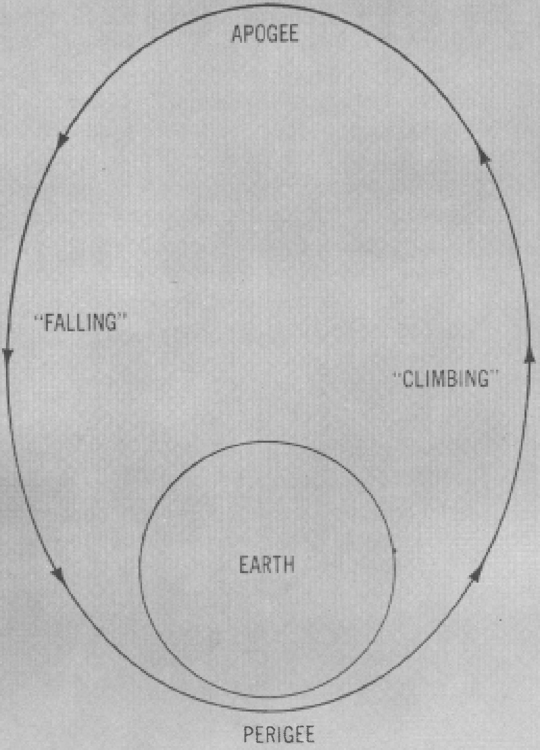
Circular orbit, in which the object in orbit remains at all times the same distance from the center of gravity of the influencing body. (In the earlier examples, we used Earth as the focal point, but the gravitational force could be supplied by any body in space. The body exerting the force is referred to as a "primary.")

Elliptical orbit, in which the path is longer than it is wide and the center of gravitational attraction is not always the same distance from the body in orbit.

These two orbits are closed loops, but a partial curve around a primary is also an orbit. For example, an object launched from Earth at minimum escape velocity would leave Earth but would not materially alter the character of its motion, or its mean distance, with respect to the sun. It would be in **parabolic orbit** relative to the Earth, were the Earth not in the vicinity of the sun; however, Conic Sections and Basic Orbits



The Satellite Ellipse



the presence of the sun causes the object to revolve in an ellipse about the sun once it has effected its escape from the Earth. If it were designed to reach another planet and had the higher velocity to do so, its orbit relative to Earth would be in the shape of a **hyperbola,** but again because of the sun's presence the hyperbola may be modified to the form of an ellipse about the sun once the body has escaped Earth. If the body were projected at a sufficiently great speed to escape both the Earth and the sun, then the orbit would be a hyperbola relative to both the Earth and the sun.

Although they qualify technically as orbits, the parabola and hyperbola are usually called "trajectories" in space flight discussion, while "orbit" is most generally applied to the circle and ellipse. A circular orbit is extremely difficult to achieve not only because it demands perfect precision in a rocket launch but also because it assumes the primary is a perfect sphere. Similarly, a parabola is difficult to achieve because even a slight deviation in speed would change the curve to a hyperbola or an ellipse. Hence, the latter two are the most important in space flight. Man-made objects sent into space will most likely move in elliptical or hyperbolic paths.

MOTION OF BODIES IN SPACE

Any man-made vehicle launched into space will move in accordance with the same laws that govern the motions of the planets about the sun, and the moon about Earth. The solar system and the Earth-moon system, therefore, provide excellent working models to study, in order to learn what to expect of man-made vehicles.

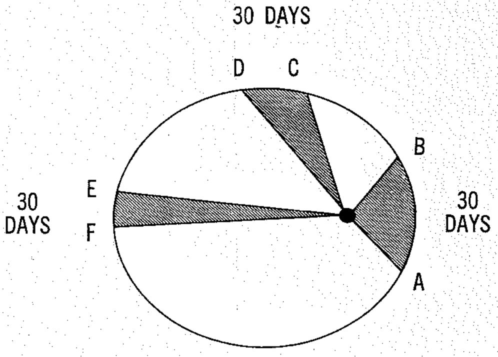
Prior to the time of Copernicus, man generally accepted the belief that the Earth was the center of the solar system. His efforts to explain the motion of the planets on this assumption failed. Copernicus pointed out that the difficulties in explaining observations disappeared if one assumed that the *sun* was the center of the solar system, and that the planets revolved about the sun.

Years later, Galileo took up the defense of Copernicus' theory. With experiments such as the dropping of two different size masses from the Leaning Tower of Pisa, he started the thinking which led to our current understanding of the laws of motion.

In the early 17th century, Johannes Kepler formulated three laws which described the motions of the planets about the sun. They are:

1. Each planet revolves about the sun in an orbit that is an ellipse, with the sun at one focus of the orbital ellipse.

2. The line from the center of the sun to the center of a planet (called the radius vector) sweeps out equal areas in equal periods of time.



Equal Areas in Equal Time

3. The square of a planet's period of revolution is proportional to the cube of its mean distance from the sun.

These laws, together with Newton's law of gravitation, are important to space research. They make it possible to deduce mathematically the motions of the planets and other bodies in the solar system and to calculate flight paths to these bodies.

FREE FALL

When a body in space is following an unrestricted course in a gravitational field, it is in "free fall." This condition is also known as "zero gravity."

This does not imply absence of gravity; it means a lack of resistance.

The weight of the human body (or any other object on Earth) is equal to the force of the earth's gravitational pull on that body or object. We can feel our weight because something is resisting earth's gravitational pull —the ground, or the floor of a building—between our body and the center of the earth's gravity. Without this resistance, we would feel no sensation of weight.

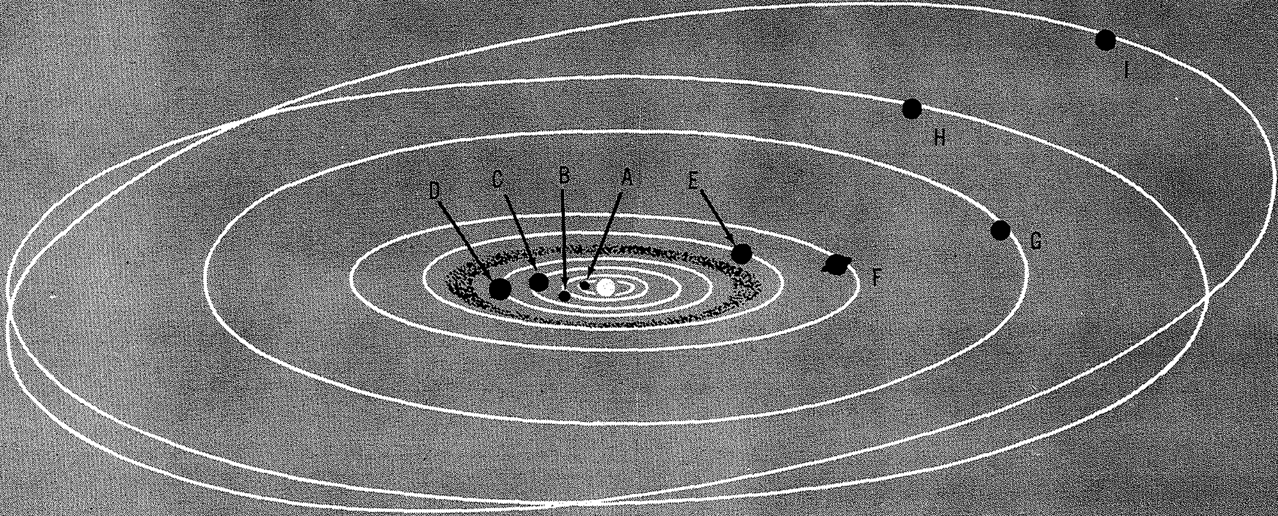
The vehicle in space has no medium of support with respect to the surface of any planet. Its only "resistance" is the pressure of the gases of combustion against the forward wall of the combustion chamber when the rocket engine is in operation. This pressure induces an "apparent weight" proportional to the amount of thrust being generated by the rocket.

When the rocket power plant is shut off, this apparent weight disappears, so the vehicle and its occupants, are in "free fall." The occupants will then experience a sensation of weightlessness.

IV

THE SPACE ENVIRONMENT

The Solar System



A-MERCURY
B-VENUS
C-EARTH

D-MARS
E-JUPITER
F-SATURN

G-URANUS
H-NEPTUNE
I-PLUTO

The solar system we hope to explore is tiny in relation to the universe as a whole, but an area of tremendous magnitude in Earth terms. Its primary, our sun, is a star located at the center of the system with nine planets revolving around it in near-circular orbits. Some of the planets, like Earth, have natural satellites of their own, and there are thousands of other bodies moving within the system.

The planets are held in their orbits by the sun's gravity. They all move in the same direction around the sun and their orbits lie in nearly the same plane, with Pluto the exception. Their orbital speeds are higher near the sun. Mercury, the planet nearest the sun, makes a circuit in 88 days. Earth's period of revolution is 365 days, or what we know as a year. Distant Pluto, more than three and a half billion miles from the sun, takes 248 years to make a circuit.

THE SUN

The sun represents more than 99 per cent of the total mass of the solar system. Its mass is 330,000 times that of Earth's and its volume more than a million times greater. The surface temperature of the sun is many thousands of degrees and the temperature at the interior is measured in millions of degrees. From the sun, Earth derives its major input of energy which influences Earth's weather and supports plant and animal growth.

Every 11 years, the number of dark spots on the solar surface, called sun spots, reaches a maximum. These spots show strong magnetic fields. During the maximum of a sun spot period, the sun shows marked activity in shorter "wavelengths"–X-rays and ultraviolet radiation. Frequent solar eruptions and solar flares occur. These produce definite effects on Earth, such as ionospheric disturbances, magnetic storms, interruptions of radio communications, unusual auroral displays and a lowering of the average cosmic ray intensity.

EARTH

Earth ranks fifth in size among the nine planets. Its mean distance from the sun as it moves in orbit is about 150,000,000 kilometers (93,000,000 miles); this is called an "astronomical unit."

Earth's atmosphere, if it were reduced to sea level conditions, would amount to only an eight kilometer (five mile) depth, although actually it extends out for hundreds and perhaps thousands of kilometers.

The pressure at the surface amounts to about 10 tons per square meter (one ton per square foot). This pressure falls off by a factor of 10 for every 10 mile (16 kilometer) increase in altitude. Thus, 99 per cent of the atmosphere lies below 20 miles (30 kilometers) and all but one one-millionth of the atmosphere lies below 60 miles (100 kilometers).

TABLE 1
SOLAR SYSTEM

	Sun	Moon	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Diameter (miles)	870,000	2,170	3,100	7,750	7,970	4,140	87,300	71,000	32,000	31,000	3,700
Mean Distance from Sun (Millions of Miles)	—	—	36	67	93	142	484	887	1,785	2,800	3,675
Escape Velocity (mi. per second)	387	1.5	2.6	6.4	7	4	37	22	13	14	?
Surface Gravity (Earth = 1)	28	.16	.36	.86	1	.40	2.64	1.17	.91	1.12	?
Eccentricity of Orbit (Circle = 0)	—	.054	.206	.007	.017	.093	.048	.056	.047	.009	.248
Inclination to Ecliptic (degrees)	—	5.8	7	3.2	—	1.5	1.18	2.3	.46	1.46	17.8
Number of Satellites	—	—	0	0	1	2	12	9	5	2	0
Period of Revolution	—	27.3 days	88 days	224 days	365 days	1.9 years	11.9 years	29.4 years	84 years	164.8 years	247.7 years

The composition of the atmosphere remains roughly the same from sea level up to 100 kilometers (60 miles), although the percentage of water vapor in the high atmosphere is far below that on the surface. At the higher levels, a small amount of ozone is formed by ultraviolet radiation from the sun. Above 100 kilometers, oxygen dissociates into atomic form due to the influx of solar radiation, while the heavier gases tend to settle out, the lighter gases rising upward. It is anticipated that at the uppermost reaches the atmosphere will be found to be largely hydrogen.

In the upper atmosphere is found the ionosphere, the portion in which the air molecules are ionized and in which there are large numbers of free electrons. The ionosphere extends outward for tens of thousands of kilometers.

Beginning at some hundreds of kilometers above the Earth's surface, and extending outward to ten to 15 Earth's radii, is the Great Radiation Belt. The belt consists of large numbers of electrons and protons in rapid motion. The outer zone appears to vary markedly in total concentration and extent with solar activity. Apparently beyond 15 Earth's radii there is simply the normal cosmic ray background. The radiation belt is formed by the trapping of charged particles in the Earth's magnetic field which extends outward into the space around the Earth.

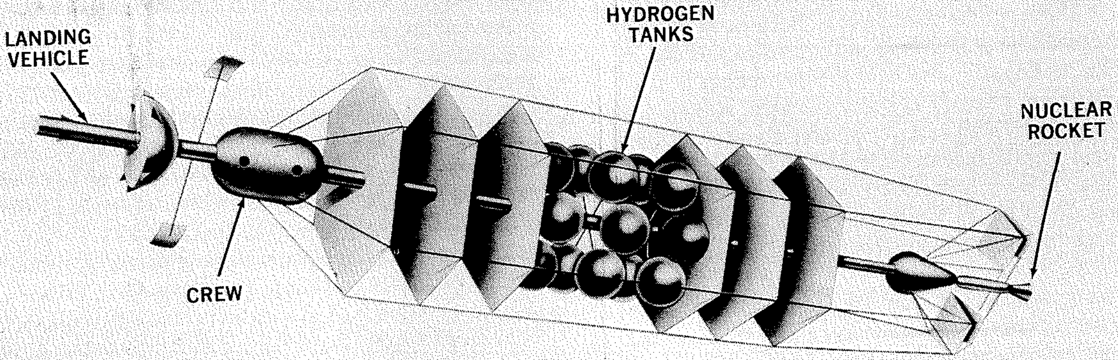
Impinging upon the Earth's atmosphere are the various radiations from the sun, stars, and galaxies. These radiations are both electromagnetic and particle. The electromagnetic radiations doubtless range from the shortest gamma rays through X-rays, ultraviolet rays and the visible, to the infrared and radio waves. Among the particle radiations striking the Earth's upper atmosphere are the cosmic rays, meteors, and the particles discovered in the Radiation Belt.

INTERPLANETARY SPACE

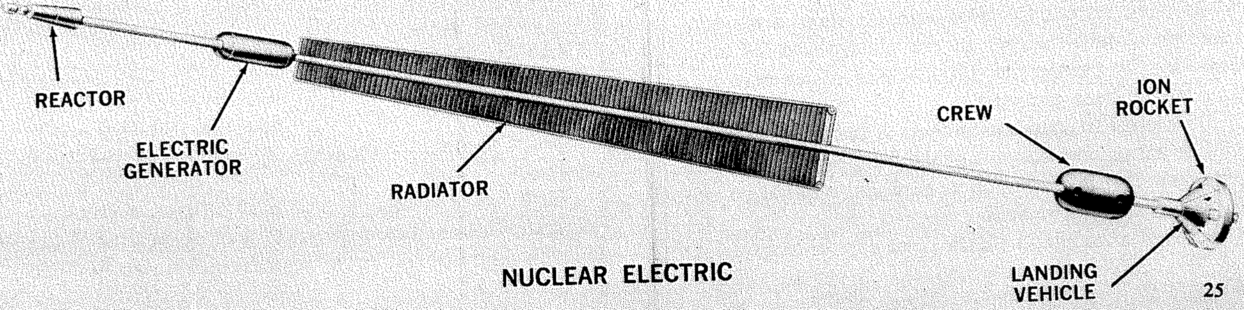
Beyond the Earth's atmosphere is a region populated by meteors, micrometeors, cosmic rays, and various electromagnetic radiations arriving from the whole universe. It is thought by many that much of the solar system may be filled with the sun's corona, and it is estimated that the density of coronal particles at the distance of the Earth may amount to a thousand hydrogen atoms and that the temperature of this thin gas may be as much as a quarter of a million degrees. As one approaches the sun the density of this gas would increase as would its temperature.

From a vantage point in interplanetary space, it should be possible to observe the sun, planets, the medium of interplanetary space itself, the galaxy, and the rest of the universe in wavelengths that are cut off by the Earth's atmosphere.

SPACE SHIP STRUCTURES



NUCLEAR ROCKET



NUCLEAR ELECTRIC

THE MOON AND PLANETS

The moon is a natural satellite of Earth and one of the oldest objects in the solar system. Because of its lack of any appreciable atmosphere, it remains to this day in essentially its original state, and for this reason it is an important object of study in space research. Among the primary questions man seeks to answer about the moon are: Does it have a trace of atmosphere? Is there a lunar ionosphere? Is there a radiation belt around the moon?

Among the planets, Venus and Mars will doubtless be the first to receive close study by means of space probes.

Observations of Venus from the surface of the Earth have shown an atmosphere containing an extensive and completely enveloping cloud cover. Carbon dioxide is a major constituent of this atmosphere, but water has not been identified with it. Temperature measured with a thermopile is approximately zero degrees Centigrade, while radio astronomy measurements show a temperature, presumably deeper in the atmosphere, of about 300 degrees Centigrade. Observation of an aurora or airglow has been reported.

Of interest to space researchers is knowledge of what are the actual constitutents of the Venusian atmosphere, again whether it has an ionosphere and a radiation belt, therefore a magnetic field.

Water is associated with the polar caps of Mars, which vary with the season. Average surface temperature is eight degrees Centigrade and surface pressure is estimated at approximately eight per cent of Earth's sea level atmospheric pressure. Clouds of dust have been observed in the Martian atmosphere, and Mars is the one planet on which there seems to be some evidence of life. Green markings on the planet vary with seasons in such a way as to suggest the possibility of a form of plant life. The question of whether life exists in any form is the matter of major interest about Mars.

The atmosphere of Jupiter is composed of a number of different gases and surface temperature is minus 150 degrees Centigrade. Thermal and pulse-type radio emissions from Jupiter have been detected and the atmosphere exhibits differential rotation at different latitudes. The atmosphere also contains the famous "red spot," the nature of which is unknown and which would appear to be a major item of research interest.

TRAVEL IN THE SOLAR SYSTEM

Certain factors about the composition and mechanics of the solar system seem to indicate that Nature is kindly disposed to the idea of man's moving about within the system.

First, space is almost a perfect vacuum, so there is no restraint to vehicle movement such as the drag of the Earth's atmosphere upon aircraft moving in it. The speeds required for interplanetary travel can be obtained only in a near-vacuum.

The relatively small size of Earth also helps. Its gravitational pull is such that relatively low velocities will permit escape and its comparatively thin atmosphere offers resistance for only a short period.

The orbital planes of the planets are nearly coincidental. This offers two advantages: 1) it simplifies interplanetary guidance problems and 2) it lowers the energy or velocity requirements for movement between the planets.

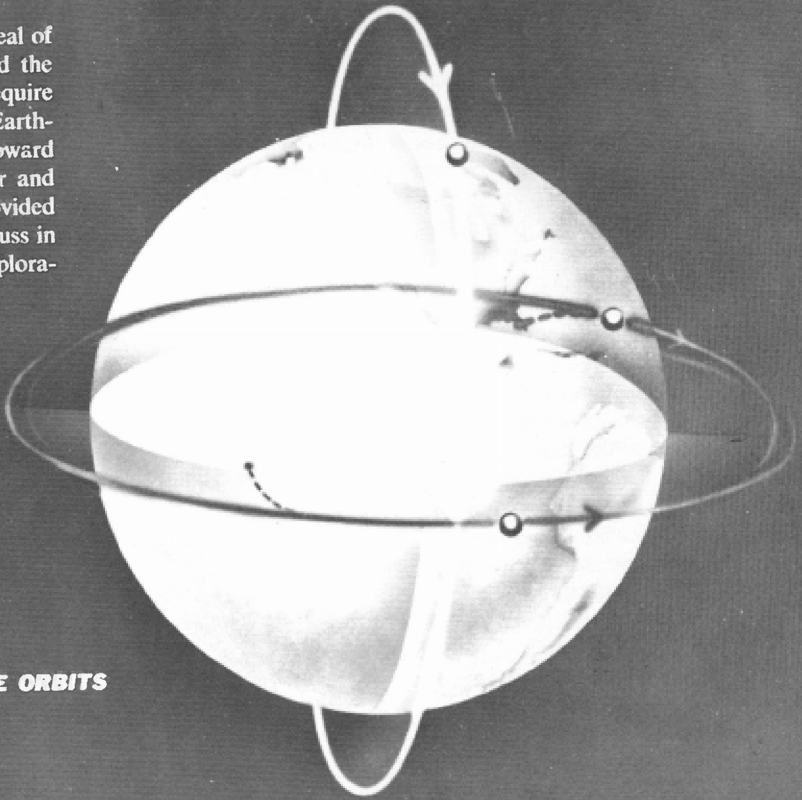
The fact that the planets move about the sun in the same direction is also a "plus," because it allows the space vehicle to take advantage of the orbital speed of one planet in achieving the required velocity to launch to another. In addition, the planets rotate about their own axes in the same direction they revolve about the sun, so the space vehicle can get a small but significant added "push" by taking off in the direction of rotation.

Finally, planetary orbits are near-circular, which means that energy requirements for transferring from one orbit to another are almost the same for all points of departure along an orbit.

V

OPERATIONS IN SPACE

Over the centuries, man has accumulated a good deal of knowledge about his planet, his solar system and the universe, but any real penetration of space will require considerably more detailed information. The first Earth-orbiting satellies and lunar probes were steps toward acquiring that information, as will be their larger and more complex successors. With the background provided by the foregoing sections, it is now possible to discuss in detail the techniques by which man can thrust exploratory vehicles into space.



POLAR, EQUATORIAL AND INTERMEDIATE ORBITS

ARTIFICIAL EARTH SATELLITES

An artifiicial satellite of the Earth is simply a man-made moon. In revolving about the Earth it must obey the same laws that the natural moon does, and that the planets obey in revolving about the sun. To create such an artificial satellite, one must use a rocket vehicle that during its motion must also obey the laws of celestial mechanics properly modified to take into account the rocket thrust during the period of burning.

The launching vehicle must perform two tasks. First, it must lift the satellite to the "altitude of injection" into an orbit. Secondly, it must at that altitude give the satellite the proper speed in the proper direction to inject it into a stable orbit.

In lifting the satellite to its orbit injection altitude, the rocket vehicle must do work against the Earth's gravitational field. Thus, part of the energy derived from burning the rocket propellants goes into this effort, and not all of it goes into imparting velocity to the satellite object.

Imagine that the satellite has been lifted to the desired orbital altitude and is about to be injected into its orbit. If one assumed the satellite to be momentarily stationary and simply permitted it to drop, it would fall straight toward the center of the Earth.

Suppose that instead of just dropping the intended satellite it were given a slight nudge horizontally. In this case the object again would fall toward the ground but because of the horizontal nudge would impact at some distance away from the point directly below the starting point. With a more forceful nudge horizontally the satellite impact point can be moved even farther away from the point directly below, and with a sufficiently hard shove the impact point on the Earth would be exactly half way around the Earth from the point directly below the starting point. With a still harder nudge, it can be seen (neglecting the resisting effect of the atmosphere) that the satellite would actually miss the Earth and after swinging by the half way point, would swing outward and upward again. It would then return to its starting point to repeat its swing around the Earth. In other words, it would be in an orbit about the Earth.

With a sufficiently forceful thrust on the satellite in a horizontal direction it is possible to make the object follow a circular path and for greater velocities than the circular velocity, the satellite will follow elliptic paths in which the launching point is the nearest point to the Earth, or the "perigee." If the injection velocity is increased to 1.4 times the circular velocity, then the satellite will be projected into a parabolic orbit and will escape.

For injection speeds greater than 1.4 times the circular velocity the orbit will be a hyperbola, and again the satellite will escape.

If the injection is made not in the horizontal direction then the perigee will lie at a lower altitude than the injection altitude. It follows that if the injection is made at too steep an angle the perigee will be too deep in the atmosphere and the satellite's lifetime will be shortened by atmospheric resistance which reduces its speed below that required for orbiting. With too steep a trajectory the perigee will lie inside the Earth and the satellite will impact the Earth's surface.

The downward injection and upward injection cases are essentially the same, the difference being that in the downward injection perigee occurs before apogee (the point in orbit farthest from Earth) while in the upward injection case the apogee occurs first. If the upward and downward angles are identical and the speeds the same, the orbital ellipses will be identical in size and shape.

The periods of revolution of an artificial satellite in circular orbit about the Earth are listed in Table 2 . The periods for orbits of equal semimajor axes would be the same. The satellite's speed in a 320 kilometer (200 mile) altitude orbit is approximately eight kilometers (five miles) per second, while the speed in a 380,000 kilometer (235,000 mile) orbit, corresponding to that of the natural moon, is about one kilometer (0.6 miles) per second.

The orbit at 36,000 kilometers (22,000 miles) altitude is particularly interesting inasmuch as the period is exactly one day. A satellite launched eastward in such an orbit above the equator would remain above the same spot on Earth. One launched at an angle to the Earth's equator but at 36,000 kilometers altitude, although it would not remain above the same spot on the Earth, would remain in the vicinity of its initial meridian, swinging north and south of the equator as it revolved in its orbit.

TABLE 2

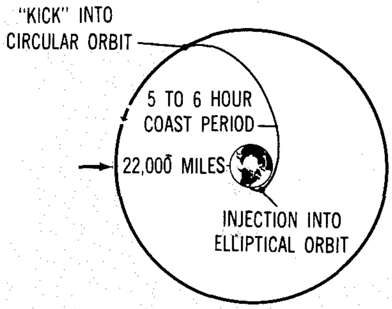
PERIOD OF REVOLUTION OF A SATELLITE IN A CIRCULAR ORBIT ABOUT THE EARTH

Height above the earth, miles	Approximate period
0*	84 min
200	90 min
1,000	2 hours
22,000	1 day
235,000	1 lunar month

* Ignoring the presence of the atmosphere.

The plane of the satellite orbit is fixed in space except for effects of the Earth's bulge. The position of this plane is not affected at all by the rotation of the Earth. As the satellite revolves in its orbit the motion of the earth rotating on its axis causes the suborbital points to move westward over the ground. As a result, in general the track of the satellite over the ground crisscrosses the belt on the Earth lying between the northernmost latitude through which the satellite goes and the southernmost latitude. When placing observing stations to track the satellite or to receive radio data from it, this fact of the Earth's rotation must be kept in mind.

The previous discussion of the behavior of an artificial Earth satellite assumed a perfectly spherical Earth. However, the Earth is not perfectly spherical but is some 21 kilometers (13 miles) flatter at the poles than at the equator. The equatorial bulge has an effect on the plane of the satellite's motion. As the satellite approaches the equator the equatorial bulge causes the satellite to be pulled down out of its orbital plane. Thus if the satellite is moving in an eastward direction the downward pull of the Earth's equatorial bulge causes the satellite to cross the equator to the west of where it would have otherwise. The effect is a gradual westward rotation of the orbital plane.



METHOD

FOR PLACING

24 HOUR

SATELLITE

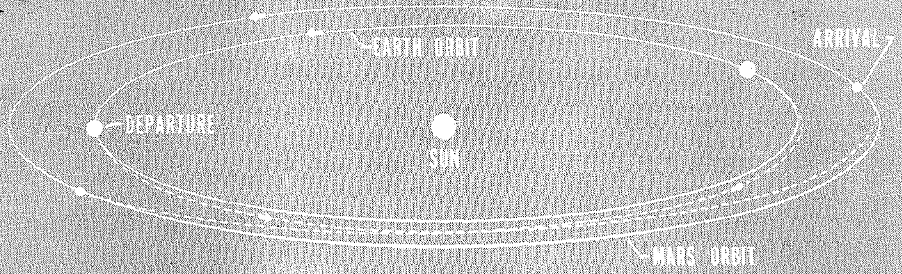
SPACE PROBES

By launching a payload at a sufficiently great speed, a rocket can be used to project scientific instruments into interplanetary space. Such payloads are called space probes. If the aim of such a space probe is simply to make measurements deep in space far from Earth, without any particular reference to any celestial body such as the moon or a planet, then it suffices to project the object at a sufficiently great speed in a generally outward direction. For such a mission, guidance requirements are at a minimum. On the other hand, if for example, it is desired to project the object close to the moon or close to Venus then stringent guidance and timing requirements must be met.

Velocity requirements vary for different missions. The velocity of escape from the Earth at the Earth's surface is about 11 kilometers (seven miles) per second, overlooking the effect of the Earth's atmosphere in order to simplify calculations. At the distance of the moon from the Earth, the required velocity of escape is one and one-half kilometers (one mile) per second, while the velocity of escape from the Earth at the distance of Venus is one-sixth of a kilometer (one-tenth of a mile) per second. It follows that Earth-to-moon missions, while not requiring quite escape velocity, require velocities approaching that of escape.

For missions other than those connected with the

MINIMUM-ENERGY FLIGHT PATH FOR MARS ROUND TRIP



TIME IN DAYS FOR MARS JOURNEY

SYSTEM	ESCAPE FROM EARTH	COAST	DESCENT TO MARS ORBIT	WAIT	TOTAL
$\frac{\text{WEIGHT}}{\text{THRUST}}$ 5,000	59	259	31	403	1062
HIGH THRUST ROCKET	—	259	—	455	973

Earth and moon, it becomes important to recall the presence of the sun. It must be kept in mind that escape from the Earth does not imply escape from the solar system. In order to escape from the sun at a distance of the Earth from the sun, a body must have a velocity slightly in excess of 42 kilometers (26 miles) per second. Thus, an object projected from the Earth at Earth escape velocity would, after moving some distance from the Earth, be in orbit about the sun at the Earth's distance and moving at roughly the Earth's velocity, which is 30 kilometers (18½ miles) per second.

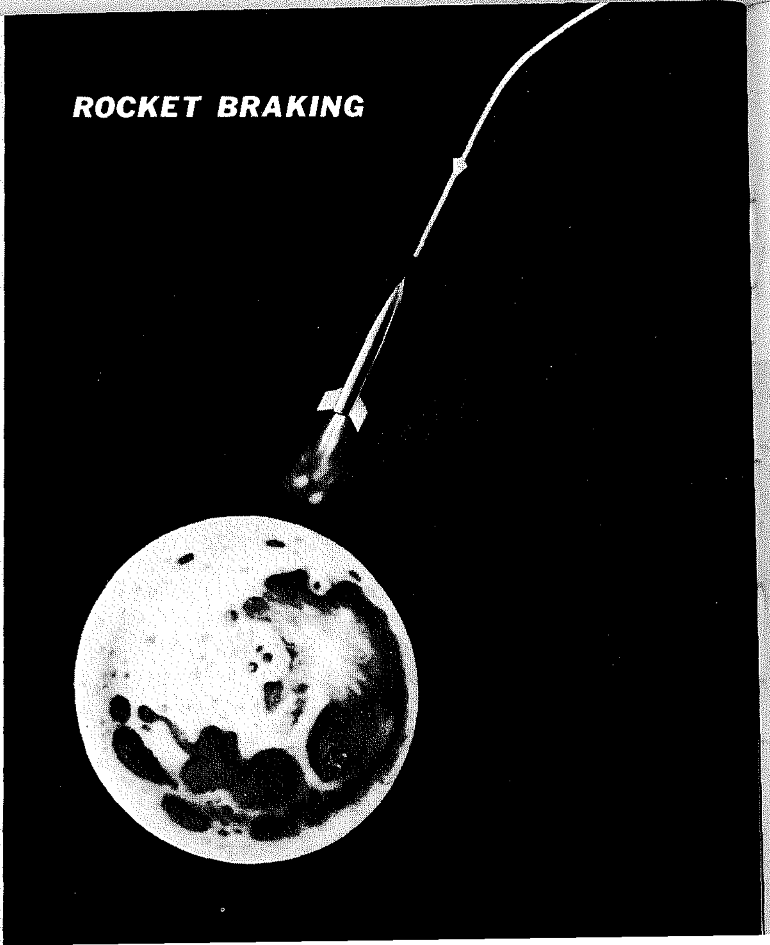
In order to make such an object escape from the sun, it would be necessary to add 12 kilometers (7½ miles) per second to bring its total velocity up to 42 kilometers per second. This velocity would have to be added in the direction of motion in the Earth's orbit.

On the other hand, suppose that one wished to send a solar probe directly into the surface of the sun. This could be done by "dropping" the object into the sun. The object would first require a velocity of seven miles per second to escape from Earth. This speed is entirely used up in getting away from the Earth into an orbit about the sun at the Earth's distance and at essentially the Earth's speed, which is 18½ miles per second. In order to cause the object to drop straight into the sun, it would be necessary to "kill off" the 30 kilometers per second about the sun by firing a rocket in the direction opposite to the direction of motion in the Earth's orbit. The object would then proceed to fall into the sun, reaching it in about 64 days.

At the present stage of technology, lunar and Earth escape missions are definitely practical, while escape from the sun in the direction of the Earth's orbit is not yet possible with useful payloads. An intermediate type mission such as a flight to Venus or Mars, with a small but useful payload, along a minimum energy orbit, would require about 14 kilometers (8½ miles) per second total velocity. This is also practicable at the present time, but dropping an object directly into the sun is not yet feasible.

LANDINGS ON THE MOON AND PLANETS

When vehicles capable of carrying adequate payloads to the moon and planets come into being, it will be possible to land instruments and, later, man on their surfaces. In the case of the moon, where no appreciable atmosphere exists, it will be necessary to use rockets to retard the incoming object in order that it may land at acceptable speeds. Without such retarding rockets, a crash landing would occur.

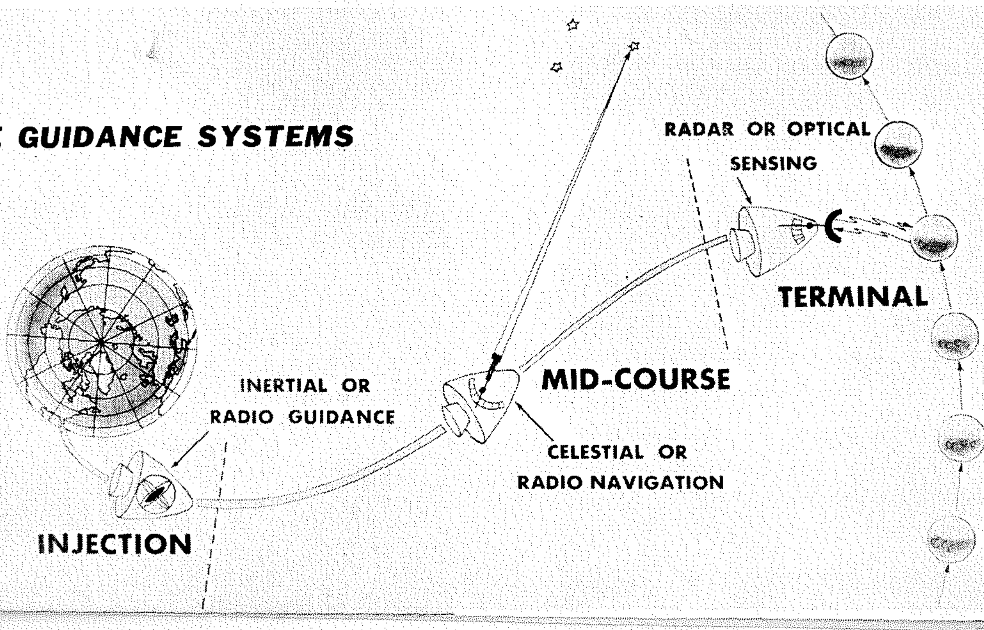


ROCKET BRAKING

For the planets such as Venus and Mars such braking rockets can also be used to slow down the motion of the incoming object, but since these planets both have atmospheres, the atmosphere can be used to cushion the approach. This can be done either by using the drag of the resisting atmosphere or its lifting effect on appropriate lifting surfaces. The velocity of escape from the surface of the moon or planet in question provides a rough measure of the gravitation that must be counteracted. *(See Table 1.)*

When return of the equipment from the moon or planet is required, then this escape velocity must again be provided to the portion of the payload that takes off for the return. On returning to Earth, once again braking rockets may be used to slow the object down for recovery at the ground, or the Earth's atmosphere may be used either through its drag or its lift to cushion the return to the ground.

SPACE GUIDANCE SYSTEMS



NAVIGATION AND GUIDANCE

The launching of space vehicles on missions to the planets will require navigational and guidance techniques beyond those that are now common to operations in the vicinity of Earth. There are several possible approaches. For example, the rocket might be given its complete guidance during the initial burning period in the vicinity of the Earth. After this initial period, the rocket would then be coasting according to the laws of celestial mechanics. This technique requires extreme accuracy at burnout, both in the direction of the motion of the rocket and in its final speed. If the rocket were being launched to Venus by this technique and it missed its burnout velocity by more than one-sixth meter (one-half foot) per second from the necessary 11,000 meters (37,000 feet) per second, then it would miss the planet. Such accuracy is not currently obtainable.

To overcome this difficulty it will be necessary to provide vehicles with onboard guidance that will permit corrections as the planet is approached. This will necessitate carrying side rockets, special attitude control systems, retrorockets, and an adequate communications system to permit sending remote instructions and commands.

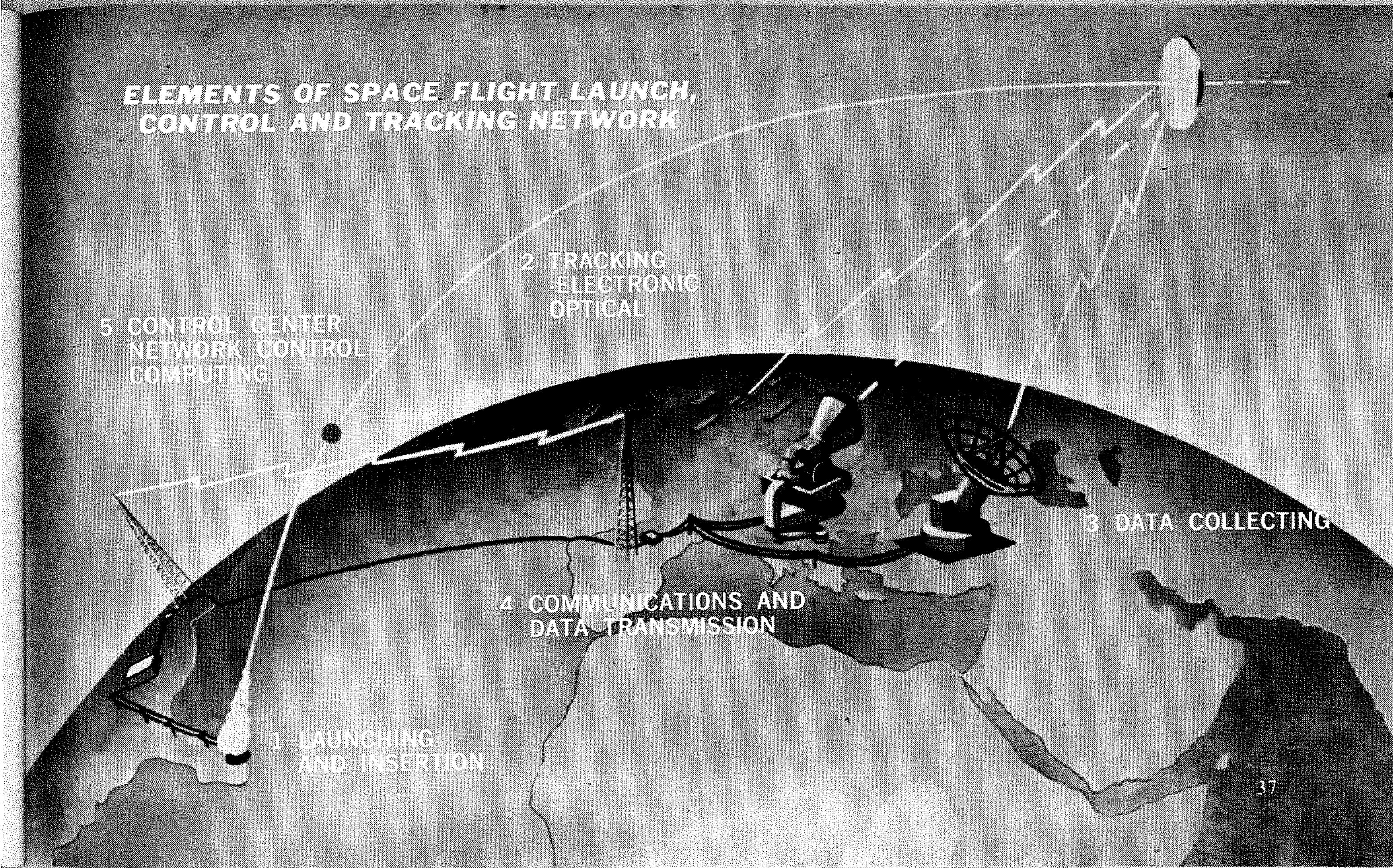
It must be remembered in this connection that within the solar system all is in motion. One cannot ever expect to be able to repeat a previous "shot," for the relative positions of the various bodies affecting the motion of the vehicle in its flight from Earth to the chosen planet will never be the same. It will be necessary, therefore, to rely on very careful calculations of the flight trajectories for each mission, obtained through use of large electronic computers.

TRACKING AND COMMUNICATIONS

In order to be able to keep track of the various satellites and space probes launched, it is necessary to have a widespread tracking network at the Earth's surface. The radio frequencies used must be those that will penetrate the ionosphere without distortion and absorption, hence they must be in the range, say, above 100 megacycles.

Because it is not yet possible to generate very large powers in the probes, it is necessary to have at the ground station large antenna dishes or their equivalent for reception of signals from the deep space probes. The requirement is not too severe in the case of near satellites of the Earth, but it becomes severe as planetary distances are contemplated.

To minimize the power requirement it may often be necessary to reduce the rate at which information is transmitted from the satellite and received on the ground to very, very low frequencies, something on the order of a fraction of a cycle per second.



ELEMENTS OF SPACE FLIGHT LAUNCH, CONTROL AND TRACKING NETWORK

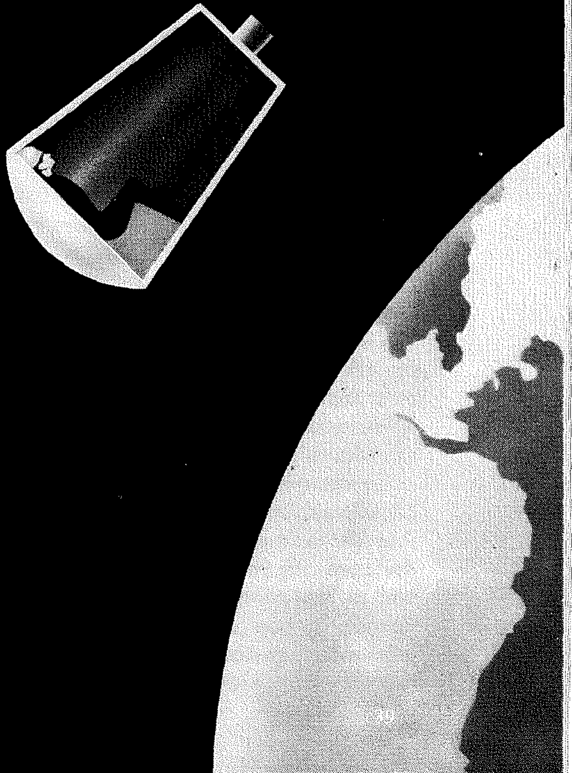
VI

MAN IN SPACE

BIO-MEDICAL CONSIDERATIONS

LONG DURATION FLIGHTS

- BIOLOGISTICS
  - FOOD
  - OXYGEN
  - WATER
- TOXICOLOGY (IN CAPSULE)
  - CARBON DIOXIDE, MONOXIDE
  - SANITATION
- RADIATION
  - COSMIC
  - GREAT RADIATION BELT
  - NUCLEAR-MAN MADE
- PHYSIOLOGICAL STRESS
  - TEMPERATURE
  - HIGH ACCELERATION
  - WEIGHTLESSNESS
- PSYCHOLOGY
  - ANXIETY
  - DISORIENTATION
  - ISOLATION



The complete knowledge space scientists seek requires man's personal participation in extraterrestrial research. Instrumented probes can provide a great amount of important data, but no matter how efficiently they operate there still remain certain tasks which require human judgment, vision and ability to analyze findings. Consider, for instance, the value of a research laboratory in space, in which man could conduct fundamental researches in both physics and biology.

Preparations are now being made to put man in space, but there are a great many problems which need solution before he can venture far beyond the atmosphere and return safely. The problems are compounded by distance and by the time he must spend away from Earth.

The problems lie in two main areas: bio-medical, involving man's ability to survive in a completely alien environment, and vehicular, involving the design and construction of spacecraft which can carry humans. They are naturally very closely related.

To survive in the near-vacuum of space, man needs considerably more in the way of structure and equipment than do instrumental probes. As atmospheric pressure decreases, the boiling point of liquids drops. Body fluids boil at any point above 20 kilometers (63,000 feet) altitude, so the spaceman must be equipped with a pressurized environment close to that to which he has become adapted through life on Earth. He must have oxygen to breathe and there is none in space, so it must be provided. In the process of breathing, he creates carbon dioxide, which must be removed from his capsule or vehicle. Above the protective layer of atmosphere that filters the sun's rays, the side of the vehicle nearest the sun would be heated red-hot, while the other side would be freezing, so the space vehicle needs a highly efficient air conditioning system. Humidity and odors must also be controlled.

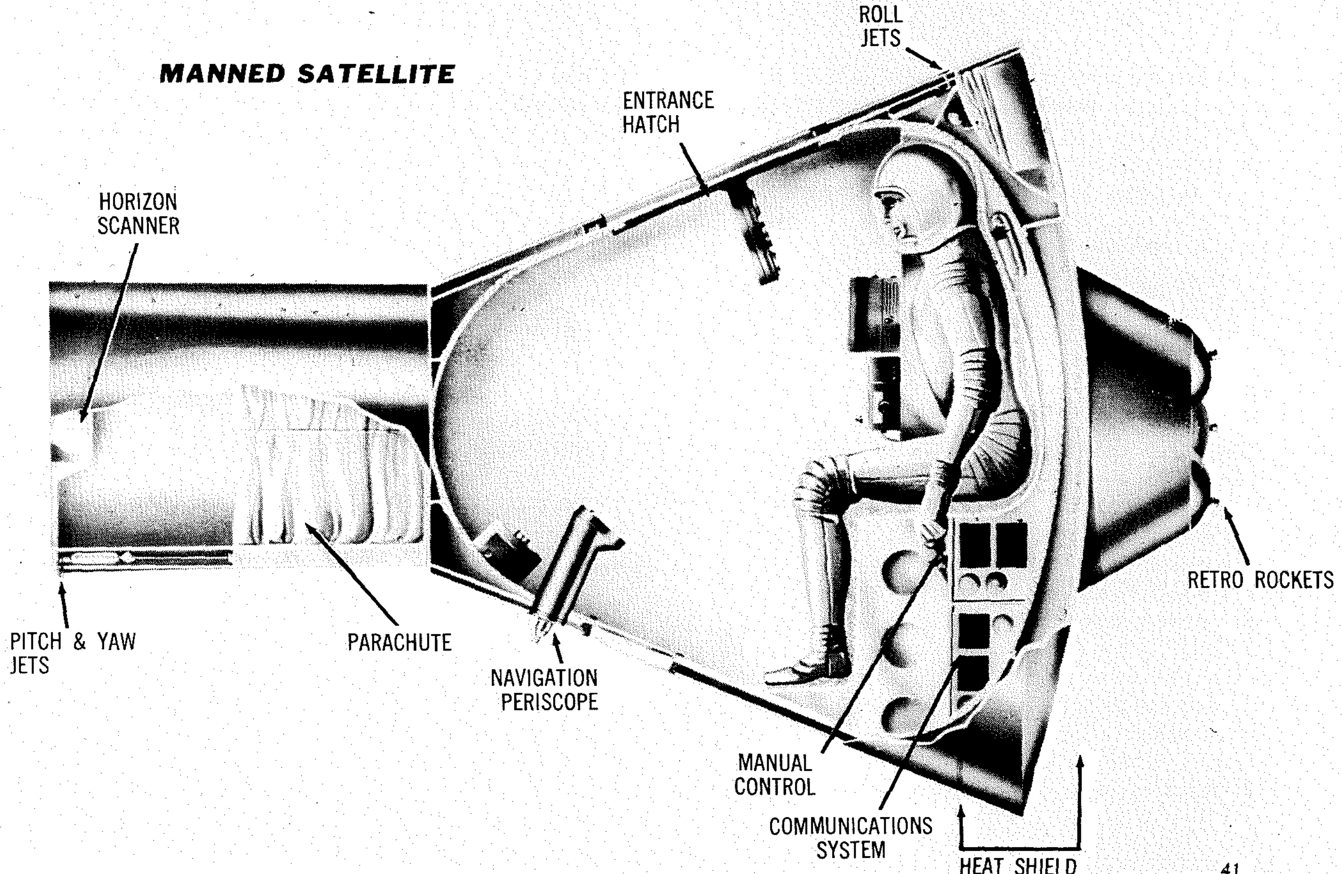
The spaceman will also be subjected to bombardment by potentially harmful cosmic radiation, no problem on Earth because again the atmosphere serves as a protective shield.

As manned space technology becomes more advanced, there will be requirements for the spaceman to venture outside his vehicle for landings on the moon or the planets. Thus, he will need equipment–a space suit—containing practically all the protective elements built into the space vehicle.

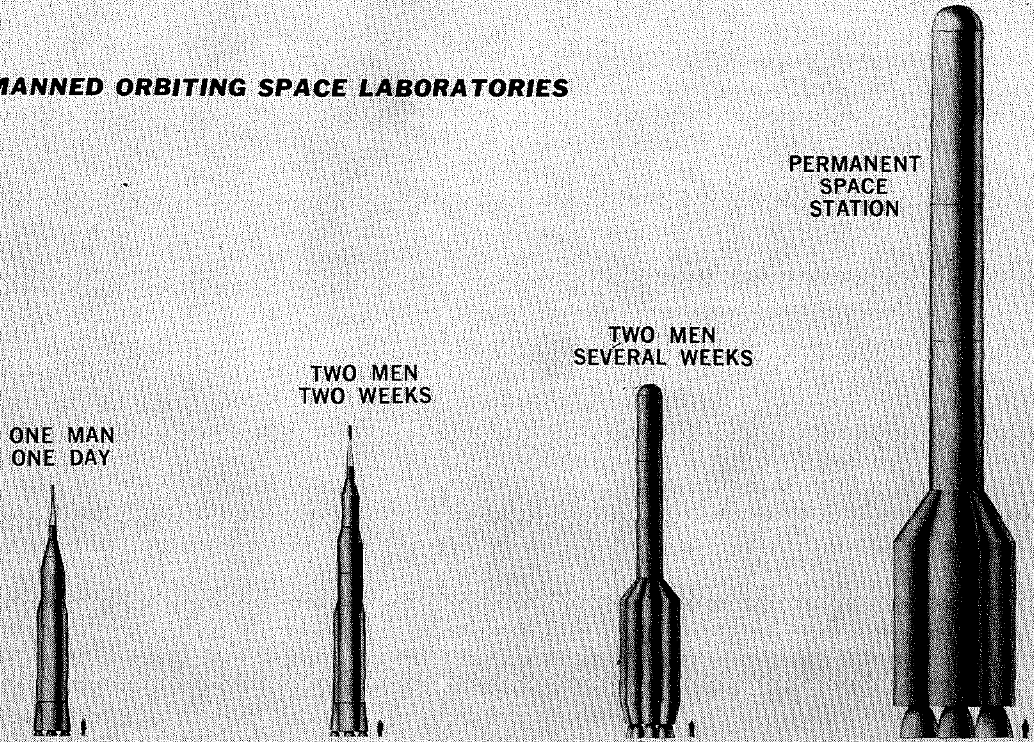
During the launching period, the spaceman will encounter very high acceleration forces, or "G" forces, which increase his equivalent weight by several times and subject him to a disagreeable "crush." Similar forces will be encountered on deceleration, as the vehicle slows down to a speed which will permit it to re-enter the atmosphere without burning up from air friction.

In an Earth orbit or in "free fall," the spaceman will

MANNED SATELLITE



MANNED ORBITING SPACE LABORATORIES



PHASE	I	II	III	IV
THRUST (LBS)	365,000	390,000	1,200,000	6,000,000
PAYLOAD (LBS)	2,200	6,500	12,000	150,000

become weightless, a condition found not unpleasant in experiments to date where weightlessness has been induced for a period measured in minutes. Conceivably, it could have adverse psychological and physiological effects when sustained for long periods of time.

There are other psychological problems, such as man's reaction to a routine in the absence of the normal Earth day-night cycle and the effects of prolonged confinement and isolation from the familiar world.

Hand-in-hand with these problems is the task of building the space vehicle. Obviously, to carry one or more men, their instruments, their equipment for survival and what amounts to a complete artificial Earth environment, large payloads will be needed, increasing thrust requirements. The artificial Earth environment itself needs protection from the space environment; for instance, the possibility of hull puncture by a micrometeorite must be taken into consideration in designing the structure.

The factor of vehicular reliability is an important one, and its importance increases in proportion to the duration of a specified mission. Some trips even within the solar system could take months or even years to complete, and during that time every minute piece of equipment aboard the vehicle must perform perfectly.

In all these areas, a great deal of research is under way. Some of this research has already shown that some of the problems are less serious than once thought, but it remains to demonstrate the fact in the actual space environment. Space research on Earth can provide only partial answers. In addition, it is quite possible that actual penetration of space will bring new problems of which we are not yet aware.

There is, however, little doubt today that man can safely enter space, and the first such experiments will take place in the near future. To what extent he will be able to explore the universe remains to be seen.

THE SPACE EXPLORATION TIMETABLE

The possibility of exploring space has challenged man's imagination to the utmost and the question most frequently heard is *when* can we reach the moon, *when* can we explore Venus.

It should be obvious from a review of the foregoing sections that an exact timetable cannot be provided. There are too many intangibles involved to predict with any degree of accuracy just when a certain mission can be accomplished. It is possible, however, to state the approximate order in which some of the scientific and technical objectives may be attained. The Science Advisory Committee to the President of the United States, headed by Dr. James R. Killian, Jr., prepared such a schedule, listed on next page:

SCIENTIFIC OBJECTIVES

Early

1. Physics
2. Geophysics
3. Meteorology
4. Minimal Moon Contact
5. Experimental Communications
6. Space Physiology

Later

1. Astronomy
2. Extensive Communications
3. Biology
4. Scientific Lunar Investigation
5. Minimal Planetary Contact
6. Human Flight in Orbit

Still Later

1. Automated Lunar Exploration
2. Automated Planetary Exploration
3. Human Lunar Exploration and Return

And Much Later Still

Human Planetary Exploration

The Committee confined this schedule of objectives to the solar system. Anything beyond that lies in the realm of conjecture. Remember, we are inhabitants of a small planet revolving about a minor star which is only one body in a vast galaxy of 200 billion stars. It has been estimated that there are five billion galaxies within two billion light years of the Earth, and there appears to be no reason to suppose that there are not countless more beyond that distance.

Flight to even the nearest star is currently beyond any predictable level of technology. It is presumptuous for man to think of exploring the distant reaches of the universe, but, his appetite whetted by the first ventures beyond the atmosphere, he will unquestionably continue to think about it, and thought is the forerunner of accomplishment.

GLOSSARY OF SPACE TERMS

Acceleration: The rate of increase of velocity.

Aphelion: The point at which a planet or other celestial object is farthest from the sun in its orbit about the sun.

Apogee: The point or position at which a moon or an artificial satellite in its orbit is farthest from its primary.

Artificial Satellite: A man-made object placed in orbit.

Astrionics: Electronics as applied especially to astronautics.

Astronautics: The science and technology of space flight.

Astrophysics: The study of the physical and chemical nature of celestial bodies and their environs.

Atmosphere: The body of air surrounding the earth; also, the body of gases surrounding or comprising any planet or other celestial body.

Bipropellant: A rocket propellant consisting of two unmixed or uncombined chemicals (fuel and oxidant) fed to the combustion chamber separately.

Booster: A propulsion unit used in initial stage of flight.

Brennschluss: [German, "combustion termination."] The cessation of burning in a rocket, resulting from consumption of the propellants, from deliberate shut-off, or from other cause; the time at which this cessation occurs.

Burnout: Same as brennschluss.

Celestial Mechanics: The study of motion in space, natural or man-made.

Centrifugal Force: The apparent force tending to carry an object away from a center of rotation.

Circular Velocity: The speed required to maintain a body in circular orbit.

Cislunar: Space between the earth and moon.

Deceleration: Negative acceleration (slowing down).

Eccentricity: The degree of deviation from a circular orbit.

Ecliptic: The plane of Earth's orbit around sun.

Escape Velocity: The velocity which if attained by an object will permit it to overcome the gravitational pull of the Earth or other astronomical body and to move into space. The escape velocity from Earth's gravity field is approximately seven miles per second.

Fission: The release of nuclear energy through splitting of atoms.

Free Fall: The motion of any unpowered body traveling in a gravitational field.

Fusion: The release of nuclear energy through uniting of atoms.

Interplanetary: Between planets.

Interstellar: Between stars.

Ion: An atom that has lost or acquired one or more electrons.

Ionosphere: A layer or region of the atmosphere characterized by ionized gases.

Light-year: The distance light travels in one year at 186,300 miles per second.

Liquid Propellant: A rocket propellant in liquid form.

Lunar: Of or pertaining to the moon.

Mass: The quantity of matter in an object.

Mass Ratio: The ratio of a rocket's mass at launch to its mass at burnout.

Monopropellant: A rocket propellant consisting of a single substance, especially a liquid containing both fuel and oxidant, either combined or mixed together.

Orbit: Path of a body relative to its primary.

Orbital Velocity: The speed of body following a closed or open orbit, most commonly applied to elliptical or near-circular orbits.

Payload: Useful cargo.

Perigee: The point at which a moon or an artificial satellite in its orbit is closest to its primary.

Perihelion: The point in an elliptical orbit around the sun which is nearest the sun.

Perturbation: The effect of the gravitational attraction of one body on the orbit of another.

Probe: An unmanned projectile sent into space to gather information.

Primary: The body around which a satellite orbits.

Propellant: A liquid or solid substance burned in a rocket for the purpose of developing thrust.

Retro-rocket: A rocket fitted on or in a vehicle that discharges counter to the direction of flight, used to retard forward motion.

Revolution: Orbital motion around a primary.

Rotation: Rotary motion on an axis.

Satellite: A body moving around a primary.

Satelloid: An artificial body or vehicle like an artificial satellite except that it is under engine thrust (intermittent or continuous) in its orbit.

Space: That part of universe between celestial bodies.

Specific Impulse: The thrust produced by a jet-reaction engine per unit weight of propellant burned per unit time, or per mass of working fluid passing through the engine in unit time.

Telemetering: The technique of recording space data by radioing an instrument reading from a rocket to a recording machine on the ground.

Terrestrial: Of or pertaining to the Earth.

Thrust: The amount of "push" developed by a rocket; measured in pounds.

Trajectory: The path described by a space vehicle.

Translunar: Beyond the moon.

Weightlessness: Lack of resistance to the influence of gravity.