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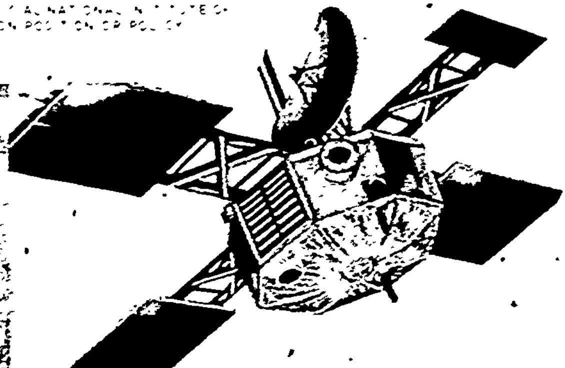
ABSTRACT

This book, one in the series on Aerospace Education I, provides a description of some of the discoveries that spacecraft have made possible and of the experience that American astronauts have had in piloting spacecraft. The basic principles behind the operation of spacecraft and their boosters are explained. Descriptions are also included on unmanned and manned spacecraft. Brief mention is made of space stations, reusable space vehicles, and spacecraft fitted with specialized equipment for planetary exploration. The book is designed for use in the Air Force Junior ROTC program. (PS)

AEROSPACE EDUCATION I



SPACECRAFT and their BOOSTERS

AIR FORCE JUNIOR ROTC

AIR UNIVERSITY MAXWELL AIR FORCE BASE, ALABAMA

2

Aerospace Education I

Spacecraft and Their Boosters

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AIR FORCE JUNIOR ROTC
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This publication has been reviewed and approved by competent personnel of the preparing command in accordance with current directives on doctrine, policy, essentiality, propriety, and quality.

This book will not be offered for sale. It is for use only in the Air Force ROTC program.

This text was developed under the direction of Maj. L. E. Darrow, AE-1 Course Director, AFJROTC.

Preface

MAN HAS BEEN SAILING on the earth's oceans ever since the beginning of history, and he has been using wheeled vehicles on land for almost as long. But only somewhat less than 70 years ago he began to fly in aircraft, and about 15 years ago he sent spacecraft into orbit around the earth for the first time.

Although space travel has been possible for but a moment in man's history, much progress has already been made. American astronauts have made landings on the moon and have taken a powered rover with them to help them in their exploration. Spacecraft have been sent as probes to Venus and Mars, and they have sent back data about these planets, as well as pictures of the surface of Mars. Other spacecraft have been launched to transmit information about the earth itself, the sun, and the regions of space between the planets. Still other spacecraft have been put to practical uses, such as in providing data for making weather observations, establishing communications across the oceans, assisting in navigation, and making surveys of the earth's surface. In the decade and a half that spacecraft have been operating, they have been greatly improved. These improvements are being continued to further increase man's knowledge and to make spacecraft of greater value to us in our everyday living.

This book tells about some of the discoveries that spacecraft have made possible and about the experience that American astronauts have had in piloting spacecraft. Its main purpose, however, is to explain the principles behind the operation of spacecraft and their boosters. How does the rocket booster generate power? What causes a spacecraft to stay in orbit? How can an astronaut make a so-called walk in space, and what difficulties does he have when he tries to work outside the spacecraft? These and similar questions are answered in this book. Although you are not expected to understand the engineering of the intricate mechanisms within spacecraft and boosters, you can understand the basic principles behind the operation of the spacecraft itself and the rocket boosters that put it into orbit.

If you know how a spacecraft is launched and why it continues in its path after it is orbited, you may be able to anticipate some of the discoveries that these launches will make possible, and you will appreciate more fully the experiences of the astronauts. When you know the basic principles behind space operations, you will be able to follow future spaceflights with better understanding. When you do this, questions may suggest themselves to you that are not now anticipated or answered in this book.

If you cannot find a specific answer to some of your questions in this book, ask your aerospace instructor to help you. He can supply you with publications of the National Aeronautics and Space Administration (NASA), or he can direct you to references in the library that go more deeply into the subject.

Grateful acknowledgment is made to NASA for the photographs used in this book and for the latest information on space launches.

Contents

7

Chapter 1

What Is a Spacecraft?

THIS CHAPTER explains what a spacecraft is and tells how present-day spacecraft differ from aircraft. It considers the great variety of spacecraft in their shape, the materials of which they are constructed, and the purposes they serve. It then introduces the two principal classes of spacecraft: unmanned and manned. When you have studied this chapter, you should be able to do the following: (1) define a spacecraft, (2) tell three ways in which spacecraft differ from aircraft, (3) explain how spacecraft get their power at launch, and (4) name the two large classes of spacecraft.

A **spacecraft** is any craft, or ship, that is designed to operate in space. Experimental aircraft might be called spacecraft because they have reached the fringes of space. The long-nosed X–15, which was used for performing valuable experiments, flew to altitudes of 50 miles or more, and the US Government recognized pilots who reached these altitudes by awarding them the rating of astronaut. Sounding rockets, which carry instruments for conducting experiments in the upper atmosphere and space, may go higher than the X–15 did and even higher than the altitudes at which some artificial satellites have orbited. Sounding rockets, however, travel in an arc and then fall back to the earth.

Experimental aircraft and sounding rockets have been valuable in preparing the way for space travel, but they were not designed to remain aloft and travel in space. Aircraft with rocket engines were slowly developing into spacecraft, but the process of transformation may have taken centuries to complete. Man took a shortcut by developing rocket boosters that would take first his instrument packages and then himself into space. In this book we are not concerned with experimental aircraft or sounding rockets, only with spacecraft especially designed to travel in space. Such spacecraft are launched into orbit by **rocket boosters.**

The next two chapters explain the way in which a spacecraft is launched from the earth and put into **orbit** and describe the forces that cause it to continue to travel along an invisible curved track, or orbit. After a spacecraft is launched into an orbit, it continues to travel in its orbit, much as the **celestial bodies** like the earth and the other planets travel in their orbits around the sun (Fig. 1). Since spacecraft are confined to travel in an orbit,

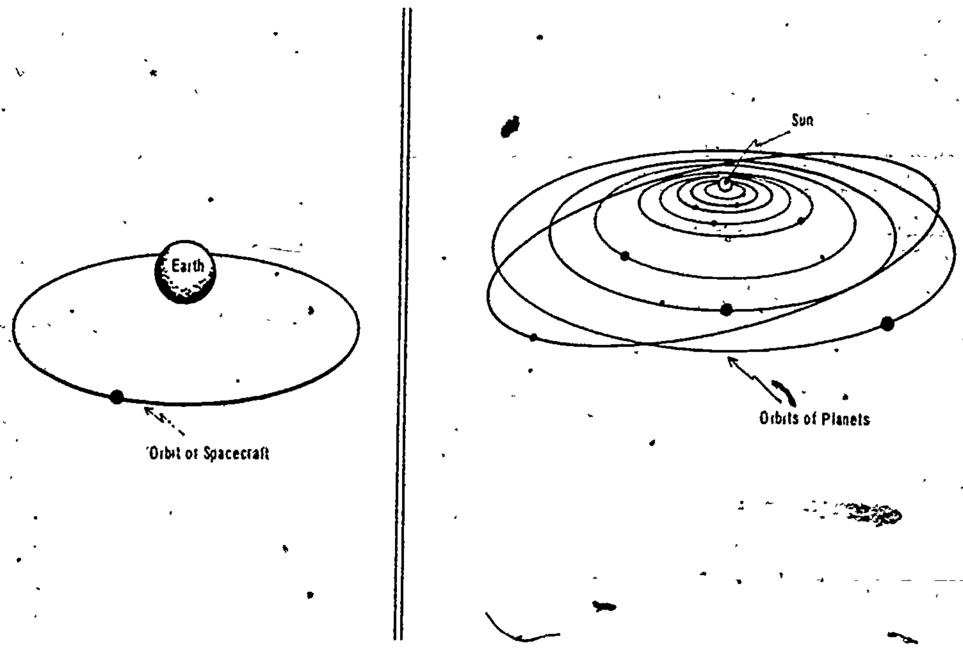


Figure 1 ORBIT OF SPACECRAFT AND ORBITS OF PLANETS A spacecraft launched into a high earth orbit continues to travel in this orbit. It follows the same laws of celestial mechanics as do the planets in their orbits around the sun.

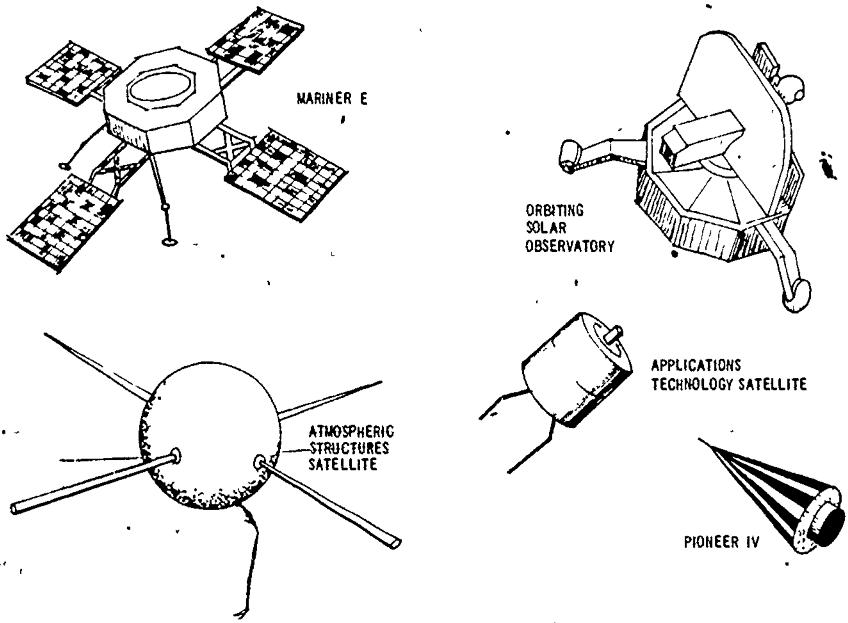


Figure 2 DIFFERENT SHAPES OF SPACECRAFT. Spacecraft do not have streamlined forms and wings like aircraft. They are designed in many different shapes. Each spacecraft shown above carries a different payload and performs a different kind of mission.

their movement might be compared with that of vehicles on earth that go along a track, such as trains and trolley cars. To change its direction of travel, a spacecraft must be transferred from one orbit to another, much as trains or trolley cars must be switched from one track to another in order to change direction. At the present stage of space travel, spacecraft follow set orbits, or tracks, through space. They do not take off horizontally and maneuver in their flight through the atmosphere, as aircraft do.

Since spacecraft do not depend upon aerodynamic forces for lift, they are not constructed with wings or other airfoils and streamlined surfaces as aircraft are. Instead they are designed in shapes that best enable them to perform their mission in space (Fig. 2). Spacecraft can be cylinders, cones, globes, or many-sided structures, or they can be shaped like a bell or a windmill. To help protect them against **atmospheric drag**, spacecraft usually have a **shroud**, or cover. Further, bulky appendages—such as antennas, paddle wheels carrying solar cells, or booms for mounting magnetically sensitive instruments—are retracted or folded back during passage through the atmosphere. Once the spacecraft is in space and its shroud has been taken off, the appendages are automatically unfolded and locked into position.

Just as there is no set shape for a spacecraft, there is no prescribed size except that all spacecraft are subject to rigorous weight limitations. They must not exceed the weight load that can be lifted by the booster available for launching them. Explorer 1, the first American satellite, weighed only about 31 pounds. Some of the first Vanguard and Pioneer satellites weighed even less. As more powerful space boosters became available, American spacecraft were made larger and could carry much heavier payloads. US spacecraft have varied in weight from the smallest Explorer satellite (Explorer 35) weighing only 2.2 pounds to the large modified Apollo spacecraft, which weighs close to 100,000 pounds.

The materials used in constructing spacecraft also vary widely. Engineers have had to exercise ingenuity in finding materials suitable for use in spacecraft, especially in the parts that are designed to survive the intense frictional heating upon reentry through the earth's atmosphere. Spacecraft may have an outer shell of aluminum, or they may be made from steel, fiberglass or other plastics, or from various combinations of manmade materials. Protective coatings are used. Some spacecraft have certain areas painted black to absorb the sun's rays (Fig. 3), thus heating the area, and other parts are painted a light color, thus reflecting the sun's rays and cooling the area. As the dark and light areas of the spacecraft are exposed to the sunlight in turn, the inside of the spacecraft is alternately heated and cooled and in this way kept at an even temperature. A shiny gold coating is especially efficient in deflecting the sun's rays. Some spacecraft have a highly polished surface so that they will offer the least possible resistance to the earth's upper atmosphere.

The one thing that spacecraft have in common is their great variety—in size, shape, and the materials of which they are constructed. Even though two spacecraft may belong to the same series and be constructed according to the same general design, each spacecraft is likely to be equipped to perform a slightly different task.

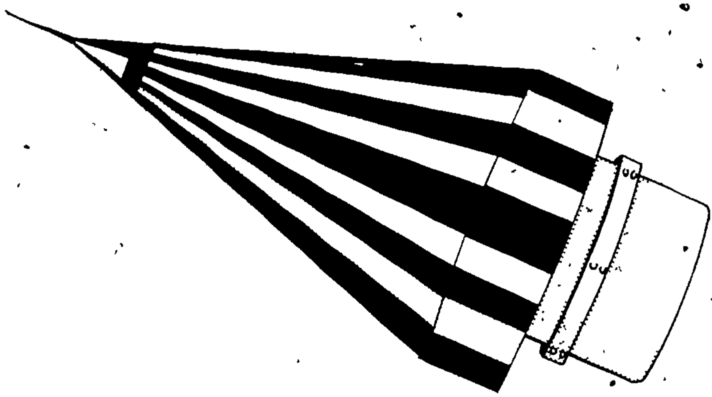


Figure 3. SPACECRAFT STRIPED TO REGULATE HEAT. The dark areas of the Pioneer 4 shown above absorbed heat, the light areas reflected heat. The principal reason for painting spacecraft is to help control the temperature inside the spacecraft.

The most marked differences between spacecraft are found between those that are manned—that is, carry space pilots, or **astronauts**—and those that are unmanned. Chapter 4 describes some of the many different kinds of unmanned spacecraft. Chapter 5 traces the advances made in constructing and navigating manned spacecraft and in enabling men to survive and work in space.

Chapter 6 takes a glimpse at future spacecraft, beginning with the space shuttle and other reusable vehicles that are now being developed as part of the new space transportation system. Such vehicles will return to the earth or to a base in space (**space station**) to be refueled and made ready for the next flight, much as aircraft are now. It is challenging to the imagination to try to picture how the gap between aircraft and spacecraft will be bridged and what the new breakthroughs in spacecraft might be.

Your look into the future will have more meaning if you understand how present-day spacecraft operate. They do not take off as aircraft do but are launched into space by powerful rocket boosters. The rocket booster is the key to present-day space travel.

TERMS TO REMEMBER

spacecraft	atmospheric drag
rocket booster	shroud
orbit	astronauts
celestial bodies	space station

IDEAS TO REMEMBER

1. Spacecraft follow an orbit in space like that of celestial bodies.
2. Spacecraft are constructed in varied sizes and shapes. and they are made of many different kinds of material.
3. Present-day spacecraft are launched into space by rocket boosters.

QUESTIONS

1. What is a spacecraft? How does a spacecraft get its power at launch?

2. What laws do spacecraft follow in their travel?

3. Why must the weight of a spacecraft be kept within rigid limits?

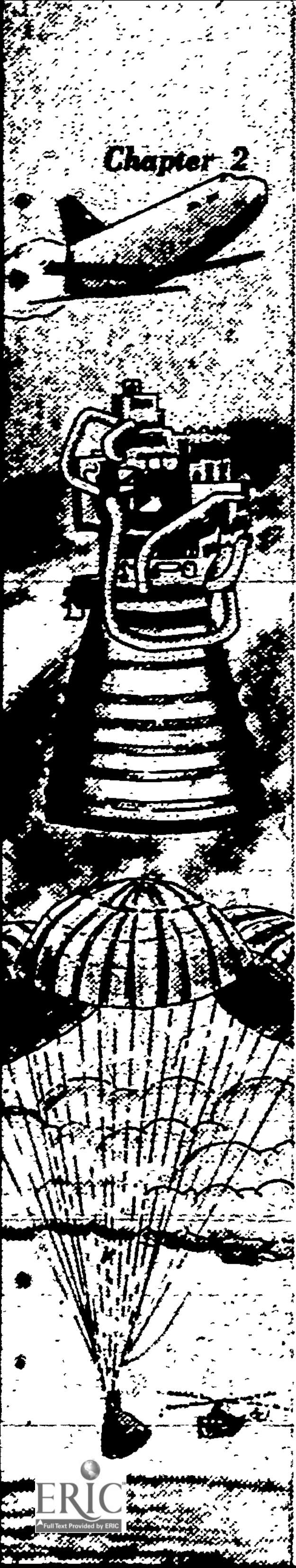
4. What is the purpose of putting special paints and coating on spacecraft?

5. Tell three ways in which spacecraft differ from aircraft.

6. What are the two large classes of spacecraft?

THINGS TO DO

1. Start a scrapbook on spacecraft and their boosters. Plan your collection of clippings. Decide if you will collect clippings on all US and USSR space launches, or if you will concentrate on either unmanned or manned spacecraft of both countries, or if you will collect information on US launches only.
2. Find a schedule of future US space launches. This will help you to be on the alert for important launches. Report to the class on the most important launches to be made during the present calendar year or during the present plus the following year.
3. Find out something about the way the US Government manages its space program. Do some research on the National Aeronautics and Space Administration (NASA), the Space Act of 1958, and the annual budget for the space program. Report to the class on your findings.



Chapter 2

Rocket Boosters

THIS CHAPTER describes the rocket boosters that launch spacecraft. It gives the principal parts of the booster and explains the principles upon which the rocket engine operates. It describes how different rocket engines use either liquid or solid chemical propellants and how the efficiency (specific impulse) of these propellants varies. Next it tells about some of the exotic kinds of propellants that might be used in future space boosters. Then it explains why boosters are staged, how rocket engines are assembled in the stages of the booster, and how the complete assembly for the booster is made up from families of standard boosters with upper stages sometimes added. Finally, the chapter describes how rocket boosters are guided and controlled during flight and the procedures followed at launch time. When you have studied this chapter, you should be able to do the following: (1) list the principal parts of the rocket booster, (2) explain the basic operating principles of the rocket engine, (3) describe the two principal kinds of propellants used in present-day space boosters, (4) explain why space boosters must be staged, (5) name two kinds of guidance systems and two kinds of control systems used in space boosters, and (6) describe gantry operations and countdown before launch.

THE DREAM of space travel did not become a reality until man was able to build the powerful rocket boosters that could lift a spacecraft above the earth and put it into orbit. In ancient times man imagined all sorts of means that he might use for traveling in space and reaching the moon, but these ideas were quite fanciful Many developments in science and engineering had to take place before man could think about space travel in more practical terms. In modern times the stories about space travel written by such men as Jules Verne and H. G. Wells began to take a more scientific turn. Such stories helped to stimulate scientists and engineers to think about generating the tremendous amounts of power that would make space travel possible.

Konstantin E. Tsiolkovsky (1857–1935), a Russian school teacher, said that Jules Verne's writings helped to inspire him with the idea that man could travel in space. Tsiolkovsky, known as the Father of Space Travel, first worked out the theory and calculations for building liquid-fueled rockets that would be powerful and accurate enough to propel a vehicle into space.

The American rocket expert Robert H. Goddard (1882–1945), working independently, also made calculations for building rockets that would make space travel possible. He went further, putting the theory into practice, and therefore became known as the Father of Modern Rocketry. Goddard launched his first experimental liquid-fueled rocket from his Aunt Effie's farm near Auburn, Massachusetts, on 16 March 1926. His rocket rose to a height of only about 41 feet and traveled about 184 feet, but this was the first rocket of a kind that could be developed to go into space.

Another pioneer rocket expert, Hermann Oberth (1894–) a Hungarian-born German, further developed the theory of using rockets for space travel. His book *The Rocket Into Interplanetary Space* was first published in 1923. Later, during World War II, Oberth worked with young German rocket experts who were interested in space travel and knew about the writings of Goddard. One of these young men was Wernher von Braun (1912–), who would later direct the development of the American Saturn boosters. The task set for the German experts at that time was to produce rocket missiles like the V–2 for military use. All the powers used some form of rocket missile during the war, but the German V–2 was the first long-range missile with a guidance system.

Both the Americans and the Soviets used the German V–2 in beginning the research that finally resulted in their intercontinental ballistic missiles. From ballistic missiles were developed the rocket boosters that are being used for the peaceful exploration of space.

Some of the boosters used are still modified ballistic missiles Later US boosters. such as the Titan III and the Saturn boosters. were developed from the beginning for launching spacecraft

A rocket booster that orbits spacecraft, or a **space booster** as it is called, must generate tremendous amounts of power rapidly in order to counteract the gravitational pull of the earth and lift the spacecraft above the earth's atmosphere, and it must. traveling at a precise speed. direct the spacecraft along a pathway that follows the curvature of the earth. A space booster must therefore be both tremendously powerful and highly accurate. This chapter tells how the basic rocket. engine has been developed to give it the power required to reach space and how the rocket booster is accurately guided and controlled. The next chapter explains how this booster orbits spacecraft.

PARTS OF A SPACE BOOSTER

At the present time no single rocket engine is powerful enough to orbit a spacecraft. A space booster is therefore made up of more than one rocket engine, and each engine is inclosed within a separate shell, or stage. All stages of a space booster are connected, and they must be able to work together as a unit. They begin firing, burn out, and drop away one after the other according to precise timing. The rocket stages for each group, or series, of spacecraft are selected and put together to provide the right amount of power and the performance needed for the task assigned.

The largest component of a rocket booster used for orbiting spacecraft is the **propellant**. This is the material that is burned to create the hot gases that are ejected from the shaped opening. or **nozzle**, at the aft end of the rocket to create power, or thrust. The propellant burns in the **combustion chamber**. Rockets burning liquid propellants need piping and pumps. together called **plumbing**, to control the flow of the propellant. The parts of each rocket are assembled and held together by an **airframe**, or shell that protects the launch vehicle as it goes through the atmosphere. The airframe is usually constructed of a lightweight material containing aluminum, and it may be pressurized to give the rocket strength and rigidity.

The rocket stages are held together with explosive bolts. These

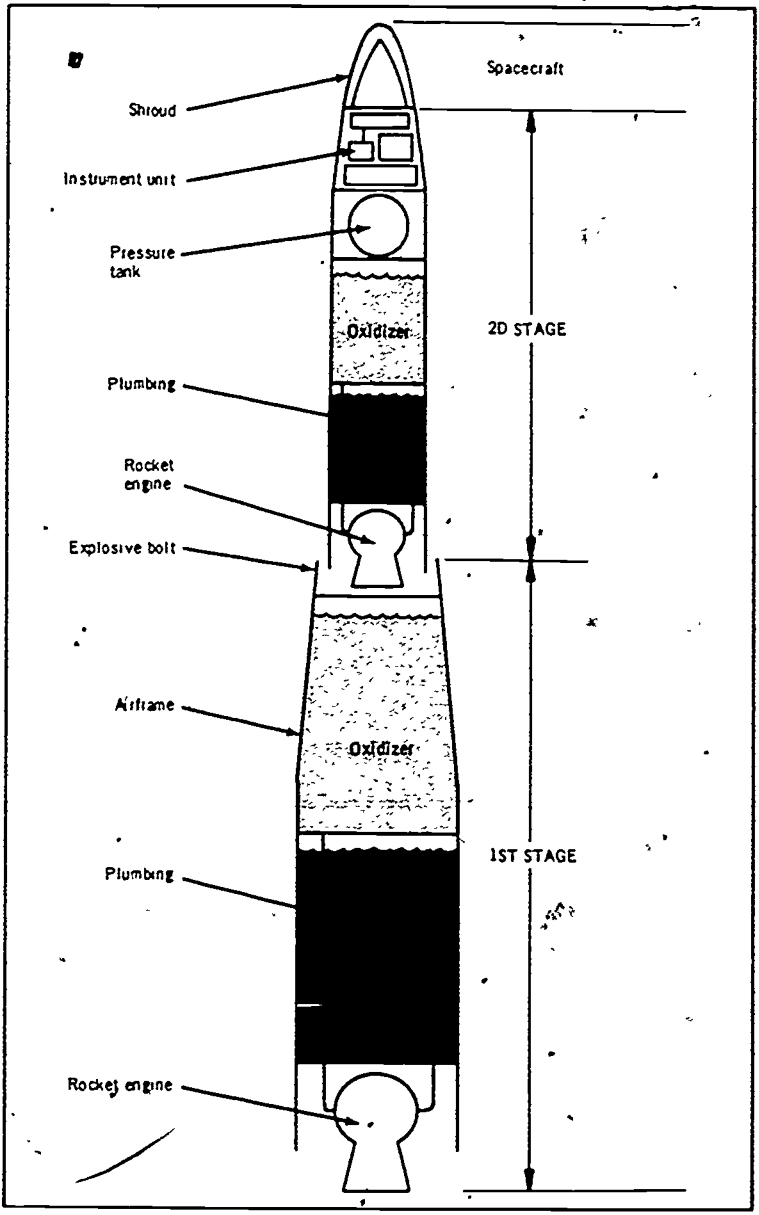


Figure 4. PARTS OF A TWO-STAGE SPACE BOOSTER. As the first stage burns out, the explosive bolts fire. Then the two stages of the booster break apart, and the first stage falls away. Next the second stage fires and begins burning. As the second stage burns out, it orbits the spacecraft. The airframe is a shell for holding the fuel and oxidizer. These are mixed in the combustion chamber of the rocket engine. The instrument unit makes up part of the guidance and control systems.

are fired during the flight to release the stages of the rocket and allow them to be dropped, or **jettisoned**, at the right time.

The complete rocket booster assembly has an instrument unit, which is part of the **guidance system**. Different kinds of control elements, such as fins and movable vanes, are distributed throughout the rocket stages. These are all part of the **control system**. The guidance and control systems in the rocket booster, working with ground units, keep the booster on the course planned for it. If the booster starts to stray from its course, the guidance and control systems put it back on course.

Figure 4 shows the principal parts of a two-stage liquid-fueled rocket booster. Each rocket stage is essentially a shell for containing one or more rocket engines with their propellant. You can get a good idea of how even the most complicated space boosters work if you understand how the rocket engine operates.

PRINCIPLE OF THE ROCKET ENGINE

When Robert Goddard successfully launched the first liquid-fueled rocket in March 1926, he demonstrated that this kind of rocket engine could work. It took the United States and the Soviet Union about 30 more years to develop liquid-fueled rocket engines that could generate enough power to orbit spacecraft. One of the first breakthroughs came in developing liquid propellants for powering rocket engines and in making precise calculations that made such development possible. Tsiolkovsky, Goddard, and Oberth had a part in making this breakthrough.

The idea of the rocket engine itself was not new when Tsiolkovsky first made his calculations. The Chinese people are known to have constructed rockets as far back as the third century. These crude rockets, burning black powder, resembled our fireworks. They could not be controlled, but they did generate some propulsive power. Gunpowder rockets represent the **rocket engine** in its simplest form. They burn gunpowder (the propellant) inside a casing (airframe). As the gunpowder burns, it creates gases that escape through an opening (nozzle) in the end of the rocket (Fig. 5). As the gases stream out of the opening, they propel the rocket in the opposite direction.

Over the centuries mankind developed more powerful gunpowder rockets for weapons. The principle underlying the rocket

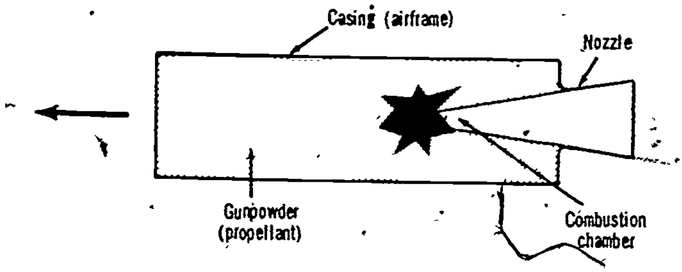


Figure 5. GUNPOWDER ROCKET. The solid mass of propellant (gunpowder) is hollowed out into a cone. Burning begins at the tip of the cone. As burning proceeds the entire casing becomes the combustion chamber. The hot gases formed by the burning gunpowder are ejected from the nozzle at the rear. The rocket shoots in a direction opposite to that in which the gases are escaping.

engine was not defined, however, until Sir Isaac Newton formulated the universal laws of motion near the end of the seventeenth century.

Newton's third law of motion states: For every action there is an equal and opposite reaction. This third law explains the operation of the gunpowder rocket. The action of the jet of gases escaping from the opening of the rocket creates the **reaction force** that pushes against the forward end of the rocket and causes it to surge forward. The burning of the gunpowder produces no propulsion by itself. It can generate heat and light, but no propulsion. But when the heat energy is changed into the energy of motion (**kinetic energy**) in the rushing jet of gases, it creates a force that propels the rocket in the opposite direction.

Newton did not himself apply his third law of motion to the rocket engine, but he predicted that some kind of space booster would one day make use of this principle. He wrote that the third law of motion would "enable mankind in later centuries to undertake flights to the stars."

Since Newton's third law of motion is basic to understanding the operation of the rocket engine, it is helpful for you to know how the law is applied in the kinds of motion you observe around you. Three examples of such application are given here. You can probably think of many others.

You may have tried jumping from a row boat to the shore. This action created an equal and opposite reaction, causing the boat to be propelled backward (Fig. 6). If the force was large

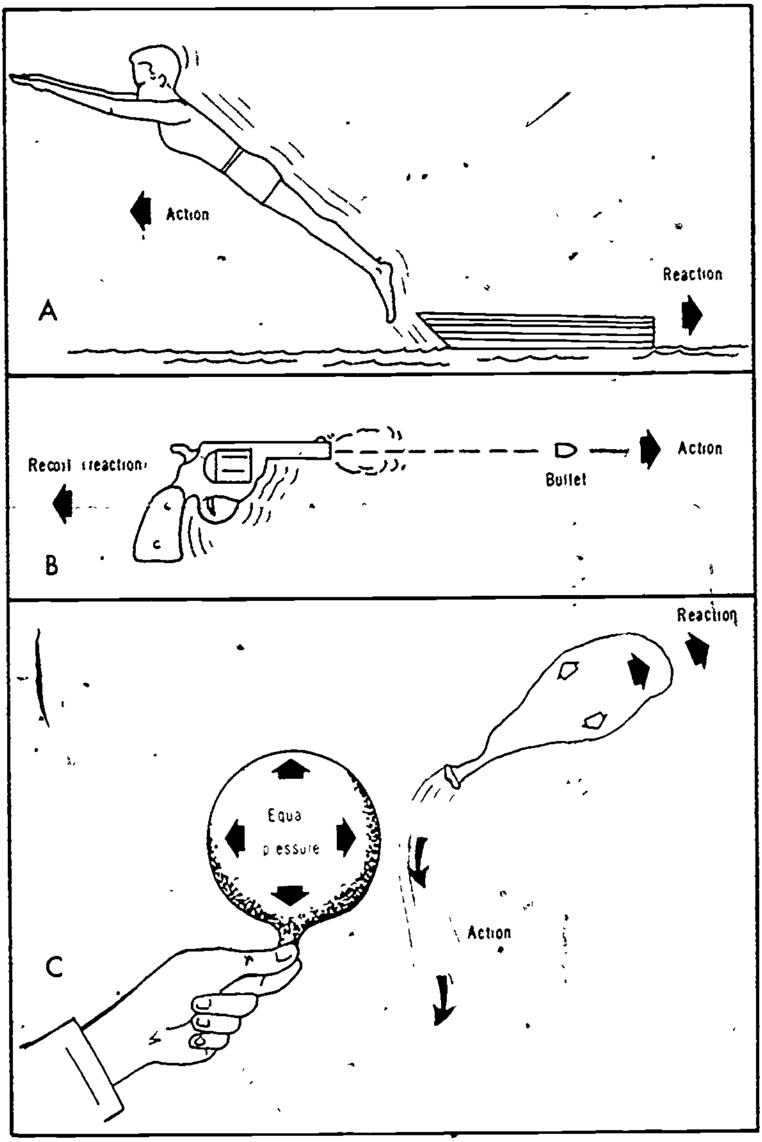


Figure 6. ACTION-REACTION PRINCIPLE. Above are three examples of the application of Newton's third law of motion. The law states. For every action there is an equal and opposite reaction. (A) As the boy jumps forward, the boat moves backward. (B) As the bullet rushes from the barrel of the gun, it causes the gun to move backward (recoil). (C) When the boy holds the opening of the toy balloon, the pressure of the air inside is equal in all directions. There is no motion. When the balloon is released, the air rushes from the opening. The balloon spurts off in a direction opposite to that of the escaping air. Newton's third law also explains the action of the gunpowder rocket and that of the giant rocket engines in the Saturn V booster

enough, you may have lost your footing and fallen into the water.

A gun provides another example. If you have ever fired a gun, you know that it recoils, or kicks back, after being fired. As the powder is ignited, the explosion creates hot gases that propel the bullet from the barrel of the gun. This action creates an equal and opposite reaction that pushes back on the gun, causing it to recoil (Fig. 6).

If you have a balloon, you can easily demonstrate the action-reaction principle for yourself. Blow up the balloon until it is nearly full of air. Then suddenly release the balloon. As the jet of air streams from the opening, it causes the balloon to shoot off in the opposite direction (Fig. 6).

The story is told that when Tsiolkovsky first thought about applying the action-reaction principle to developing the rocket engine, he was watching some young people in Moscow. The youngsters were out for an evening of fun in a horse-drawn wagon. As the boys jumped from the wagon, their action caused the wagon to lurch in the opposite direction. The idea of the modern rocket **reaction engine** was born.

The rocket engines in the space booster generate the tremendous amounts of power that they do according to the principle defined by Newton's third law of motion. They propel the spacecraft into orbit as the result of a reaction force. This is a force equal and opposite to that produced when the hot gases are ejected from the nozzle (Fig. 7). As the gases are ejected, flames strike against the launch pad and the atmosphere, and many persons get the mistaken idea that a booster builds up power as the ground and atmosphere resist the flow of gases. This is not the case. Actually the ground and atmosphere act as a hindrance rather than a help. A space booster operates most efficiently after it reaches space, where there is no atmosphere to offer resistance to the jet of hot gases being ejected from the nozzle.

Beginning with Newton's law and then using other laws of physics, engineers have worked out formulas that enable them to construct rocket engines that derive increasingly more power from the propellant. To understand something about these formulas for computing the power, or **thrust**, of a rocket engine, you need to consider the **jet of the exhaust gases**, as this is the source of the energy that moves the rocket booster. To produce a great amount of thrust in the rocket launch vehicle, a large mass of gases is

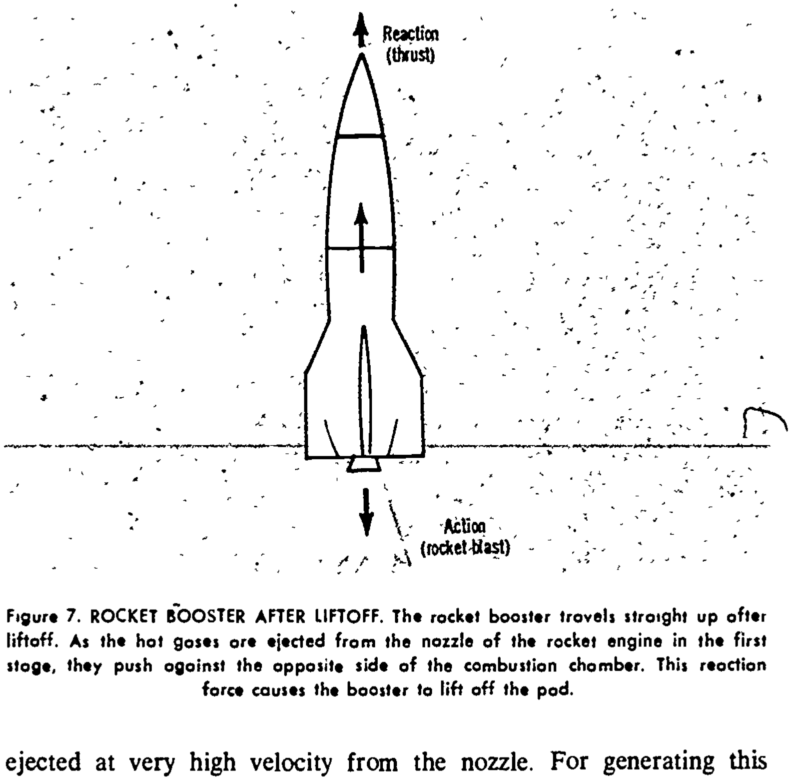


Figure 7. ROCKET BOOSTER AFTER LIFTOFF. The rocket booster travels straight up after liftoff. As the hot gases are ejected from the nozzle of the rocket engine in the first stage, they push against the opposite side of the combustion chamber. This reaction force causes the booster to lift off the pad.

ejected at very high velocity from the nozzle. For generating this fast-moving jet of exhaust gases, tremendous quantities of propellant must be burned within a short time. For example, the five giant rocket engines in the first stage of the Saturn V booster burn some 534,000 gallons of propellant in about 2½ minutes.

Design features also help in increasing thrust. In order to bring the exhaust gases up to the extremely high speeds required in the modern engines used in space boosters, rocket engineers have designed specially shaped nozzles. By using a pinched nozzle, or a **convergent-divergent nozzle**, like the one shown in Figure 8, they are able to accelerate the flow of gases to velocities of more than 5,000 mph. The principle applied is the same as that demonstrated when you pinch a garden hose and cause the water to spurt out at a greatly increased velocity. The nozzle of a rocket engine is used to convert a decrease in the pressure of the hot gases into an increase in their velocity, according to Bernoulli's law. The nozzle continues to act to speed up the flow of the gases as long as the propellant is burning.

The thrust of a rocket booster is expressed in either of two ways: (1) the total thrust produced by all the rocket engines in the first stage at liftoff or (2) the number of pounds that can be lifted by the booster to a certain orbit. The Saturn V that launched the Apollo–15 spacecraft generated about 7.5 million pounds of thrust at liftoff. Expressed in another way, the Saturn V generated enough thrust to boost a payload of about 280,000 pounds into a near-earth orbit. The Saturn V is at present the most powerful space booster in the world.

The largest part of the thrust produced by a rocket booster must be used in lifting the weight of the booster itself, including its heavy load of propellants. Only a relatively small part of the thrust is left over for lifting the payload, or the spacecraft. Saturn V weighs more than 6 million pounds when fully fueled. It can put a payload of about 280,000 pounds into a near-earth orbit, as noted. The Jupiter C booster that launched the Explorer 1,

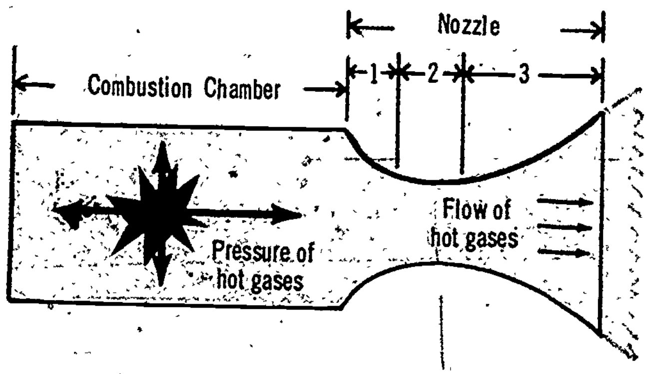


Figure 8. CONVERGENT-DIVERGENT (PINCHED) NOZZLE. Pressure builds up as the hot gases are held in the combustion chamber. The convergent, or narrowing, portion of the nozzle (1) keeps the gases from moving out freely, and pressure increases in the combustion chamber. As the gases start to move through the convergent portion of the nozzle, pressure begins to decrease, and velocity increases to sonic speed in the throat (2). In the divergent, or widening, portion of the nozzle (3) pressure falls rapidly, and the gases reach supersonic speed. The convergent-divergent nozzle applies Bernoulli's law. As the pressure of fluid particles (liquids or gases) decreases, velocity is increased, and conversely.

the first American satellite, into an earth orbit weighed about 80,000 pounds. Explorer 1 weighed only about 31 pounds.

Although the rocket booster may at first consideration appear to be a poor weight-lifter, such is not the case. The rocket booster is in fact a highly efficient weight-lifter. It must lift the spacecraft from the earth against the strong pull of the earth's gravity and the drag force of the atmosphere and carry the spacecraft for great distances at extremely high velocities. To do this requires tremendous amounts of thrust even though the weight lifted is relatively small. Actually rocket boosters generate great amounts of thrust in proportion to their weight (have a high **thrust-to-weight ratio**).

The jet engine used in aircraft, like the rocket engine in the space booster, is a modern reaction engine. Both kinds of engines depend for their power upon energy generated as a reaction against a jet of hot gases ejecting from a nozzle. Both transfer power directly to the vehicle without the need of moving parts. Aircraft powered by the most advanced ramjet engines could not travel at speeds higher than about 4,000 mph in the earth's atmosphere. A spacecraft that is being put into a low earth orbit, together with its booster, is traveling at a velocity of about 17,500 mph. Of the two kinds of modern reaction engines, only the rocket engine can generate the high velocities required for orbiting spacecraft, and only the rocket engine can operate in space. Jet engines depend upon the atmosphere for the oxygen required for burning their fuel. Rocket engines take their own oxygen and fuel with them in the rocket propellant.

PROPELLANTS FOR ROCKET ENGINES

Each stage of a rocket booster is actually little more than a shell for containing the tremendous amounts of propellant, or working material, that must be burned to produce the thrust required for propelling the spacecraft. To gain more room for storing propellants, all fittings within the airframe of a rocket are reduced to a minimum. The airframe is often used as the walls of the combustion chamber or as part of the storage tank for the propellant. Large amounts of propellant are required for space boosters not only because of the tremendous amounts of thrust that must be generated but also because the propellant must comprise both fuel and oxidizer. The rocket engine carries its own oxidizer with it into space. The jet engine takes its oxygen from the air around it.

In some rocket engines the fuel and oxidizer are mixed in one kind of material, as they are in gunpowder rockets and modern solid-fueled rocket engines. In the liquid-fueled engines, the oxidizer and the fuel are usually two separate fluids. For example, the early V–2 rockets and many of the modern rocket engines in space boosters use kerosene as the fuel and liquid oxygen (LOX) as the oxidizer.

Present-day propellants are of two principal kinds: **liquid and solid chemicals**. The first breakthrough in producing space boosters came when scientists and engineers realized the possibilities that liquid propellants had for generating great amounts of power and developed these propellants. Later, solid chemicals were also developed for use as propellants. Now solid-fueled rocket engines are being used to provide additional power, but liquid-fueled engines are still the mainstay for powering space boosters. Therefore liquid propellants are considered first and in more detail. Before you can compare the different kinds of propellants, it is necessary to have some measure of their efficiency.

Specific Impulse: Measure of Efficiency

Rocket engineers measure the efficiency of a propellant in terms of its **specific impulse**. This is the measure of the amount of power, or thrust, that the propellant will deliver. When a rocket engineer says that a propellant has a specific impulse of 350 seconds, he means that it produces 350 pounds of thrust for each pound of propellant burned in one second. The higher the specific impulse of a propellant is, the more efficient it is.

In general, liquid propellants are much more efficient than solid propellants, and they burn for a longer time. Specific impulses for solid propellants range from 175 to 250 seconds. Those for liquid propellants now range up to about 450 seconds. Formerly the theoretical limit for chemical propellants was set at 400 seconds, but new chemicals are being used, and old chemicals have been improved. By keeping in mind the range of efficiency ratings, or specific impulse, of the propellants just noted, you will have a measure for comparing present-day liquid and solid chemical propellants with the exotic propellants likely to be used in the future.

Liquid Chemical Propellants

Liquid propellants are especially suited for use in space boosters because their burning can be controlled. By regulating the flow of liquid propellants, it is possible to speed up the engine, throttle it (slow it down), and accurately control burnout.

In rocket engines burning liquid propellants, the fuel and the oxidizer are usually stored in separate tanks. They are fed into the combustion chamber where they are combined and burning takes place (Fig. 9). The most frequently used liquid fuels and oxidizers require firing, and an electric spark is used for the purpose. Such propellants are highly explosive. For this reason the booster cannot be fueled until just before launch. Some fuel and oxidizer combinations, such as that used in the Titan II booster, which launched the Gemini spacecraft, ignite upon contact and do not require firing. Such a propellant, known as a **hypergolic propellant**, can be stored. Then fueling does not have to be delayed until the booster is about ready to be launched, and preparations before launch can be speeded up as a result.

Although the theory of the liquid-fueled rocket, as shown in Figure 9, is simple in itself, in practice complications arise. The liquids must be kept in place, and they must be made to flow into the combustion chamber at a precise rate. As a result, an intricate system of valves, pumps, and pipes is required.

There are two principal ways of controlling the flow of liquid propellants. They may simply be forced into the combustion chamber by using gas under pressure (Fig. 10), or they may be pumped into the combustion chamber (Fig. 11). The pressure-fed system has the advantage of being extremely simple, but it is limited in practical value. It is used for rockets that develop only a small amount of thrust and burn for only a short time. Pump-fed systems are generally used in space boosters. They are designed to burn large volumes of propellant and produce great amounts of thrust. With both kinds of systems the flow of fuel and oxidizer into the combustion chamber is carefully controlled so that the two liquids are mixed in the correct proportion. The total amount of each liquid is measured accurately to control the time that the engine burns. If unused propellant remains in the rocket at burnout, it adds to the deadweight of the booster.

As the propellant burns, temperatures as high as 4,000 to 6,000 degrees F. are reached in the combustion chamber and the nozzle.

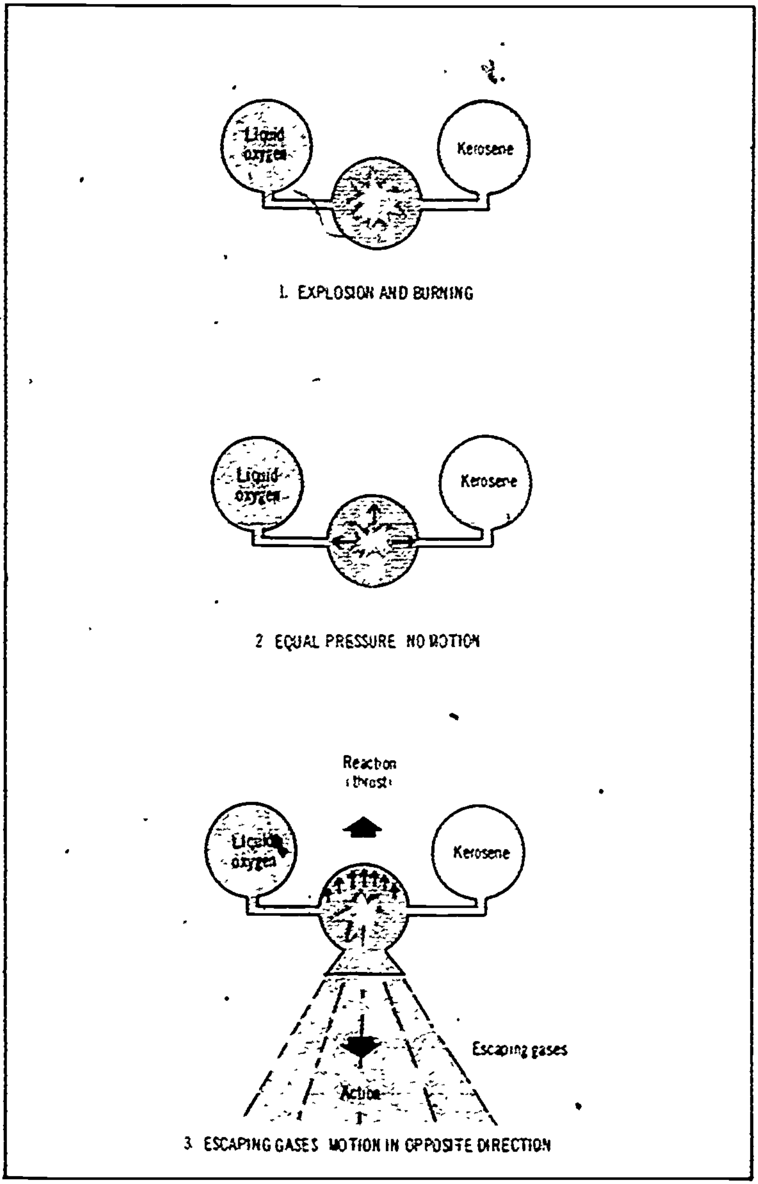


Figure 9. PRINCIPLE OF LIQUID FUELED ROCKET ENGINE. The fuel (kerosene) and the oxidizer (liquid oxygen) are stored in separate tanks. They are mixed in the combustion chamber. Here they are fired, and an explosion and burning takes place. If the gases are kept within the combustion chamber, pressure builds up equally on all sides of the chamber. If the chamber has an opening (nozzle), the hot gases escape. As they rush from the nozzle, they create an equal and opposite reaction, causing the rocket to move upward.

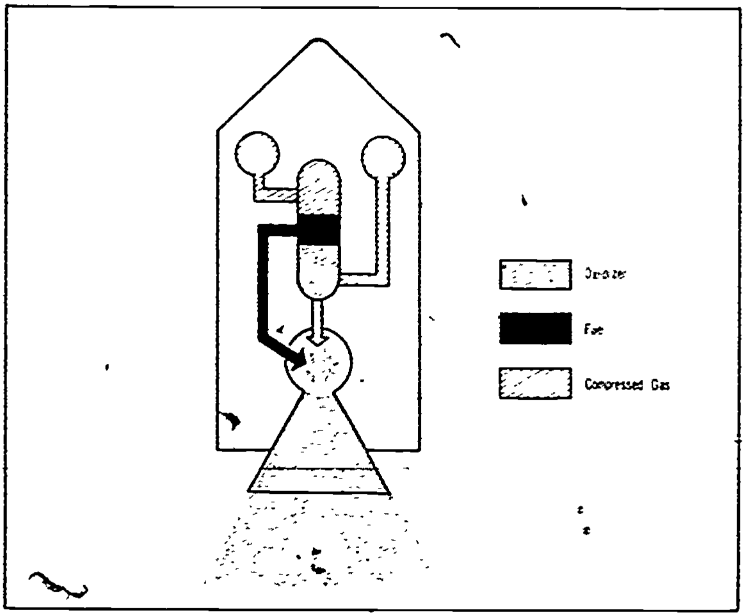


Figure 10. PRESSURE-FED LIQUID-FUELED ROCKET ENGINE. The above diagram shows one version of a pressure-fed rocket engine. Compressed air or other gases are used to force the liquid fuel and oxidizer into the combustion chamber. The pressure-fed system is simple but limited in practical value. It is too heavy to compete favorably with pump-fed systems.

At such high temperatures the materials in the walls of the chamber and the nozzle would soon melt. To keep the walls of the combustions chamber and the nozzle from overheating, supercooled oxidizer or fuel is circulated through the hollow walls of the chamber and nozzle before being fed into the combustion chamber (Fig. 12).

In theory, a rocket engine could burn its propellant gradually over a period of time. In practice, this is never done. If a rocket were to develop just enough thrust to counter gravity and support its weight, it would hang suspended in the air until all its fuel burned. If a rocket engine is to do the job intended (boost a spacecraft into orbit), it must be able to deliver large amounts of thrust within minutes. To do this, it must support rapid combustion of the propellant and hurl large amounts of hot gases from the nozzle at extremely high velocities. One way to increase thrust is to speed up the rate of burning in the combustion chamber. Another way is to use a propellant that introduces lightweight gases, which can reach high velocities, into the exhaust system.

To obtain a fuel with a higher rate of efficiency, or a higher specific impulse, engineers decided to try using hydrogen. This would put hydrogen gas into the exhaust stream. Hydrogen had been suggested as a rocket fuel by both Tsiolkovsky and Oberth, but it was not actually used by the United States until this country developed the Centaur upper stage. The Centaur was still under development when engineers began work on the engines to be used in the second and third stages of the Saturn V moon booster. These engines also use liquid hydrogen as fuel and liquid oxygen as oxidizer. This propellant combination can develop a specific impulse as high as 450 seconds. The combination of kerosene and

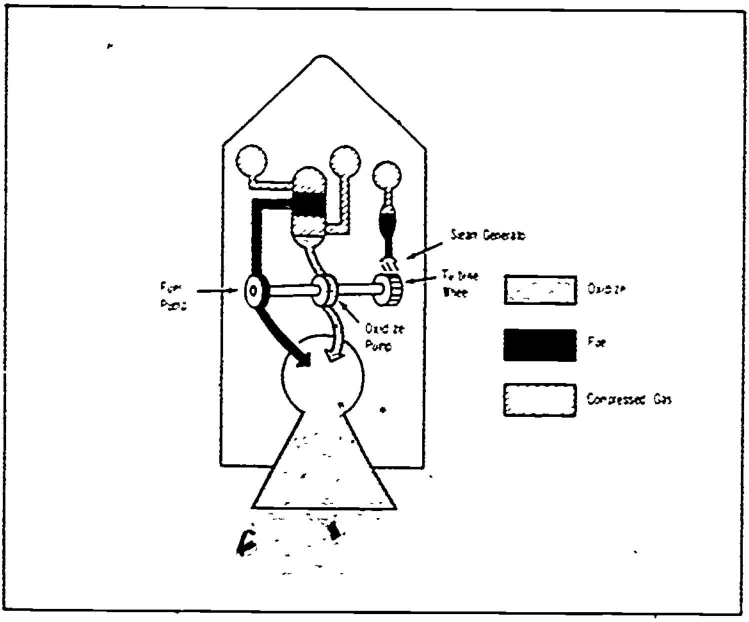


Figure 11. PUMP-FED LIQUID FUELED ROCKET ENGINE. The above diagram shows one version of a pump fed rocket engine. Such a system has an oxidizer pump and a fuel pump. Both pumps are driven by a turbine wheel. Power for driving the turbine wheel is obtained from the same kind of fuel as is used in the rocket engine. It may also be obtained from chemicals. Pump fed rocket engines are relatively lightweight and can handle large quantities of propellant.

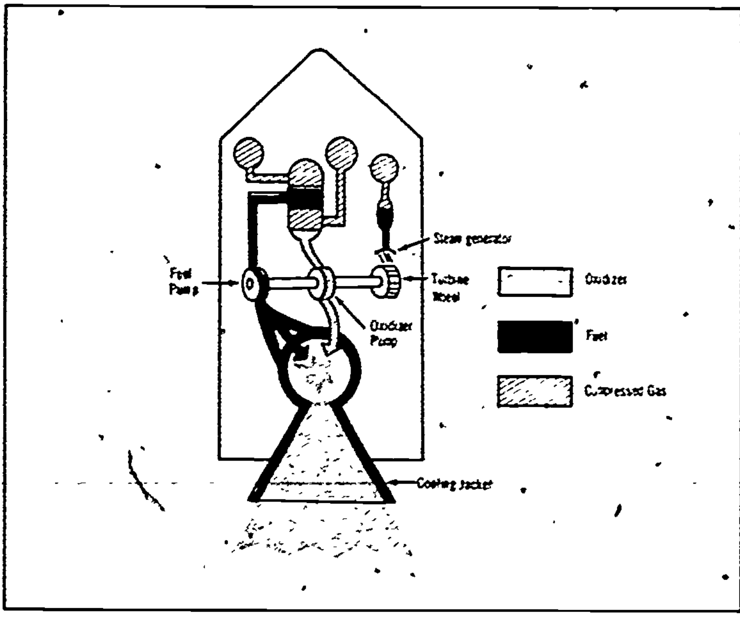


Figure 12. SYSTEM FOR COOLING COMBUSTION CHAMBER AND NOZZLE. In the version of a pump-fed engine shown in the above diagram, fuel is diverted for cooling. Before the fuel is injected into the combustion chamber it is circulated through the hollow walls of the nozzle and combustion chamber. The fuel represented above is liquid hydrogen, a supercooled liquid. In some systems the oxidizer is used as a coolant instead of the fuel.

liquid oxygen, which is used in the first stage of the Saturn V, has a specific impulse of 250 to 300 seconds.

Rocket engineers try to find the best combination of fuel and oxidizer (usually liquid oxygen) to produce the highest specific impulse and give the kind of performance needed. Unfortunately, the fuels and oxidizers that produce the highest specific impulse are usually the ones that are the most difficult to handle and store. They are highly poisonous, corrosive, or flammable, or they have to be kept at extremely low temperatures to keep them from boiling away. Liquid oxygen is difficult to handle because it must be kept at a very low temperature (−297 degrees F.). Liquid hydrogen is much more difficult to store and handle, as it must be kept at a much lower temperature (−423 degrees F.).

Usually a liquid chemical is a good rocket fuel or oxidizer because it is highly active. Such propellants challenge engineers to find materials for building storage containers for them and for handling them in the booster. All the piping required for handling liquid propellants adds to the deadweight of the booster. Therefore rocket engineers are interested in the possibilities of using solid propellants.

Solid Chemical Propellants

Rocket engines burning solid propellants are much less complicated than liquid-fueled engines. In solid-fueled engines the combustion chamber and the tank for storing the propellants are one and the same. In the gunpowder rocket, one of the simplest forms of the rocket engine, the solid mass of propellant is hollowed out in the shape of a cone (Fig. 5). After the rocket is fired, it starts to burn, causing hot gases to be ejected from the nozzle.

The modern solid-fueled rocket engines used in space boosters operate according to the same basic principle. The propellant is usually not a simple powder, however, but a complex mixture of chemicals with gunpowder and oxygen blended together. Usually, smokeless gunpowder is used. When the solid propellant is manufactured, it is passed through a die to form a grain, or shape, that allows for burning over a large area at one time, as shown in Figure 13. In the simplest firecracker rocket, the burning takes place in a highly restricted area at the tip, and the propellant burns much as a cigarette does. In the high-powered rocket engine, the larger burning area allows for the production of greater thrust and higher velocities. Burning is controlled by the design of the grain and by an inhibitor (material to prevent burning) inserted between the charge and the wall of the rocket chamber.

Although solid propellants can be controlled during burning, the specific impulse of solid fuels is usually lower than that of liquid propellants, as noted. Solid propellants can be more easily stored, however. They are generally used for upper stages of space boosters, and they are useful for supplying additional power in any stage.

Since both solid and liquid chemical propellants are approaching the upper limits of their efficiency, engineers are looking for new sources of energy.

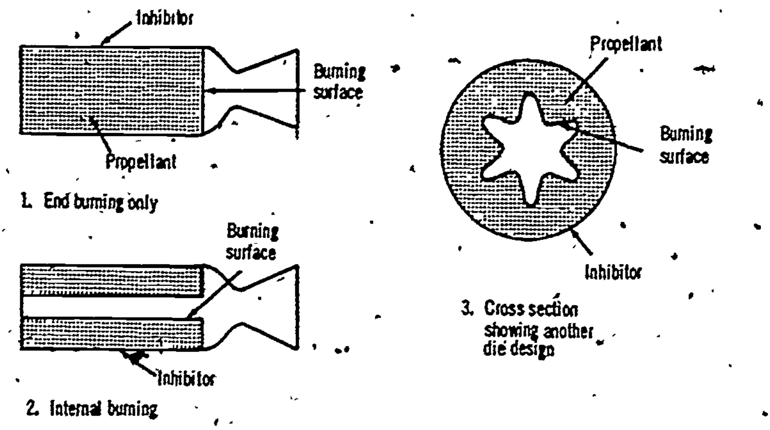


Figure 13. END BURNING AND INTERNAL BURNING IN SOLID-FUELED ROCKETS. In the firecracker rocket (1) burning is restricted. The powder charge (propellant) completely fills the casing. After the charge is ignited, it burns on the end only. In the modern solid-fueled rocket engine (2) burning takes place internally, and there is a much larger burning surface. The solid propellant may be shaped in many different forms. Above is shown the star design (3). This provides for a large burning surface.

New Kinds of Propellants

The liquid and solid propellants just described produce energy through chemical means. Chemicals are burned in the combustion chamber to produce a jet of hot gases that is ejected from the nozzle. Other means could be found for producing static energy that could be converted into kinetic energy in the rocket engine, and other substances besides hot gases could be ejected from the nozzle to produce a reaction force. Nuclear energy or solar energy (heat from the sun) could be used to produce a stream of hot gases. Also, the hot gases rushing from the nozzle could be replaced by other forms of energy, such as streams of photon energy (high-energy light beams) or electrical energy (ions, or charged particles). All these exotic kinds of energy are being studied for use in future space boosters and spacecraft.

Most of the new kinds of energy would produce propellants with a much higher specific impulse, or higher efficiency, than those now in use. The theoretical specific impulse of the solar rocket is 450 seconds, of the ion rocket, 10,000 to 20,000 sec-

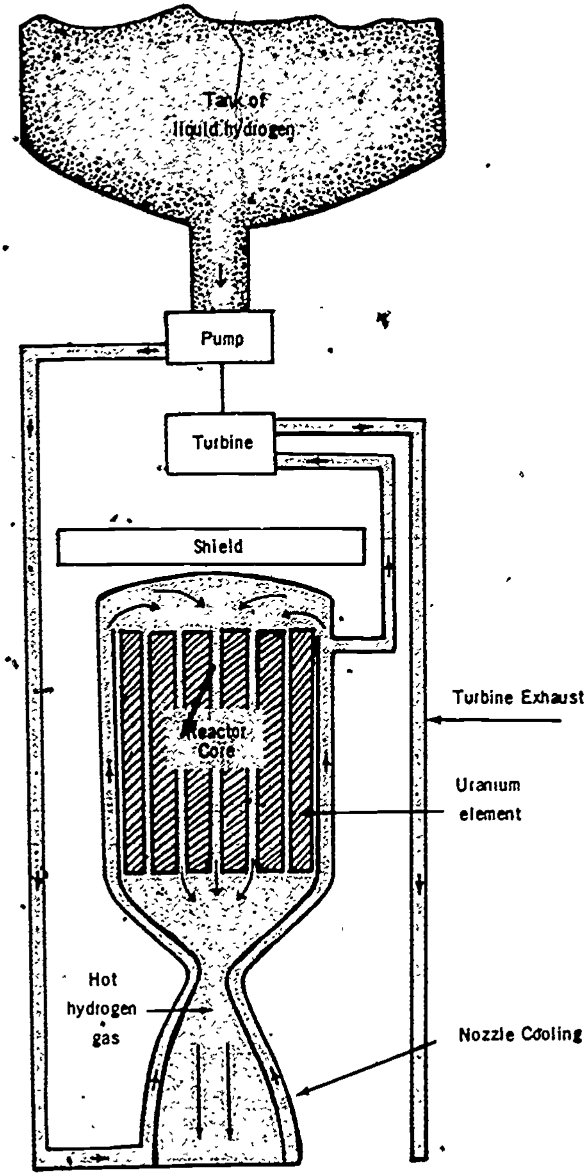


Figure 14. PRINCIPLE OF THE NUCLEAR ROCKET. The diagram above shows how the NERVA rocket operates. Liquid hydrogen is first circulated to cool the nozzle. The partially heated fluid, possibly a mixture of liquid and gas, then enters the reactor. As it passes through the reactor the hydrogen gas reaches an extremely high temperature. As the hot gas passes through the nozzle, pressure is decreased and velocity increased. The hot gas is ejected at great velocity from the nozzle. The large NERVA nuclear rocket engine has been cancelled, but its principle of operation can be applied in developing smaller nuclear rockets.

onds; of the nuclear rocket, 600,000 to 1,000,000 seconds, and of the photon rocket, 30,000,000 seconds.

Although these new kinds of propellants would be highly efficient in space and could generate extremely high velocities, they could not produce large amounts of thrust at any one time. Since the machinery required for generating such energy would be quite heavy in relation to the amount of thrust produced, such rocket engines would have a low thrust-to-weight ratio. Although chemically fueled rockets must carry heavy loads of propellants, they produce great quantities of thrust in proportion to the load carried (have a high thrust-to-weight ratio). Chemically fueled rocket boosters would still have to do the heavy work of giving the spacecraft its first boost up from the earth. The new propellants could be used in the upper stages of the booster or for propulsion in the spacecraft after it is released from the booster.

Of the new kinds of propellants, only that for a **nuclear rocket** is likely to be ready for use in the near future. The first static tests of a nuclear rocket engine, the NERVA, have already been completed. This engine works according to a simple theory. Liquid hydrogen is used as the propellant. This is heated by passing it through a nuclear reactor (Fig. 14). As the hot gas leaves the reactor and passes through a pinched nozzle, its speed is increased, and it is ejected from the nozzle at extremely high velocities, producing thrust in the opposite direction. Work is no longer being done on the large NERVA rocket, but the technology already developed can be used in producing smaller nuclear rockets.

While the new forms of rocket propellants are being studied, engineers are obtaining greater amounts of thrust from chemically fueled space boosters by improving the methods of assembling the engines in the booster.

ASSEMBLING ROCKET ENGINES IN THE BOOSTER

In designing and assembling space boosters, engineers follow the old adage: There is strength in numbers. To gain power and employ it to best advantage, they use more than one, and usually several, rocket engines in a booster. The engines are assembled in three ways. (1) by **staging**, (2) by **clustering**, and (3) by **adding strap-on engines**. All space boosters are staged. The larger and more advanced boosters gain additional thrust by clustering engines within a single stage or by adding strap-on engines.

Staging

The step principle, or the idea of staging rockets by placing one above the other, was first advanced by Tsiolkovsky. It has been followed since the beginning of space travel and has been a key to securing the vast amount of thrust required for orbiting spacecraft.

In staging rockets, engineers put the largest and most powerful rocket at the bottom, a smaller and less powerful rocket next, and above this a still lighter and less powerful rocket (Fig. 1.5). The spacecraft rests on top of the stack. Theoretically at least, a booster could have any number of stages, but practical considerations usually limit the number of stages to two or three. The first stage must be the most powerful. When it fires, it must lift the complete assembly up from the earth and begin the vertical climb. It must counter the strongest gravitational pull and the heaviest atmospheric drag force. After the first stage burns out, it is separated and falls away. The second stage fires and speeds up the booster. By this time the booster has begun to tip over, and the drag forces acting upon it are greatly reduced. After the second stage burns out, it is jettisoned, and the load is further lightened. Deadweight is eliminated each time a stage drops off. The top stage, which is the lightest in weight, fires to accelerate the spacecraft to the speed required for orbiting.

As each stage of the booster fires, the velocity generated is added to that attained by the previous stage. For example, the first stage begins at zero velocity. It may accelerate the booster to 10,000 mph. The second stage begins at this speed, and it may accelerate to 14,000 mph. The third stage, beginning at 14,000 mph, may accelerate the spacecraft to 17,500 mph, a speed high enough to cause it to orbit.

Although staging makes possible a more efficient use of power, the number of stages is limited by the deadweight added. This may more than offset the increase in thrust produced by adding another stage. At this point it may be necessary to cluster engines.

Clustering Engines

When the Saturn boosters were being developed, clustering engines within a rocket stage was a new approach. Engines that are clustered are arranged about the center line, or axis, of the

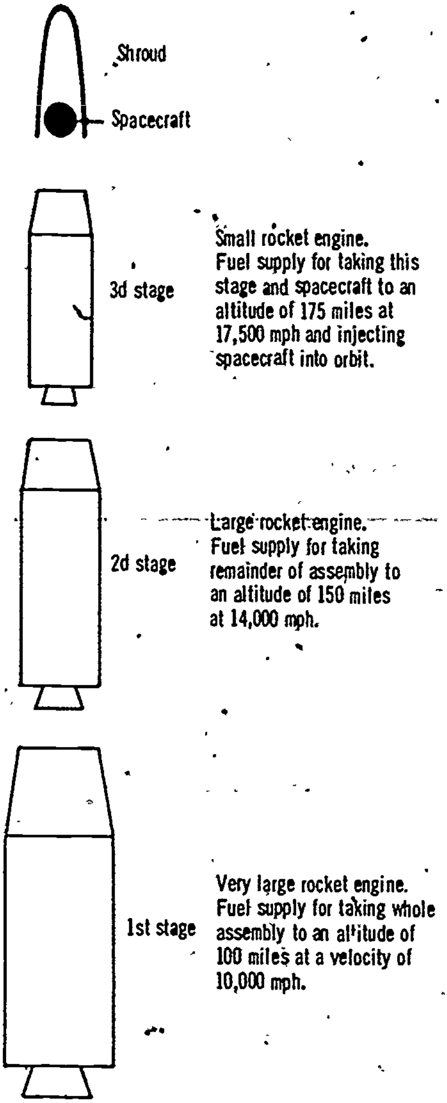


Figure 15. STAGES OF A ROCKET BOOSTER. The three stages of the rocket booster shown above are clamped together at launch. The whole assembly (three stages and spacecraft) is stacked up on the launch pad with the spacecraft at the top Note that the first, or bottom, stage is the largest and has the most powerful rocket engine. The second stage has a less powerful engine. The third stage has the smallest engine This top stage reaches the high velocity required for orbiting the spacecraft. The velocity of each stage is added to that of the preceding one.

rocket so that balance is achieved and the booster will be stable in flight. The engines may be placed one beside the other (parallel staging), or they may be arranged in a circle about the center of the rocket (Fig. 16). All engines in the cluster are fired at one time to produce a great burst of power.

In the Saturn V, five engines are clustered in the first stage and five engines in the second stage. The giant kerosene-fueled engines in the first stage each develop about 1.5 million pounds of thrust, making a total of about 7.5 million pounds of thrust at liftoff.

Another way of increasing the thrust of a space booster is to add strap-on engines.

Adding Solid-Fueled Strap-on Engines

By adding strap-on engines to the original rocket booster, engineers are able to gain large amounts of additional thrust. Solid-fueled engines, which do not require piping, are used for the strap-ons. Usually strap-on engines are added in groups of twos or threes. The total thrust produced by the strap-on engines may actually be several times more than that produced by the engines in the original rocket booster.

The giant Titan III may use several strap-on engines to generate a much greater burst of power at liftoff.

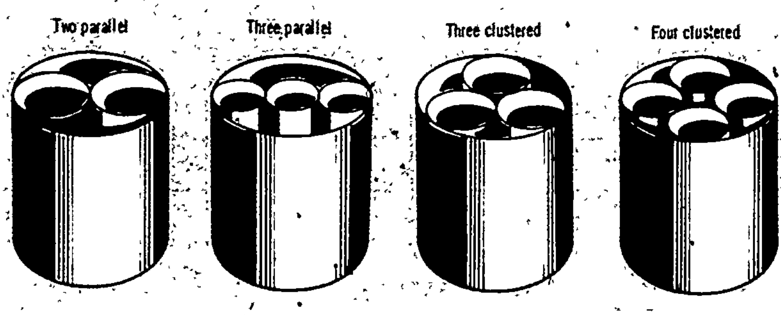


Figure 16 CLUSTERING ROCKET ENGINES. The engines are positioned within each rocket stage in such a way that they are balanced about the center line of the rocket. The engines may be placed one beside the other (parallel staging), or they may be placed in a circle about the center line of the rocket.

To provide the right amount of thrust needed for a particular mission, planners begin by selecting a basic booster from the families of standard boosters.

FAMILIES OF BOOSTERS

In the United States space boosters developed along "family" lines. Instead of attempting to develop a different kind of booster for each type of mission, US planners developed families, or series, of standard launch vehicles and then selected the booster for each mission from the families of boosters. In this way it was possible to develop each standard vehicle more fully and to obtain a wealth of information on its launches.

The families of boosters includes a series of standard boosters. Each family has developed within a certain thrust range and is therefore capable of boosting spacecraft within a certain weight category. Beginning with the smallest booster family and ascending in order to the largest and most powerful, the standard US space boosters are the Scout, the Thor (Delta), the Atlas, the Titan, and the Saturn boosters (Fig. 17).

Each family of boosters began with a basic booster and then developed in either of two directions: (1) by improving the original design of the booster or by using devices to increase thrust, and (2) by using the booster with various combinations of upper stages. The upper stages used most often at the present time are Burner II, Agena, and Centaur.

The Scout, a solid-propellant booster, is used in three-stage or four-stage combinations to orbit small spacecraft carrying scientific payloads. It is an exception to the rule that solid-fueled boosters are not used as first stages of space boosters.

The original Thor booster, a liquid-propellant intermediate-range missile, had its thrust increased through the use of both solid-fueled strap-on engines and additional liquid propellant. One version of the Thor booster is the three-stage Delta booster. The basic Thor booster, combined with many different upper stages, used to be the workhorse of the space program. Among other upper stages used with the Thor is the standard Agena upper stage.

The Atlas (Fig. 18), a liquid-fueled booster, was, in the earliest stage of development, the first US intercontinental long-range missile. It was modified for launching the first US manned spacecraft, the Mercury. The Atlas rather than the Thor is now the

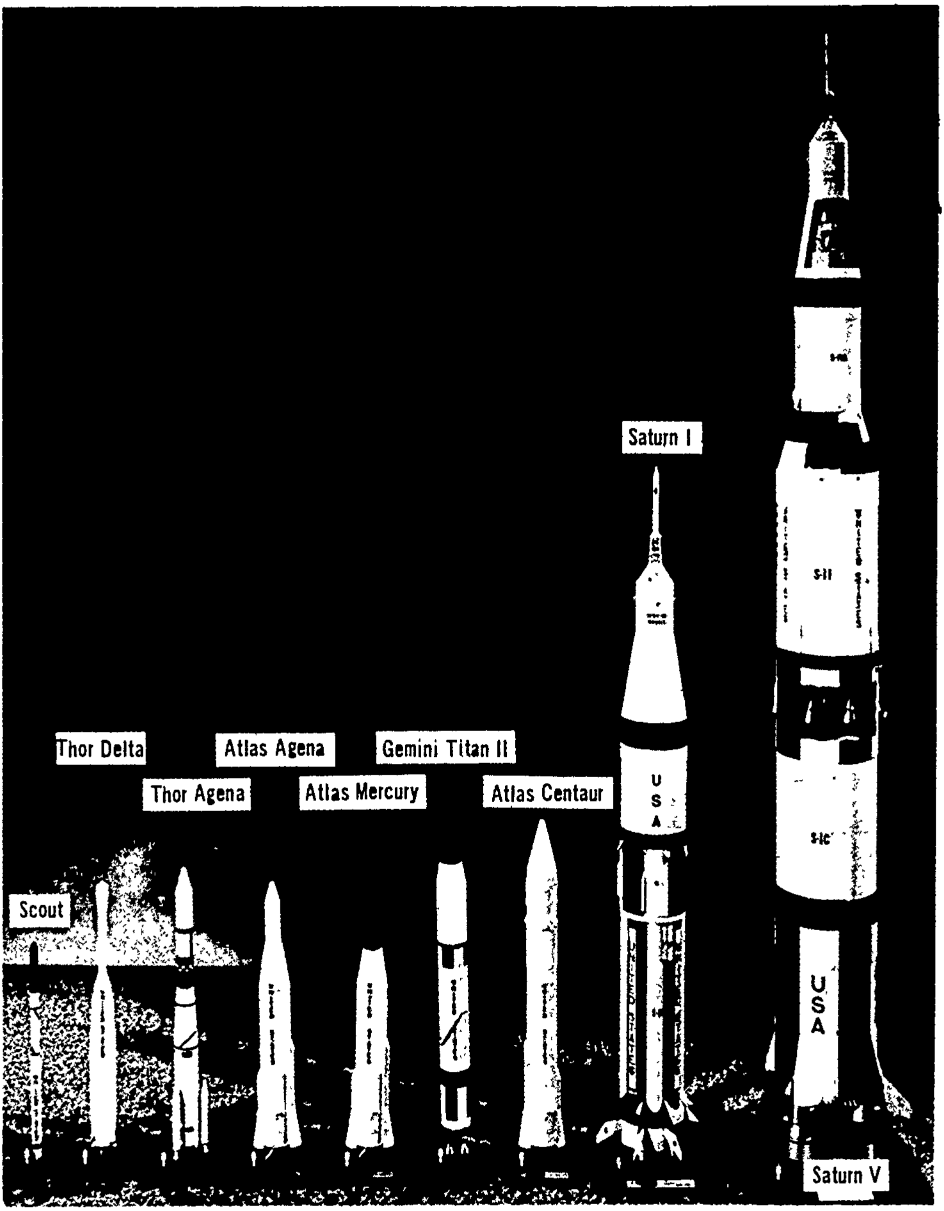


Figure 17. US STANDARD SPACE LAUNCH VEHICLES Above are shown models of some of the launch vehicles made up from the families of standard boosters, together with upper stages. The Delta is a basic Thor booster with three strap-on engines added to the first stage and a Vanguard third stage. Note the size of the Saturn boosters.

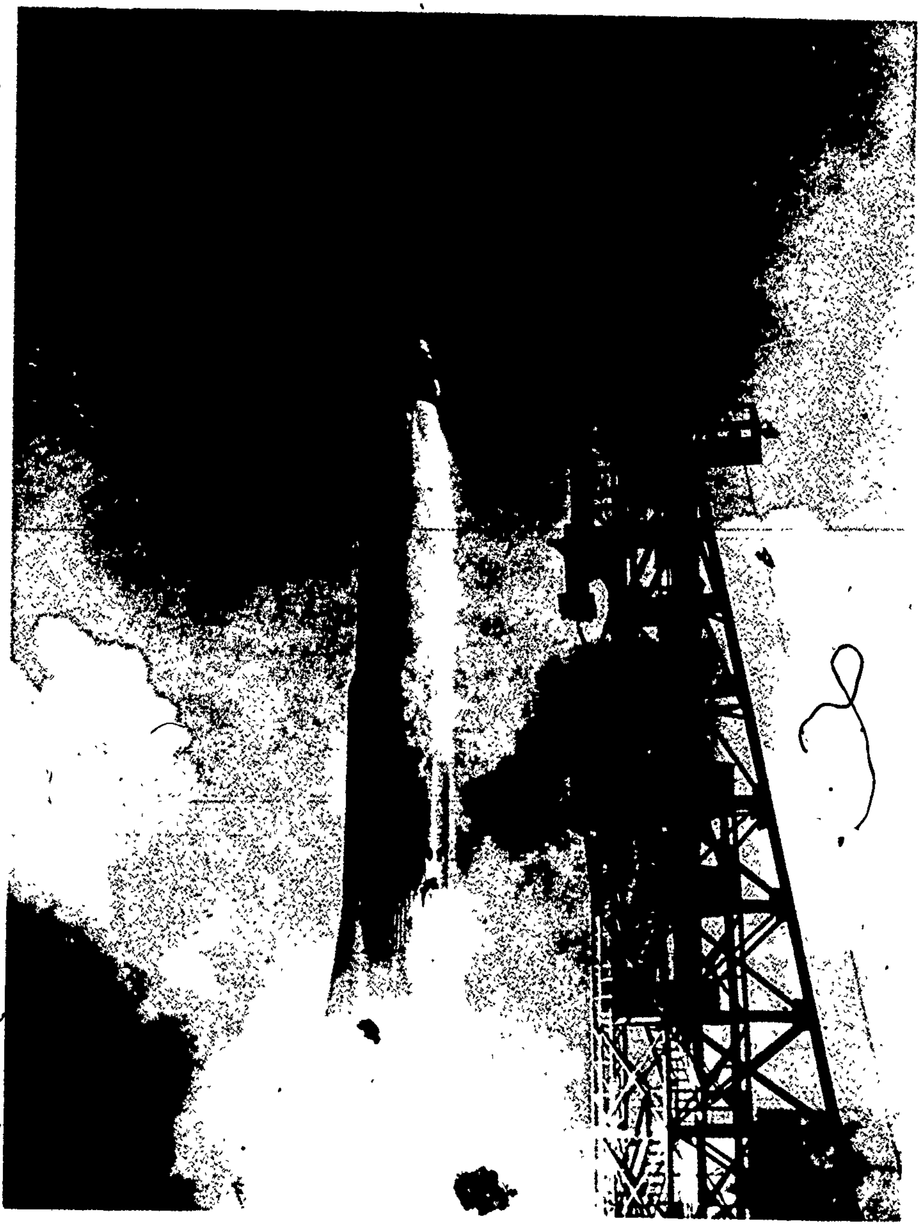


Figure 18 ATLAS BOOSTER LAUNCHING MERCURY SPACECRAFT Above is shown the liftoff of the Atlas-Mercury 6 flight carrying Astronaut John Glenn into orbit Glenn made the first US orbital flight The Atlas booster was used for launching the Mercury spacecraft on all the manned orbital flights

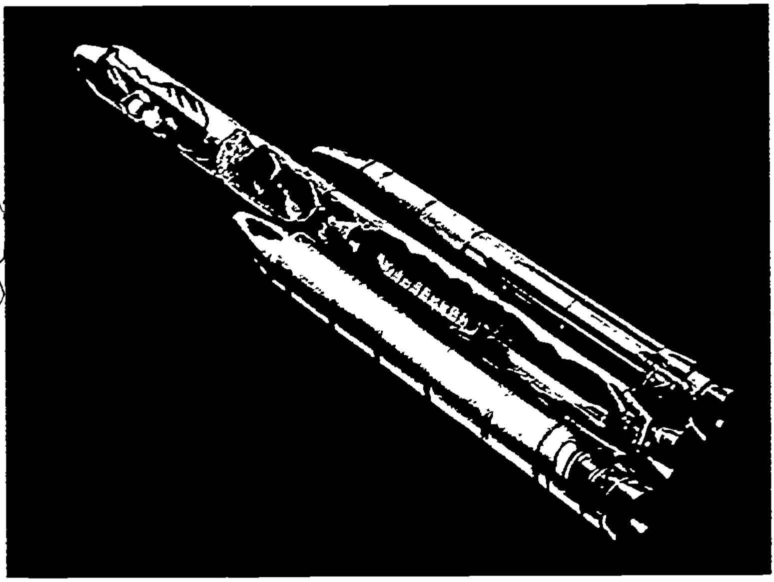


Figure 19 TITAN IIID WITH SOLID FUELED STRAP-ON ENGINES The artist's cutaway drawing above shows a two-stage version of the Titan III with two giant strap on engines These engines, called the zero stage, can generate 2.3 million pounds of thrust at liftoff. This is far more than the thrust produced by the two liquid-fueled engines in the first stage (520,000 pounds). The total height of the booster is 144 feet

workhorse of the space program. The Atlas has been combined with Burner II. the Agena. and the Centaur upper stages

The Titan III (Fig. 19) is the largest booster of the Titan family It uses either an additional third stage or solid-fueled strap-on engines for increasing thrust to lift extremely heavy spacecraft It is second only to the Saturn boosters in weight-lifting ability. The Titan II. an earlier booster of the Titan family. was used for launching the Gemini spacecraft The Titan III was developed as a space booster. not as a missile.

The Saturn boosters (Fig 20). the largest boosters. are used to lift the heavy Apollo spacecraft. The Saturn IB. an uprated version of the first Saturn booster. was used to put the first Apollo spacecraft into earth orbit This smaller Saturn has two stages. The second stage of the Saturn IB is used as the third stage of the Saturn V The giant Saturn V. with its three stages. is used to orbit the Apollo spacecraft when it goes to the moon When the Saturn V. together with the Apollo spacecraft and escape tower, is prepared for launch, the complete stack rises 364 feet above the launch pad.

Now that we have taken a look at the five launch vehicles in the US families of boosters, we should consider the standard upper stages used with some of these boosters.

The Burner II, a solid-propellant rocket, is the lightest upper stage, but it has a second stage that can be used with it. The two-stage combination, teamed with an Atlas booster, can lift a spacecraft into a high earth orbit.

The Agena, a liquid-propellant upper stage, has an engine that can be restarted in space. The Agena upper stage was modified for use as the target vehicle for the Gemini astronauts. It

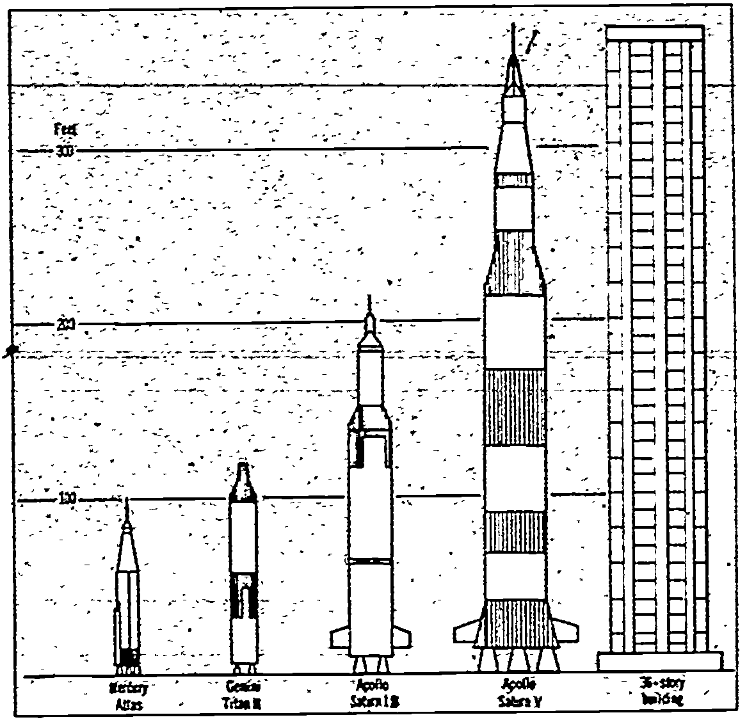


Figure 20. RELATIVE SIZE OF THE SATURN BOOSTERS. The three-stage Saturn V, ready for launching the Apollo spacecraft into a lunar orbit, rises as high as a skyscraper. The two-stage Saturn IB shown beside it was used to launch the Apollo spacecraft for flights in earth orbit. Compare the size of the Saturn boosters with that of the Atlas and Titan II boosters, used to orbit the Mercury and Gemini spacecraft, respectively.

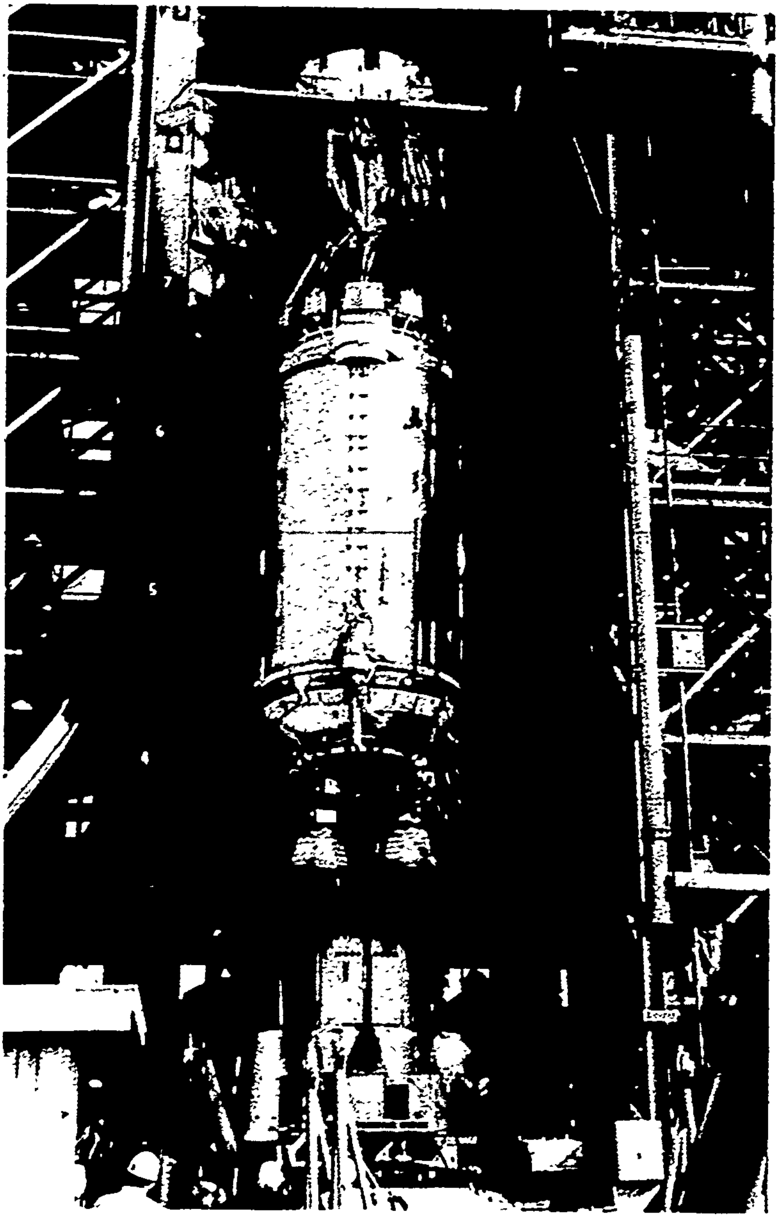


Figure 21 CENTAUR UPPER STAGE This Centaur is being mated with an Atlas booster in preparation for launching a Surveyor probe to the moon The Centaur upper stage has been used for lunar and planetary probes

was boosted by the Atlas. The Agena is used as an upper stage with the Thor and Atlas boosters, as noted earlier.

The Centaur (Fig. 21), which is fueled with liquid hydrogen, is the heaviest upper stage. It serves many purposes. With the Atlas booster (Atlas-Centaur), it was used to launch the Surveyor soft-landers on the moon. The Centaur is also used as an upper stage in launching probes to the planets.

The combinations of standard boosters and upper stages just described should give you some idea of how boosters are assembled for launching many different kinds of spacecraft. Stages are assembled that can be mated and made to work together. Each booster unit assembled is provided with a guidance system and a control system to keep it on course.

GUIDANCE AND CONTROL SYSTEMS

Before speacecraft could be orbited, boosters had to be developed that could not only generate vast amounts of thrust but also direct the spacecraft along the precise course required for orbiting. Rocket power was the key. Although guidance and control of this power were also necessary, engineers were able to meet this challenge when the rocket engines were ready. As rapidly as rocket engines were developed for more powerful boosters, the computers, communication systems, and other electronic devices needed for steering the boosters were ready. When Doctor Goddard began to develop the first liquid-fueled rockets, he also began to develop a guidance system for them. The first breakthrough in the guidance of long-range rockets, however, came with the German V–2 missiles launched during World War II. They contained a guidance system that worked. This is one of the reasons why the Americans and the Soviets wanted to secure V–2 missiles for use in rocket research.

A space booster is directed to keep it on a trajectory planned in advance. Information about this trajectory is fed into computers that are part of the guidance and control systems. Each system is a separate unit, but the two systems are described together because they work closely together. The guidance system might be compared with a man's brain. It receives signals from instruments, just as a man's brain receives signals from his five senses, and then makes decisions. The guidance system tells the control system what movements to make. The control system might be compared with a man's feet and legs. It actually makes the movements required to keep the booster on course.

The guidance system of a space booster must be highly accurate. At the great velocities at which such boosters travel, any slight delay or error in the instructions given to the control system would cause the launch to fail.

There are two principal kinds of guidance systems used in space boosters. the inertial guidance system and radio command guidance (radar guidance system). Elements of the two systems may be combined within a single system.

The **inertial guidance system** (Fig. 22) is self-contained within the booster. Such a system is able to make its own decisions without help from the outside once the booster is in flight. The system provides for computers within the booster. The information about the course required for orbiting the spacecraft is pre-

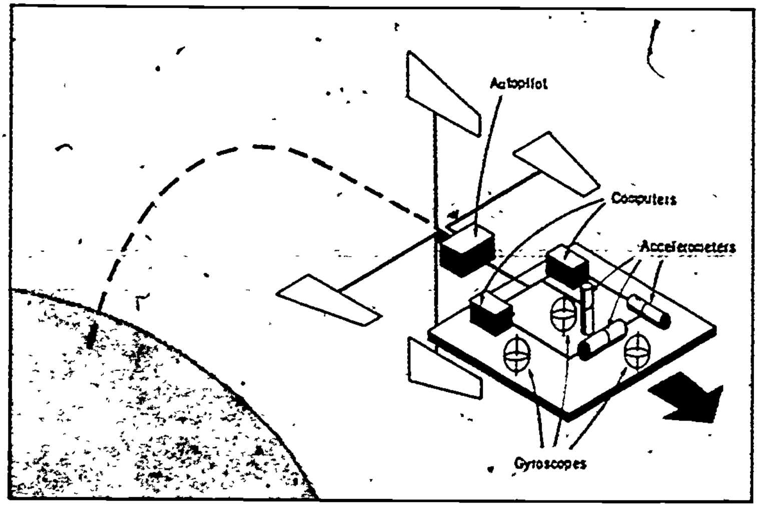


Figure 22. BASIC ELEMENTS OF INERTIAL GUIDANCE SYSTEM. The diagram above shows the elements of an inertial guidance system used in a rocket booster. The system is self-contained in the booster. The gyroscopes and accelerometers are mounted on what is called a stable table. This table always keeps the same plane in reference to the earth. The accelerometers give the computers information about the direction the booster is traveling, the rate of travel, and the time that the booster has been traveling in this direction at that rate. The system shown above is connected with a clock. The data fed into the computers enables them to give the autopilot information necessary for directing the control system. The control system makes the corrections in the flight path.

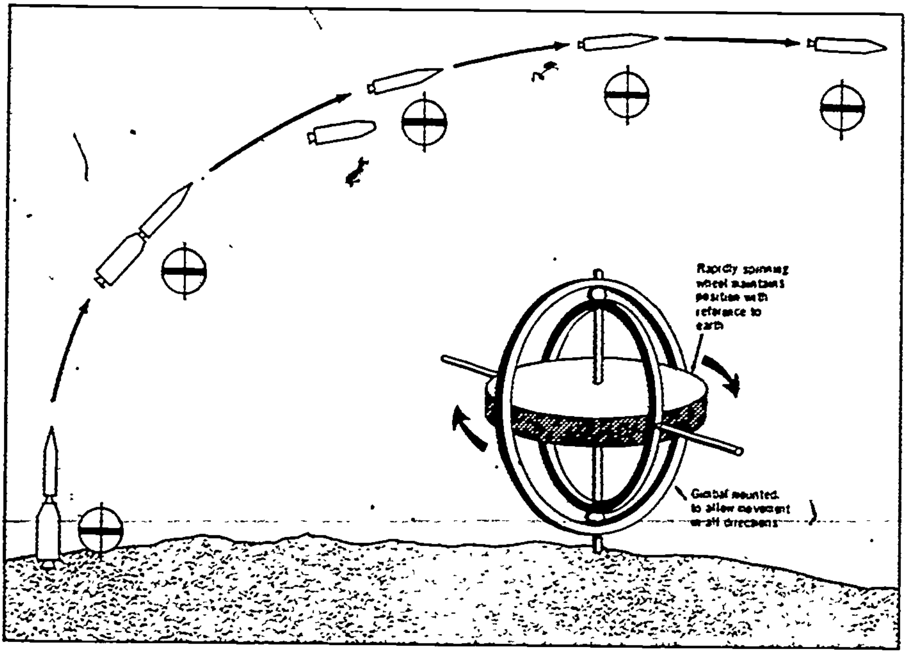


Figure 23. PRINCIPLE OF THE GYROSCOPE As the rocket booster travels along its trajectory the gyroscopes in the inertial guidance system always maintain the same position with reference to the earth. The gyroscope is given its position at the beginning of the flight and is made to spin rapidly. The rapid spinning enables the gyroscope to maintain its position during flight, as shown in the insets above. The principle is the same as that underlying the operation of the gyroscope top. In the rocket booster three gyroscopes are used to keep the booster in level flight in all three directions. This prevents rolling, pitching, or yawing.

set, or programmed, into these computers before launch. Each of three **accelerometers** measures the acceleration, or the rate of change in velocity, of the booster in one of three possible directions. Each accelerometer is made stable by being mounted on a platform controlled by a **gyroscope** (Fig. 23). Signals from the accelerometers are fed into the computers. If the calculations made by the computers show that the missile is off course, the computers send signals to the **autopilot**, or the flight control center. The autopilot relays directions to the control system for putting the booster back on course.

In **radio command guidance** (radar guidance system) the computers that make the decisions for the booster are on the ground

(Fig. 24). They are connected with radar equipment that tracks the booster on a radar screen. If the radar signals received from the booster show that it is going off course, the computers on the ground calculate the amount and the direction of the movement off course, and they send instructions to the autopilot in the booster for correcting the course. The booster has an antenna and a radio set for receiving the instructions, which are transmitted to the control system.

If the booster begins to stray from its course, the guidance system will bring the **control system** into operation. The control system may be one of three principal kinds or a combination of two or more of these systems.

The control system may consist of **movable jet vanes** placed in the stream of the exhaust gases of the rocket engine (Fig. 25A).

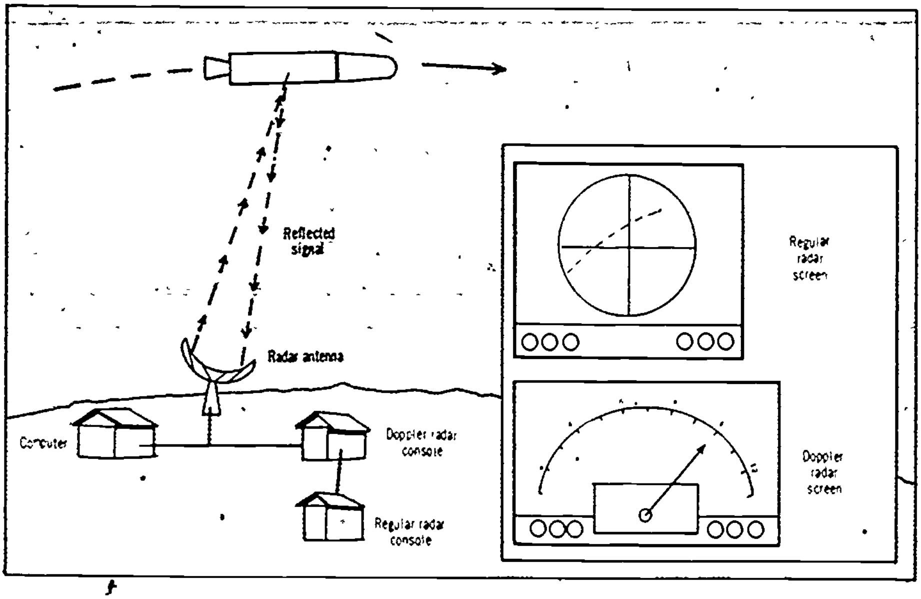


Figure 24. RADIO COMMAND GUIDANCE. Most of the equipment used in this system is on the ground. The radar antenna on the ground sends a radio signal to the rocket booster, and the signal is reflected back to the earth. Two kinds of radar interpret the return. The regular radar shows the direction of flight (upper inset). The Doppler radar shows the velocity of the booster (lower inset). Information about the direction and rate of travel is fed into the computer. It compares the actual path of the booster with the planned path. If the booster is straying from its course, the information is relayed to the autopilot in the booster. The autopilot gives the instructions to the control system to correct course.

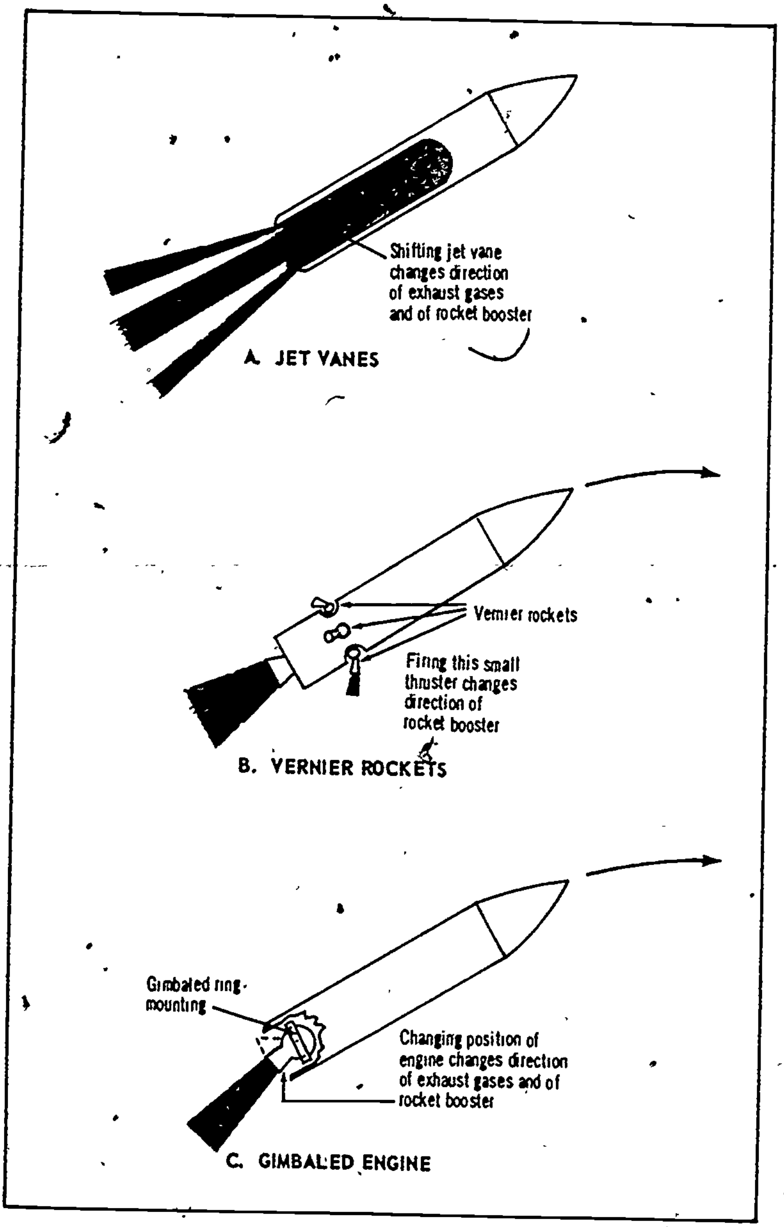


Figure 25. SOME CONTROL SYSTEMS USED IN ROCKET BOOSTERS. The control system is activated by the autopilot to change the direction of the booster. Three control systems are shown in the above diagrams. A. The jet vane can be moved to deflect the flow of the exhaust gases. This causes the booster to change direction. B. Vernier rockets are tiny rocket engines located on the airframe of the booster. One or more of these tiny engines may be fired to cause slight changes in the direction of the booster. C. The main rocket engine itself may be moved to cause a change in the direction of the exhaust gases, and consequently of the booster.

As the vanes are moved, they divert the flow of the exhaust gases and cause the booster to go back on course.

A second kind of control system is made up of a series of **jet thrusters**, or vernier rockets (Fig. 25B). These are actually tiny rocket engines used to make fine adjustments. One of these engines can be fired to produce a tiny jet of gas that will push the booster back on course.

A third kind of control system consists of moving the rocket engine itself, or using a **gimbaled engine** (Fig. 25C). The engine is mounted on a gimbal, or a ring that permits movement. If the booster strays from its course, the engine is moved so that the direction of the jet of gases is changed. This produces a change in the direction of the thrust, putting the booster back on course.

When the stages of the booster have been assembled, and the guidance and control systems are operational, the booster is ready for countdown and launch.

COUNTDOWN AND LAUNCH

You are probably familiar with the last few minutes of the countdown just before **launch**, especially with the excitement at this time when astronauts are being launched. The countdown begins much earlier, however, sometimes as much as two days before the final count. The **countdown** is actually a roll call of all systems and facilities to find out whether they are ready for launch. The launch manager, who is in charge of the countdown, stays by his telephone in the **blockhouse**. This is a reinforced steel and concrete structure that is located just as near the launch pad as safety allows. The launch manager and his staff control the launch from the blockhouse (Fig. 26).

During countdown the launch manager calls to see whether each system or facility is ready. The answer he expects is either "Go" or "No go." If a report is "No go," the manager tries to find out what the trouble is and to see that it is corrected. While he is checking on the problem, he calls a **hold** on the countdown. If the problem cannot be solved within a reasonable time, the manager must **scrub**, or cancel, the launch. It may be rescheduled later.

Figure 26. LAUNCH MANAGER DIRECTING OPERATIONS FROM BLOCKHOUSE. This is a view in Firing Room No. 1 of the Launch Control Center at Cape Kennedy. The manager is directing the launch of the Apollo-13 flight by the Saturn V booster.

The launch manager also gets a report from the supervisor of the launch facilities. This supervisor lets the manager know when the range is clear. Warnings are issued in advance to all aircraft and ships that might be operating in the area, but a check of the area is also made just before firing.

As a further measure for preventing accidents, the launch manager sees that the range safety officer is on the alert. This officer takes over control of the launch just after the firing. If the booster strays too far off course, he issues an order for **destruct**—that is, for the automatic destruction of the booster. If trouble should develop on the pad when astronauts are in the spacecraft, the **escape tower** would fire to boost the astronauts

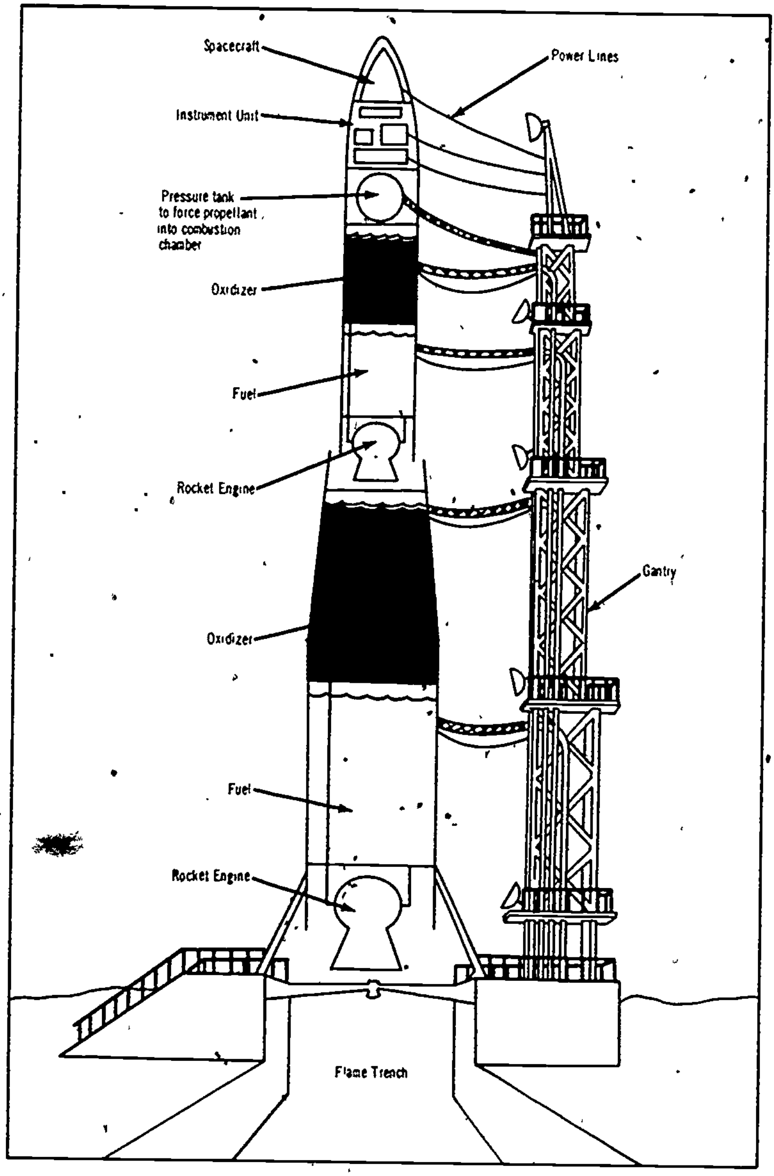


Figure 27. TWO-STAGE ROCKET BOOSTER AND SPACECRAFT ON LAUNCH PAD. The gantry, or service tower, is shown to the right. Umbilical cords carrying oxidizer, fuel, and electric power connect the gantry with the booster and spacecraft. The diagram shows a generalized unmanned spacecraft. An actual manned spacecraft would require many more umbilicals.

clear of the launch pad. They would then have to be recovered from the ocean.

Each missile is supported by a **gantry**, or a service tower, at launch. A gantry (Fig. 27) is a cranelike steel structure with different floors, or levels, permitting men to service the different parts of the booster and spacecraft. The gantry may be permanently installed, or it may be moved back and forth on a track. The **launch pad** is a heavily reinforced concrete slab with a flame trench. During countdown, when the gantry is in place, **umbilical cords**, or cables, are fitted to the booster and spacecraft for carrying to them propellant, oxygen, power, or whatever else is needed for servicing them. The umbilicals have quick-disconnect plugs that permit them to be released automatically when the booster is fired.

The size and complexity of the launch facilities vary with the booster. The Saturn V, the largest of the boosters, has by far the most elaborate facilities. A gigantic Vertical Assembly Building (VAB), which is 525 feet high and covers more than eight acres, allows the three stages of the booster to be assembled and mated with the Apollo spacecraft indoors. The gantry for the Saturn V is a mobile launcher with a 410-foot-high service tower (Fig. 28). By means of a giant crawler transporter, which operates much like a caterpillar tractor, the launcher moves the complete Saturn-Apollo assembly from the VAB to the launch pad about 3½ miles away. If a storm should threaten the Saturn-Apollo before launch, the complete assembly could be moved back into the VAB again. Facilities for the smaller boosters are much simpler, and they do not provide for assembling the booster and spacecraft indoors.

As the countdown nears the end, the launch manager completes his checks, and everything is in readiness. At the zero count, flames and hot gases rush from the nozzles in the engines of the first stage as the booster quickly builds up thrust. Powerful clamps hold the booster down until it reaches the right thrust level for launch. Then the clamps are released automatically, and the booster rises slowly from the pad.

The booster will provide not only power but also direction for the spacecraft. It will accelerate the spacecraft at a precise velocity to an exact position, thus injecting it into orbit.

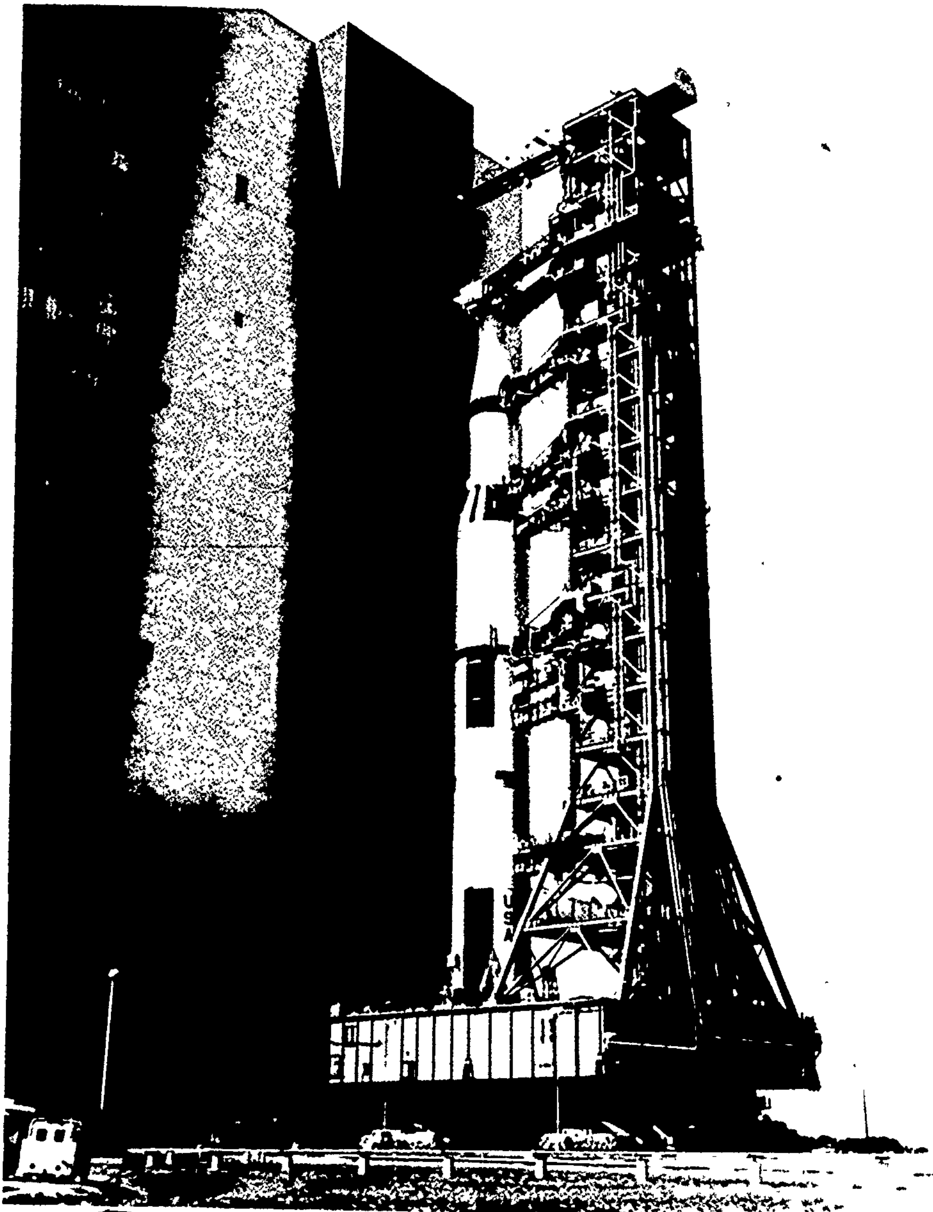


Figure 28 SATURN V WITH MOBILE LAUNCHER. This Saturn-Apollo assembly is being rolled out of the Vertical Assembly Building (VAB). In the VAB it was put together and checked out. Note the size of the assembly by comparing it with the large truck standing nearby.

TERMS TO REMEMBER

space booster
propellant (fuel and oxidizer)
nozzle
convergent-divergent nozzle (pinched nozzle)
combustion chamber
plumbing
airframe
to jettison a stage of the booster
rocket engine
modern reaction engines (jet and rocket engines)
reaction force
kinetic energy
jet of exhaust gases
thrust
thrust-to-weight ratio
specific impulse
liquid chemical propellant
hypergolic propellant
solid chemical propellant
nuclear rocket
staging
clustering engines
adding solid-fueled strap-on engines
families of boosters
guidance system
inertial guidance system
accelerometer
gyroscope
autopilot
radio command guidance (radar guidance system)
control system
movable jet vanes
jet thrusters (vernier rockets)
gimbaled rocket engine
launch
countdown
blockhouse
to hold the countdown
to scrub a launch
destruct
escape tower
gantry
umbilical cords
launch pad

IDEAS TO REMEMBER

1. A space booster must *(a)* generate tremendous amounts of thrust and *(b)* direct the spacecraft along an accurate pathway at the exact velocity required for orbiting.

2. The rocket engine is a reaction engine. It works according to Newton's third law of motion: For every action there is an equal and opposite reaction.

3. The jet engine is also a reaction engine, but it requires air for its operation. Only the rocket engine can be used in a space booster.

4. The rocket engine carries its oxygen with it in the oxidizer. A rocket propellant contains both fuel and oxidizer.

5. The efficiency of a rocket propellant is measured in seconds of specific impulse. The higher the specific impulse, the more efficient the propellant is.

6 The propellant used in the engines of present-day space boosters are either liquid or solid chemicals. Liquid chemicals are still the mainstay of the space booster.

7 All space boosters are staged. To gain additional thrust, the engines may be clustered within the stage, or solid-fueled strap-on engines may be used.

8 US space boosters have been developed in families, or series, according to their weight-lifting ability.

9. To keep the booster on course, it must have both a guidance system and a control system.

10. At countdown the launch manager sees that all parts of the booster and spacecraft are operational and that they will work together to insure the success of the launch.

QUESTIONS

1. What are the principal parts of the space booster?
2. How is Newton's third law of motion applied in the rocket engine?
3. What important advancement in the rocket engine made possible the space booster?
4. How is greater thrust obtained in rocket engines?
5. Why are jet engines not used in space boosters?
6. What is the purpose of the pinched nozzle (convergent-divergent nozzle) in rocket engines?
7. What is a propellant? What are the two parts of a liquid propellant?
8. What are the two principal kinds of liquid-fueled rocket engines?
9. What is a nuclear rocket?
10. Why must a space booster be staged?
11. Why are engines clustered? How are the clustered engines arranged and how are they fired?
12. What kind of engines are used for strap-on engines? What booster uses very large strap-on engines?
13. Name four families of standard US boosters and one standard upper stage.
14. How is the inertial guidance system different from the radio command guidance (radar guidance system) used in rocket boosters?
15. Describe how two different kinds of control systems for space boosters operate.
16. What is the purpose of the rocket gantry? umbilicals? and launch pad?

THINGS TO DO

1. Add to your scrapbook clippings on the US standard families of space boosters and the standard upper stages. Have any important advances been made in these boosters and upper stages? Has progress been made in developing small nuclear rockets? What will happen to the standard space boosters as progress is made in developing the space shuttle and other reusable space vehicles?

2. Demonstrate the principle of the rocket engine. You might begin with a diagram and then use a toy balloon for showing how the action-reaction principle is applied. Perhaps the instructor will let you help him with a demonstration using the model rocket.

3. Explain how the pinched nozzle (convergent-divergent nozzle) applies Bernoulli's law and increases thrust in the rocket engines used in space boosters. Use a diagram or model to help you. Perhaps you can use a pinched hose with flowing water to get your point across. With the help of the instructor, you might work out a demonstration of the nozzle with the model rocket.

4. If you have a special interest in mathematics, explain some of the basic formulas for computing the thrust of the rocket engine Explain how thrust can be increased in a rocket engine to secure the great amounts of energy required for orbiting spacecraft.

5. Secure a gyroscope top for demonstrating the principle upon which the gyroscope in an inertial guidance system operates. Read the instructions that go with the top. They should explain how the top demonstrates the principle upon which the gyroscope operates The gyroscope is the key to the inertial guidance system. It is used for establishing the stable table in reference to the earth.

6. Demonstrate the operation of radio command guidance (radar guidance system) Use simple table models to represent the ground equipment or draw diagrams.

7. Explain how one of the control systems in a rocket booster operates Conclude your explanation by telling the class why the control systems on a space booster must operate with precision.

8. Make a study of an important launch operation Outline the procedure followed and any significant problems that developed Make a report to the class on the launch, and be prepared to answer questions

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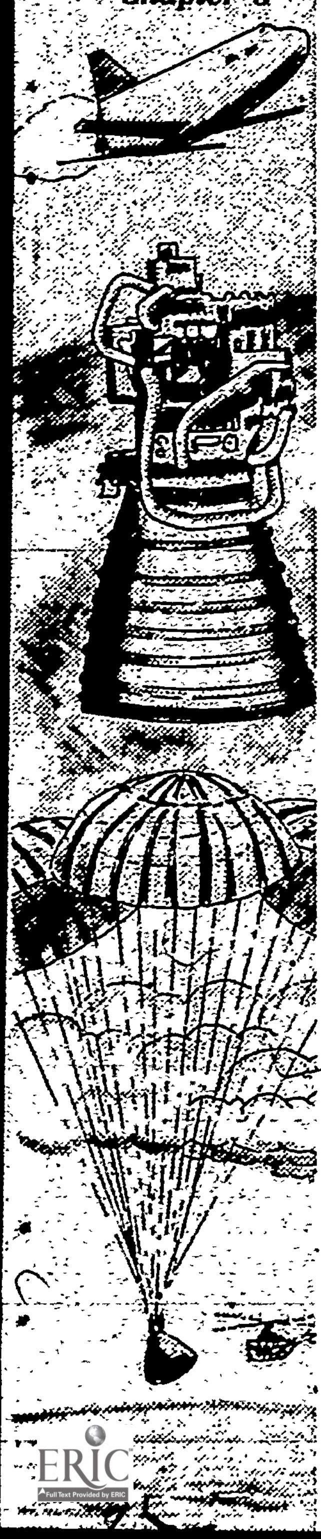
Chapter 3



Orbiting and Tracking Spacecraft

THIS CHAPTER explains how a spacecraft becomes an artificial satellite of the earth or other body being orbited and how the spacecraft is tracked and controlled to enable it to perform its mission. It begins by describing Newton's theory of an artificial satellite and tells how this is applied in orbiting spacecraft with modern rocket boosters. It then defines orbit and trajectory and describes the principal kinds of orbits and trajectories that spacecraft follow. It tells how these flight paths of spacecraft follow the laws of celestial mechanics, as defined by Kepler, and how they are related to the sections of a cone. Then the chapter describes special orbits and trajectories that spacecraft follow to perform different kinds of missions. Finally, the chapter explains the different means used to track spacecraft in orbit and the way in which unmanned spacecraft are controlled and stabilized and manned spacecraft are navigated. When you have studied this chapter, you should be able to do the following: (1) tell the three conditions that must be met for orbiting spacecraft; (2) describe an elliptical earth orbit and show the points of perigee and apogee; (3) tell the principal means used for tracking spacecraft, and (4) explain the different purpose served by the large maneuvering engine and the small thrusters used in spacecraft.

A ROCKET BOOSTER that puts a spacecraft into orbit generates tremendous velocity and guides the spacecraft along an accurate pathway, as noted in Chapter 2 Great precision, as well as large amounts of power, is required for orbiting spacecraft. The requirements for orbiting a spacecraft are so exacting that the process has been likened to finding the eye of a needle in space and threading it. The booster must deliver the spacecraft at a precise point in space, the spacecraft must be traveling at a certain velocity, and it must be pointed in the right direction. If all conditions are met, the spacecraft becomes an artificial satellite of the earth or of some other body in space.

As the decade of the 1970s opened, more than 1,000 spacecraft had met requirements and been orbited about the earth, the moon, and the sun by all nations. Somewhat less than half the number of spacecraft orbited, or a little less than 500, were still in orbit. About this same number might be expected to be in orbit at any one time in the future, together with discarded rocket stages and other space junk. To identify the spacecraft that are orbiting, NASA and the Air Force keep track of all spacecraft and space junk, and they study the orbits and trajectories of spacecraft. The information compiled enables scientists to plot the future course of spacecraft and predict when they will be in a particular position.

Scientists can make predictions about spacecraft because they know that orbiting spacecraft follow the same laws of **celestial mechanics** that the moon, the earth, and other natural bodies do as they move through space. If you understand the basic laws of celestial mechanics, you will understand how spacecraft travel. Spacecraft are artificial satellites of the body they orbit.

A SPACECRAFT AS AN ARTIFICIAL SATELLITE

The Soviet Sputnik I was put into orbit in October 1957. This was the first man-made object ever to orbit the earth and the first such object that remained in space. Many people wondered why this spacecraft did not fall back to the earth as sounding rockets had done before, but space scientists did not wonder. They understood that man had at last met the requirements for producing an **artificial satellite** of the earth.

Our own era contributed the practical means for creating the first artificial satellite. It provided the tremendous rocket power, the computers for making complex mathematical calculations, and the electronic devices for guiding the rocket booster. The idea of an artificial satellite was not new in modern times, however. The laws upon which the calculations for an artificial satellite were based had been formulated by physicists and astronomers centuries before.

Sir Isaac Newton (1642–1727), an English astronomer and mathematician, formulated the basic laws of motion and gravity. He is credited with bringing together the works of previous scientists and laying the foundation of theory upon which the space scientists could build. On the day when the first American astronauts landed on the moon, fresh flowers were placed on Newton's tomb in Westminster Abbey. Soviet Cosmonaut Yuri Gagarin (1934–1968), the first man to orbit the earth, also paid tribute to Newton, saying that without Newton's work his trip into space would not have been possible.

Newton was able to reach the conclusions that he did because he studied the work of other scientists. The laws about the motion of heavenly bodies were formulated by the German astronomer Johannes Kepler (1571–1630), some seventy years before. Kepler, in turn, based his laws upon the careful observations of the planets recorded by the Danish astronomer Tycho Brahe (1546–1601) who watched the heavens without the aid of a telescope, and upon the work of the Italian astronomer and physicist Galileo (1564–1642), who built a telescope and conducted basic experiments to study gravity.

Newton, according to a story, was led to study gravity when he was hit on the head by a falling apple. **Gravity** is the force that constantly attracts all objects on or near the earth toward the center of the earth. It acts on free-falling objects and on our bodies as they rest on the surface of the earth. Gravity is the force that pulls your feet to hold them on the ground as you walk, and it is the force that causes your body to bear down on the seat of the chair as you sit. Newton's study of gravity made him see the connection between that force as it acted upon objects on earth and upon all celestial bodies in space, holding them in their orbits. He noted that a bullet, impelled forward by **inertia**, did not continue in a straight line but, because of the earth's gravitational pull, fell in a curve through the air (followed a **ballistic trajectory**), as shown in Figure 29 Newton formulated the basic laws of motion and gravity to explain the action of the celestial bodies and of an artificial satellite of the earth.

Newton's description of an artificial satellite appears in his great work, *Mathematical Principles of Natural Philosophy (Principia)*.

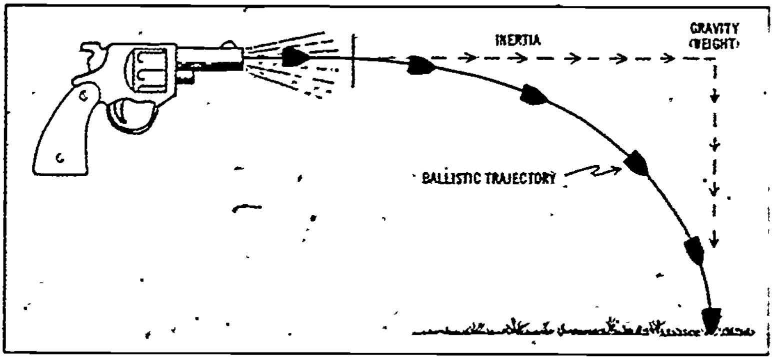


Figure 29. BALLISTIC TRAJECTORY. A bullet fired from a gun follows a ballistic trajectory like that shown above The bullet is acted upon by a force resulting from both inertia and gravity. Inertia tends to propel the bullet forward in a straight line, and gravity pulls it toward the center of the earth. A rocket booster follows a modified ballistic trajectory.

published in 1687. Newton was interested only in the theory of a satellite, however, not in producing one. He was actually describing the motion of the natural satellite of the earth, the moon. To make his explanation clearer, he described how man might himself create an artificial satellite that would follow the same laws that the moon does.

Following Newton's explanation, try to imagine a very high mountain, well above the earth's atmosphere, with a gigantic cannon placed on top of it. The cannon is pointed horizontally, or parallel to the earth's horizon. If a relatively small amount of gunpowder is placed in the barrel and the cannon is fired, the ball will go only a short distance before it falls back to the earth (Fig. 30). Suppose that more gunpowder is used and greater speed is imparted to the cannonball each time it is fired. The cannonball would travel farther each time until finally it would not fall back to the earth but would follow a curved path, or orbit, around the earth The cannonball would then be an artificial satellite of the earth.

Newton described only the theory of the artificial satellite. There was no mountain high enough or cannon powerful enough to make the plan practical. But substitute a modern rocket booster, like those described in Chapter 2. for both the very high mountain and the giant cannon, and you have the theory for launching an actual artificial satellite, or spacecraft, to orbit the earth.

For producing an artificial satellite of the earth, or a spacecraft orbiting the earth, three conditions must be met. (1) the spacecraft must be orbited above the earth's atmosphere, where there is no appreciable amount of atmospheric drag, (2) the spacecraft must be propelled forward fast enough; and (3) it

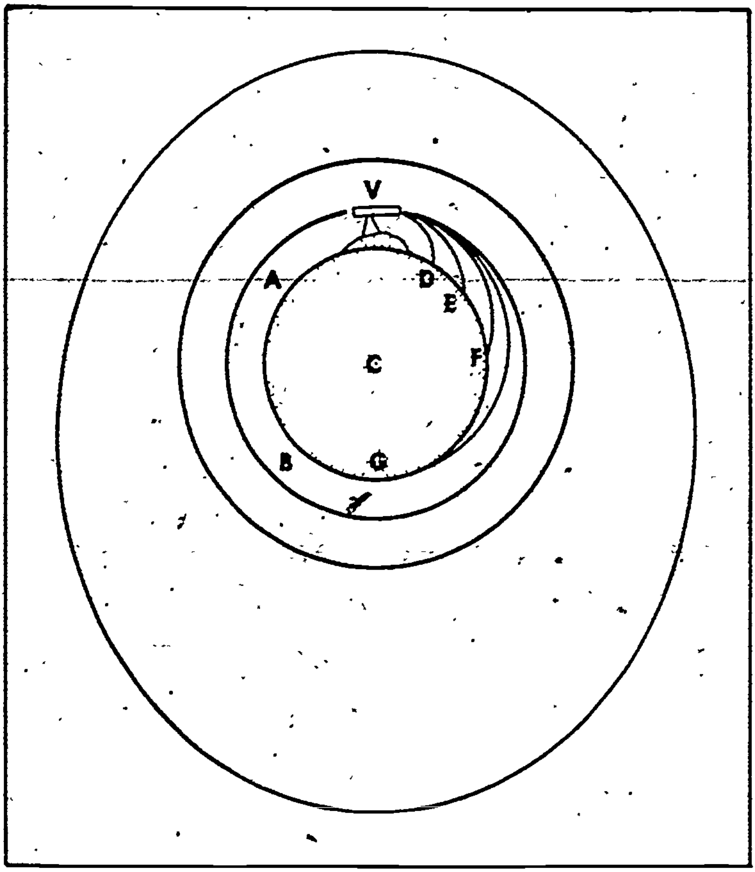


Figure 30. THEORY OF AN ARTIFICIAL SATELLITE. Sir Isaac Newton explained the theory of an artificial satellite by imagining a cannon fired from a very high mountain. Each time the cannon was fired, more gunpowder was added, and each time the cannonball went farther. Finally a point was reached when the cannonball would no longer fall back to the earth. Instead it would follow a path parallel to the curvature of the earth and remain in orbit. It would then be an artificial satellite of the earth

must travel in a path that follows the curvature of the earth. If all the conditions are met and the precise velocity is attained, the spacecraft will go into a circular orbit. If the velocity is considerably less than required, the spacecraft will fall back to the earth, just as the cannonball did in Newton's example. If the speed is only somewhat less or is somewhat greater than that required for a circular orbit, the spacecraft will go into an elongated, or elliptical, orbit (Fig. 31).

As the rocket booster launches the spacecraft into a low earth orbit, at a distance of about 100 miles above the earth, it will be traveling at a velocity of about 17,500 mph. Spacecraft orbited at higher altitudes require less velocity, but it takes much more rocket thrust to boost them to these higher altitudes. As the third or final

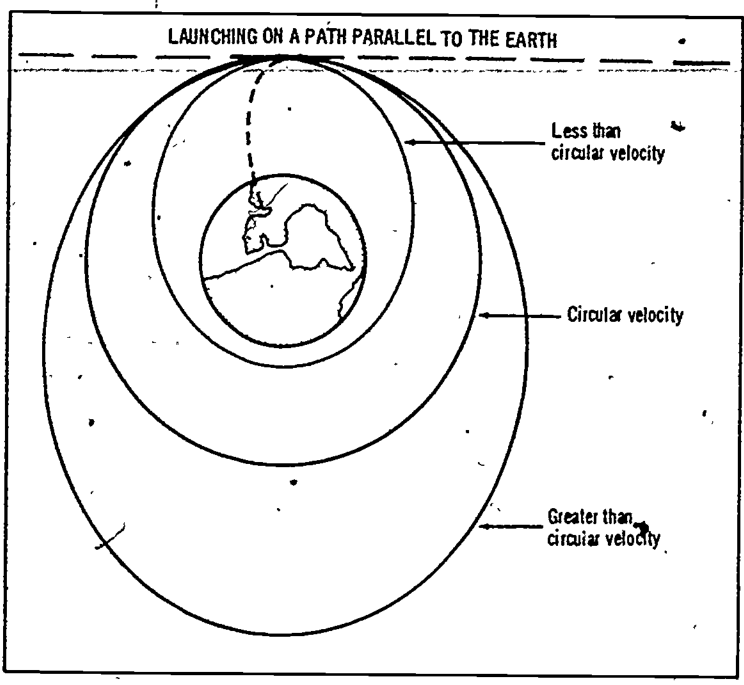


Figure 31 SHAPE OF ORBIT AND VELOCITY The kind of orbit that a spacecraft goes into depends upon its velocity at launch. All spacecraft that are successfully orbited are launched precisely horizontally, or on a path parallel to the earth, and within a certain velocity range If the velocity is exactly that required for orbiting at the altitude reached, the spacecraft goes into a circular orbit. If the velocity is somewhat less or somewhat more, the orbit is an ellipse.

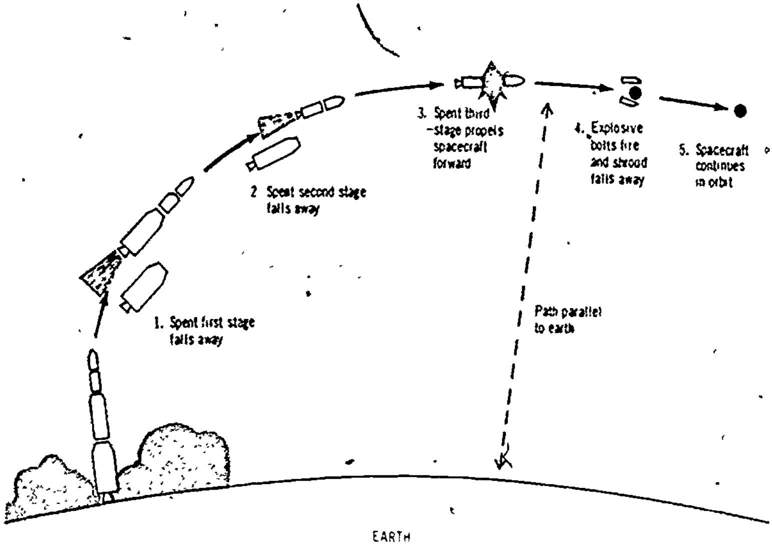


Figure 32. INJECTING A SPACECRAFT INTO ORBIT. The diagram above shows the five principal steps followed as a three-stage booster launches a spacecraft. Note that the path of the spacecraft is precisely parallel to the surface of the earth at the time of orbiting. Each step in the launch is carefully timed and controlled.

stage of the booster burns out, explosive bolts fire, the shroud of the spacecraft drops away, and the spacecraft is injected into orbit (Fig. 32). The spacecraft is now on its own.

To understand why a spacecraft continues to travel in an orbit around the earth after it has left the booster, you need to take a closer look at the forces that are acting upon it. When the spacecraft leaves the booster, it is propelled forward by the force given to it by the booster. According to Newton's first law of motion, the law of inertia, the spacecraft (or any object) tends to remain at rest or to continue in motion in a straight line unless acted upon by an outside force. The spacecraft, propelled forward by the force imparted to it by the rocket booster, tends to continue in motion in a straight line. The inertial force in this case is a **centrifugal force,** or one that pulls the spacecraft away from the center of the earth. At the same time the earth's mass, or gravity, is attracting the spacecraft toward the center of the earth. The centrifugal force and gravity act in opposite directions (Fig. 33).

If the velocity of a spacecraft is the exact velocity required

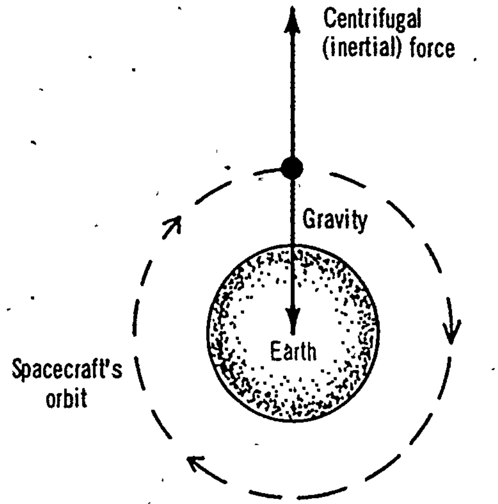


Figure 33. CENTRIFUGAL FORCE VERSUS GRAVITY (CIRCULAR ORBIT) The balance between centrifugal force and gravity keeps a spacecraft in orbit. If the forces balance exactly at every point along the spacecraft's path, the orbit is circular.

for orbiting at a particular altitude, the centrifugal force (inertial force) and gravity balance. The spacecraft then goes into a circular orbit, and the speed of the spacecraft is the same at all points in the orbit. Actually the velocity of most spacecraft upon orbiting is somewhat less or somewhat greater than the amount required for a circular orbit. Therefore, most spacecraft go into an elliptical orbit.

When the orbit is elliptical, the speed of the spacecraft is not the same at all points in the orbit. The centrifugal force and gravity are not in balance at all times. When they are not in balance, gravity causes acceleration of the spacecraft until a balance is reached. Suppose that the velocity of the spacecraft is somewhat greater than that required for a circular orbit. In this case the spacecraft starts to arc out from the earth after it is put into orbit. It will continue to travel along this arc until its velocity gradually decreases. Then gravity causes the spacecraft to fall toward the center of the earth. (Fig. 34). As the spacecraft falls, its speed increases. Then it starts to arc out from the earth again until it slows down once again. Then gravity overcomes the centrifugal force, and the

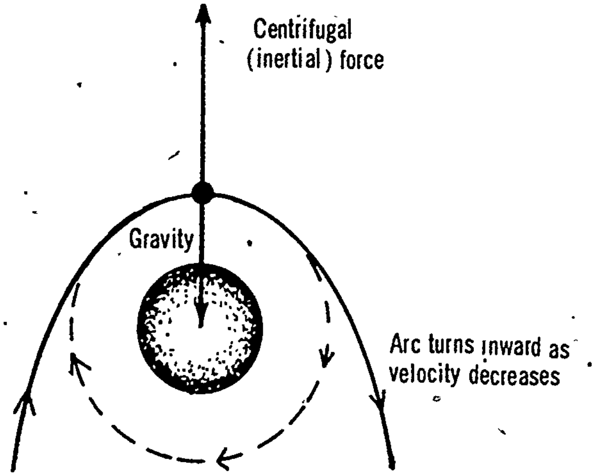


Figure 34. CENTRIFUGAL FORCE VERSUS GRAVITY (ELLIPTICAL ORBIT). If a spacecraft is in an elliptical orbit, centrifugal force and gravity are not in balance at all points along the orbit. If the velocity of the spacecraft in orbit is somewhat greater than circular velocity, the spacecraft begins to arc outward. As it does so, its velocity gradually decreases until gravity becomes dominant, and the spacecraft falls toward the earth. As it falls, its velocity increases, and the process continues to be repeated.

spacecraft falls toward the earth again. It falls just enough to speed it up again, and the process continues to be repeated.

A spacecraft that is in orbit and is not disturbed by another force (the propulsive force of an engine) is in a **condition of weightlessness.** The spacecraft and everything in it have no apparent weight. In this situation the gravitational force acting upon a body tends to be balanced by equal and opposite centrifugal (inertial) force. The only force causing acceleration, or an increase in speed, is gravity, as noted above. When the spacecraft falls toward the earth, it is in a condition of free fall, but this situation exists during only part of the time the spacecraft is in a weightless condition. Weightlessness is sometimes referred to by the term zero gravity, which is descriptive but not accurate. The force of gravity seems to disappear because it is balanced or cancelled out by another force (centrifugal or inertial force), but gravity force does not really disappear.

The balance of forces that causes a spacecraft to remain in orbit might be compared with the balance of forces that exists when you swing a bucket of water at the end of a rope (Fig. 35). The centrifugal force holds the water in the bucket, and the bucket is held in place by the rope, which represents the earth's gravitational pull. As you swing the bucket around faster and faster, the centrifugal force increases until it finally causes the rope to break and the bucket is hurled away. If the velocity of a spacecraft is greatly increased, the centrifugal force will finally overcome gravity, and the spacecraft will **escape from the earth.**

Once man could successfully launch spacecraft into earth orbit, he was ready to generate the high velocities that would allow them to escape from the earth and go on more distant voyages. Spacecraft can become artificial satellites of the moon, of another planet, or of the sun (artificial planets).

As a spacecraft leaves the gravitational force field of the earth and comes within that of another body, the gravity force of that body becomes dominant, and it is necessary to know the amount of this force. Scientists are able to compute the gravitational force acting upon a spacecraft by applying Newton's law of universal gravitation. This law states: Every body in the universe attracts every other body with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Every body in the universe, from the largest star to the smallest

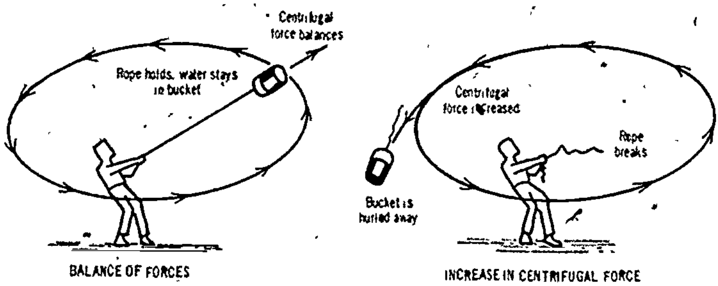


Figure 35. INCREASED VELOCITY AND ESCAPE. A comparison can be made between a spacecraft in orbit and a swinging bucket. If the bucket is swung just fast enough to create a balance of forces, the rope (gravitational force) holds, and the water remains in the bucket. If the bucket is swung faster and faster, a point will be reached when the rope (gravitational force) will break, and the bucket will be hurled away. A spacecraft escapes from the earth if its velocity is increased until centrifugal force overbalances gravity.

particle of matter, attracts every other body, and the force of the attraction is called gravity. Since the mass of a spacecraft is very small in relation to the mass of a celestial body, the weight of the spacecraft is negligible. The problem then becomes that of computing the gravitational pull on a body of negligible weight moving within a central force field. The amount of gravitational pull exerted on a spacecraft depends upon its distance from the center of the body and upon the mass of that body. The moon's gravitational pull, for example, is only one-sixth that of the earth. The giant planets would exert a much stronger gravitational pull on a spacecraft than the earth does.

With the knowledge of the gravity force of the moon and the planets, scientists were able to plan the orbits and trajectories, or the pathways, of spacecraft that would go on more distant voyages and perform more difficult tasks.

ORBITS AND TRAJECTORIES

The management and control of unmanned spacecraft and the navigation of manned spacecraft consist first of all in computing the orbits or trajectories that these spacecraft must follow to place them in the position intended. Space travel is essentially ascent from the earth and travel along an orbit or trajectory. Sometimes the mission ends in descent to another celestial body, but usually the spacecraft continues to orbit in space. At this stage of space travel the United States has landed spacecraft on the moon only, and only parts of spacecraft have returned to make reentry through the earth's atmosphere. Most spacecraft have been sent out to orbit the earth and remain there, or to fly by another planet and become a satellite of the sun.

When the required orbits and trajectories are plotted for the voyage, the spacecraft is launched so that it will follow the planned pathway as closely as possible. If inaccuracies develop in the path of the spacecraft, a rocket engine in the spacecraft is fired, and a **midcourse correction** is made. Spacecraft that orbit the earth do not require a change in orbit unless they have a special mission to perform. When a spacecraft is to be maneuvered, its course is planned to combine as many operations as possible into one. This is done to keep from firing the engine more than necessary and thus save valuable propellant.

To get a better idea of how spacecraft travel, it is necessary to know more about the shape of their orbits and trajectories.

Shape of Orbits and Trajectories

The terms orbit and trajectory are used to refer to the flight paths of spacecraft or of other bodies in space. In describing spacecraft, scientists generally use the word orbit to refer to a closed pathway, such as a circular or elliptical orbit. They use the term **trajectory** to describe an open path that has a definite beginning and end. Thus they talk about a spacecraft that is in *orbit* about the earth or the moon, or a spacecraft that is injected into a *trajectory* from the earth to the moon.

To understand the mathematical properties of the orbits and trajectories that spacecraft follow, scientists refer to the sections of a cone. The pathways of all spacecraft can be located at some position on a cone. You might construct a cone by rolling up a piece of paper, and try to picture some of these orbits and trajectories for yourself. Figure 36 shows how to locate the principal kinds of orbits and trajectories of spacecraft as cross sections of a cone.

The difference between the orbits and trajectories shown can be described in terms of velocity. A **circular orbit** is a special case, representing the exact velocity for orbiting at a particular altitude, as noted earlier. If the velocity is somewhat greater or somewhat less than that required for a circular orbit, the spacecraft goes into an **elliptical orbit.** If the velocity becomes so great that gravity no longer holds the spacecraft in orbit, it is said to escape from the earth, much as the bucket in the example was hurled away when the rope broke.

An **escape trajectory** is open-ended with respect to the earth (or other body from which escape is made). When a spacecraft reaches the minimum velocity for escape from the body being orbited, the trajectory attained (Fig. 36), like the circular orbit, is a special case. As the velocity increases beyond the minimum, the curve opens up and the spacecraft goes farther out into space. The minimum velocity for escape from the earth is about 25,000 mph. A spacecraft traveling at this velocity would escape from the force field of the earth to that of the moon. At a velocity of about 26,000 mph the spacecraft would escape to Mars, and at about 32,000 mph it would escape to Jupiter. In giving

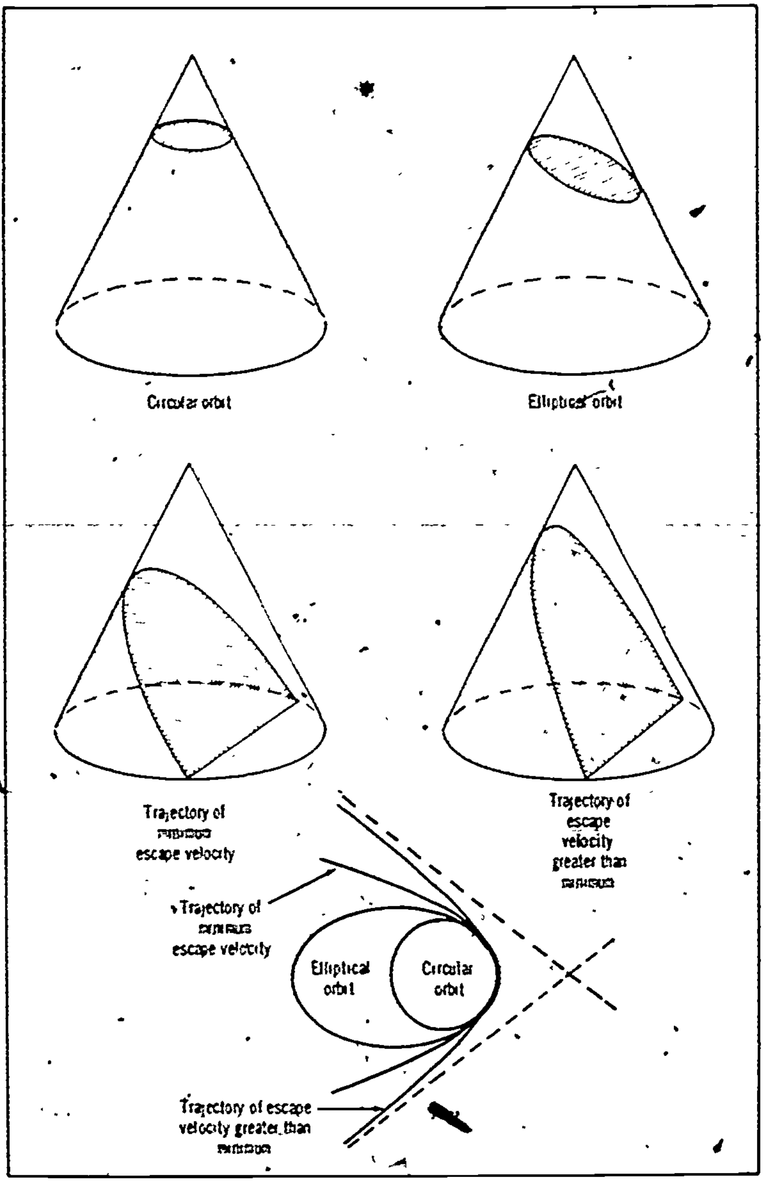


Figure 36 ORBITS AND TRAJECTORIES AS RELATED TO SECTIONS OF A CONE. The principal kinds of orbits and trajectories of spacecraft are shown above They are shown first in cross section and then as viewed when looking down on the cone Only a part of each escape trajectory is shown

complete information about an escape trajectory, it is necessary to state the body from which the spacecraft escapes and the body to which it goes.

In planning the orbits and trajectories of spacecraft that are to be launched and in studying those of the spacecraft already in flight, scientists make use of the laws of Kepler.

Johannes Kepler, once the youthful assistant of Tycho Brahe, made profound studies of the movement of celestial bodies. These studies established the fact that the sun, not the earth, is the center of revolution of the solar system. From Kepler's works astronomers derived three basic laws about the movement of bodies within the solar system. These laws, which also apply to the movement of spacecraft, are stated as follows:

1. Each planet moves around the sun along an ellipse, the sun being at one focus of the ellipse.

2. The radius vector of each planet (the line joining its center with that of the sun) moves over equal areas in equal times.

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

With Kepler's laws as a foundation, scientists are able to describe the nature of the elliptical orbits of spacecraft, and they make precise calculations about the time that it will take for a spacecraft to move through different parts of its orbit, as well as the **period** (the time it takes the spacecraft to make one complete revolution). To enable you to interpret reports that scientists make on the orbits and trajectories of spacecraft in flight, it is helpful to note the application made of Kepler's first two laws.

The planets like most spacecraft move in elliptical orbits. The orbits of most planets are so little flattened, however, that they are almost circular. The orbits of spacecraft may vary from being almost circular to being highly flattened or elongated. The shape of the orbit that a particular spacecraft is placed in depends upon its mission, which determines the points in space to be reached.

To distinguish between a circular and an elliptical orbit, it is helpful to consider an ellipse with a noticeable amount of flattening, or elongation. An ellipse can be drawn by making use of a pencil, a piece of string, and two pins, as shown (Fig. 37). The position of each of the pins marks a **focus** (plural **foci**) of the ellipse. In case of a spacecraft orbiting the earth, the earth (not the sun) is at one focus of the ellipse.

The point in the orbit at which the spacecraft approaches closest to the earth is known as the **perigee** (from two Greek words meaning near the earth). The point at which the spacecraft is farthest from the earth is known as **apogee** (meaning away from the earth). Usually the orbit of a spacecraft is given in terms of its altitude at perigee and apogee.

Another way of describing a spacecraft's orbit is to give its period. The period of the Mercury spacecraft, or the time required to make one complete revolution of the earth, was about 90 minutes. The Mercury spacecraft was put into an elliptical orbit around the earth at a low altitude.

To compare the periods of spacecraft orbited at different altitudes, it is necessary to consider circular orbits. The period is progressively longer as the satellite or spacecraft is orbited at a higher altitude. Some examples of circular orbits at different altitudes and their periods are given below:

Height above the earth's surface, miles	*Period*
100	1 hr 28 min
200	1 hr 30 min
300	1 hr 34 min
22,300	23 hr 56 min
239,000	27 3 days

A spacecraft orbiting the earth above the equator at an altitude of 22,300 miles would have a period equal to the time required for the earth to turn once on its axis. Such a satellite would remain above the same area of the earth as the earth turned beneath it. The movement of this spacecraft is **synchronous** with the rotation of the earth. The spacecraft is said to be in an **earth synchronous orbit** (stationary orbit). The last orbit given is that of the moon, the earth's only natural satellite, which has a period of 27.3 days.

When spacecraft are in an elliptical orbit, they do not travel at the same speed at all points of their orbit, as explained earlier. Kepler's second law, that of equal areas, tells why this is true. At apogee the spacecraft is traveling at its lowest speed, at perigee at its highest speed. Figure 38 shows how this is explained in terms of equal areas.

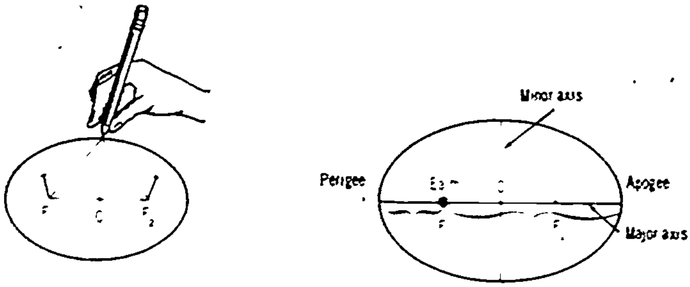


Figure 37 AN ELLIPTICAL ORBIT. An elliptical orbit can be drawn with string and pins as shown above. The pins mark the foci of the ellipse (F_1 and F_2). If the orbit is that for an earth satellite, the earth is at one focus of the ellipse (F_1). Perigee (point closest to the earth) and apogee (point farthest from the earth) are at opposite ends of the major axis.

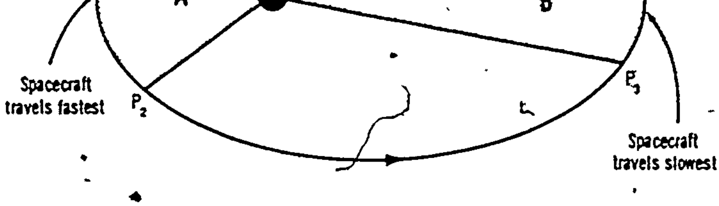


Figure 38 KEPLER'S LAW OF EQUAL AREAS This second law of Kepler's states that the radius vector (line joining the earth's center with the spacecraft) moves over equal areas in equal time Area A equals Area B, and the time for travel from P_1 to P_2 equals that for travel from P_3 to P_4. Since the arc between P_1 and P_2 is larger than that between P_3 and P_4, the spacecraft travels faster at perigee than at apogee.

Planning the course of a spacecraft, then, becomes a matter of accurately plotting its position in space according to precise laws. The shape of the orbit or trajectory that a particular spacecraft is placed in depends upon the mission. This is planned to begin and end at a precise time, and all maneuvers to be made during the mission are planned in terms of points to be reached on an orbit or trajectory at a specified time. In the course of space travel certain orbits and trajectories have been put to use for special purposes.

Special Orbits and Trajectories

Most spacecraft are launched from Cape Kennedy toward the east, the same direction in which the earth is rotating. This allows the velocity imparted by the rotating earth to be added to the velocity generated by the rocket booster. When spacecraft are launched due east from Cape Kennedy, they are put into an orbit inclined about 29 degrees to the equator (Fig. 39). The reason

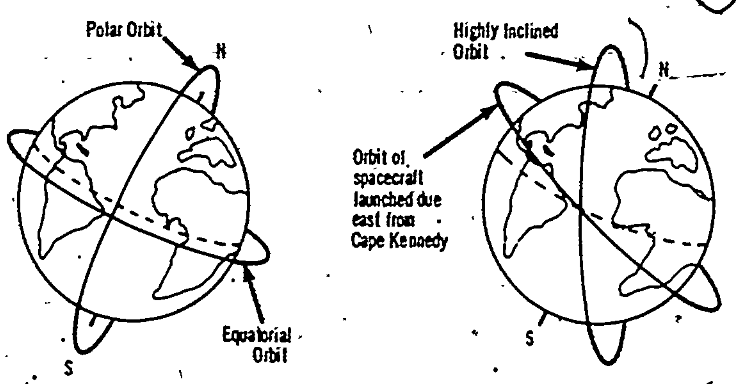


Figure 39. ORBITS IN DIFFERENT PLANES Above are shown some of the planes of earth satellites. The near-equatorial orbit shown at the right (latitude 29° N and S) is that followed by earth satellites launched due east from Cape Kennedy. By now earth satellites have been launched at about all degrees of inclination from 0 to 90 degrees.

for this is that Cape Kennedy is about 29 degrees north of the equator (about latitude 29° N.). A spacecraft that is to be put directly into an **equatorial orbit** would have to be launched due east at the equator. If spacecraft are to be launched from Cape Kennedy into a highly **inclined orbit** (one at a large angle with the equator), they must be equipped with an engine that can be fired upon radio command from the earth to allow a change in orbit after launch. Spacecraft that are to be put immediately into a **polar orbit** are launched from the Western Test Range at Vandenberg Air Force Base, California. From this range they travel south and quickly reach the Pacific Ocean, where their rocket boosters do not present a hazard to inhabited areas. Spacecraft launched into a polar orbit can survey all portions of the earth as it rotates below them.

A special earth orbit according to altitude is the earth synchronous orbit (stationary orbit) at 22,300 miles above the earth's equator, just described. Communication satellites and other spacecraft that must remain in a fixed position in relation to the earth are placed in this orbit.

Figure 40 shows orbits and trajectories for sending spacecraft to the moon.

The first of these pathways into deep space is the **parking orbit.** When it is difficult to get a spacecraft in the right position with a direct launch from the earth, the spacecraft is first put into a parking orbit around the earth. The spacecraft coasts in this orbit until it reaches the right point for launch into deep space. Then the final rocket stage, which has remained attached to the spacecraft, is fired to send the spacecraft off in the right direction into deep space. The parking orbit was used by the later lunar probes, and it is used by the Apollo spacecraft going to the moon.

The second pathway is the **direct earth-moon trajectory.** This course is a theoretic one as far as the United States is concerned. The successful US Ranger spacecraft, which made hard landings on the moon, were not put on a direct earth-moon trajectory. They were first put into a parking orbit.

The third course shown is the figure-of-eight trajectory, or the **free-return trajectory.** The Apollo spacecraft is placed on this trajectory, rather than on an escape trajectory, as it begins its flight to the moon. If trouble should develop early in the flight, the astronauts can loop around the moon and return to the earth

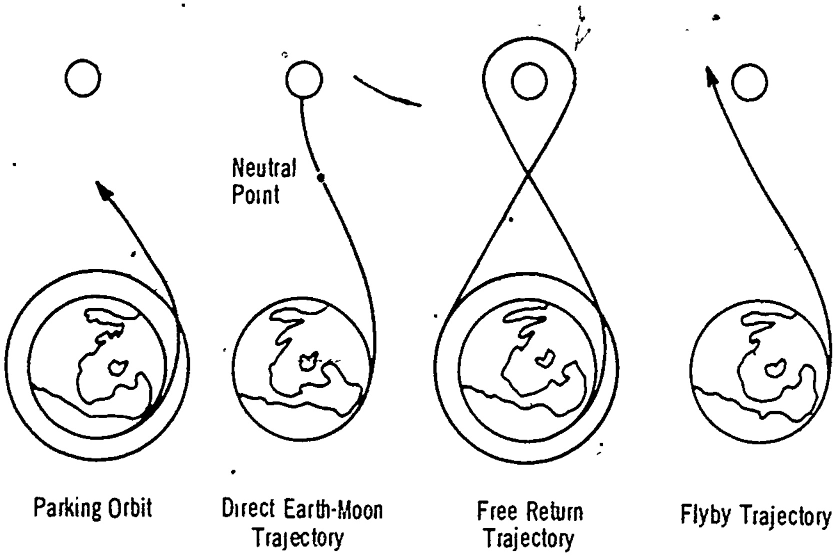


Figure 40. ORBITS AND TRAJECTORIES FOR LAUNCHING SPACECRAFT TO THE MOON. Most US probes of the moon were first put into a parking orbit around the earth A probe making a hard landing on the moon could be put into a direct earth-moon trajectory. The neutral point shown on the direct earth-moon trajectory above marks the point where the spacecraft leaves the gravity force field of the earth and enters that of the moon. All Apollo moon flights begin on a free-return trajectory The earliest US probes of the moon were put on a flyby trajectory.

without firing the big propulsion engine in the spacecraft. If all is well when the moon trip is underway, the astronauts fire the propulsion engine to put the spacecraft on what is called a mixed trajectory, or one directed toward the landing site selected for that particular flight.

The fourth kind of pathway shown is the **flyby trajectory.** This is an escape trajectory from the earth to the moon (or planet being probed). Such a trajectory allows the spacecraft to obtain information about the moon or planet from a distance. All the Mariner spacecraft launched to the vicinity of Venus and Mars during the 1960s were put on a flyby trajectory.

Just as soon as a spacecraft starts travel on its orbit or trajectory, tracking begins.

TRACKING SPACECRAFT

After the spacecraft is launched, the Space Center at Cape Kennedy turns it over to the control of the agency responsible for it. The Manned Spacecraft Center at Houston, Texas, takes over control of spacecraft piloted by astronauts, for example. Unmanned spacecraft making a flyby or orbit of one of the planets are controlled by the Jet Propulsion Laboratory at Pasadena, California. Communication satellites are turned over to the organizations that pay for orbiting them. Even after NASA relinquishes control of a spacecraft, its stations continually track them and provide information to the agency that controls the spacecraft.

NASA **tracking stations** are distributed worldwide (Fig. 41). These stations receive signals from space through the aid of large radio antennas. Except when spacecraft are blocked out from the earth by passing behind another celestial body, they are in constant communication with the earth. It is especially important that manned spacecraft are kept continually in communication with Mission Control at Houston, Texas. Important decisions involving the astronauts' safety must be made during a mission, and these can usually be made only at specific points on the orbit or trajectory.

There are four means of tracking spacecraft: (1) visual observation, (2) specially designed cameras, (3) radar, and (4) radio.

In the beginning of space travel amateur observers helped to track spacecraft in orbit. They watched for such objects as the large Echo balloon satellites, which could be seen with the naked eye. They also followed the course of smaller satellites that were not visible to the naked eye. Some of these could be observed with a pair of good binoculars, but these satellites required careful watching. Small satellites are difficult to follow as they move among the stars at night, or as they are seen only dimly along the horizon at sunset and dawn.

Cameras have long been used with telescopes for the study of astronomy. Giant cameras specially designed for the purpose, such as the Baker-Nunn Camera, are used for recording the orbits and trajectories of spacecraft.

Like other bodies in space, artificial satellites can be tracked by radar. A radar pulse is sent out to the spacecraft, and a return signal is received. The equipment required for radar tracking is

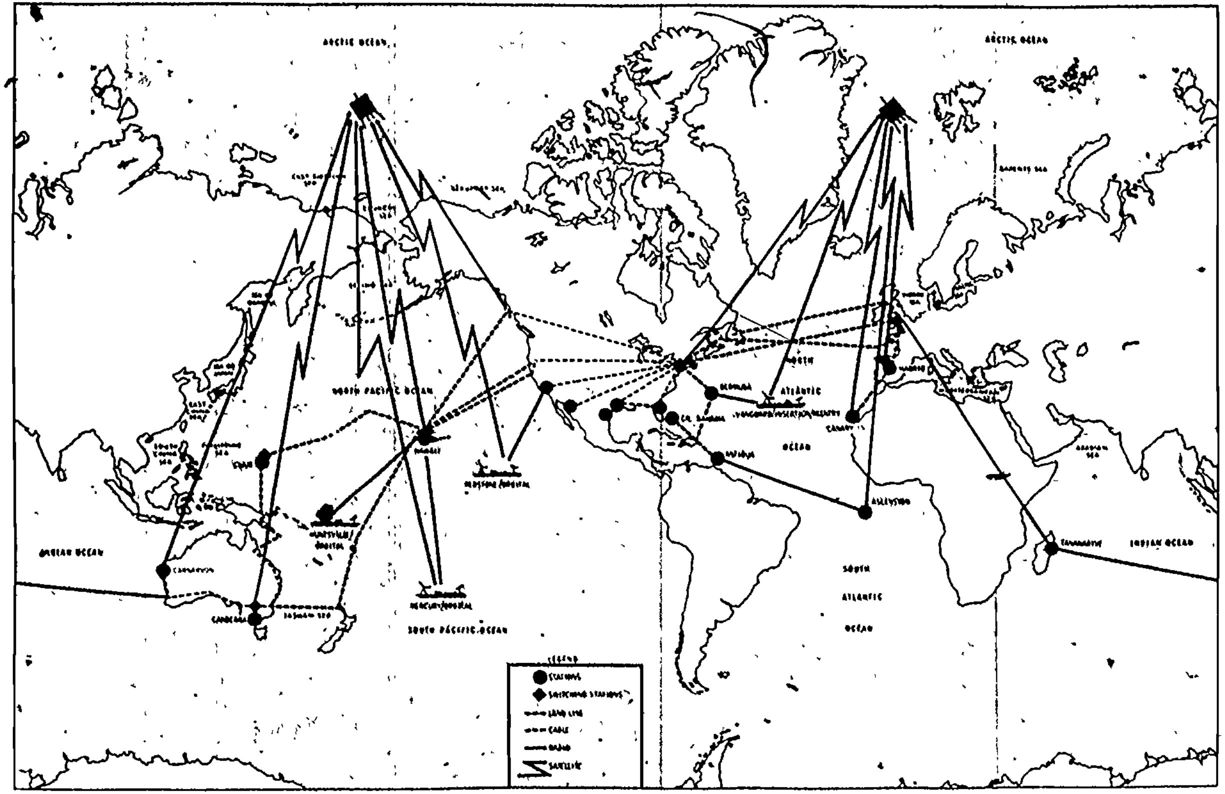


Figure 41. NASA WORLDWIDE COMMUNICATIONS NETWORK. The network was expanded to take care of the Apollo flights. The network shown above was that used for the Apollo-9 flight. This flight was made in earth orbit to test the lunar module.

77

highly expensive, and the method is not always reliable. Fiberglass and other synthetic materials used in constructing spacecraft do not always give a radar return, and spacecraft are only very small objects moving in the vastness of space.

The fourth method, radio, is the most reliable of all, but it can be used only if the satellite is active—that is, if it has a radio transmitter in it (Fig. 42). If a command is to be sent to the spacecraft, it must also have a radio receiver on board. In making use of radio, scientists devise electronic sensors and instruments for measuring and then transmitting the information by means of coded radio signals. The technique of transmitting by radio the results of measurements or observations which were made by instruments in satellites is called **telemetry.** The word comes from two Greek words meaning measuring at a distance.

Astronauts communicate with the ground by means of voice radio, and messages are sent to them in the same way. In addi-

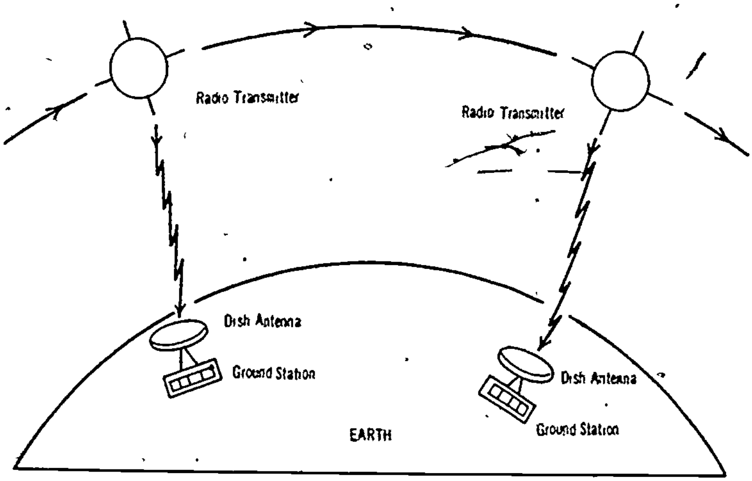


Figure 42. TELEMETRY. A spacecraft usually carries several instruments that gather data as coded radio signals. The signals are combined in the spacecraft and transmitted to the ground, as shown above. At the ground station the signals are decoded and separated into the original instrument readings, such as degree of temperature or amount of radiation or magnetism. A spacecraft may telemeter data to one or many stations as it travels through its orbit.

tion, medical and biological information about the astronauts is communicated automatically to the ground by means of telemetry. This automatic method of obtaining data by radio is the sole means of obtaining information from unmanned spacecraft that do not return a protected capsule to the earth.

A system of telemetry transmits radio signals from instruments that measure such quantities as temperature, density, and radiation. Data is usually relayed to a central communications point in the spacecraft. where it is collected and compiled into coded radio signals. These are sent to the ground on a designated frequency. A ground station tuned in on the frequency receives the coded message, which is then unscrambled, or interpreted. US scientists and engineers have shown remarkable ingenuity in developing miniature instruments and electronic devices for obtaining and assembling data in spacecraft and telemetering it to the ground.

To keep information from being lost, more advanced telemetry systems store data on board the spacecraft. The signals from sensors and instruments are recorded on tapes, and the tapes are stored. When the spacecraft approaches a ground station, the station transmits a radio signal to "ask" the spacecraft to broadcast all or any portion of the data it has stored. A tape recorder in the spacecraft then plays back the data. and it is transmitted to the earth.

Television is used for telemetry whenever pictures are needed. The Tiros weather satellites, for example, took pictures of cloud cover and stored them on magnetic tape. Upon a signal from a ground station, the Tiros transmitted the pictures to the earth. The specially developed television cameras used by the Apollo astronauts have enabled them to share their experiences in the spacecraft, in space, and on the moon.

The giant radio telescopes located at astronomy observatories, like the one at Jodrell Bank, England, can be used to track satellites and receive information from them. The dishes of such telescopes have not been constructed for this purpose, however, but rather for the study of radio astronomy. The large **dish-shaped radio antennas** located worldwide at the NASA tracking stations are specially constructed for tracking spacecraft. Three of these ground stations. located at roughly equidistant points of the globe —Goldstone. California; Madrid. Spain. and Canberra, Australia

—communicate with spacecraft and the astronauts when in deep space. The gigantic new dish antennas (210 feet in diameter) that are being constructed at these stations (Fig. 43) have improved television coverage of the Apollo astronauts on the moon, and they will provide for communication throughout the entire solar system.

NASA makes extensive use of radio in tracking spacecraft, but the other three methods—visual observation, cameras, and radar—are used to supplement radio. An efficient method of tracking is required to permit the stabilization and navigation of spacecraft.

STABILIZATION AND NAVIGATION OF SPACECRAFT

When space scientists speak of the flight control of spacecraft, they mean the **stabilization** of spacecraft and the use of radio commands to the spacecraft to cause equipment on board to operate automatically. Astronauts **navigate** spacecraft in the sense that

Figure 43. GIANT DISH ANTENNA. This is the 210-foot (in diameter) antenna at Goldstone, California. It is used for planetary probes and for communicating with the astronauts when they are on the moon or near it. Two similar giant antennas, one in Australia and the other in Spain, will be part of the NASA Deep Space Network.

they make adjustments, or midcourse corrections, to make small changes in the orbit or trajectory. In addition, they may make large changes in orbit or a series of small changes to enable them to **rendezvous** with another spacecraft—that is, search for another spacecraft and meet with it. Then the two spacecraft **dock,** or link together, and their power and electrical systems are joined so that they can operate as one unit.

To change an orbit or trajectory, a spacecraft must have a powerful **rocket propulsion engine.** This engine operates on the same principle as the engines used in the booster. Only rocket engines will operate in the spacecraft, just as in the booster, because only rocket engines carry their oxygen with them in the propellant and can therefore burn fuel and generate power in the vacuum of space.

To make smaller corrective maneuvers to change the attitude, or position, of the spacecraft in the orbit in which it is traveling, small **jet thrusters** are fired. These create tiny pulses of power that steady the spacecraft (Fig. 44). Usually a spacecraft drifts during flight, much as floating objects drift on the water. The only way to steady the spacecraft is to use these jet thrusters, which are tiny rocket engines (*not* air-breathing jet engines). The small thrusters are used on both manned and unmanned space-

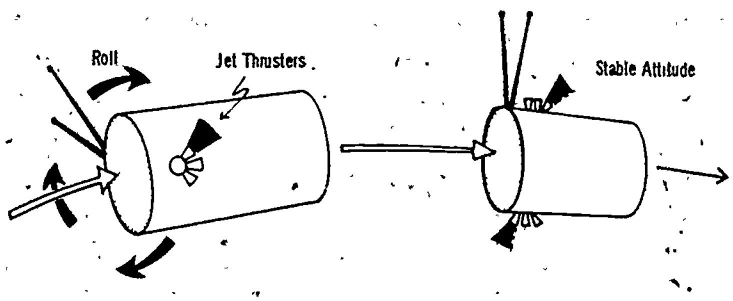


Figure 44. JET THRUSTERS USED TO CONTROL ATTITUDE OF SPACECRAFT. Tiny jet thrusters may be located at any point on a spacecraft to control yaw (sidewise movement), pitch (nose-up and nose-down movement), or roll. Spacecraft rotate about their axis in the same three directions as aircraft do. The jet thrusters are fired to create a reaction thrust that steadies the spacecraft in its orbit. The tiny thrusters do not cause the spacecraft to change orbit. For making changes in orbit a large rocket propulsion engine is used.

craft. The Apollo astronauts fire the small thrusters to adjust the attitude of their spacecraft, turning it to control heating and cooling in what they call the "barbecue mode." On unmanned spacecraft the jet thrusters are fired automatically to keep cameras, instruments, or communications antennas pointed in the right direction. The same result may be obtained by spin-stabilizing a spacecraft—that is, by making it steady by spinning, much as a toy top is stabilized.

A spacecraft may be equipped with **retrorockets.** These are rocket engines that fire in a direction opposite to that in which the spacecraft is traveling. Their action brakes the spacecraft and causes it to fall out of orbit. Retrorockets are fired to begin a descent trajectory to put the spacecraft into a lower orbit or to make a landing.

Like the rocket booster, unmanned spacecraft must be equipped for automatic guidance and control if a correction in course is necessary. In addition, unmanned spacecraft are sometimes required to perform orbit changes, descent, or other maneuvers. When spacecraft perform maneuvers requiring changes in orbit, they must be guided in the course of the transfer from one orbit to another. Besides inertial and radio command guidance systems, spacecraft make use of **star tracking,** or fixing on a star, usually the bright star Canopus. The automatic star-tracking equipment is made to operate by keeping instruments turned toward the star being used, much in the way that the human navigator in a ship or aircraft trains his astrolabe on different stars as he plots and checks his course.

To provide electricity for operating the spacecraft's radios, computers, electronic instruments, and the life-support systems on manned spacecraft, adequate electric power must be generated aboard the spacecraft. The vehicle may be equipped with conventional batteries, fuel cells, nuclear power plants, or solar cells for producing electricity. The **solar cells** have been developed for use in space. In the vacuum of space, the sun's radiation is not obstructed except for those periods when the spacecraft passes behind a planet. In space, sunlight can be used in its pure form by tiny solar cells, which convert sunlight into electricity. Since each cell can generate only a small amount of electricity, hundreds of such cells may be required. These are exposed to the sunlight

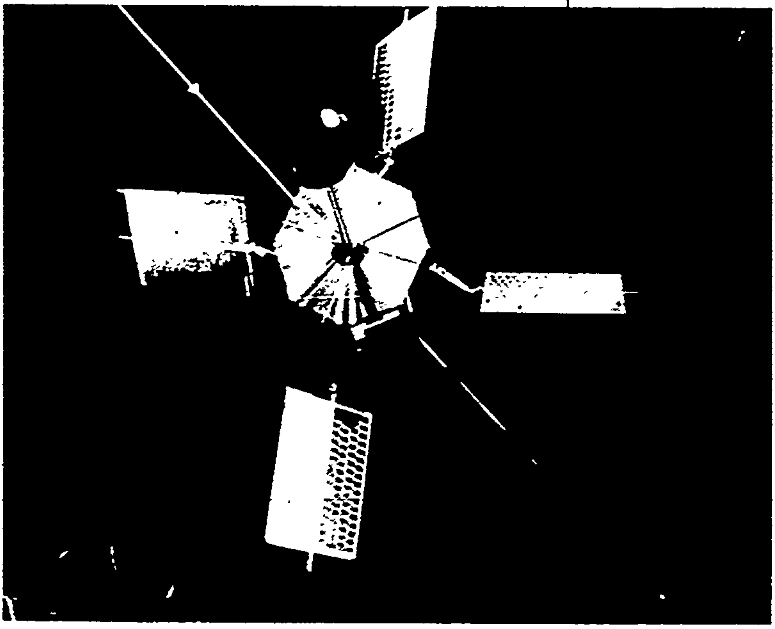


Figure 45 PADDLE WHEELS CARRYING SOLAR CELLS The four paddle wheels on the Explorer research satellite shown above (Explorer 30) carry many tiny solar cells The cells generate electricity when exposed to sunlight in space Solar cells are one source of electric power for spacecraft

on the surface of the spacecraft or on large **paddle wheels** that protrude from the spacecraft (Fig 45). Solar cells can, of course, generate power only when they are in the sunlight. A battery backup is generally used during periods when the spacecraft is not in sunlight.

The kinds of systems that a spacecraft has for guidance and control and the means used to power the systems depends upon the spacecraft and its mission You can get a better idea of how spacecraft are guided and controlled by considering some of the unmanned and manned spacecraft that have been flown and the purposes they have served.

TERMS TO REMEMBER

celestial mechanics	inertia
artificial satellite	ballistic trajectory
gravity	centrifugal force

condition of weightlessness
escape from the earth
midcourse correction
trajectory
circular orbit
elliptical orbit
escape trajectory
period of a spacecraft
focus of an ellipse (two foci)
perigee (nearest point of orbit)
apogee (farthest point of orbit)
equatorial orbit
inclined orbit
polar orbit
earth synchronous orbit
(stationary orbit)
parking orbit
direct earth-moon trajectory
free-return trajectory
flyby trajectory
tracking stations
telemetry
television
dish-shaped radio antennas
stabilization in orbit
navigation of spacecraft
rendezvous
docking
rocket propulsion engine
jet thrusters
retrorockets
star tracking
solar cells
paddle wheels

IDEAS TO REMEMBER

1. To become an artificial satellite of the earth, a spacecraft must meet three conditions. (a) be orbited above the earth's atmosphere, (b) be propelled forward fast enough, and (c) follow a path parallel to the curvature of the earth at the point of injection into orbit.

2. An artificial satellite follows the laws of celestial mechanics, just as the moon and other natural bodies do. An artificial satellite is held in orbit by the balance of centrifugal force (inertia) and gravity.

3. A spacecraft in orbit is in a condition of weightlessness.

4. Spacecraft follow a curved path through space. A closed path is called an orbit, an open path a trajectory. The principal kinds of paths are the circular orbit, the elliptical orbit, and the escape trajectory. Most spacecraft, like the planets, follow an elliptical orbit.

5. A spacecraft in an elliptical orbit does not travel at the same speed at all points in its orbit. Its speed is greatest at perigee and least at apogee.

6. The length of the period of a satellite or spacecraft increases with altitude

7. Spacecraft are tracked by stations located worldwide. There are four means of tracking spacecraft. (a) visual observation, (b) cameras, (c) radar, and (d) radio. The most reliable means is radio, but this can be used only when there is an operating radio transmitter in the satellite.

8. Spacecraft travel along fixed orbits or trajectories. To make a change in their course, a rocket propulsion engine must be fired. The small jet thrusters are used only to stabilize spacecraft in orbit.

QUESTIONS

1. How did Newton explain the theory of an artificial satellite of the earth? How is this theory applied to spacecraft orbited by modern rocket boosters?
2. What are the three conditions that must be met for orbiting spacecraft?
3. Why are objects in orbit in a condition of weightlessness? Can the condition be reproduced on the earth?
4. Why do most spacecraft go into an elliptical orbit? Draw an ellipse representing the orbit of an earth satellite. Show the satellite at perigee and at apogee.
5. Does a spacecraft in a higher orbit have a shorter period or a longer period? What is the period of a satellite in an earth synchronous orbit? of the moon?
6. What is an equatorial orbit? a polar orbit?
7. What is meant by a parking orbit? What kind of spacecraft use this orbit?
8. Name three means used for tracking spacecraft. What is meant by telemetry?
9. What means are used for tracking the Apollo astronauts and communicating with them during the moon flights?
10. What is meant by rendezvous and docking?
11. What is the purpose of the large propulsion engine used in some spacecraft? For what purpose are the small thrusters on spacecraft used?
12. How does an unmanned spacecraft maneuver? How is it stabilized?

THINGS TO DO

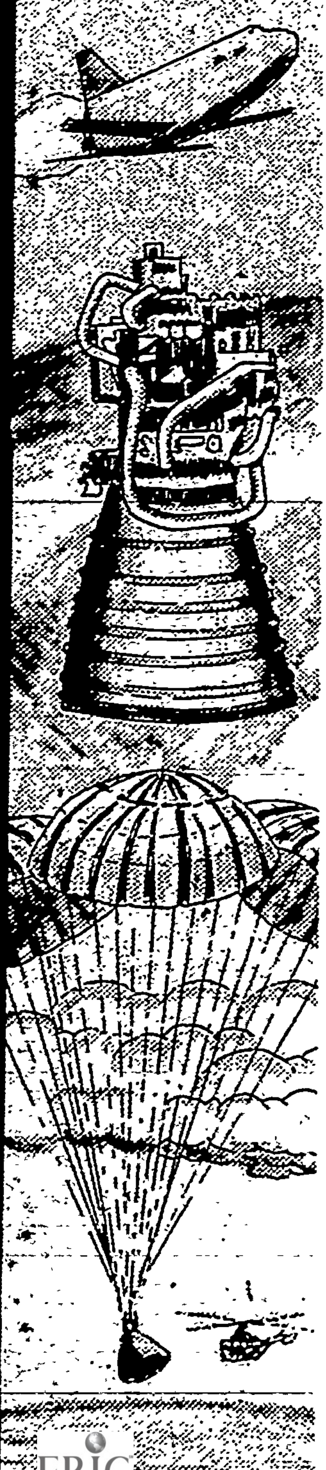
1. Look up the accounts of three recent space launches. Try to get data describing the orbit or trajectory that the spacecraft is following. If it is an earth satellite, find out its altitude at perigee and apogee. Explain why the spacecraft was put into its particular orbit or trajectory. What has this to do with its mission? Were midcourse corrections made? Has the spacecraft been successful, or is it likely to be successful in performing its mission?
2. If you are especially interested in mathematics, demonstrate to the class how the orbits and trajectories of spacecraft are related to the sections of a cone. Show where these sections are to be found on the cone, and then make drawings showing how these sections appear as one looks down on the cone. Put emphasis on the ellipse, as most spacecraft follow an elliptical orbit. Show the major axis and the minor axis of the ellipse and the foci. Explain why computer calculations are necessary to get the precision required for orbiting spacecraft. Tell why some rocket boosters have failed to orbit spacecraft.

3. Draw the orbits and trajectories followed by the Apollo astronauts on one of the flights to the moon. Explain in general terms how these flight paths were planned and how the astronauts navigated the spacecraft to keep it on course.

4 Find out what you can about the telemetry system used for one of the unmanned spacecraft that had an especially interesting mission, such as the Surveyor or the Lunar Orbiter. How was the data collected and stored? How were the television cameras used?

5. Study the means used for communicating with the Apollo astronauts on the moon. What part of the NASA network is used at this time? How does the flight surgeon obtain medical data on the astronauts? How were we able to secure the pictures of the lunar module at liftoff? Note how the television coverage of the astronauts on the moon has been gradually extended as the flights progressed Report to the class on your findings.

Chapter 4



Unmanned Spacecraft

THIS CHAPTER describes the kinds of missions performed by the two large classes of unmanned spacecraft: research satellites and applications satellites. It tells about the three kinds of research satellites (1) those investigating the space environment and the earth, (2) those probing the moon, and (3) those probing the planets. It names the most important series of each kind of research satellite and tells of some of the most significant discoveries made possible by research satellites. Next the chapter describes the four kinds of application satellites: (1) communications satellites, (2) weather satellites, (3) navigation satellites, and (4) survey satellites. It tells about the progress made with the applications satellites and describes one or more series of each kind of applications satellite. When you have studied this chapter, you should be able to do the following: (1) name one series of each of the three kinds of research satellites, (2) tell three significant discoveries made possible by research satellites, (3) name the four kinds of applications satellites, (4) describe the work done by communications and weather satellites and name one series of each kind, and (5) describe the kind of work that might be done by navigation and survey satellites in the future.

OF ALL the spacecraft orbited by the United States only about 4 percent have been manned. By the end of 1971 this country had made only 25 manned flights, but it had launched more than 600 unmanned spacecraft into orbit. Although the manned flights, climaxing in the lunar landings and the exploration of the moon, represent the peak of US achievements in space, they by no means tell the whole story of the progress made. Unmanned spacecraft have carried out investigations of the space environment that made the lunar voyages possible. Even more important, they have opened up possibilities for further exploration of space that will continue to produce results long after the Apollo flights are completed, and many unmanned satellites are already performing useful tasks in space.

Unmanned spacecraft that orbit the earth, or **earth satellites** as they are usually called, are able to perform a wide variety of tasks simply because of their unique position in space. Because they are orbiting at some distance from the earth, they can "see" over large portions of the earth at one time. Without any additional expenditure of fuel for propulsion, they continue in their orbit, making observations and measurements for an extended time. As long as their sensors and instruments remain active and the radio transmitter in the satellite can telemeter information to the earth, the useful life of the satellite continues. For this reason scientists and engineers strive to construct and equip satellites so that they are as reliable as it is humanly possible to make them.

Lessons learned from orbiting earth satellites have been extended to satellites sent to investigate deep space and to probe the moon and the two neighboring planets, Venus and Mars. US spacecraft have become **hard-landers** on the moon, and later **soft-landers** and **orbiters** of the moon. Other spacecraft have made **flybys** of Mars and Venus, and already one spacecraft, Mariner 9, has become a Mars orbiter.

The first US spacecraft were **research satellites** designed to seek for new information. But this country moved forward quickly to put satellites to work, doing earth jobs that could be done better in space or jobs that could not be done on the earth, such as relaying messages across the ocean without underseas cable. The working satellites came to be known as applications satellites, since they applied the knowledge obtained from space research. There are at present two large classes of unmanned satellites research satellites and applications satellites.

RESEARCH SATELLITES

The first artificial satellites were launched as part of the program for the International Geophysical Year (IGY), an 18-month period (1957-58) during which scientists of the world cooperated to learn more about the planet earth and the effects of the sun upon the earth. Later the United States and the Soviet Union extended their programs of research with satellites to include the moon and the two nearest planets. As the result of measurements made by research satellites during the fifteen years that they have been orbiting, results have been achieved that can best be described as revolutionary. They have changed the ideas that man had in the 1950s about the earth, the moon, and the two neighboring planets. In addition, a number of totally new and unexpected phenomena have been discovered.

Research satellites might be conveniently divided into three kinds. (1) satellites that investigate the space environment between the earth and the moon, what is called **cislunar space,** and the earth itself, (2) satellites that have probed the moon. and (3) satellites sent to probe the planets.

Satellites Investigating Space and the Earth

Even before satellites were put into space to make measurements of radiation. scientists realized that the earth's magnetic field was affected by ionized radiations that come from the sun and from the cosmos beyond, but they did not have a clear picture of how these energy particles interacted with the **earth's magnetic field.** They knew that the earth, which acts as though it had a gigantic bar magnet buried in its interior, is surrounded by an invisible magnetic force field (Fig. 46) They understood that lines of this force field dip down to the earth at the north and south magnetic poles and bulge outward high above the earth at the equator, but they did not know where the limits of the force field lay.

Dr. James A. Van Allen (1914–), a research physicist from Iowa State University, after conducting experiments with rockoons (rockets fired from balloons), concluded that energy particles entered the earth's magnetic field at the openings over the magnetic poles. But he was unable to determine what happened to these ionized particles once they entered the magnetic field. Therefore, Van Allen and other scientists were eager to put instruments far out into space to make measurements that would help them find out how **cosmic rays** and other ionized particles coming to the earth from space interacted with the earth's magnetic field.

Although Explorer 1 was much smaller than the Soviet Sputniks, it made possible an important discovery. Equipped with a

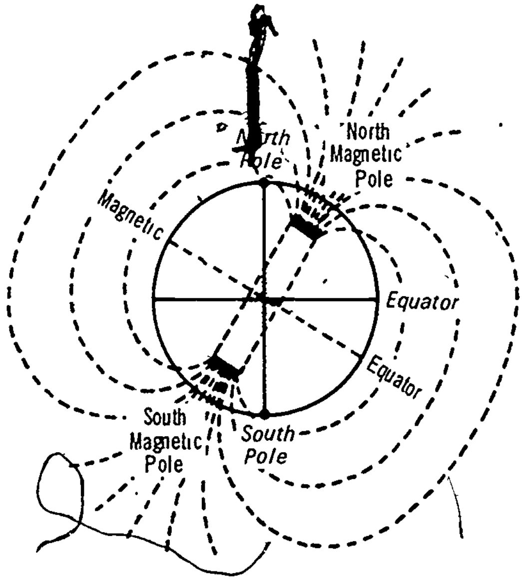


Figure 46 EARTH'S MAGNETIC FIELD One way to picture this is to imagine a gigantic bar magnet buried in the earth The poles of this magnet would be deflected slightly from the earth's geographic poles. The lines of magnetic force would arc out from one magnetic pole to the other Some of the early US research satellites were used to find out how radiations from space react to the earth's magnetic field

Geiger counter and launched into a high earth orbit near the equator, it returned signals telling of radiation encountered. Finally the transmitter became silent, and observers on the ground assumed that the instruments had failed Suddenly Explorer 1 began to send signals again. Later it became silent once more. Scientists observed that the satellite became silent whenever it reached an altitude of about 600 miles The cause could have been either overloading of the counter or faulty instrumentation Testing a Geiger counter in his laboratory, Van Allen concluded that Explorer 1 had encountered radiation too intense to record. Explorer 3, equipped with tapes for storing signals, was able to record radiation of much greater intensity. After examining the great store of taped signals transmitted by Explorer 3, Van Allen announced discovery of the inner radiation belt Then began the systematic search for a second radiation belt This second belt was discovered by Pioneer 3 at a distance of about 12,000 miles above the earth. By this time it was clear that at least some of the ionized particle radiation that entered the earth's magnetic field was trapped in two wide belts above the equator, which came to be called the **Van Allen radiation belts** (Fig. 47).

The early Pioneers, intended as probes of the moon, did not reach their planned orbits. Instead they were teamed with the Explorer satellites to map out the Van Allen belts and the magnetic force field of the earth, as shown in Figure 48. Information transmitted by Explorer and Pioneer satellites showed that cosmic rays were not the only kind of ionized particle radiation reaching the earth from the sun. These satellites in fact confirmed the presence of a stream of much more abundant ionized radiation in space, now known as the **solar wind.** Reports from the satellites showed that the solar wind created a shock front as it impacted with the earth's magnetic force field, flattening the boundary of the field on the sun side and stretching it out on the side away from the sun (Fig. 49). The newly defined magnetic blanket of the earth came to be called the **magnetosphere.** This magnetic blanket, together with the atmosphere, protects the earth from the deadly radiations that come from outer space, making it possible for life to survive on the earth.

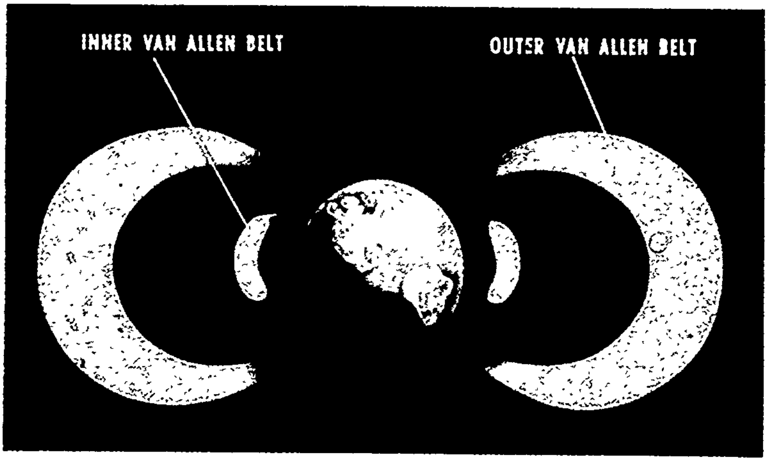


Figure 47. VAN ALLEN RADIATION BELTS. This artist's drawing shows a cross section of the two doughnut-shaped radiation belts surrounding the earth. Note that the belts are shaped according to the earth's magnetic force lines. The belts are believed to be formed from ionized particles of matter from outer space that become trapped in the earth's magnetic field. Scientists continue to study the Van Allen belts to find out more about their nature and extent.

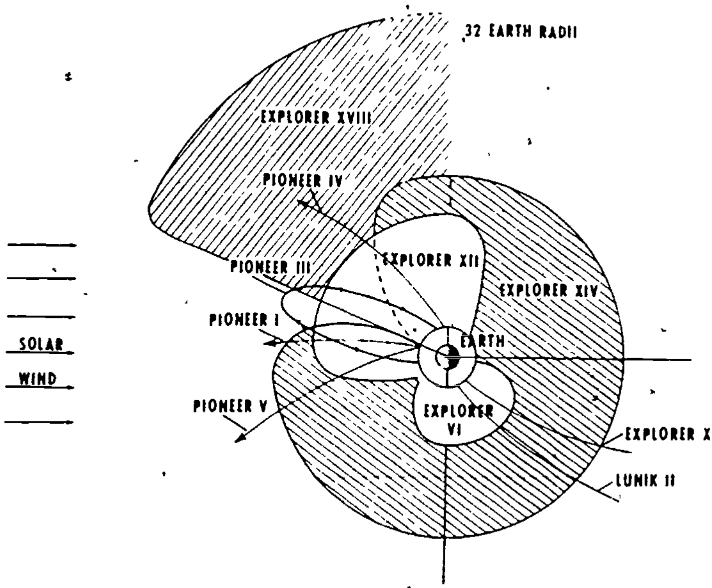


Figure 48. PATHS OF EARLY RESEARCH SATELLITES EXPLORING THE EARTH'S MAGNETOSPHERE The shaded portion shows the areas of space swept over by these satellites as the earth orbits the sun during the year All are US satellites except Lunik 2, an early Soviet moon probe.

The Explorer satellites are the largest group of research satellites. By the end of 1969 more than forty Explorers had been launched, and the program continues. Some of the later Explorers are known by other names. Among these are the Interplanetary Monitoring Platforms (IMPs) (Fig. 50). Usually launched into highly elliptical orbits, the IMP Explorers swing out to the vicinity of the moon and then return to a point near the earth, making measurements over a vast region of space. The most recent Explorers, the Atmosphere Explorers, have on-board propulsion systems that will make it possible for them to change orbit and make detailed studies of the earth's upper atmosphere.

Although an Explorer rather than a Vanguard was the first US satellite orbited, the three Vanguard satellites that were orbited made important contributions to space research. The small Vanguard 1, the 3¼-pound second US satellite, made possible the discovery that the earth is somewhat pear-shaped rather than a sphere slightly bulged at the equator, as formerly thought. By studying the orbits of satellites, scientists are able to make more precise measurements of the body orbited. In the case of the earth, the measurements have made possible more exact navigation and mapping. After the three Vanguard satellites were put into permanent orbits, the Vanguard program was absorbed into the Explorer program.

The largest and most complex of the research satellites are the Orbiting Observatories, which carry telescopes and other instruments for conducting experiments. They are spin-stabilized to keep the instruments pointing in the right direction. There have been three series of Orbiting Observatories. These have observed the earth (Orbiting Geophysical Observatory, OGO), the sun (Orbiting Solar Observatory, OSO), and the stars (Orbiting Astronomical Observatory, OAO). Studies made by the OSO (Fig. 51)

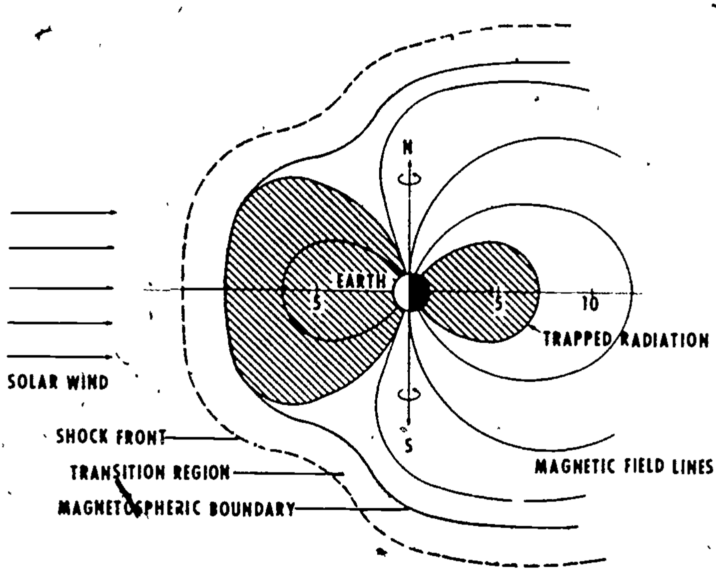


Figure 49. CROSS SECTION OF THE EARTH'S MAGNETOSPHERE As the solar wind strikes against the earth's magnetic field, it creates a shock front. The solar wind then flows around the earth's magnetic field, defining the boundary of the magnetosphere. As the solar wind impacts with the earth's magnetic field lines, it causes the magnetosphere to be flattened on the sun side of the earth and pulled out on the side away from the sun Some radiation from outer space penetrates the magnetosphere and becomes trapped in the earth's magnetic field, forming the Van Allen radiation belts.

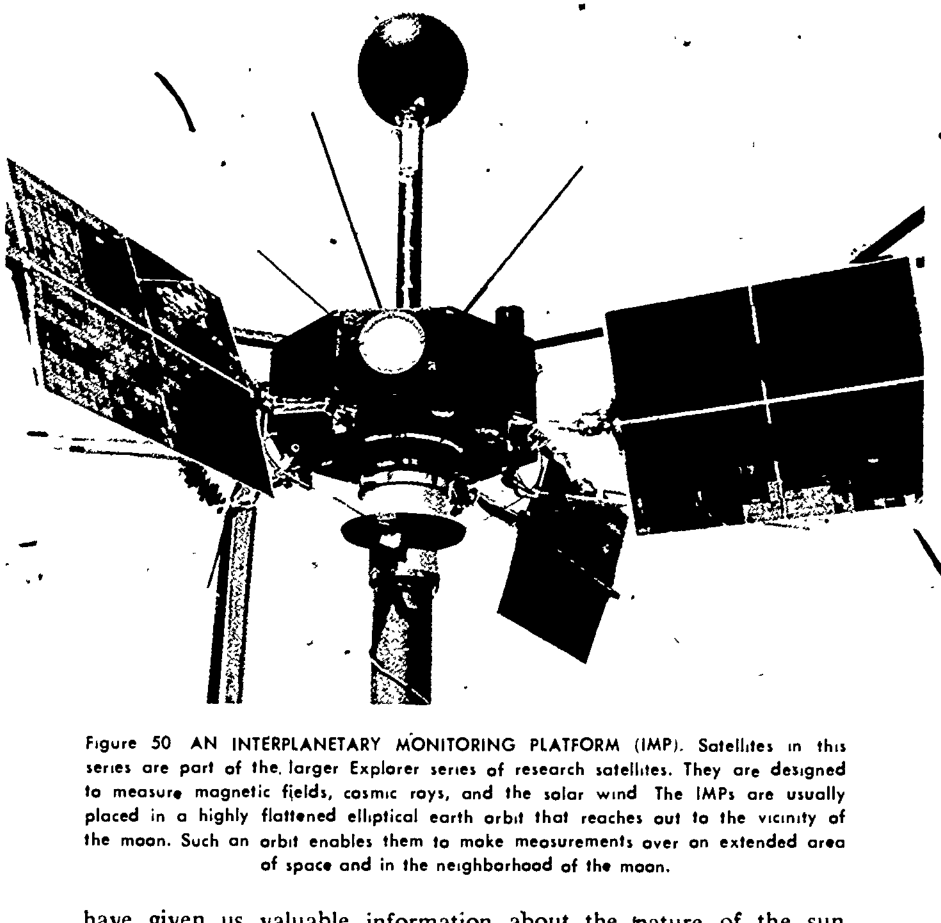


Figure 50 AN INTERPLANETARY MONITORING PLATFORM (IMP). Satellites in this series are part of the larger Explorer series of research satellites. They are designed to measure magnetic fields, cosmic rays, and the solar wind The IMPs are usually placed in a highly flattened elliptical earth orbit that reaches out to the vicinity of the moon. Such an orbit enables them to make measurements over an extended area of space and in the neighborhood of the moon.

have given us valuable information about the nature of the sun and the way radiations from the sun are transmitted through interplanetary space.

The Orbiting Observatories are important for space research because they have shown how it is possible to make a whole new range of observations in space, free from the obscuring effects of the atmosphere. The earth's atmosphere admits **electromagnetic radiations** from the sun at only three areas in the entire electromagnetic spectrum. The earth's atmosphere is therefore said to have only three openings, or "windows" (Fig. 52), to receive electromagnetic radiations from the sun All other electromagnetic radiations are shut out by the atmosphere The openings or "windows," in the atmosphere admit the following electromagnetic rays: (1) visible light rays, (2) the short radio waves, and (3) narrow bands of infrared rays. Instruments in an Orbiting Observatory or in any satellite in the vacuum of space can sense and record readings of any of the known wavelengths in the electromagnetic spectrum (Fig. 53).

The Orbiting Observatories report on distant bodies from their position in earth orbit. Other spacecraft are launched on escape trajectories to study the moon and the planets at closer range. These are known as lunar or planetary probes.

Lunar Probes

To enable a spacecraft to reach the moon, which is traveling in its orbit around the earth, space scientists must direct the trajectory to a point where the moon will be when the spacecraft reaches it, not where the moon is at the time of launch. They

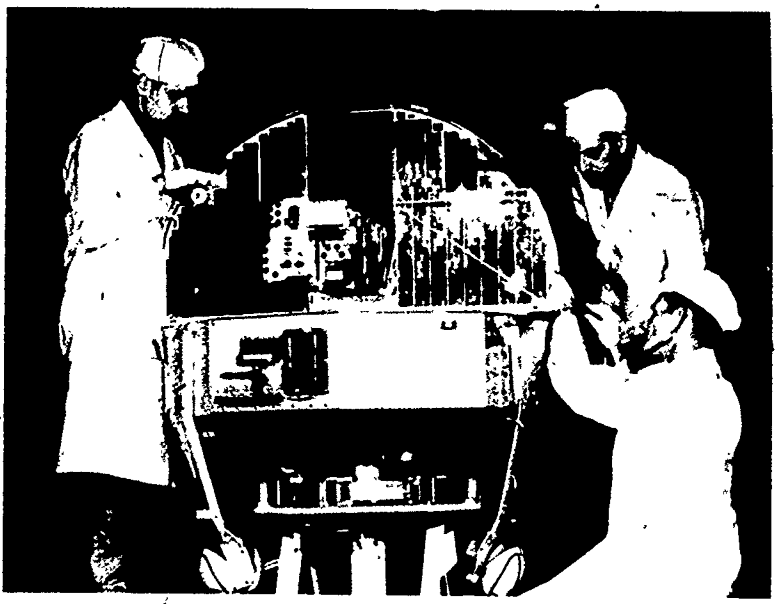


Figure 51. TECHNICIANS PREPARING ORBITING SOLAR OBSERVATORY (OSO) FOR LAUNCH. This research satellite, successfully orbited in March 1967, became OSO-3. It carried nine experiments, and these returned data. The data told scientists more about the nature of the sun and its influence on the earth's atmosphere. Note the white robes and caps that the technicians are wearing. Spacecraft and their boosters are manufactured and checked out under clean-room conditions.

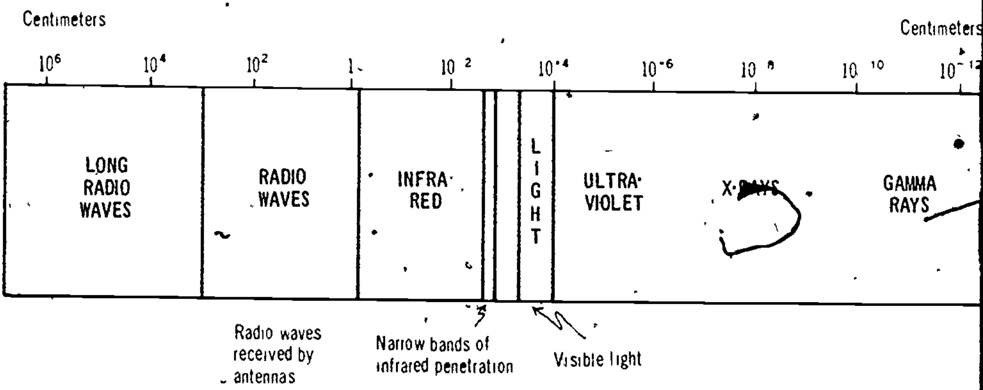


Figure 52. "WINDOWS" IN THE EARTH'S ATMOSPHERE FOR ELECTROMAGNETIC RADIATION. Above is shown a portion of the electromagnetic spectrum with the longest wavelengths at the left and the shortest at the right. The three red shaded areas show the three bands of electromagnetic radiation that penetrate the earth's atmosphere. These are the so-called windows, or openings, in the earth's atmosphere for electromagnetic radiation. The windows admit some radio waves, narrow bands of infrared waves, and visible light rays. The remainder of the spectrum is shut out by the earth's atmosphere.

must shoot ahead, much as the duck hunter does in order to hit his target. Computing the correct trajectory for a **lunar probe,** adjusting the velocity of the rocket booster, and making midcourse corrections at first presented US scientists with difficult problems. Not only did the first Pioneers fall short of their mark as lunar probes, but four of the six Ranger spacecraft directed toward a hard landing on the moon failed to reach their target.

Finally, in July 1964, Ranger 7 succeeded in hitting the target and in transmitting a series of television pictures as it fell toward the moon. The Ranger (Fig. 54), a large spacecraft equipped with television cameras and instruments, was designed to take a series of pictures of one site on the moon as it sped toward a hard landing. The success of Ranger 7 was followed by that of Rangers 8 and 9.

No instruments on the Ranger spacecraft survived the crash landing, however, no matter what measures scientists took to protect them. What was needed were other kinds of spacecraft that could protect scientific instruments so that they could give scientists information about prospective landing sites and about the moon generally. Preparations for the Apollo moon landings were underway, and more information about the moon was urgently needed. Experience gained in launching the Ranger spacecraft had taught US scientists and engineers how to put a spacecraft into a parking orbit around the earth and then refire the final rocket stage to put the spacecraft on an accurate trajectory to the moon. The way was open for more advanced spacecraft

Two highly automated spacecraft, the Surveyor soft-lander and the Lunar Orbiter, followed on the trail blazed by the Ranger. Five of the seven Surveyors and all of the Lunar Orbiters launched were successful Not only were the tasks performed by these advanced spacecraft more difficult, but their travel called for more maneuvers. As the Lunar Orbiter approached the moon, retro-

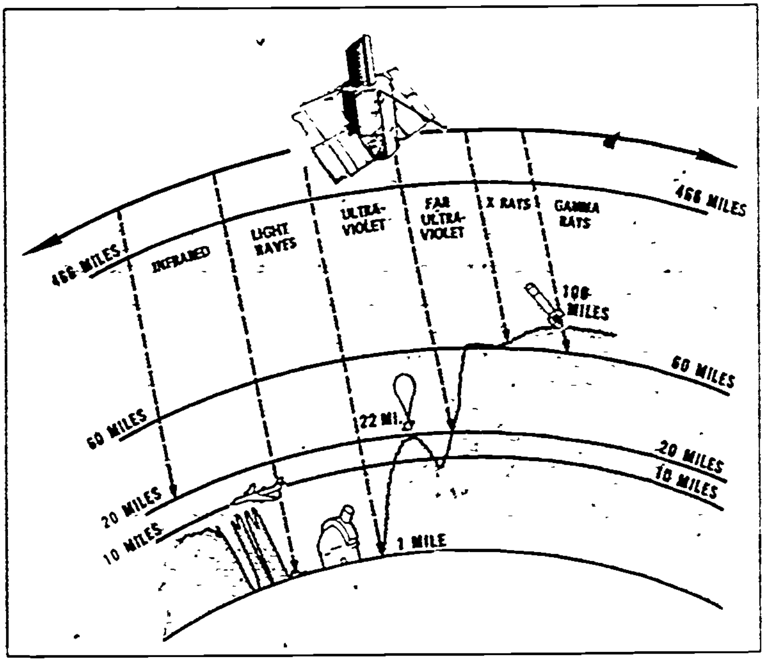


Figure 53 ORBITING ASTRONOMICAL OBSERVATORY OAO UNHAMPERED BY EARTH S ATMOSPHERE The OAO and other satellites that orbit high above the earth s atmosphere, can make observations in all wavelengths of the electromagnetic spectrum The OAO can make studies of the ultraviolet light coming from the stars This is not possible for observatories on the earth The shaded portion of the above diagram shows the electromagnetic radiations shut out by the earth s atmosphere

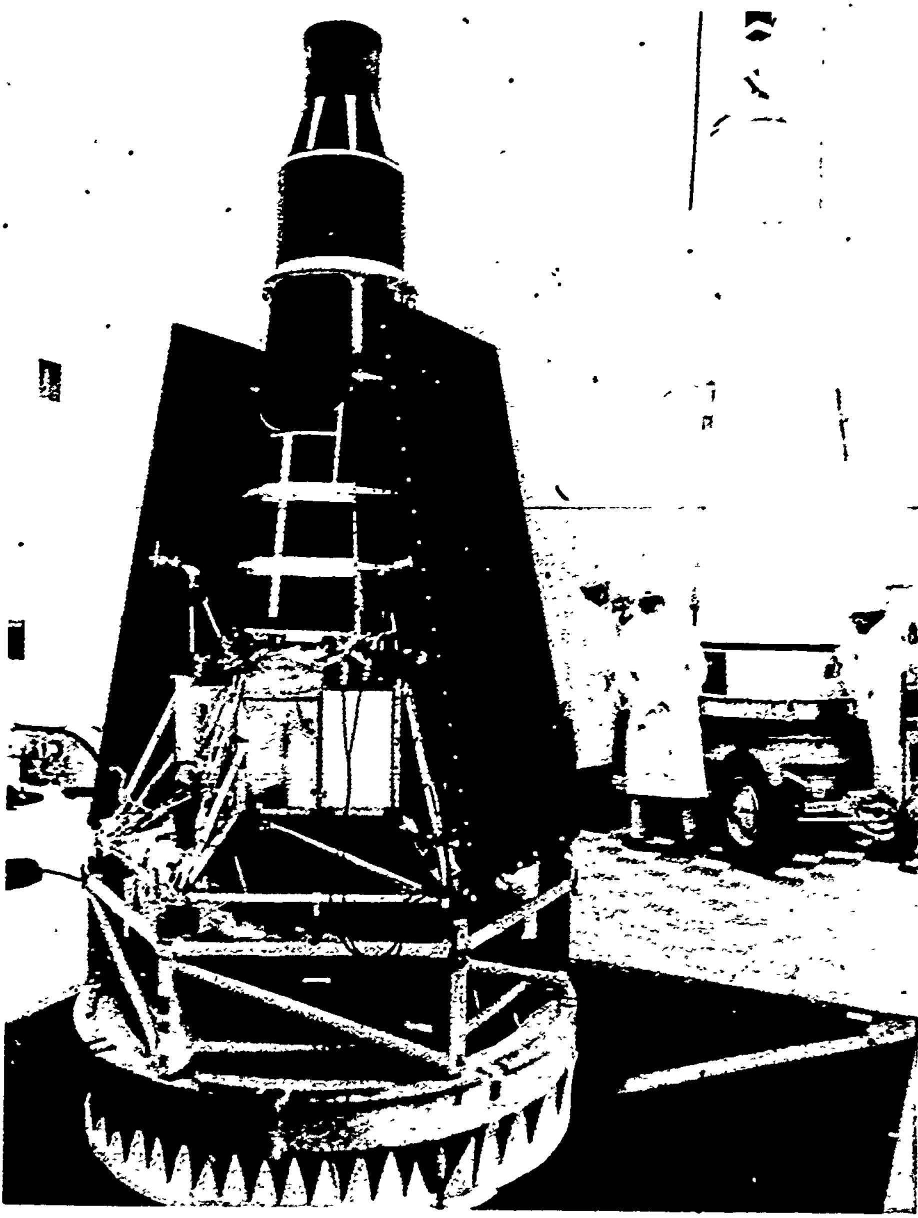


Figure 54 RANGER SPACECRAFT Ranger 8 is shown in the foreground as it is being prepared for launch Engineers in the background are checking out its subsystems

rockets were fired to brake the spacecraft and put it into an orbit around the moon.

The Surveyor also had to be braked by firing retrorockets as it approached the moon. Then it began a descent trajectory similar to that later used by the astronauts in their landings. As the Surveyor gradually went down to the moon, its descent engine was fired to cut down the speed of the spacecraft and enable it to make a soft landing on the moon. Since there is no atmosphere on the moon, neither wings nor parachutes can be used for easing the spacecraft down to the moon. Only rocket braking can do the job.

Surveyor 1, the first US spacecraft to make a soft landing on the moon, prepared the way for the Apollo astronauts to follow in their lunar module. This Surveyor and the ones that followed showed that the moon's surface could withstand the shock caused by landing a heavy spacecraft, and the Surveyors provided more precise information about landing sites. Two of the Surveyors even released a gold box for making chemical tests of the lunar soil (Fig. 55).

The Lunar Orbiter (Fig. 56), equipped with scientific instruments and with an automated laboratory for developing its own pictures, transmitted much information and thousands of detailed pictures of the moon used for study of sites and for mapping. The wiggles that showed up in the pathway of the Lunar Orbiters, as they traveled around the moon, gave the first clues to the existence of the moon's **mascons** (mass concentrations of matter). These large chunks of matter seem to be scattered below the surface of the moon, much as raisins are mixed inside a cake.

The later lunar probes made real progress in preparing for the Apollo moon landings. Lessons learned from these probes are also being applied to probes of the planets.

Planetary Probes

During the first 14 years of space travel (1958–1971), the United States concentrated its efforts on probes of the two neighboring planets, Venus and Mars. The Mariner spacecraft, which can be instrumented to suit a particular mission, was modified for use for all these **planetary probes.**

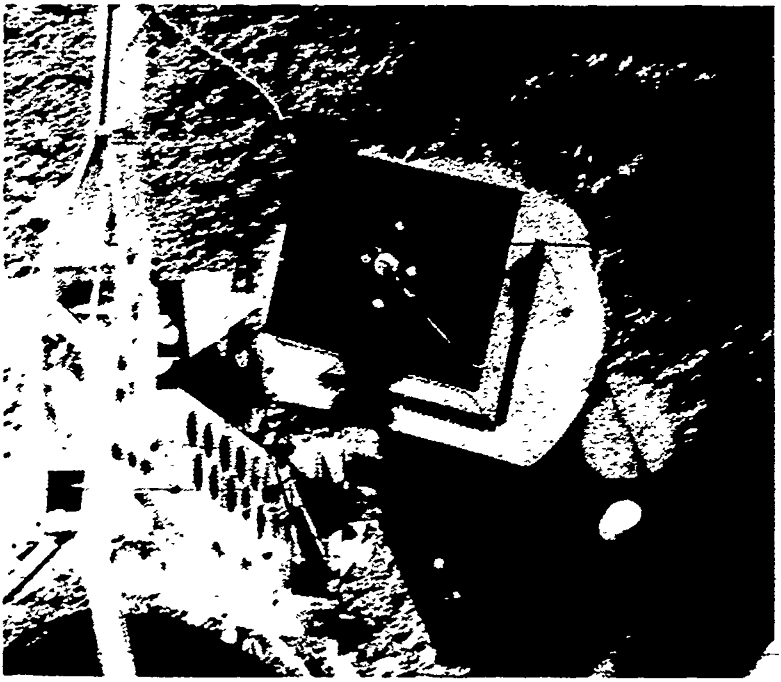


Figure 55. SURVEYOR SPACECRAFT ON THE MOON. This remarkable picture, taken by Surveyor 6 in 1967, shows the gold box deployed to make chemical tests of surface material on the moon. The spacecraft telemetered data on the tests and television pictures of the surface of the moon at the landing site The information telemetered by the Surveyor spacecraft helped in selecting landing sites for the astronauts.

Up to 1971 Mariner spacecraft made only flybys of the planets. approaching more closely to the planet at each successive encounter and securing more information each time. Then in November 1971, Mariner 9 (Fig. 57), the world's first planetary orbiter, went into position around Mars and began taking pictures as a dust storm on the planet was ending. We did not send spacecraft to make hard landings on the planets. as the Rangers had made on the moon. Flybys of the planets promised to give better results even if they were made at some distance from the planet During a flyby instruments remain intact, and the Mariner can telemeter some information and transmit pictures of the planet as long as the spacecraft remains in the vicinity of the planets and its radio transmitter is operating.

If putting the Pioneer and Ranger spacecraft on a trajectory to the moon created problems for US scientists and engineers, they have even more difficult problems in putting the Mariner spacecraft on a flyby trajectory to Venus and Mars. The moon is about a quarter of a million miles from the earth. At its nearest approach Venus is about 24 million miles from the earth and Mars about 34 million miles. Venus and Mars range out on slightly elliptic orbits around the sun, just as the earth does. Venus is on an orbit closer to the sun than the earth is and Mars on an orbit farther from the sun. In their travel in orbit, Venus and Mars are not always in a favorable position to receive flyby probes from the earth. Probes can be sent only when a **favorable**

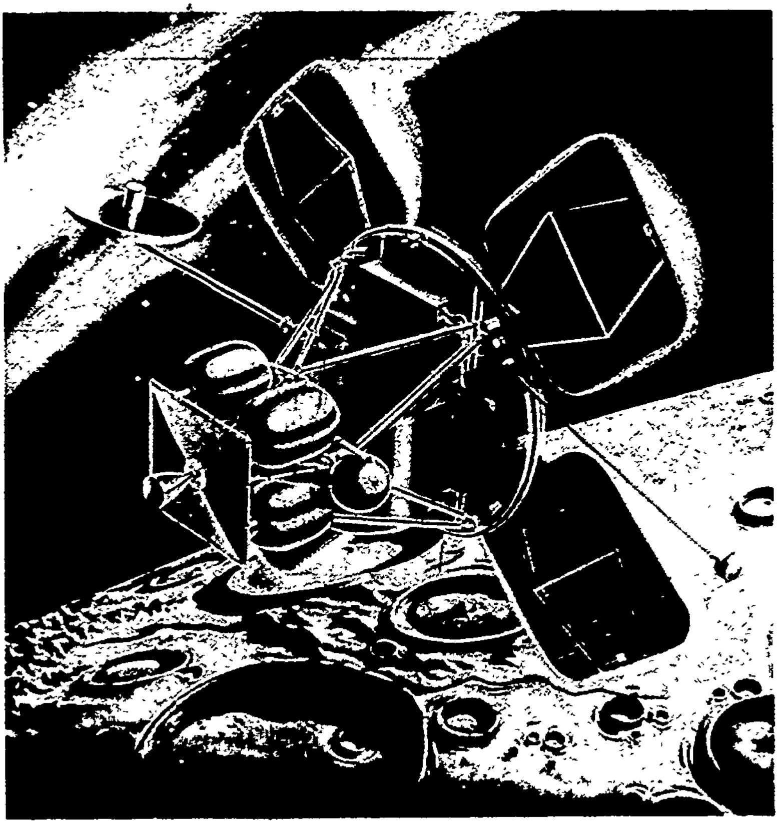


Figure 56 LUNAR ORBITER. This artist's cutaway drawing shows the Lunar Orbiter taking television pictures of the moon The spacecraft was stabilized in three axes

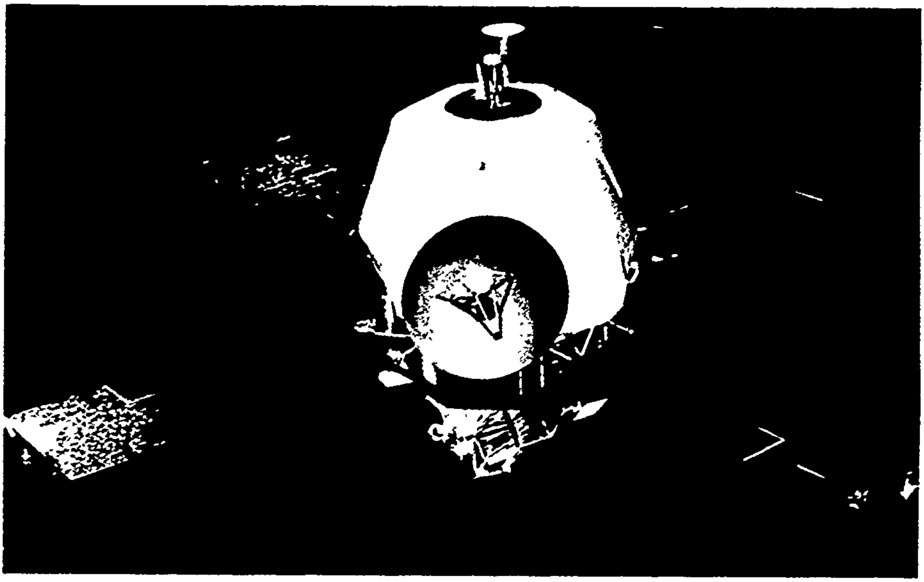


Figure 57 MARINER SPACECRAFT MODIFIED FOR ORBITING MARS The above drawing shows the Mariner spacecraft that began orbiting Mars in November 1971. Note the four solar panels and the nozzle of the large rocket engine for maneuvering at the top Tiny attitude control jets at the tip of the solar panels were used to keep the solar panels turned toward the sun The Mariner 9 spacecraft orbited Mars and took many pictures of the surface features for use in mapping the planet.

opportunity, or a favorable position, exists. A favorable opportunity exists only once every two years for Mars, and once every 19 months for Venus.

When the favorable opportunity occurs, spacecraft are not sent to Venus or Mars in a straight-line course from earth orbit, as one might expect. Instead a probe is sent on a long curving escape trajectory, which amounts to about half an ellipse (Fig 58) This is done to save propellant in the rocket booster making the launch. At the present time there are no boosters powerful enough to put a spacecraft on a straight-line course from one orbit to another Even if this could be done, it would not be the best course for a flyby mission As the Mariner spacecraft travels on the long curving escape trajectory, it gradually approaches the planet, traveling for an extended period in the vicinity of the planet, where it takes pictures and gathers information that is telemetered to the earth.

Spacecraft launched to make a flyby of Mars, the outer neighbor of the earth, must gain speed to go into a larger orbit around the sun; they are launched in the direction of the earth's rotation. Spacecraft launched toward Venus, the inner neighbor, must lose velocity to fall into a smaller orbit; they are launched in a direction opposite to the earth's rotation.

In the decade that the United States has been making planetary probes, it has launched nine Mariner spacecraft. Of this number, six have been successful. At first the Mariner flights were divided between Venus and Mars. The Mariners going to Mars took television cameras, but those bound for Venus carried no cameras but additional instruments. The lenses in the television cameras in use at the time were unable to pierce the dense cloud cover of Venus, whose atmospheric pressure was found to be 75 to 100 times that of the earth. The later Mariner probes con-

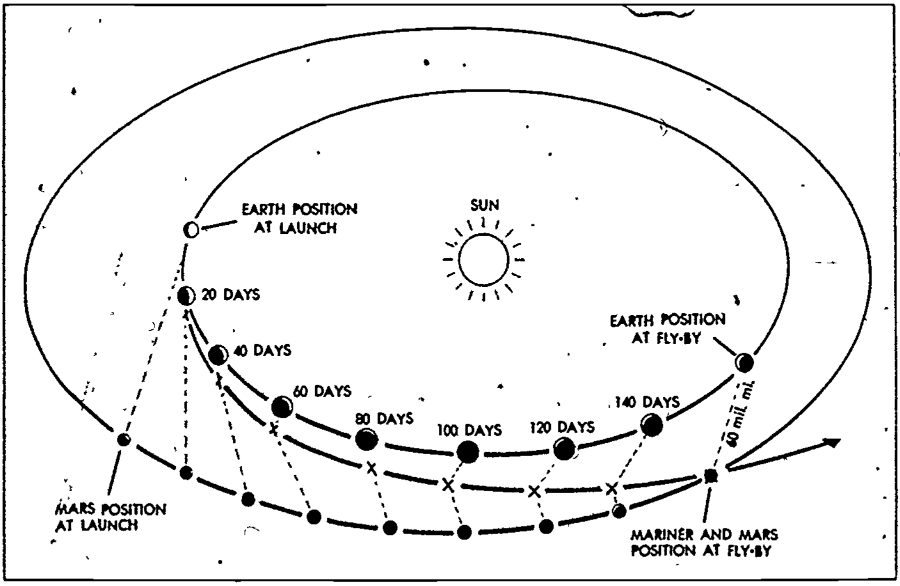


Figure 58. TYPICAL MARINER FLIGHT PATH TO MARS. The Mariner spacecraft travels on a long curving escape trajectory from the earth to the vicinity of Mars. The plan for a flyby shown above is similar to that used for the pair of Mariner probes (Mariner 6 and 7) that flew by the planet in July and August 1969. The drawing shows the relative position of the earth, the Mariner spacecraft, and the planet Mars at 20-day intervals during the trip.

centrated on Mars because of the hope that some kind of living matter might be found on this planet. During the first decade of planetary probes, the Mariner spacecraft made the flights shown in Table 1.

Beginning in 1972, the United States will extend the reach of its planetary probes beyond Venus and Mars. Later Pioneers have become trail blazers for planetary probes, as planned. In March 1972 the first Pioneer probe (Fig. 59) was launched to the vicinity of Jupiter, the largest of the giant planets. Another such probe is to be launched in 1973. Scientists have recommended that the United States extend the reach of its probes to take in all the

TABLE 1

MARINER FLIGHTS TO THE PLANETS

Mariner number	*Planet to be Probed*	*Date of launch*	*Date of encounter*	*Results*
1	Venus	22 July 62		Went off course; was destroyed.
2	Venus	27 Aug. 62	14 Dec. 62	Successful. Passed as close as 21,600 mi. and transmitted data.
3	Mars	5 Nov. 64		Communications failed; lost.
4	Mars	28 Nov. 64	14 July 65	Successful. Took pictures of Mars from 6,120 mi.
5	Venus	14 June 67	19 Oct. 67	Successful. Transmitted additional information. Passed within 2,480 mi. of Venus.
6	Mars	24 Feb. 69	31 July 69	Successful. Took many pictures from closer to planet.
7	Mars	27 March 69	5 Aug 69	Successful. Took many pictures. Probes 6 and 7 used as a pair. Much additional information transmitted.
8	Mars	8 May 71		Failed to orbit.
9	Mars	30 May 71	13 Nov. 71	World's first planetary orbiter. Reached within 860 mi. of Mars. Took pictures for mapping 85 percent of the surface.

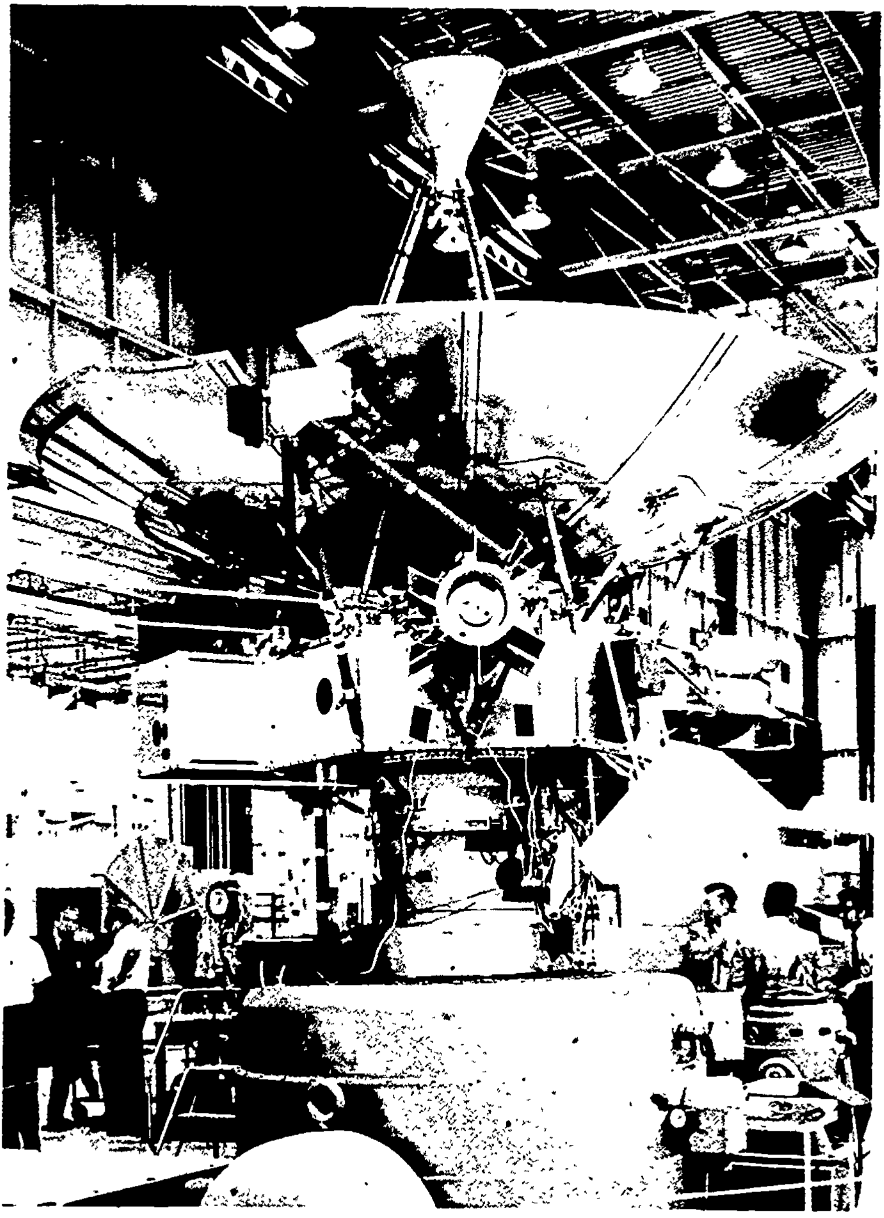


Figure 59. PIONEER SPACECRAFT FOR PROBING JUPITER. A test model of the Pioneer 10 spacecraft is shown above as it is being checked out. The Pioneer 10 was launched to the vicinity of Jupiter in March 1972. This Pioneer spacecraft is designed to obtain scientific information on interplanetary space, the asteroid belt between the orbits of Mars and Jupiter, and the planet Jupiter and its environment.

planets in the solar system rather than concentrate all effort on the two neighboring planets. As scientists obtain information about the outer planets, they can make further comparisons and thus obtain a much better understanding of the solar system as a whole.

While long-range plans for probing other planets are in the making, the United States is reaping a rich harvest of practical benefits from its applications satellites.

APPLICATIONS SATELLITES

The United States has pioneered in all kinds of **applications satellites.** By 1960, just two years after our first artificial satellite was launched, we had orbited an operating version of each kind of applications, or working, satellites. There are four kinds of applications satellites: (1) communications satellites, (2) weather satellites, (3) navigation satellites, and (4) survey, or reconnaissance, satellites, which class includes those satellites that survey earth resources. There is no special class of military satellites. The Armed Forces can make use of all four kinds of satellites.

In the decade or more that the applications satellites have been orbiting, they have been greatly improved and their usefulness extended. Communications satellites orbited by US rocket boosters are in regular use by the Intelsat organization, a 79-nation semicommercial enterprise; and reports from weather satellites are routinely used by the National Weather Service in preparing forecasts.

Communications Satellites

Live television programs are transmitted across the ocean through the use of **communications satellites (comsats).** Without such satellites overseas television would not be practicable. But the transmission of overseas television broadcasts makes up only about 2 percent of the present workload of communications satellites. Most of their work is done in the routine transmission of telephone messages over long distances. The great need now is to put more communications satellites into orbit and to increase the **channel capacity** of each satellite so that more messages can be sent.

Before the time of communications satellites, it was necessary to relay radio signals across the ocean by underseas cables and overland by means of tall relay towers spaced about 30 miles apart. The shortwave radio signals used in television and ordinary commercial communications travel in a straight **line-of-sight path.** They do not bend to follow the curvature of the earth. To enable radio signals to travel long distances, they are now beamed from an earth station to a satellite, which relays the signals to another satellite or back to an earth station. Communications satellites act as tall towers or relay stations in the sky.

The great advantage of artificial satellites for point-to-point communications was noted some time before the first artificial satellite was orbited. In 1945 Arthur C. Clarke (1917–), who was then chairman of the British Interplanetary Society, published a magazine article in which he recommended that three satellites be equally spaced (placed about 120 degrees apart) in a synchronous orbit. From their perch high above the earth these three satellites could relay radio signals and provide communications for the whole earth (Fig. 60). As pointed out in Chapter 3, a satellite placed in a synchronous, or stationary, orbit—an equatorial orbit about 22,300 miles above the earth—continually "sees" over the same area of the earth. At the time, Clarke's proposal seemed so fantastic that readers of his article complained about making the public the butt of such a joke. Years later, when communications satellites were actually in orbit, the Franklin Institute in Philadelphia awarded Clarke a gold medal for his foresight. Much work had to be done, however, before the value of Clarke's recommendation was appreciated.

Before scientists and engineers could test the value of the synchronous orbit for communications satellites, they first had to put some kind of artificial satellite into orbit and then see if such a satellite could actually transmit radio signals. In 1946 the US Army bounced a radar signal off the moon, the earth's only natural satellite. Although there was only a brief delay between the time when the signal was sent and when it was received, the delay was too long for the moon to have practical value for relaying radio signals. Artificial satellites, which could be placed in an orbit much closer to the earth, could return a radio signal almost instantly and therefore would be more useful for relaying radio signals from one point to another on the earth. In December 1958, under Project Score, an Atlas rocket carried a tape recording and a radio transmitter into an earth orbit. Upon radio com-

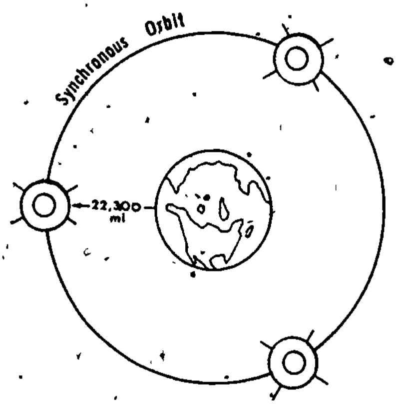


Figure 60 COMMUNICATIONS SATELLITES IN SYNCHRONOUS ORBIT. Three communications satellites placed an equal distance apart in a synchronous orbit (an equatorial orbit at an altitude of 22,300 miles) would provide 24-hour communication coverage of the entire earth. Each satellite would move at the same rate that the earth rotates and would therefore remain above the same area of the earth. Because of the difficulties experienced in getting satellites into an exact synchronous orbit, more than three satellites are used to get complete coverage.

mand from the earth, the tape recorder began to play back President Eisenhower's Christmas message and transmit it to the earth. The experiment showed that radio signals could be transmitted from earth orbit. We were ready to launch our first communications satellite.

American scientists believed that the first operating communications satellite should be large and lightweight, permitting it to be easily located so that radio signals could be bounced from it. The American rocket expert Wernher von Braun conceived the idea of producing a large reflecting satellite from chemical foam released in orbit. What finally resulted was Echo 1, the first large balloon satellite, which measured 100 feet in diameter. This satellite was made from a Mylar plastic casing covered with a thin coating of aluminum. The balloon inflated after reaching the vacuum of space simply from the expansion of the tiny amount of air left in the folded casing. Echo 1 was orbited about 1,100 miles above the earth, and radio signals were successfully bounced from it, transmitting both television pictures and voice messages.

All nations of the world were invited to make use of the satellite

The Echo satellite was an impressive sight in the sky, resembling a star of the first magnitude. The story is told that when Von Braun was attending a conference in Sweden, both he and the Soviet rocket expert Leonid I. Sedov were guests at an evening garden party. Sedov was twitting Von Braun about American slowness in space. Just at this moment the clouds parted and Echo 1 glided majestically into view. Von Braun pointed to the sky and said, "But see what the Americans can do."

After spending about eight years in orbit and being battered by the bombardment of micrometeorites, or tiny specks of cosmic dust, Echo 1 reentered the earth's atmosphere and was burned up. A second Echo satellite was launched about four years after the first one. The Echo satellites, besides bouncing back radio signals, were valuable in verifying the presence of the solar wind. These satellites were so large and lightweight that they were actually deflected from their orbit by the pressure of sunlight.

The Echo satellites were passive communications satellites, mere reflectors of radio waves. They were relatively cheap and easy to produce, but the signals they reflected were very weak ones, which required powerful ground equipment to receive them. What was needed next was an active communications satellite, one that would receive radio signals and rebroadcast them to the earth (Fig. 61). With such satellites in use, it would not be necessary to have such highly sensitive receiving equipment on the ground as was necessary with the Echo satellites.

The US Army orbited the first active communications satellites, called the Courier satellites. They did not remain in orbit long, only long enough to show that active communications satellites would work. The first commercial communications satellite, Telstar 1, orbited in 1962, was such a satellite, and all others that have followed have likewise carried transmitters for rebroadcasting signals as they relay them to the earth.

Up to 1963 none of the communications satellites had been placed in the synchronous orbit, as Clarke had recommended. Therefore we had no data to tell us whether it was better to place a few communications satellites in the synchronous, or stationary, orbit, or to put more satellites into a lower orbit and relay the message from one satellite to another. By February 1963 we had developed enough rocket power and know-how to place

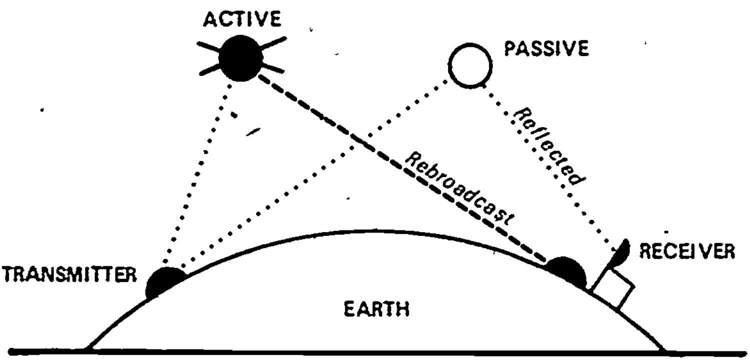


Figure 61. ACTIVE AND PASSIVE COMMUNICATIONS SATELLITES The early communications satellites, like the Echo satellites, were passive satellites. They merely reflected a radio signal Later communications satellites, like those in the commercial Intelsat series, are active communications satellites. They rebroadcast the radio signal before returning it to the earth The rebroadcast signal is much stronger than the reflected signal and does not require such powerful ground equipment to receive it.

a communications satellite in synchronous orbit, and Syncom 1 was orbited. Another Syncom was launched about six months later. The results obtained with the two Syncom satellites were compared with those obtained with two satellites launched into lower orbits (Relay 1 and 2). The study showed that the satellites placed in synchronous orbit were superior. Since that time all US communications satellites have been placed in that orbit or an approximation of it.

The most recent commercial communications satellites are designated Intelsat followed by a serial number These satellites are orbited by NASA with American rocket boosters, and are then turned over to the Intelsat organization

Because the synchronous orbit will have significant value for all kinds of applications satellites—weather, navigation, and survey satellites, as well as communications satellites—NASA is making special studies of this orbit with the Applications Technology Satellite (ATS) (Fig. 62). These experimental satellites combine studies that will help in the development of all four kinds of applications satellites.

An Applications Technology Satellite is scheduled to test a large directional antenna that will receive television signals sent to it from the earth and rebroadcast them directly to television receivers on

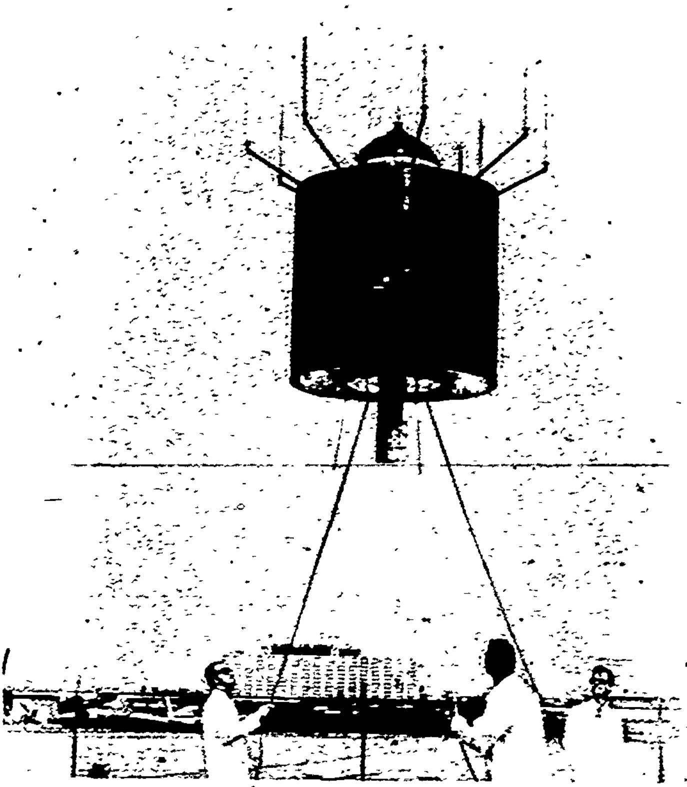


Figure 62. APPLICATIONS TECHNOLOGY SATELLITE (ATS) BEING TESTED. Technicians are rotating the Applications Technology Satellite to test its antenna pattern before launch. An ATS is put into a synchronous orbit. Satellites in this series are used for testing technology for navigation and weather satellites, as well as for communications satellites.

the earth without the necessity of first going through a ground broadcasting station. Such a system, called **direct broadcast from a satellite**, would be useful for mass education. An ATS is presently scheduled for trying out such a program in India. Large-scale direct broadcast of television from a satellite to community receivers or to home sets might be possible in the future.

The immediate goal for growth in communications satellites is to make additional channels available for use. By February 1970 communications satellites provided more than 6,000 two-way communications channels. The first Intelsat 4, put into service in 1971, by itself provided some 6,000 two-way channels. Later satellites may furnish as many as 10,000 such channels.

Like the communications satellites, the weather satellites have already proved their worth.

Weather Satellites

Before the first **weather satellites** were in use, it was not possible to get much information about weather conditions over large areas of the earth. About 75 percent of the earth is covered with oceans, and much of the land area consists of uninhabited jungles, deserts, and frozen wasteland. Formerly only about 5 percent of the earth's surface was covered by continuous weather surveillance. With this coverage, it was not possible to view large areas of the earth at one time or get a picture of the movement of large air masses above the earth, which directly influences weather conditions on the earth.

The first weather satellite, Tiros 1, launched in April 1960, was placed in a highly inclined orbit at a height of about 450 miles above the earth. The Tiros satellite carried cameras that took a whole series of pictures of cloud cover at intervals of about 1½ hours. This timing made it possible for weathermen to observe the nature of the cloud cover, its movement, and the direction of the movement. Revolving around the earth as they did, the first Tiros satellite and the nine other Tiros satellites that followed it were able to photograph cloud cover over a large part of the earth during a 24-hour period.

Weather forecasts became more reliable. The cloud pictures, taken by satellites, such as that shown in Figure 63, detected the buildup of destructive storms and made it possible for the weatherman to track them and estimate when they might hit inhabited areas. But the multitude of pictures provided by Tiros satellites certainly did not guarantee that the weatherman would make no errors in his forecasts. Air masses do not always continue to move as expected. Since the cameras in the Tiros satellites could not take pictures during the night or in bad weather, there were nearly always significant gaps in the information provided by the Tiros satellites, as well as by the Essa and the early Nimbus satellites that followed them.

Beginning with Nimbus 3, launched in April 1969, weather satellites carry both day cameras and **infrared cameras**, which make use

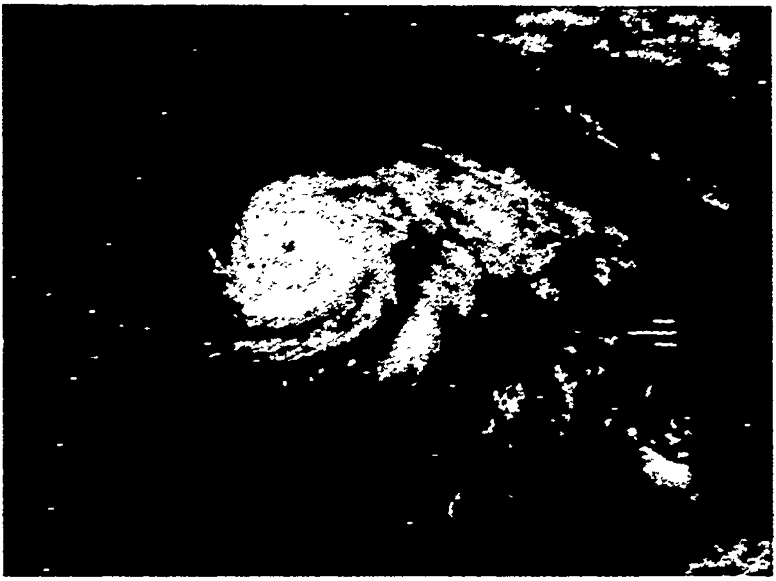


Figure 63. STORM CENTER PHOTOGRAPHED BY WEATHER SATELLITE This photograph of the whirling clouds and the eye, or center, of Hurricane Ginger was taken by Nimbus 4 on 13 September 1971 The satellite was then at an altitude of about 690 miles. The storm was some 600 miles east of Bermuda.

of infrared (heat) rays to take pictures at night and in bad weather (Fig. 64). The improved Nimbus satellites also make a whole series of temperature readings and carry many scientific instruments These satellites are in reality small weather stations in orbit. They should help us reach a much better understanding of the origin and nature of weather conditions on the earth. All the Nimbus satellites, as well as the other later weather satellites, have been launched into a polar or near-polar orbit, from the Western Test Range at Vandenberg Air Force Base, California. From their polar orbit, weather satellites are able to take pictures over almost all the earth each day.

The Improved Tiros Operational Satellites (ITOS) (Fig. 65), like the Nimbus satellites, are equipped with infrared cameras. ITOS 1 was launched in January 1970. Both the ITOS and the Nimbus satellites regularly supply information to the National Oceanographic and Atmospheric Administration of the US Department of Commerce, of which the National Weather Service is a part.

Developments made with future satellites should enable the weatherman to give people earlier warnings about hurricanes, storms, and other natural disasters, and they should help him make more accurate long-range forecasts. In the course of time the sensors and cameras in the weather satellites will be improved even more, and other instruments will be added. The next step may be to place weather satellites in synchronous orbit, just as communications satellites now are.

Figure 64. INFRARED PHOTOGRAPH TAKEN BY WEATHER SATELLITE. This photograph was taken by the Improved Tiros Operational Satellite 1 (ITOS 1) on 19 October 1970, at an altitude of about 860 miles. It shows the Great Lakes and the part of the Eastern seaboard extending from Cape Hatteras toward Nova Scotia. The black areas are water, the gray areas land, and the white areas clouds.

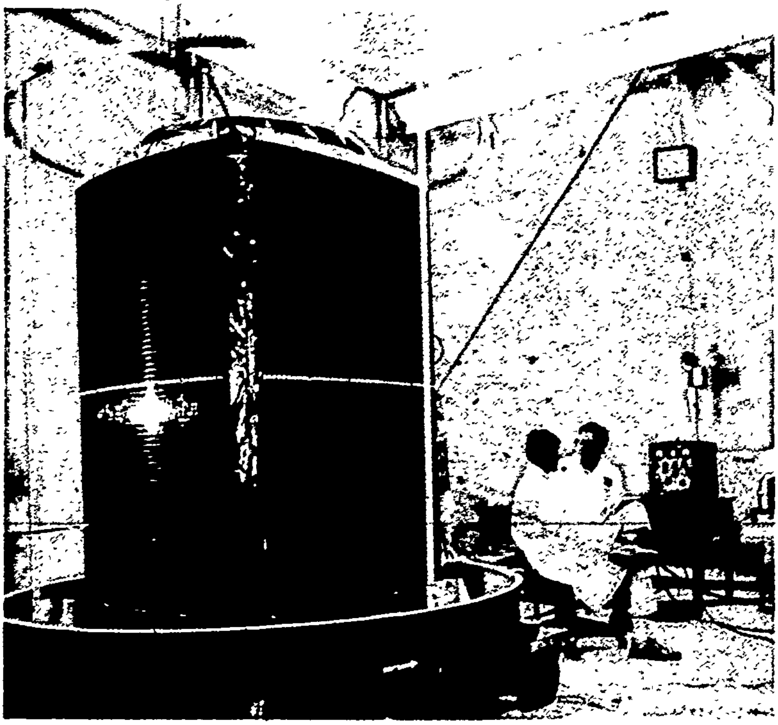


Figure 65. IMPROVED TIROS OPERATIONAL SATELLITE (ITOS) Technicians are checking this ITOS in preparation for launch. The ITOS was made possible as the result of the experience gained from the early Tiros weather satellites.

Navigation Satellites

For centuries man steered his ships by locating his position in relation to that of the stars. Then he developed better time pieces and more precise instruments to improve navigation. With the orbiting of **navigation satellites,** man took another step forward. He had an artificial star above the ocean by which he could steer his ships during the daytime and in bad weather. It was not necessary for a navigator to see the artificial star, only to have his radio messages received by the satellite and to be able to interpret the return.

The first navigation satellite, Transit IB, was launched in April 1960. Other Transit satellites followed. These are launched into a polar orbit about 690 miles above the earth. The Navy has several Transit satellites in orbit at one time to aid in the navigation of its submarines and ships worldwide. A ship's navigator knows where the Transit satellites are, and he can get the exact position of the nearest Transit satellite in relation to the ship by consulting a specially prepared table—that is, if he has estimated his position accurately. To check his estimate, the navigator queries the satellite with a radio signal. He can tell by the satellite's return just how far his estimate was off, and he can then make the necessary correction in the ship's course. The system of navigating by satellites calls for a series of ground stations, computers aboard ship, and tables showing the exact location of the navigation satellites. The Navy has released information about its satellite navigation system so that this system can be put to use by commercial ships. The system is valuable in aiding ships and aircraft in distress (Fig. 66).

The Navy, the Air Force, and NASA are not the only Government agencies interested in navigation. The Federal Aviation Administration (FAA), as well as the entire Department of Defense and the Departments of Commerce, of the Treasury, and of the Interior, all have an interest in making use of navigation satellites

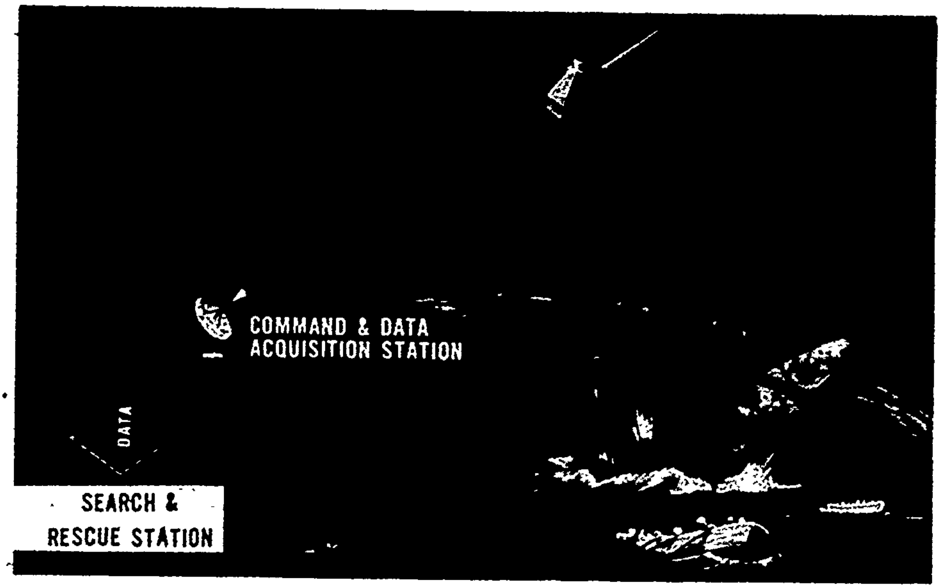


Figure 66. NAVIGATION SATELLITE USED FOR SEARCH AND RESCUE. Navigation satellites are valuable aids in locating ships in distress and directing rescue efforts. Such satellites may be used in the future for controlling sea and air traffic.

for precision navigation and for the improvement of traffic control. With the developments made possible by navigation satellites and improvements in satellite technology, it will soon be possible for both aircraft and ships to make highly accurate fixes at all times and in any position on the earth and in the air above it.

A fourth class of applications satellites, which has features common to all the other classes of applications satellites, is the survey, or reconnaissance, satellite.

Survey Satellites

The first operating **survey satellite** was Midas 2, a military reconnaissance satellite, launched in May 1960. Other such reconnaissance satellites have followed. Our interest in this fourth group of applications satellites is not with the military satellites, however, but rather with the new **earth resources satellites,** which have much promise for solving some of the most urgent problems of today.

At the present time earth resources survey satellites are only in the research stage, but their development is likely to take place much more rapidly than that of the other applications satellites because they can benefit from technology already developed. The earth resources satellites are closely related to advanced weather satellites and can profit from experience gained with infrared cameras and other remote sensors used in them. The earth survey satellites will also be able to apply lessons learned about the synchronous orbit, as these satellites should ultimately be put into such an orbit.

Already, from the many pictures of the earth taken by the astronauts and by weather satellites, scientists have been able to make large-scale studies of the planet earth and its resources. They have made observations of such phenomena as mineral deposits, ice fields, and fish populations. From these studies already made, it is clear that an earth resources satellite system, using a variety of remote sensors, will help us control erosion, fight crop diseases, manage our forest better, clean up our lakes and streams, and combat air pollution. Such satellites will also assist in finding new natural resources, as well as in conserving those in use today. These are critical tasks if the earth is to harbor the greatly increased population predicted. Earth resources satellites, then, are to have three principal uses: (1) discover new resources, (2) help improve the management of present resources, and (3) spot trouble zones that require remedial action.

The first experimental Earth Resources Technology Satellite (ERTS) (Fig. 67), is to be launched in 1972, and a second in 1973. These satellites are to make observations that should be of importance in such fields as agriculture, forestry, the study of the earth's oceans, and map making. The experiments will include studies to develop ground stations for handling the data received from the survey satellites, interpreting the data, and distributing it where ~~it is~~ needed.

The experiments with the ERTS will be supplemented with an experiment of the survey of earth resources conducted by astronauts in the Skylab. The survey satellites, like the other applications satellites, could be operated more efficiently if they could be maintained after they were in orbit. During the first decade and a half of space travel man was not able to travel out into space to service applications satellites. He was absorbed with the enormous task imposed upon him in learning how to construct and operate manned spacecraft.

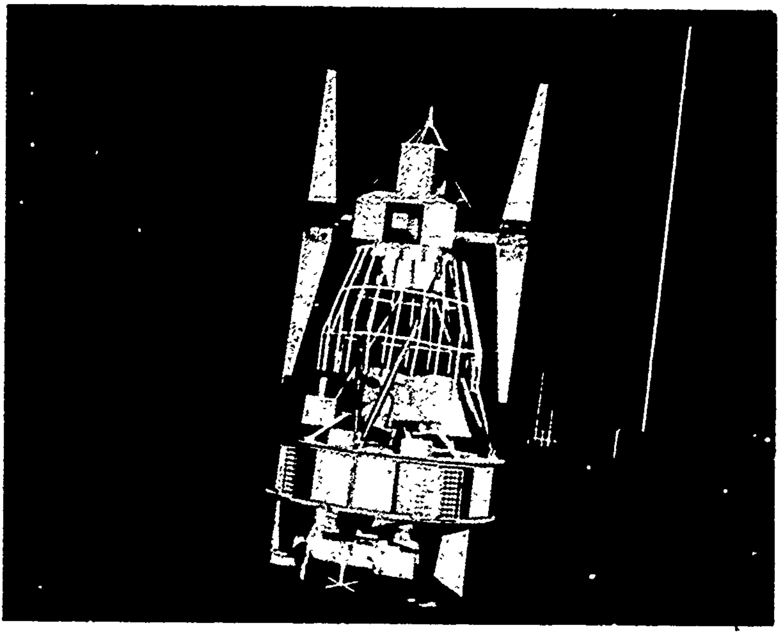


Figure 67. EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS). This artist's sketch shows an ERTS similar to the one that was launched in July 1972. This first ERTS will be used for research to find out how satellites can best be used for obtaining information about earth resources, such as forests, mineral deposits, and crops, and in managing these resources.

TERMS TO REMEMBER

earth satellites
hard-landers
soft-landers
orbiters
flybys
research satellites
cislunar space
earth's magnetic field
cosmic rays
Van Allen radiation belts
solar wind
magnetosphere
electromagnetic radiations
"windows" (for electromagnetic radiations) in earth's atmosphere
lunar probes
mascons (mass concentrations of matter)
planetary probes
favorable opportunity for a planetary probe
applications satellites
communications satellites (comsats)
channel capacity
line-of-sight path
direct broadcast from a satellite
weather satellites
infrared cameras
navigation satellites
survey (reconnaissance) satellites
earth resources satellites

NAMES OF UNMANNED SPACECRAFT

Research Satellites

Explorer
Pioneer
Vanguard
Orbiting Geophysical Observatory (OGO)
Orbiting Solar Observatory (OSO)
Orbiting Astronomical Observatory (OAO)
Ranger
Surveyor
Lunar Orbiter
Mariner
Viking

Applications Satellites

Echo
Telstar
Syncom
Relay
Intelsat
Applications Technology Satellite (ATS)
Tiros
Essa
Nimbus
Improved Tiros Operational Satellite (ITOS)
Transit
Midas
Earth Resources Technology Satellite (ERTS)

IDEAS TO REMEMBER

1. Research satellites helped to discover the Van Allen radiation belts. confirm the presence of the solar wind. and define the boundaries of the earth's magnetosphere.

2. The Explorers make up the largest group of research satellites. They were teamed with the early Pioneer satellites to investigate cislunar space. The later Pioneer probes have become planetary probes.

3. Three kinds of spacecraft were used to probe the moon. the Ranger hard-landers, the Surveyor soft-landers. and the Lunar Orbiters.

4. The Orbiting Observatories study the earth, the sun, and the stars. They are able to make use of all wavelengths of the electromagnetic spectrum in their studies because they orbit above the earth's atmosphere.

5. Up to 1971 all planetary probes were flybys. In November 1971 Mariner 9 became the world's first planetary orbiter. Mariner spacecraft have been used to make probes of both Venus and Mars.

6. The four kinds of applications satellites are (a) communications satellites, (b) weather satellites. (c) navigation satellites, and (d) survey (reconnaissance) satellites. By 1960 the United States had orbited a working version of each kind of applications satellite.

7. The fourth group of applications satellites, those surveying earth resources, shows the most promise for the future. Such satellites offer opportunities for solving some of our most urgent problems of today.

8. All four groups of applications satellites could be orbited and maintained more economically if man could maintain them in space.

QUESTIONS

1. **What are the two large classes of unmanned spacecraft? What is the main difference between them?**

2. **What was the first US artificial satellite? What important discovery did it make possible?**

3. **What are the three kinds of research satellites? Name one series of each kind.**

4. **What are some of the phenomena in space that research satellites investigate? Why is it possible to observe phenomena in space that cannot be observed on the earth? Tell three important discoveries made through the use of research satellites.**

5. **What are the three so-called windows in the earth's atmosphere?**

6. **What are the Orbiting Observatories? What is their purpose?**

7. **What task did the Ranger spacecraft perform? the Surveyors? the Lunar Orbiters?**

8. **What spacecraft made probes of the planets during the 1960s? Which planets were investigated?**

9. What is our next step in planetary exploration? What spacecraft will be used for this step? Which planets will be investigated next?

10. What is meant by a planetary flyby? Can such a flyby be made at any time?

11. What are the four kinds of applications satellites?

12. What is the advantage of putting communications satellites into a synchronous orbit?

13. What do commercial communications satellites do? How are they able to relay television broadcasts over the ocean?

14. What are some of the most recent weather satellites? What can they do that the early weather satellites were not able to do?

15. What is the advantage of using satellites for navigation?

16. How might earth survey satellites be used to solve some of the most urgent problems of today? What are the Earth Resources Technology Satellites? What is their chief purpose?

THINGS TO DO

1. Make a study of the Van Allen radiation belts. Prepare a model to explain these belts. You might use a small ball to represent the earth, wires to represent the earth's magnetic field, and molded clay to denote the radiation belts. A cross-sectional diagram could be substituted for the model. Find out what important facts about the Van Allen belts were made known through research satellites. Outline the kind of investigations of these belts that might be made in the future. Tell about the questions that are still unanswered.

2. Select one of the more recent Explorer satellites (or a group of these satellites) and describe the kinds of investigations made. Tell about the instruments used and the kinds of measurements made. What findings were made as the result of the data telemetered by the satellite(s)?

3. Make a study of probes of the planet Mars up to the present time. Which spacecraft was used? Were all the probes flybys? What were some of the findings made? What new spacecraft is scheduled to make a visit to Mars in the future? What is the purpose of this probe? What progress has been made in constructing the spacecraft?

4. Make a study of probes of Venus up to the present time. Which spacecraft was used for these probes? Did the probes carry a television camera? Why or why not? What were some of the scientific findings made? What spacecraft is scheduled to make a flyby of Venus in the future? Why is this flyby especially significant? What other planet is this spacecraft scheduled to probe?

5. Make a study of probes of Jupiter. What spacecraft has been sent to probe in the vicinity of Jupiter? What probe is scheduled for 1973? What kind of measurements will these spacecraft make? Why do scientists want to make probes of Jupiter?

6. Explain how communications satellites operate. What is meant by an active communications satellite? a passive communications satellite? What kind of equipment does a direct-broadcast satellite have to carry? What is the purpose of the communications satellite program the United States is sponsoring in India?

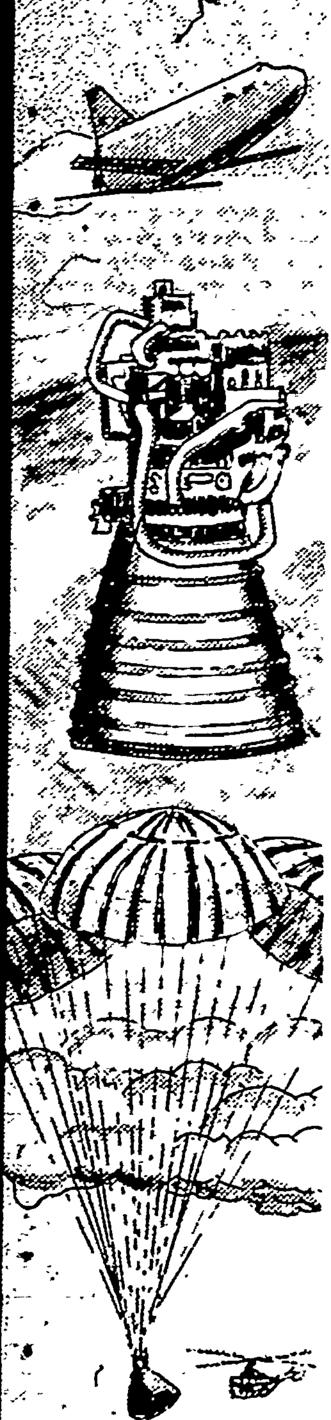
7. Make a study of one of the most recent weather satellites, such as the Improved Tiros Operational Satellite (ITOS). Explain what the infrared cameras do and what kinds of measurements are made by the satellite. Why are these improved weather satellites described as small weather stations in orbit?

8. If you are especially interested in ocean navigation, make a study of the Navy's navigation satellites. Explain how these satellites operate What equipment is needed on board ship to make use of the system? Why is use of the system limited at present? What use may be made of navigation satellites in the future?

9. Make a study of the use of survey satellites for spotting pollution and cleaning up the environment. Compare the surveys made from satellites with those made from aircraft. How might infrared cameras be used in making the surveys?

10. Make a study of the use of survey satellites for managing earth resources Describe the work to be done with the Earth Resources Technology Satellites (ERTS) How will infrared cameras be used? Explain the importance of having a system for receiving and handling the data telemetered by the survey satellites.

Chapter 5



Manned Spacecraft

THIS CHAPTER describes the three series of manned spacecraft (Mercury, Gemini, and Apollo) that the United States developed in advancing toward the moon and the spacecraft that is to take astronauts to our first experimental space station, the Skylab. The chapter first explains how the single-module Mercury spacecraft was used for Step 1 in the advance toward the moon. It describes the module, the selection and training of astronauts for spaceflight, the historic first suborbital and orbital flights, and the results of the Mercury flights. Next the chapter explains how the Gemini spacecraft, made up of two modules, was used for Step 2. It describes how the Gemini astronauts built up endurance in spaceflight, performed rendezvous and docking, and engaged in extravehicular activity (EVA). Then the chapter explains how the Apollo spacecraft was used for Step 3, reaching the moon. It describes how the spacecraft is constructed and how it operates on the trip to the moon and upon landing. Finally, the chapter explains how the modified Apollo command and service modules will be used to visit the Skylab. When you have studied this chapter, you should be able to do the following: (1) explain how the Mercury spacecraft was used for Step 1, the Gemini for Step 2, and the Apollo for Step 3 in reaching the moon; (2) describe how the cone-shaped module is used for recovery of the astronauts; (3) tell which three manned flights were most important for history; (4) outline the plan for an Apollo moon flight; and (5) describe the spacecraft to be used for visits to the Skylab.

AS THE FIRST American satellites began telemetering data to the earth, American scientists and engineers began to see the need for sending men into space. Automated spacecraft can perform many jobs better than man, but they cannot feel and sense and think the way man can. It was not enough to control spacecraft remotely from the earth. We could never truly explore space until man had observed at firsthand what occurred there. Man had to learn to sail upon the new ocean of space.

Learning to pilot a spacecraft was one part of the challenge. Designing and building the spacecraft was another part. In October 1958, a year after the Soviets launched the first artificial satellite, the United States began Project Mercury, its first man-in-space program. In April of the following year, President Eisenhower announced the selection of the original seven astronauts These highly skilled pilots were to test and fly the Mercury spacecraft, as well as help in designing and constructing it.

A spacecraft that could shelter man in the hostile environment of space had to be much heavier and more complex than an unmanned spacecraft. Besides carrying the weight of a man and all his food and water supplies, it had to transport a large supply of oxygen and all the equipment needed for maintaining a pressurized atmosphere for breathing and protecting the body against the instantly fatal vacuum of space.

While the Americans were proceeding with plans for the Mercury, the Soviet Union was rapidly advancing toward manned spaceflight. The first Soviet Sputniks were much heavier than the first American satellites, and in the beginning the Soviets had boosters that were much more powerful than those of the United States The first Sputniks were followed by Soviet satellites carrying dogs and other animals. Then, on 12 April 1961, the late Cosmonaut Yuri Gagarin became the first man ever to orbit the earth

The flight of Cosmonaut Gagarin gave new impetus to American plans for manned spaceflight. On 5 May 1961 Astronaut Alan Shepard made the first suborbital flight in the Mercury spacecraft Just 20 days after Shepard's flight, President John F. Kennedy, in a special message to Congress, proposed that this nation should commit itself to achieving, before the end of the 1960s, the goal of "landing a man on the moon and returning him safely to the earth" President Kennedy said. "No single project in this period will be more impressive to mankind, or more important for the long-range exploration of space." Thus the Apollo moon project was begun even before the first American astronaut had gone into orbit

The Mercury spacecraft would take an astronaut into a low earth orbit and return him to earth. It would be like a coastal voyage on the ocean of space. The Apollo spacecraft would take men out on the open ocean of space to the moon about a quarter of a million miles away and return them to the earth. To fill in the gap between the two kinds of voyages, Project Gemini was planned, and announcement of the project was made on 7 December 1961. Thus three spacecraft for transporting man were being developed at the same time. The Mercury spacecraft was to be used for Step 1, the Gemini for Step 2, and the Apollo for Step 3 in man's advance toward the moon (Fig. 68).

Landing on the moon and returning safely to the earth was the first long-range goal of manned spaceflight. The second long-

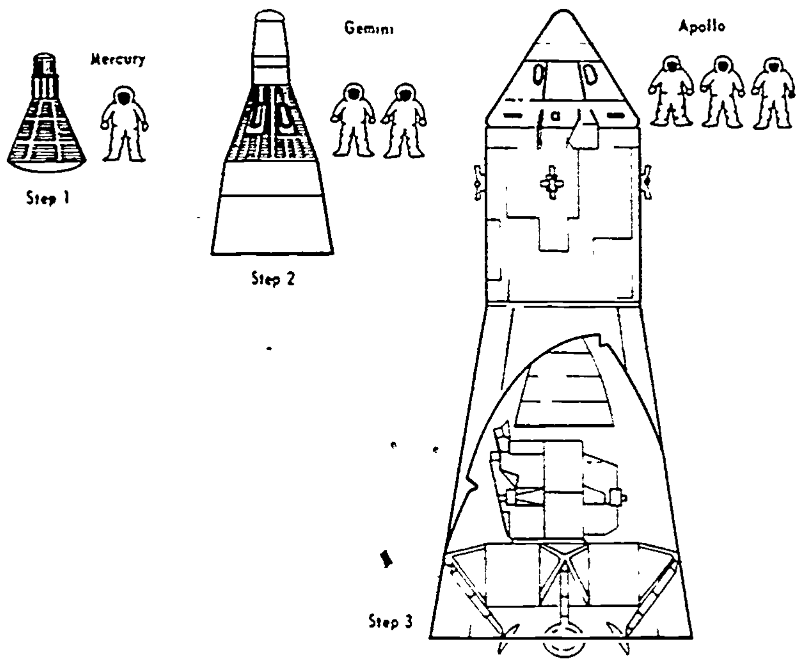


Figure 68 SPACECRAFT USED FOR THE THREE STEPS TO THE MOON The Mercury spacecraft was used for simple flights in earth orbit, the Gemini spacecraft for earth orbital flights including rendezvous and docking, and the Apollo spacecraft was used for the actual flights to the moon The single module of the Mercury spacecraft, the reentry module of the Gemini spacecraft, and the command module of the Apollo spacecraft (marked in blue) were similar in form and in the job they did. These modules brought the astronaut(s) back for recovery on the earth

range goal is to put a space station into earth orbit. With this second goal in view, American engineers constructed the first experimental space station, the Skylab, which is to be orbited in 1973. Since attainment of the second goal lies in the future, this chapter is concerned mainly with the first goal. The Mercury spacecraft was used for taking the first step toward achieving the first goal.

MERCURY SPACECRAFT: STEP 1

The Mercury spacecraft was flown first to see whether manned spaceflight, in a capsule launched by a rocket booster, was possible, and then to make longer flights in orbit. The final objective of Project Mercury was a one-day flight in earth orbit. Although Cosmonaut Gagarin's flight had shown that man could survive in space, there were still many unanswered questions. Each Mercury flight was awaited with anticipation because man was then entering a strange new environment.

One-Module Spacecraft

The Mercury spacecraft, which carried a single astronaut, was a **one-module**, or one-part, spacecraft not much larger than a telephone booth (Fig. 69). The astronauts used to say: "You don't climb into the Mercury. You just put it on." Although the Mercury was small, it was a marvel of engineering know-how with its 200,000 parts and seven miles of wiring. Inclosed in the Mercury capsule an astronaut could be rocketed into an orbit in space and survive the intense frictional heating upon reentry through the earth's atmosphere. A complex instrument panel, which the astronaut could reach as he reclined on his **form-fitting couch**, offered the astronaut some control over the flight. In case of an emergency he could override almost any automatic system with a manual one, but the Mercury astronaut was at first to be a passenger rather than a pilot.

Since the Mercury spacecraft carried no large rocket propulsion engine, it could not change orbit during flight. The astronaut on board could fire small hydrogen-peroxide thrusters to control the **attitude**, or the in-flight position, of the spacecraft. But no matter in what direction the astronaut pointed the nose of the spacecraft, it would continue to speed through space in the same orbit until braked for reentry.

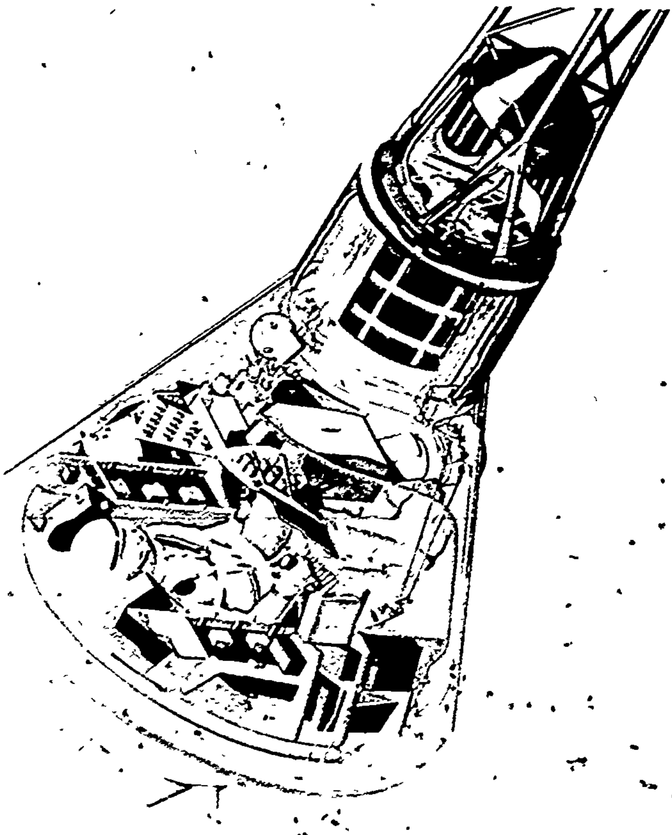


Figure 69 MERCURY SPACECRAFT AT LAUNCH This cutaway drawing shows the retrorockets and part of the launch escape tower The Mercury capsule was 9 feet high and 6 feet wide at the base Most of the space in the capsule was taken up by equipment to give life support to the astronauts The retrorockets are shown projecting from the base of the capsule The escape tower was placed on top of the capsule

To provide for the astronaut's safety during flight, each important flight control system had one or more extra, or redundant, systems to back it up. In case one system failed during flight, another system could take over. There were, for example, three systems for controlling retrorockets, or rockets that fired in reverse, to brake the Mercury spacecraft for reentry. These rockets could be fired automatically by an onboard system, they could be set off manually by the astronauts, or they could be activated by a radio command from the earth. The plan of providing extra systems is called **redundant engineering.**

In the Mercury there were enough redundant systems to provide for complete automatic operation of the spacecraft in case the astronaut was disabled. Redundant engineering was carried over from the Mercury to the Gemini and then to the Apollo spacecraft.

In addition to (1) redundant systems, the Mercury spacecraft had the following features to provide for the survival and safety of the astronauts. (2) a complete **life-support system,** (3) double walls to protect against harmful radiation and punctures by micrometeorites, and (4) a **heat shield** for use at reentry. These same kinds of features for life support and safety have been built into the reentry modules of the Gemini and Apollo spacecraft.

The life-support system on the Mercury, as on the Gemini and the Apollo, was a completely sealed system that supplied the astronaut with oxygen at a reduced pressure, similar to the pressure of the atmosphere at high altitudes (about 5 psi instead of the 14.7 psi of the atmosphere at sea level). The pressurized oxygen in the spacecraft is used for breathing and for **counterpressure** (pressure against the body) to keep the body from ballooning and to prevent the blood and other body fluids from boiling, as they would otherwise do in the vacuum of space.

In the Mercury the astronaut remained in his **space suit** at all times. The suit was not always pressurized, but it was kept connected with the life-support system so that it could be inflated automatically in case of an emergency. The silver space suit of the Mercury astronaut was developed from the flight suit worn by combat pilots, but the astronaut's space suit had additional safeguards to permit him to spend long periods of time under full space conditions.

On the Mercury spacecraft the heat shield covered the large blunt end, or bottom, of the module shaped like a cut-off cone. This cone design is in itself a protective feature. It was chosen for the Mercury because engineering studies had shown that it was the shape best suited for taking the astronauts safely through the atmosphere. At launch, the small end of the capsule was pointed upward. In this position the spacecraft offered the least resistance to the air as it sped upward. Before the retrorockets were fired for reentry, the Mercury capsule was turned in orbit so that the blunt end would impact with the atmosphere, thus offering the greatest amount of resistance for braking the spacecraft

(Fig. 70). When the capsule impacted with the heavier atmosphere and heat became intense, the coating on the heat shield melted away, thus allowing the heat to escape—a process known as **ablation.** The cone shape has been repeated in the Gemini and Apollo spacecraft.

As a special safety feature in case trouble would develop on the pad, the Mercury had a launch escape tower placed on top of it. In an emergency the rocket engine in the tower would fire to lift the spacecraft clear of the pad and put it into a ballistic trajectory over the Atlantic Ocean. The escape tower was jettisoned shortly after launch. (A similar tower is used on the Apollo spacecraft. The Gemini used ejection seats similar to those in jet aircraft.)

As each Mercury capsule was delivered to Cape Kennedy, the astronaut assigned to the next flight worked with the capsule

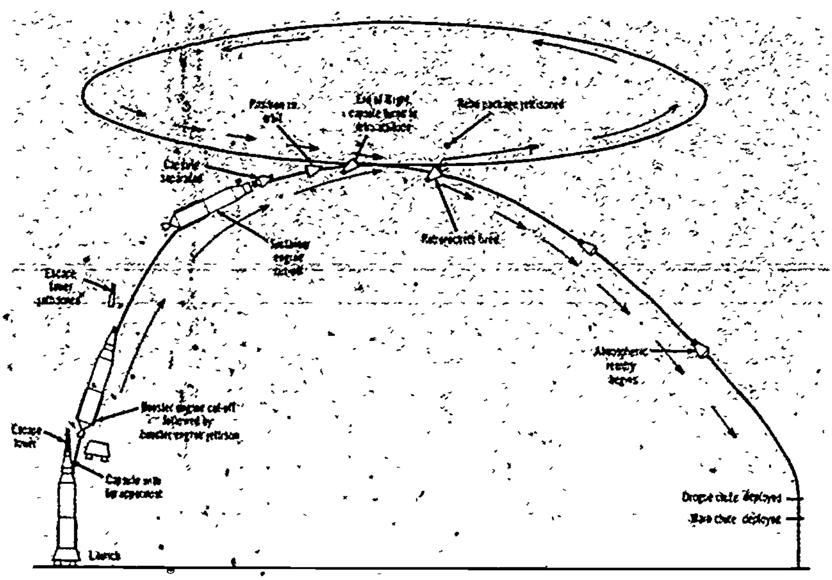


Figure 70. DIFFERENT POSITIONS OF MERCURY CAPSULE DURING FLIGHT. At launch the small end, or tip, of the capsule was pointed upward. As the capsule went into orbit the tip was foremost. At the end of the flight the capsule turned in orbit so that the large blunt end faced forward, and the retrorockets fired, causing the capsule to fall out of orbit. At reentry the atmosphere impacted against the large blunt end, braking the capsule. The reentry module of the Gemini spacecraft and the command module of the Apollo spacecraft assumed similar positions at the beginning and end of the flight.

until he became familiar with the feel of its instruments and equipment, much as a pilot becomes familiar with his aircraft. But just as the Mercury was a new kind of craft, the astronauts were a new breed of pilots. They were specially selected and trained for their flights.

Selection and Training of Astronauts

To find pilots who could operate the new spacecraft, NASA made a nationwide search. As one official expressed it, NASA was looking for "ordinary supermen." No one type of personality makes the best astronaut. An astronaut is an ordinary person in the sense that he reacts to happenings in a normal way, but he is expected to have capacity for enduring flight stresses far beyond the ordinary. Among other requirements, each of the original astronauts had to be a test pilot and a jet pilot, and to have an engineering degree or its equivalent.

Of more than 100 men who met all requirements and volunteered, only seven were finally chosen. All seven original astronauts (Fig. 71) were from the military services, three each from the Air Force and the Navy, and one from the Marines. The first seven astronauts, in the order in which they flew, were Alan B. Shepard, the late Virgil I. (Gus) Grissom, John H. Glenn, Scott Carpenter, Walter (Wally) Schirra, and L. Gordon (Gordo) Cooper. The seventh astronaut, Donald (Deke) Slayton[1], was disqualified for flight because of a slight heart irregularity but remained with the program and became Director of Flight Crew Operations at the Manned Spacecraft Center. When other astronauts were later added to the original seven, requirements were changed slightly, but standards were not lowered. Scientists selected to become scientist-astronauts must learn to become proficient jet pilots.

The astronauts have been put through what is probably the most rigorous training ever devised. Astronauts make many kinds of **simulated spaceflights** (practice flights on the ground), are given tests in sea and desert survival, fly regularly in jet aircraft, and study subjects related to spaceflight, such as astronomy and lunar geology (study of moon rocks).

The astronauts have become known for their courage, skill, and fine teamwork. Each astronaut begins his flight with full

[1]Recently Astronaut Slayton has been qualified to fly He is not likely to make a flight, however, because crews for all the scheduled flights have already been named.

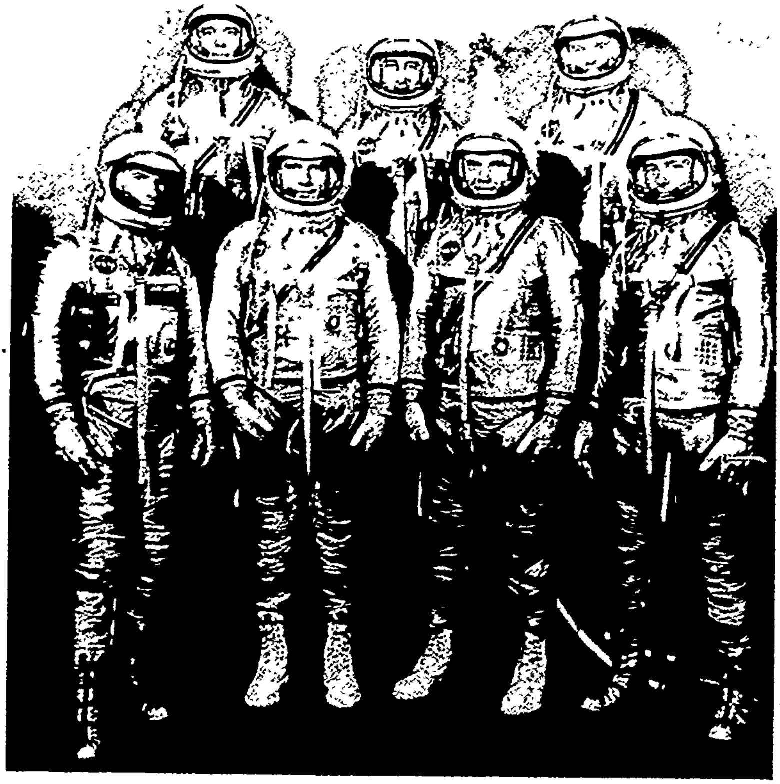


Figure 71. SEVEN ORIGINAL ASTRONAUTS. In the front row, left to right, are Astronauts Walter Schirra, Donald Slayton, John Glenn, and Scott Carpenter. In the back row, left to right, are Alan Shepard, the late Virgil Grissom, and Gordon Cooper.

knowledge of the hazards he faces. When asked what he considered the most dangerous part of the trip, the late Gus Grissom quipped: "The part between liftoff and landing."

Beginning with the Mercury flights and continuing through the Apollo flights, all astronauts have shared their experiences so that those who were to follow them could benefit. The Apollo astronauts have faced more dangers on the difficult landings and takeoffs from the moon, but they have had the earlier experiences of the astronauts to guide them. The first Mercury astronauts faced many unknowns.

Before the Mercury flights began, NASA officials were especially concerned about two problems. How well would the astronauts be able to endure the extremely high **G-forces** (increased gravity) as the booster accelerated at launch and again as the spacecraft decelerated upon reentry? How would the astronauts be affected by the opposite condition—that of **weightlessness**?

In anticipation of the high G-forces they would encounter, the astronauts practiced on **centrifuges.** These are chambers, or gondolas, swung at the end of a long arm. As they whirled on these giant wheels, the astronauts learned how to adjust their bodies to forces as high as 14-G to 16-G, forces slightly higher than they expected to experience in flight. The Mercury astronauts knew that aircraft pilots have blacked out at 5-G, but the astronaut, reclining on his form-fitting couch, would be able to take the G-forces across his body from chest-to-back, not from head to foot, as a seated pilot would (Fig. 72). What was not known was just

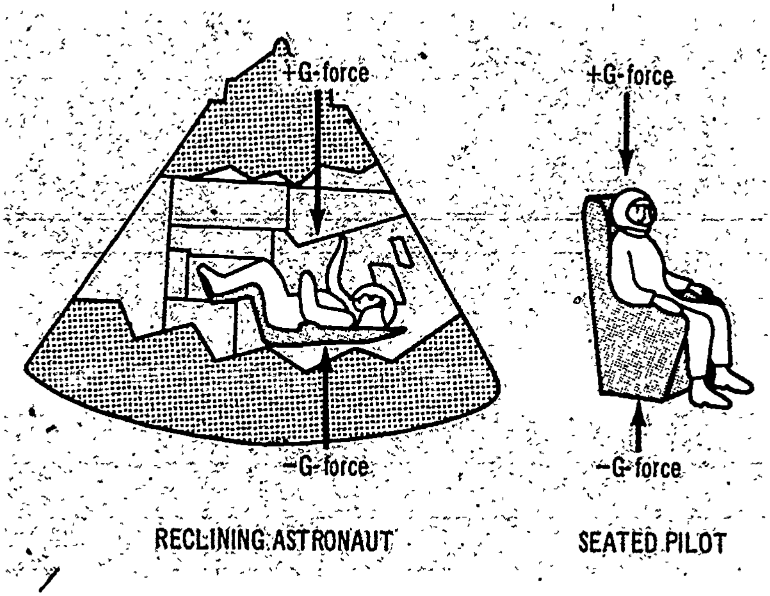


Figure 72. POSITION OF ASTRONAUT AND AIRCRAFT PILOT. The Mercury astronaut reclined on his back with feet up during liftoff. In this position he took the increased G-forces across his body rather than from head to foot, as a seated pilot does. Increased G-forces affect the flow of blood between the heart and the brain. An astronaut in a reclining position has less stress placed on his heart-blood system. At reentry the large blunt end of the Mercury capsule again faced toward the earth.

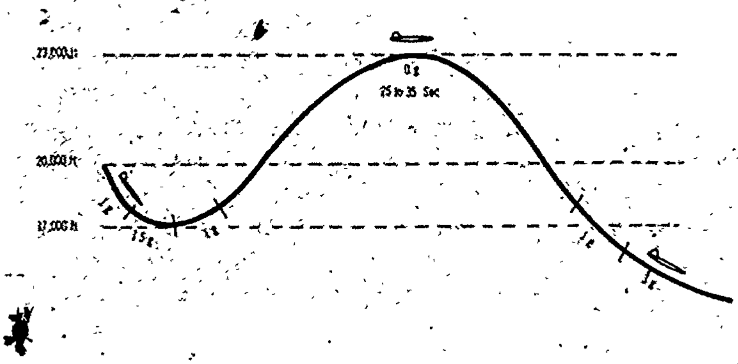


Figure 73. WEIGHTLESS TRAJECTORY. The only way the weightless condition can be reproduced on earth is for an aircraft pilot to fly a weightless trajectory. This is done by making a dive, then a steep climb, and another dive, as shown above. When the aircraft is at the top of the trajectory, everything in the aircraft loses weight for a matter of seconds. Objects float in the aircraft.

how high the G-forces would become and how long the increased G-forces would last.

The astronauts also had to prepare themselves for weightlessness. Although we can experience a feeling of free fall on a roller coaster or in an elevator that is going down rapidly, the actual condition of weightlessness can be duplicated on the earth for only seconds at a time. This is done during the pushover period following a high-speed drop and then a rapid pullup in an aircraft. The flight pattern is called a **weightless trajectory** (Fig. 73). The astronauts flew weightless trajectories as often as possible so that they could practice eating, drinking, and performing their tasks while weightless. (On later flights on the Gemini the astronauts were to practice underwater in order to simulate the weightless condition.)

As the astronauts trained, they gained confidence in their skills and in the Mercury spacecraft, which they were helping to make ready for flight. They were eager to have the Mercury launched into orbit to find out what true spaceflight was like.

Mercury Flights

In all, the Mercury spacecraft made 25 flights. It was launched first by the Redstone booster and then by the larger Atlas booster, which was to put man into orbit. Of the 25 flights, only 6 were manned, and only 4 of the manned flights were orbital (Table 2). The manned flights were preceded by the flights of four animals. Although the American public was impatient to get an astronaut into orbit, NASA officials proceeded cautiously. The Mercury, just like the Gemini and Apollo, could be tested only in spaceflight. Unlike an aircraft, which can be checked out gradually at low speeds and altitudes, a spacecraft launched into orbit is fully committed to orbital flight. Once the spacecraft takes off from earth, there is no turning back until at least one orbit has been completed.

SUBORBITAL FLIGHTS.—To reduce risks, the Mercury flights were begun with two **suborbital flights,** or flights made at less than orbital speed and on a ballistic trajectory. After Ham the chimpanzee was successfully recovered, the way was clear for man. Alan Shepard, a Navy commander from New Hampshire, won the coveted assignment of being the first Mercury astronaut to go into space. With his characteristic humor, he said he was "acting as the link between Ham and man."

The choice of the first astronaut was a closely guarded secret up to flight time. Gleaming in his silver space suit, Shepard stood ready to walk from the hangar and reveal himself to the public. Then bad weather caused the flight to be scrubbed, as were many of the later flights, and Shepard had to go through the preparations all over again on the following day.

On 5 May 1961 everything went well. The Redstone booster launched the Freedom 7 into a trajectory about 119 miles above the Atlantic Ocean. G-forces upon acceleration reached only about 6-G. When the retrorockets fired, the spacecraft was braked. As the capsule reentered the atmosphere, atmospheric friction heated the spacecraft, but the heat shield worked well. Then, as the Mercury took a long plunge back to earth, deceleration pinned Shepard back in his couch with a force of about 12-G. But his training served him well, and he felt no ill effects. Finally, the drogue chute popped out to stabilize the capsule. Then the main chute billowed out against the sky. As the Mercury rocked back and forth on the main chute, Shepard braced himself for impact with the water. About 11 minutes after impact he was recovered by a

TABLE 2

MERCURY MANNED FLIGHTS

Flight number and name of spacecraft	Astronaut	Date of launch	Length of flight hr.	min.	sec.	Number of orbits	Perigee mi.	Apogee mi.	Description of flight
MR-3[a] Freedom 7[b]	Alan B. Shepard	5 May 61	0	15	22				Suborbital flight; altitude about 119 mi.; over 5 min. of weightlessness.
MR-4 Liberty Bell 7	Virgil I. Grissom	21 July 61	0	15	37				Suborbital flight; reached altitude of about 121 mi.; about 5 min. of weightlessness. Mercury capsule lost.
MA-6[c] Friendship 7	John H. Glenn	20 Feb. 62	4	55	23	3	100	163	First orbital flight; manual attitude control for large part of trip; manual reentry. Recovery in Atlantic Ocean.
MA-7 Aurora 7	Scott Carpenter	24 May 62	4	56	05	3	100	167	Manual reentry; recovered several hundred miles from target area in Atlantic Ocean.
MA-8 Sigma 7	Walter M. Schirra	3 Oct. 62	9	13	11	6	100	176	Automatic reentry; recovered within 5 mi. of carrier in Pacific Ocean.
MA-9 Faith 7	L. Gordon Cooper	15 May 63	34	19	49	22	100	166	Met and exceeded final objective of project; manual reentry within 4 mi. of carrier in Pacific Ocean.

[a]MR is the abbreviation for Mercury-Redstone. The unmanned Mercury flights and the suborbital manned flights were launched by the smaller rocket booster, the Redstone, also known as the Jupiter A. This was the first rocket developed by the Wernher von Braun team, which was eventually to develop the Saturn boosters.

[b]The 7 after the name of each spacecraft stands for the seven original astronauts. Although only one astronaut rode in each spacecraft, all seven astronauts participated in some way in each flight.

[c]MA is the abbreviation for Mercury-Atlas. The Mercury manned orbital flights were launched by the Atlas booster, a modified ICBM.

Navy carrier, and the first US trip into space was successfully completed (Fig. 74).

Astronaut Gus Grissom, an Air Force major, repeated the suborbital flight. All went well on the flight. Grissom's Liberty Bell landed in the ocean, and the recovery helicopter hovered overhead when suddenly the explosive bolts fired too soon, blowing the hatch off the capsule. Water poured into the capsule, and it began to sink. The Liberty Bell 7 was lost, but Grissom was rescued just in time. No other reentry module has been lost.

ORBITAL FLIGHTS.—The two suborbital flights of the Mercury spacecraft were followed by one made with the chimpanzee Enos. This flight tested the Atlas booster and the Mercury spacecraft in the weightless condition in orbit. Enos was strapped on his couch (Fig. 75) to enable him to withstand the increased G-forces at launch and reentry. During the flight the automatic equipment did not work as planned, but Enos successfully ate banana pellets and drank water while weightless. He was drenched with perspiration and somewhat wobbly when recovered. After regaining his balance, Enos jumped for joy at being back on earth again. The

Figure 74. ASTRONAUT ALAN SHEPARD AFTER FIRST SUBORBITAL FLIGHT. Astronaut Shepard is shown with his flight surgeon as he arrived at the Grand Bahama Islands after recovery. Astronaut Donald Slayton (left) was present to greet him.

Figure 75 ENOS BEING PREPARED FOR MERCURY FLIGHT Enos, a chimpanzee, was fitted into his pressure couch before flight Enos made a successful orbital flight, testing the life support system on the Mercury spacecraft for orbital flight. Three other animals were used to test the Mercury spacecraft on suborbital flights

people of the United States rejoiced because the Mercury now seemed reliable enough to take an astronaut into orbit.

John Glenn, a Marine lieutenant colonel from Ohio (Fig. 76), was chosen to be the first American to make an orbital flight The oldest of the seven astronauts, Glenn was their natural leader, and he had accumulated the most flight time with jet aircraft.

After many disappointing postponements because of bad weather and technical difficulties, the Friendship 7 was at last ready for flight on 20 February 1962. Just as Glenn was taking the elevator to the capsule, the sun burst forth from behind the clouds. It seemed an auspicious sign. As the Atlas roared from the earth in a burst of flame, it boosted the Mercury toward its first orbit, and the crowds cheered. The G-forces began to build up. Finally there was release. Glenn had a pleasant sensation when he became weightless in orbit. Upon looking down at the earth, he was overcome with awe at the grandeur of the view below. There was little time to enjoy what he saw, however, because there were soon more things to do than one man could easily handle. Trouble developed with the automatic attitude control system, and Glenn began to fire the thrusters manually.

Busy with the controls of the spacecraft, Glenn was not aware that more serious trouble had developed. Just as he was beginning his second orbit, ground control received a telemetry signal indicating that the heat shield was loose. There was no way to check the signal. When man is part of a semiautomatic flight control system, he has to learn to fly with many kinds of alarm systems, and he has to know when they really mean business. Warning equipment has gone wrong about as often as the flight equipment it-

Figure 76. ASTRONAUT JOHN GLENN CHECKING MERCURY SPACECRAFT. John Glenn made the first US orbital flight on 20 February 1962 in the Mercury spacecraft named the Friendship 7. During this flight Glenn showed that an astronaut could be more than a passenger in the spacecraft. He took over manual control of the attitude-control thrusters when they failed to work automatically

self. Similar problems were to arise on future flights, but this presented one of the most serious problems that has developed so far. If the heat shield were lost, the Friendship 7 would burn up upon reentry.

Without alarming Glenn, engineers on the ground tried to find some solution. Finally, just as Glenn was completing his third orbit and was ready for reentry, ground control agreed upon a solution. The package containing the retrorockets would be held after firing the rockets. The straps on the package would keep the heat shield in place until the impact with the atmosphere would seal it in position. John Glenn, still unaware of what had happened, was puzzled when ground control gave him the command to hold the retrorocket package after firing. But Glenn followed instructions, and everyone waited breathlessly. When the searing hot capsule, in its plunge through the atmosphere, reached its highest temperature, there was a radio blackout, as expected. The silence was agonizing. Finally, Glenn's voice came through, "Boy, that was a real fireball." The heat shield had held. Later investigation revealed that the warning signal had been false.

Modest John Glenn, eloquent in his praise for all that others had done to make the flight a success, was greeted upon his return by President Kennedy, Vice President Johnson, and a group of Senators. Astronaut Glenn had become a national hero.

Later, in addressing the members of Congress, John Glenn said: "We are just probing the surface of the greatest advancement in man's knowledge of his surroundings that has ever been made." On the later flights, other emergencies developed, but there was no further threat from loss of the heat shield.

Another three-orbit flight was made by Scott Carpenter in the Aurora 7. Then the length of time in flight was increased: to 9 hours on Wally Schirra's flight, known as the "textbook flight" because all went according to plan; and to almost a day and a half on the last flight, that of Gordon Cooper in the Faith 7. The Mercury had more than exceeded the goal set for it.

RESULTS OF THE FLIGHTS.—On the Mercury flights the astronauts showed that man has a place in spaceflight. In spite of the emergencies that developed, the astronauts remained calm and in control of the situation. They were able to sleep, eat, and drink while in the weightless condition. Although they had suffered some ill effects from the flights, they recovered quickly once back on earth. During the flights the astronauts advanced rapidly from being passengers and the subjects of an experiment to being pilots of the spacecraft. When difficulties were encountered with the automatic systems, they were able to override them, using manual controls to adjust the position of the spacecraft in orbit or to make preparations for reentry and recovery. As a result of the six flights, the Mercury became a proved spacecraft. Many of its features were carried over into the Gemini spacecraft.

GEMINI SPACECRAFT: STEP 2

The Gemini, a spacecraft for carrying two astronauts instead of one, was to make flights in earth orbit, just as the Mercury had done. Although the Gemini went to considerably higher altitudes than the Mercury, its main purpose was not to probe a new environment but rather to prepare for the Apollo moon flight while in earth orbit. On the 10 manned Gemini flights, made in rapid succession over a period of less than two years, American astronauts accumulated experience in maneuvers that would serve them well on the Apollo flights. On the Gemini flights the astronauts were no longer regarded as subjects of an experiment. They were rapidly becoming space pilots, learning the elements of space navigation and of living and working in space.

Two-Module Spacecraft

The Gemini spacecraft weighed more than twice as much as the Mercury, but it was much more than the Mercury redesigned to take care of two astronauts instead of one. It was a new kind of spacecraft that could stay in orbit much longer, that was more maneuverable, and that made use of the pilot's judgment in the control circuits. On the Gemini all equipment was neatly packaged and well organized so that the spacecraft could be more easily checked out and maintained. The two most important additions in the Gemini were (1) the **large propulsion thrusters** that made it possible for the Gemini to change orbit; and (2) the adapter module, which contained these large maneuvering thrusters and the extra supplies needed for a longer stay in space.

The Gemini was made up of two large parts. the cone-shaped reentry module, which brought the astronauts back to the earth, and the adapter module, which was jettisoned before reentry (Fig. 77).

The reentry module resembled the Mercury but was much larger. It contained the space cabin for housing the two astronauts and the section at the tip of the spacecraft that held the radar to be used for **rendezvous**, or meeting, with a target vehicle in space In the space cabin were crowded the two couches for the astronauts and duplicate instrument panels. One of the new controls on the duplicate panels was the push-pull lever that operated the large propulsion thrusters for changing orbit. On a central panel was a control stick for firing small thrusters to adjust the attitude of the spacecraft. In front of each pilot was a small window that allowed him to see the rendezvous and **docking**, or linkup with another spacecraft that followed rendezvous. Two hatches that opened from the inside were provided to allow the astronauts to leave the spacecraft for **extravehicular activity (EVA)**, or activity outside the pressurized space vehicle. To enable the astronauts to make the computations they would need for rendezvous, the

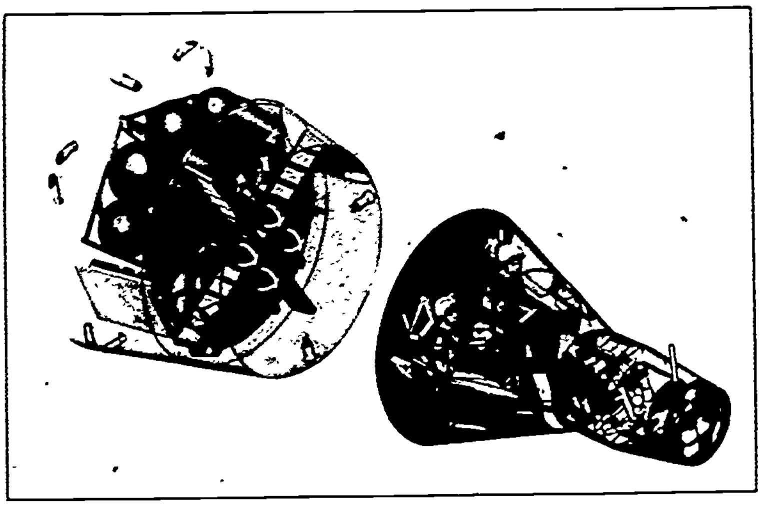


Figure 77. GEMINI SPACECRAFT. The Gemini spacecraft consisted of two large parts, the adapter module (left) and the rentry module (right). The adapter module contained supplies and equipment like reserve oxygen, the thrusters used for maneuver, and the retrorockets, which were used during orbital flight. The adapter module was jettisoned in two parts, the equipment section and the retro section. The reentry module, shaped somewhat like the Mercury spacecraft, contained the equipment needed during reentry and recovery.

Gemini had a miniaturized computer about the size of a hat box. (The Apollo spacecraft has three computers; the Mercury had none.)

The adapter module, positioned below the reentry module on the stack at launch, connected the Gemini spacecraft with the Titan II booster. The adapter module was the forerunner of the service module in the Apollo spacecraft, but, unlike the Apollo service module, the Gemini module did not remain in one part during flight. It was made up of two sections, which were jettisoned at different times: the equipment section and the retro section. The equipment section contained the rocket thrusters for orbital maneuvering, a supply of oxygen, and batteries and fuel cells for providing electrical power. The retro section contained the retrorockets used for braking the spacecraft before reentry.

Since the Gemini astronauts were to develop and then master the techniques for rendezvous and docking, they needed target vehicles for practice.

Targets for Rendezvous and Docking

The Agena target vehicle (Fig. 78) was to be the principal and final target used by the Gemini astronauts. It would give them a definite point in space for rendezvous and docking. Once the Gemini was linked with the Agena, the systems of the two vehicles would interlock, and the astronauts could make use of the fuel stored in the Agena to perform more maneuvers and to take the Gemini to higher orbits. In this way the Agena target vehicle served as a kind of filling station in space.

The Agena target was a modified Agena booster. It had a special docking collar, parts of a communication system, and a secondary propulsion system. Most important of all, the engines could be restarted in space. The Agena was launched separately from Cape Kennedy on an Atlas booster.

When there was no Agena target vehicle available for practice, the Gemini astronauts made use of two dummy targets that they released from their spacecraft: the Augmented Target Docking Adapter (ATDA) and the Radar Evaluation Pod (REP). The ATDA had a docking collar; the REP did not have one.

With the much improved Gemini spacecraft and the targets for rendezvous and docking, the astronauts were well equipped to reach goals that would prepare them for the Apollo moon flights.

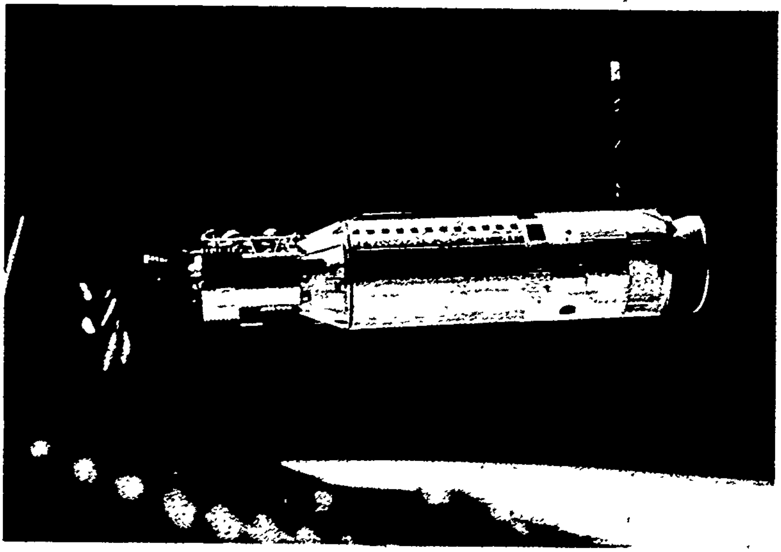


Figure 78. AGENA TARGET VEHICLE. Above is a photograph of the Agena target vehicle taken by Astronaut David Scott from the Gemini-8 spacecraft as it approached for the first docking. Note the mechanism for receiving the docking probe on the forward end of the Agena (right).

Goals for Project Gemini

Even before the last Mercury flights had been completed, NASA officials had decided upon the method American astronauts would use in going to and from the moon. The decision allowed engineers to begin construction of the Apollo spacecraft, and it gave the astronauts a more definite idea of the kinds of maneuvers they would need for the moon flights. Since the Apollo moon landing was to be made by **lunar orbit rendezvous (LOR)**—by sending a part of the Apollo spacecraft down to the moon from lunar orbit and then returning that part for rendezvous and linkup with the main spacecraft—the astronauts would have to master the techniques for rendezvous and docking. The two moon-landers would need to seek out the main spacecraft for rendezvous and linkup.

The Gemini flights were planned to reach three principal goals in preparation for the Apollo flights: (1) extend time in space up to about two weeks, (2) be able to rendezvous and dock with the Agena target vehicle and use the combined systems for maneuvers, and (3) perform extended EVA in space, moving about (making so-called space walks) and performing useful work. Experience gained in EVA outside the Gemini spacecraft would give astronauts the kind of experience they would need for the moon walks. During their walks on the airless moon, they would have to depend solely upon their space suits and backpacks for survival. Then, too, the more the astronauts would be able to move about in space and perform useful work, the better prepared they would be for any kinds of emergencies, both in space and on the moon.

With the goals for Project Gemini clearly in mind, NASA officials prepared detailed plans for the flights.

Gemini Flights

After some delay, the Gemini spacecraft was ready. This time there was no long series of preparatory flights. After two unmanned flights to test equipment, manned orbital flights were begun in March 1965 and progressed rapidly (Table 3). The time for making the Gemini ready for flight could be shortened because the rocket booster, the Titan II, burned hypergolic propellant, or fuel and oxidizer that ignited upon contact.

The first manned Gemini flight was commanded by the late Gus Grissom, the first astronaut to make a second spaceflight. The other pilot was John W. Young. Although the flight was a brief one, a three-orbit flight lasting less than 5 hours, it was significant. It marked the first time any space pilot had used large rocket thrusters to change the orbit of his spacecraft. The test showed that the Gemini spacecraft would be capable of making a rendezvous and achieving the other goals set for it. The astronauts were ready to extend flight time.

EXTENDING TIME IN SPACE.—Although the medical records of the Mercury astronauts had been reassuring, NASA officials were cautious about making a sudden large increase in flight time. There was good reason to believe that continued exposure to the weightless condition might produce harmful changes in the body. Some subjects flying the weightless trajectory had experienced unpleasant sensations, and some Soviet cosmonauts reported motion sickness while in orbit. There was further possible danger to the astronauts from continued exposure to the pure oxygen atmosphere of the spacecraft.

The longest Mercury flight had lasted only a day and a half. It was like a rather hectic weekend for one astronaut alone in

TABLE 3

GEMINI MANNED FLIGHTS

(March 1965 - November 1966)

Number of flight	Astronauts	Date of launch	Length of flight days	hr.	min.	Number of revolutions	Description of flight
GT-3[a]	Virgil I. Grissom John W. Young	23 Mar. 65		4	53	3	First maneuvers to change orbit.
GT-4	James A. McDivitt Edward H. White	3 June 65	4	1	56	62	First US space walk (22 min.). Used REP.
GT-5	L. Gordon Cooper Charles Conrad	21 Aug. 65	7	22	56	120	Used REP. Had difficulties with new fuel cell.
GT-7	Frank Borman James A. Lovell	4 Dec. 65	13	18	35	206	World record for length of flight. Served as rendezvous for Gemini 6.
GT-6	Walter M. Schirra Thomas P. Stafford	15 Dec. 65	1	1	51	16	Rendezvous within 1 ft. of Gemini 7. World's record for first rendezvous.
GT-8	Neil A. Armstrong David R. Scott	16 Mar. 66		10	42	7	Rendezvous and docking with Agena. Flight terminated early because of difficulties with small thruster on the Gemini. Recovery in Pacific Ocean.[b]
GT-9A	Thomas P. Stafford Eugene A. Cernan	3 June 66	3	0	21	44	Three practice rendezvous with ATDA; unable to dock because shroud was not removed; space walk 2 hr. 7 min. by Cernan.
GT-10	John W. Young Michael Collins	18 July 66	2	22	47	43	Space walk of 39 min. and standup EVA of 49 min. by Collins. Highest atlitude reached 475 miles.
GT-11	Charles Conrad Richard F. Gordon	12 Sept. 66	2	23	17	44	Space walk of 33 min. and standup EVA of 2 hr. 5 min. by Gordon. Highest altitude reached 850 miles.
GT-12	James A. Lovell Edwin E. Aldrin	11 Nov. 66	3	22	35	59	Two standup EVAs: 2 hr. 29 min. and 55 min. Space walk of 2 hr. 6 min. by Aldrin. All space work completed.

[a]GT is the abbreviation for Gemini-Titan. All Gemini flights were launched by the Titan II, a modified second-generation ICBM.

[b]GT-8 made an emergency landing in the Pacific Ocean. Astronauts on the other Gemini flights were recovered in the Atlantic Ocean.

the spacecraft. Pressed with many tasks and with the emergencies that developed, he could not devote the time he needed to eating, sleeping, and taking care of his physical well being. On longer flights, with two-man crews and then with the three-man crew on the Apollo spacecraft, the astronauts would be able to settle down to a schedule of working, eating, and sleeping in space.

To protect the astronauts, they had instruments attached to their bodies that recorded blood pressure, breathing rate, body temperature, and heart beats. These readings were telemetered to the ground and relayed to the flight surgeon. Often, though, at a crucial time when **medical data** was needed most, the readings had to be interrupted.

Of the six astronauts selected for Gemini 4, 5, and 7—the three flights planned for extending flight time—only Astronaut Gordon Cooper had had previous spaceflight experience. On Gemini 4, two new astronauts, James McDivitt and the late Edward White, advanced flight time in orbit up to 4 days. No medical problems developed. On Gemini 5, Astronauts Gordon Cooper and Charles Conrad extended time in orbit up to 8 days.

On Gemini 7, which brought time in flight up to almost 14 days, Frank Borman and James Lovell performed well. They completed all but one of the 20 experiments assigned to them. One of the most important experiments was the test to determine if there is a loss of bone calcium during the weightless condition. The test showed that the astronauts, confined to the cramped quarters of the spacecraft, did lose some bone calcium, much as bed patients do.

Although they did not have room to move about, Borman and Lovell were able to relax in their **space coveralls**, or "space underwear." For the first time they enjoyed what has come to be known as the "shirt-sleeve environment." The new lightweight space suits, which they wore at the beginning of the flight (Fig. 79), were removed after the flight was underway, but they kept these space suits close by so that they could be put on quickly in case of an emergency. During most of the flight Borman and Lovell wore the space coveralls, a constant-wear garment and not a space suit. The shirt-sleeve environment was given some of the credit for the astronauts' well being at the end of the flight. By this time it was believed that the life-support equipment on the spacecraft had proved reliable enough so that the space suit

Figure 79. ASTRONAUTS BEFORE RECORD ENDURANCE FLIGHT. Astronauts Frank Borman and James Lovell are wearing the lightweight space suit designed for longer flights. The suit was first used on the Gemini-7 record endurance flight in December 1965. The suit could be easily removed during the flight.

could be taken off during the flight. Now the astronauts wear their space suits only during the most hazardous parts of the flight or when they depressurize their spacecraft for extravehicular activity (EVA) or are actually engaged in EVA.

Once the flights testing endurance were completed, the astronauts could concentrate on practicing maneuvers such as rendezvous and docking.

RENDEZVOUS AND DOCKING.—The Gemini astronauts at first found it difficult to rendezvous with another vehicle in space. The operation may seem somewhat like refueling an aircraft in midair, but actually it is quite different. Spacecraft in orbit follow the laws of celestial mechanics, as explained in Chapter 3. If an astronaut would fire his thrusters to speed up the spacecraft and gain on a target in the same orbit, his spacecraft would go into a higher orbit and slow down. If he would brake his spacecraft, it would drop into a lower orbit and speed up, but it would never overtake the target unless he maneuvered again to change orbit. Each rendezvous has to be calculated in advance on a computer before an astronaut can make the maneuver. Rendezvous is usually a matter of chase in circles or on a long curved trajectory rather than in a straight line.

One way to rendezvous is to let the spacecraft fall into a lower circular orbit just behind the target vehicle. The spacecraft in the lower orbit will travel faster than the target. Just as the spacecraft is about to overtake the target, the pilot can give his thrusters a precise burn to bring him up to the target (Fig. 80).

The astronauts on the Gemini-4 and Gemini-5 flights practiced with the Radar Evaluation Pod but they had difficulties with a badly tumbling pod and with a power failure in the equipment.

The astronauts on Gemini 6 were to make use of the actual Agena target vehicle, but it exploded at launch, and the original mission was scrubbed. Wally Schirra and Tom Stafford, two disappointed pilots, were getting out of the spacecraft when NASA officials decided upon a substitute plan. Why not let the Gemini 7 be launched as scheduled and then have the Gemini 6 rendezvous with the Gemini 7? The two Gemini spacecraft could not dock because no mechanism had been provided for this purpose, but they could approach close enough to simulate a docking. Rendezvous was arranged to take place on the dark side of the earth

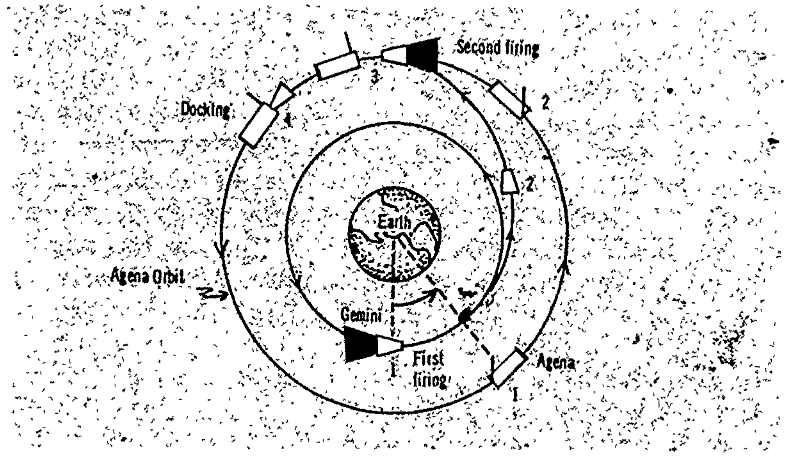


Figure 80. RENDEZVOUS BETWEEN GEMINI SPACECRAFT AND AGENA TARGET VEHICLE. The above diagram shows how a rendezvous might be made. The two vehicles would each be put into a circular orbit. The Gemini spacecraft in the lower orbit would travel faster than the Agena target vehicle in the higher orbit. Gradually the Gemini would begin to catch up with its target. When the Gemini is at the correct angle, the engine is fired (1). The Gemini begins to travel on a long curving trajectory (2). When the Gemini approaches the Agena, the Gemini's engine is fired to circularize its orbit (3). The two vehicles dock (4). Rendezvous and docking require precise computer calculations based on the laws of celestial mechanics.

so that Schirra and Stafford could see the flashing lights on the Gemini 7.

Schirra made a whole series of maneuvers before the Gemini 6 approached the Gemini 7 and the astronauts could see it as a point of light in the distance. The point gradually grew until the Gemini 7 looked like a harvest moon. The Gemini 6 continued to close on the Gemini 7. As the Gemini 6 approached the target vehicle, Schirra flew chase around it (Fig. 81), much as aircraft pilots do when they examine a new plane. Finally the two spacecraft faced each other. The tip ends of the spacecraft were about a foot apart, and the astronauts could see each other through the windows. The meeting of the Gemini 6 with the Gemini 7, which took place over the Pacific Ocean above Hawaii, on 15 December 1965, marked the world's first rendezvous. After the meeting, the two spacecraft flew formation within about 100 feet of each other for nearly 5 hours, another significant first.

On Gemini 8, in March 1966, the astronauts were to complete rendezvous by docking the Gemini with the Agena target vehicle.

The command pilot of the Gemini 8 was Neil Armstrong (Fig. 82), a civilian veteran X–15 pilot, who would be the first man to step onto the moon. The other pilot was Air Force Capt. David R. Scott, who later flew on the Apollo 9 and commanded the Apollo-15 flight. Gemini 8, launched into an orbit at about 100 miles above the earth, went to seek out the Agena target vehicle, which was in orbit about 185 miles above the earth. The Gemini made a rendezvous with the Agena, and the docking was smooth. The two vehicles had been linked for about half an hour when they began to spin violently, presenting a serious threat because of the propellant stored in the Agena. Armstrong acted quickly. He fired emergency thrusters to back away from the Agena. Once the emergency thrusters were used, the astronauts had to return to earth just as soon as ground control could arrange for an emergency landing in the Pacific Ocean. An investigation revealed that the Gemini spacecraft, not the Agena, had caused the trouble. A small thruster on the Gemini had short-circuited and kept firing, causing the spacecraft to go out of control.

Once rendezvous and docking had been successfully completed, the astronauts soon developed skill with the maneuver.

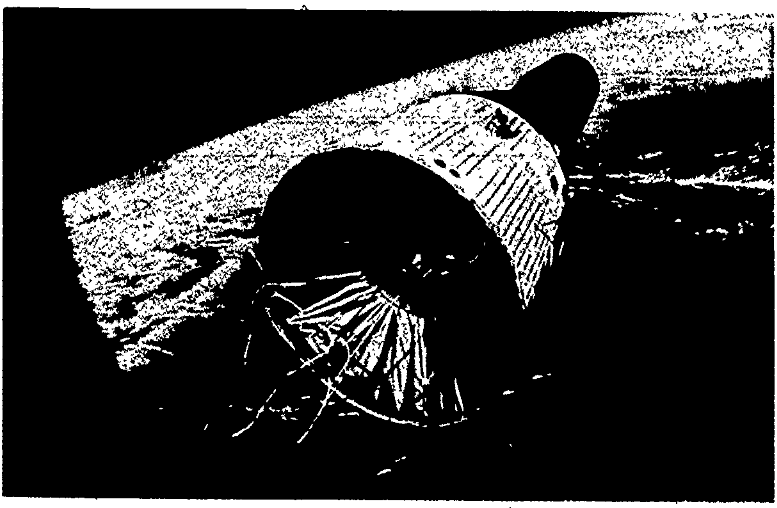


Figure 81. TARGET VEHICLE AFTER WORLD'S FIRST RENDEZVOUS. This view of the Gemini 7 was photographed from the Gemini-6 spacecraft after the rendezvous over Hawaii on 15 December 1965. The Gemini 6 flew around the Gemini 7, and the tip of the two spacecraft almost touched. Astronaut Walter Schirra piloted the Gemini 6 during the rendezvous.

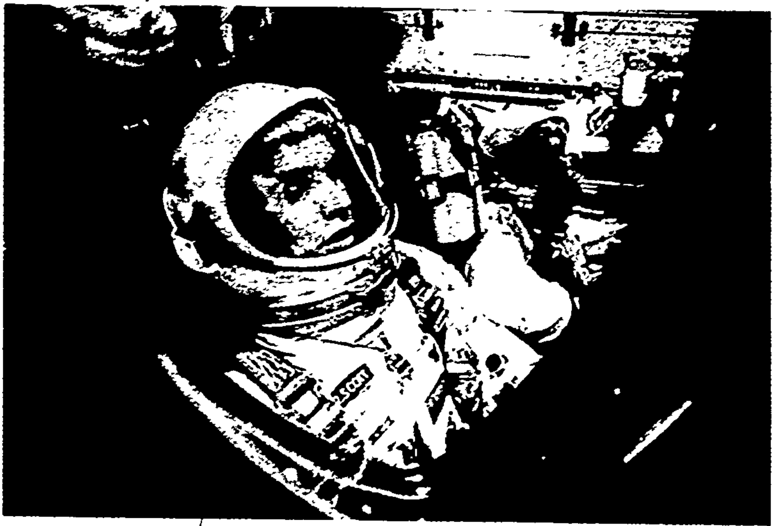


Figure 82. ASTRONAUTS PREPARING FOR THE FIRST DOCKING MISSION Astronauts Neil Armstrong (right) and David Scott (left) docked the Gemini-8 spacecraft with the Agena target vehicle for the world's first docking in March 1966. The docking itself was successful, but an emergency landing was made soon after because trouble developed in the Gemini spacecraft.

On Gemini 9A, Astronauts Tom Stafford and Gene Cernan made three rendezvous with a target vehicle. On Gemini 10, Astronauts John Young and Michael Collins, docked with the Agena target vehicle and for the first time used its propellant for maneuvers. They pushed the Gemini-Agena up to a record altitude of 475 miles. On the Gemini 11, Astronauts Charles Conrad and Richard Gordon also docked with the Agena. This time the combined Gemini-Agena soared to a new record altitude of 850 miles.

On the Gemini flights rendezvous and docking were combined with EVA.

EXTRAVEHICULAR ACTIVITY (EVA) —The first extravehicular activity (EVA) by an American astronaut was the so-called space walk made by the late Edward White (Fig. 83) on the Gemini-4 flight in June 1965.

Before opening the hatch for EVA, Astronauts McDivitt and White made sure their space suits were pressurized and properly attached to the oxygen supply. White wore a heavy space suit especially designed for EVA, he had on a chest pack, and he carried a maneuvering gun with small thrusters. An umbilical cord, or long cable, would supply oxygen for his space suit. This was wrapped with the long tether that would fasten him to the spacecraft. Once they felt secure in their space suits, the astronauts let out all the oxygen to depressurize the space cabin before opening the hatch.

When White emerged into space, he had no sensation of falling, and he did not lag behind the Gemini. He became in effect another spacecraft traveling at the same speed as the Gemini and in the same orbit. Even at the speed of about 17,500 mph at which he was going through space, White had no more sensation of speed on the outside than he had on the inside of the Gemini, and he was not disoriented. To get his bearings, he fixed his eyes on the spacecraft.

By firing his gun, White was able to maintain good balance,

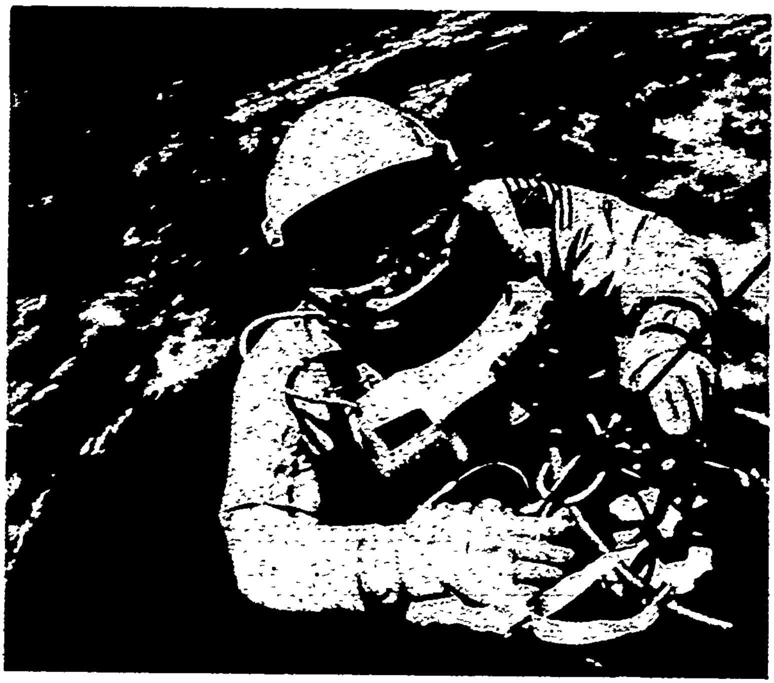


Figure 83. ASTRONAUT MAKING FIRST US SPACE WALK. The late Astronaut Edward White is shown during the first US extravehicular activity (EVA) on the Gemini-4 flight in June 1965. He is wearing a specially designed EVA space suit, and he has a chest pack with an emergency oxygen supply. He is holding a maneuvering unit.

and he could move around with ease. Unfortunately, the fuel for the gun was exhausted in a few minutes, and then he had to hold onto the umbilical cord to move about. White was surprised at all the details he could see on the ground below, and he was highly elated by the feeling of freedom in space. He was reluctant to go back into the spacecraft. It took some time to get back, as White had to make his way hand over hand on the umbilical cord.

After successfully completing the first EVA, the Gemini astronauts concentrated on rendezvous and docking but returned to EVA practice on the Gemini 9A. On this flight Astronaut Gene Cernan, a Navy lieutenant, made a space walk of more than two hours. Some of the space work planned for the flight had to be cancelled, however, when Cernan's visor fogged over because he was perspiring excessively. In the vacuum of space, work is not easy. Any slight movement sets up a **reaction force** in the opposite direction, as explained by Newton's third law of motion (action-reaction principle).

EVA practice was continued on Gemini 10 and Gemini 11. Time spent in EVA was increased considerably on Gemini 11, but no taxing work was done. Much of the EVA was simply standup EVA.

Finally, on Gemini 12, Astronaut Edwin (Buzz) Aldrin, who was to be the second man to set foot onto the moon, completed all the space work assigned to the flight. He had carefully practiced for the flight ahead of time by workouts underwater, during which he tried to simulate conditions found in space. During the flight he made skillful use of handholds, footholds, and a restraining tether. In this way Aldrin was able to apply force to perform useful tasks and was not sent spinning off into space by the reaction force.

The Gemini-12 flight brought to a conclusion the 10 highly successful Gemini manned flights. All goals had been reached in preparation for the launch of the Apollo spacecraft.

APOLLO SPACECRAFT: STEP 3

The Apollo spacecraft took the third and final step in achieving the goal set by President Kennedy, in May 1961, of landing American astronauts on the moon and returning them safely to the earth. The Apollo was built with experience gained during

Projects Mercury and Gemini, and Project Apollo resembles both earlier projects. It is like Project Mercury because it took astronauts into a new environment—this time, deep space. It is like Project Gemini because it developed additional maneuvers. Before Project Apollo began no manned spacecraft had as yet traveled on the long **earth-moon trajectory** or had gone into orbit around the moon to make a descent to the airless moon and an ascent into orbit afterwards. While Projects Mercury and Gemini had taught us much about manned spaceflight, there was still much to learn. The successes achieved with the Mercury and Gemini spacecraft, however, made us confident that we could learn what was necessary to land men on the moon.

Preparations for the Apollo flights were progressing rapidly when, in January 1967, fire broke out in the command module during a ground test. The fire took the lives of Astronauts Gus Grissom, Ed White, and Roger Chaffee, who were scheduled for the first Apollo flight. Grissom and White had already made significant spaceflights, as noted earlier. Chaffee was to make his first spaceflight on the Apollo. The tragedy showed that the command module, as then designed, was not safe for use with the highly flammable **pure-oxygen atmosphere.** Consequently, flights were delayed for 21 months until the command module and Apollo space suits could be redesigned to make them fireproof. The tragedy also showed that no detail could be overlooked. All the complex flight equipment would have to function perfectly to make a moon landing possible. As a result everyone responsible for Project Apollo dedicated himself anew to making the Apollo spacecraft safe for flight.

From the time of the first Mercury flights the astronauts had striven to assure their own safety and gain as much control over the spacecraft as possible. During the Gemini flights the astronauts had clearly shown that they were pilots, not subjects in the experiment of spaceflight. By the time the Apollo flights were underway, Astronaut Frank Borman, commander of the Apollo 8, could say, "The approach now of the astronauts to controlling the spacecraft is more allied to considering it as an aircraft rather than as a super type of guided missile." The control that the astronauts have gained over the Apollo spacecraft is impressive in view of its awesome size and complexity.

Three-Module Spacecraft

The Apollo spacecraft represents a much greater advance over the Gemini than the Gemini did over the Mercury spacecraft. The Apollo spacecraft was redesigned to carry three astronauts rather than two, but these changes were small in comparison with those made to take care of much more complex flight operations: the flight on the earth-moon trajectory, the orbiting of the moon, the descent to the moon, and the ascent to lunar orbit.

To enable two of the astronauts to make the lunar landing, a third module, the spiderlike lunar module, was added to the Apollo spacecraft. This module, which detaches from the main body of the spacecraft to make the landing on the moon and return to lunar orbit. contains its own rocket booster and launch pad for use on the moon. This was the first time a rocket booster for launching was inclosed in a US spacecraft.

The Apollo spacecraft consists of three modules: the command module, the service module, and the lunar module (Fig. 84). The cone-shaped command module might be compared with the Mercury spacecraft and the reentry module of the Gemini, the service module with the adapter module of the Gemini. The lunar module, as noted, is new with the Apollo spacecraft.

When the Apollo spacecraft rests on the Saturn V booster in readiness for the moon launch, the entire stack rises 364 feet above the launch pad (Fig. 84). Of the total height, the Apollo spacecraft makes up only about one-fifth, or 82 feet, of the stack. The remainder is made up of the giant Saturn V booster. Generating 7.5 million pounds of thrust at liftoff, the Saturn V raises the heavy Apollo spacecraft, which has ranged in weight from 97,000 to almost 100,000 pounds, and puts it into a parking orbit around the earth. The third stage of the booster remains attached for firing later to put the spacecraft into the earth-moon trajectory. Of all the flight equipment on the stack, the only part that finally returns to the earth is the relatively small cone-shaped command module.

The command module. which rests at the top of the stack under the launch escape tower. has the small end up, just as the Mercury and Gemini had. The command module is the command post of the spacecraft and the part in which all three astronauts ride for most of the trip. It contains the couches for

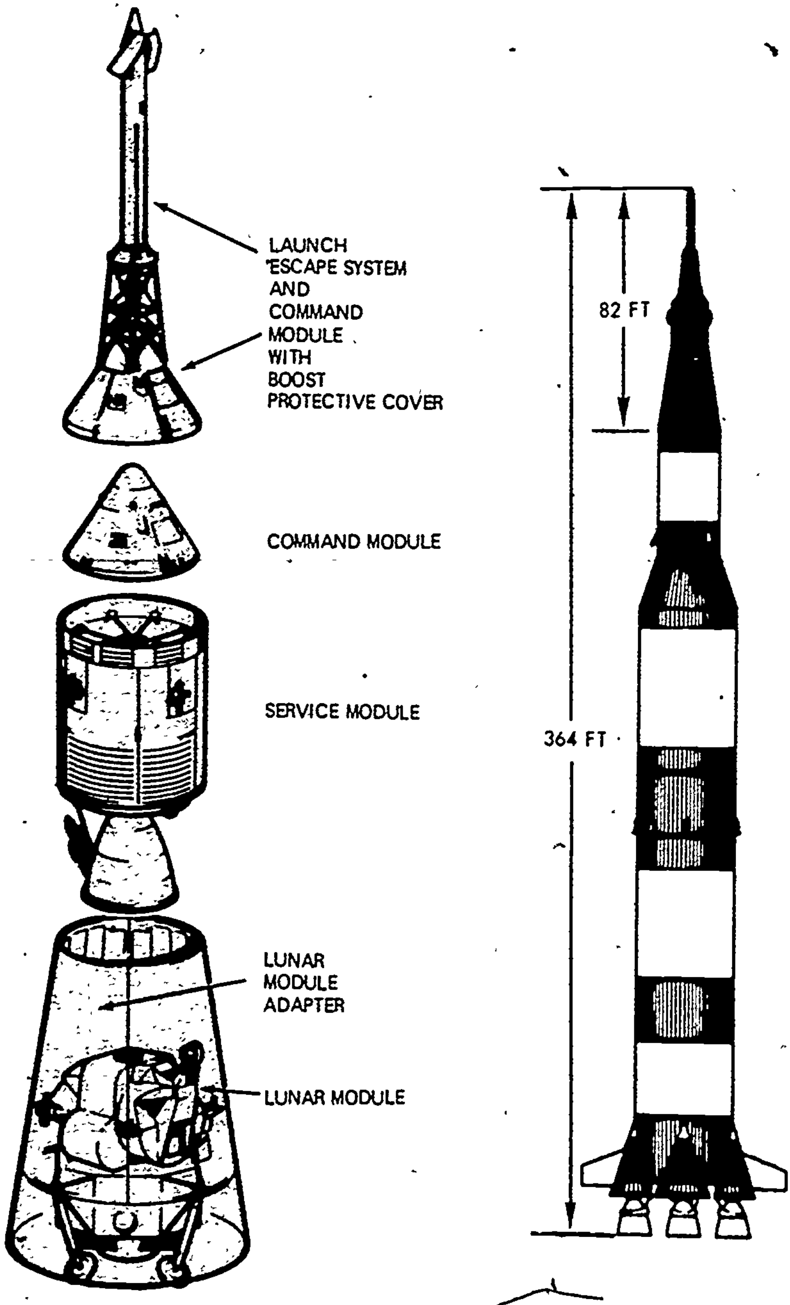


Figure 84. THREE MODULES OF APOLLO SPACECRAFT. At the right the three modules (blue portion) are shown assembled on the stack. At the left each module is shown separately. The lunar module is inclosed in the adapter (shroud) at launch. At the upper left is a drawing showing how the escape tower is connected to the command module at launch. The escape tower is jettisoned soon after launch.

the three astronauts, the instrument panel, small thrusters to control the attitude of the spacecraft, the life-support equipment, and the parachutes and all other equipment needed for reentry. The quarters are still cramped, but the center couch can be folded back. With the seat portion up, two astronauts can stand up at one time to check equipment and navigation instruments. The command module has double walls. On the Apollo command module the heat shield covers the entire module to protect it against temperatures as high as 5,000 degrees F., which are reached when the module returns from the moon at speeds of more than 24,500 mph.

Attached to the command module is the service module. This houses the large propulsion engine, which is fired for making mid-course corrections, for braking the spacecraft to go into orbit around the moon, and finally for putting the spacecraft on a trajectory from the moon to the earth. The large bell-shaped nozzle of the propulsion engine is a conspicuous feature at the aft end of the spacecraft in flight. The service module also contains reserve supplies of power, oxygen, and water.

The command and service modules, which are identified by a single code name, remain attached all during flight up to the time of reentry. The command module cannot operate alone except for the brief period at reentry. The combined command-service modules remain in orbit around the moon, piloted by one astronaut, while the other two astronauts take the lunar module down to the moon.

At the tip end of the command module is the docking probe that is inserted into the lunar module, together with the tunnel that connects the command module with the lunar module. When the two astronauts are ready to begin preparations for the landing, they equalize the oxygen pressure in the two modules before opening the pressure hatch to enter the lunar module and check systems. Both the lunar module and the command module are pressurized for breathing; the service module is not, as the astronauts do not enter it. The command module docks with the lunar module during flight.

At launch the lunar module rests at the bottom of the Apollo spacecraft. It is housed in the adapter to protect it during the flight through the earth's atmosphere. The lunar module remains in the adapter until docking, which takes place on the trajectory from the earth to the moon. When it is time for docking, thrusters fire to release the command-service modules and to cause the parts of the adapter to fall away much like the petals of a flower, leaving the lunar module exposed (Fig. 85). The command-service modules turn through 180 degrees, dock with the lunar module, and pull the lunar module away from the third stage of the

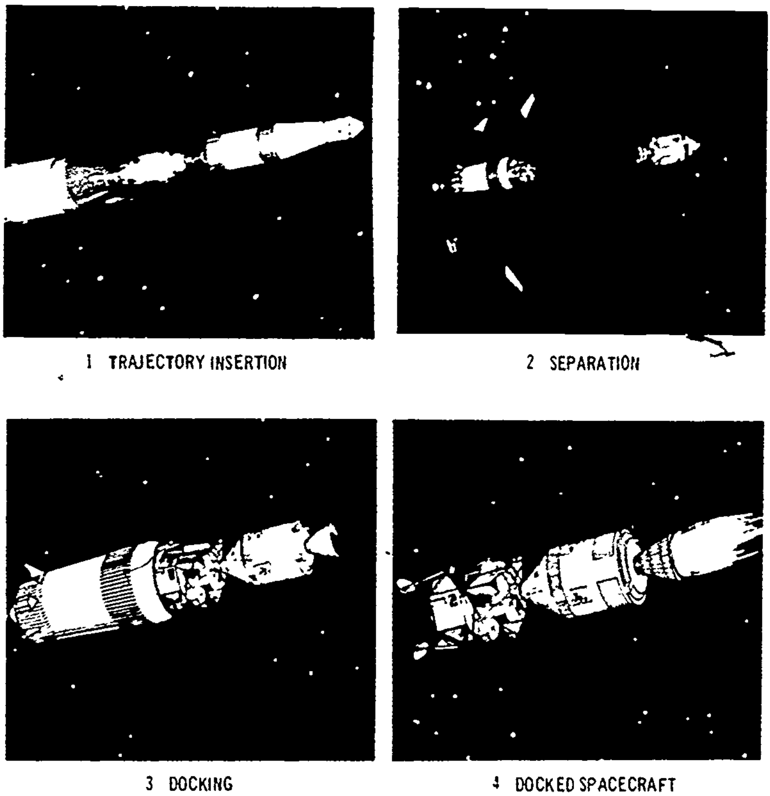


Figure 85 DOCKING COMMAND SERVICE MODULES WITH LUNAR MODULE. This docking, done early in the flight, is one of the key maneuvers of an Apollo moon flight. After the Apollo spacecraft is inserted into the earth-moon trajectory, the third stage of the Saturn V booster is still attached (1). To begin the maneuver, the command-service modules are first separated. Then explosive bolts fire, causing the sections of the lunar module adapter to fall away (2) Next the command-service modules turn in a half circle (180 degrees) and dock with the lunar module (3). The lunar module is pulled away from the spent rocket stage, and the Apollo spacecraft is now in its flight configuration (4) The nozzle of the large propulsion engine in the service module is then exposed, allowing a burn of the engine for making a midcourse correction.

Saturn V booster. The spacecraft is now in its flight configuration and ready for landing on the moon.

When the lunar module descends from lunar orbit toward the moon, the descent engine fires to brake it gradually. As the astronauts guide the lunar module down toward the moon, they stand up and peer through two small openings onto the moonscape below. Just before landing, the lunar module hovers briefly, much as a helicopter does, to allow the pilot to select a suitable landing spot. Once on the moon, the lunar module becomes the base of operations for the astronauts. It provides the water and oxygen to supply their moon suits during EVAs, as well as all other life-support supplies they will need until their return to the main spacecraft.

Because so much more complicated flight equipment had to be put together and work precisely to make the moon flights possible, each module had first to be flight-tested separately to see that it operated as it should. Before taking up the preliminary Apollo test flights, it is helpful to consider the overall plan for the moon landing, as this shapes the plans for all flights.

Flight Plan for the Moon Landing

No two Apollo moon flights have followed exactly the same plan. Variations have been made to adjust to such conditions as the location of the landing site, the kind of lighting, the amount of stay-time plannned, and the kind of experiments to be done. After the time of launch and recovery is set, each flight is planned, beginning with recovery time and working backwards. The general plan given here outlines the main events in a moon flight in the order in which they occur.

At launch the giant first stage of the Saturn V fires to lift the Apollo spacecraft from the earth. After burnout, the first stage is jettisoned, and the second stage begins to burn. Next the launch escape tower is jettisoned. When the second stage burns out, it falls away, and the third stage fires. This final stage remains attached to the spacecraft as it goes into a parking orbit around the earth (Fig. 86).

While in earth orbit, the astronauts check systems and navigation instruments. After the spacecraft orbits the earth about one-and-a-half times, the third stage of the booster refires at a

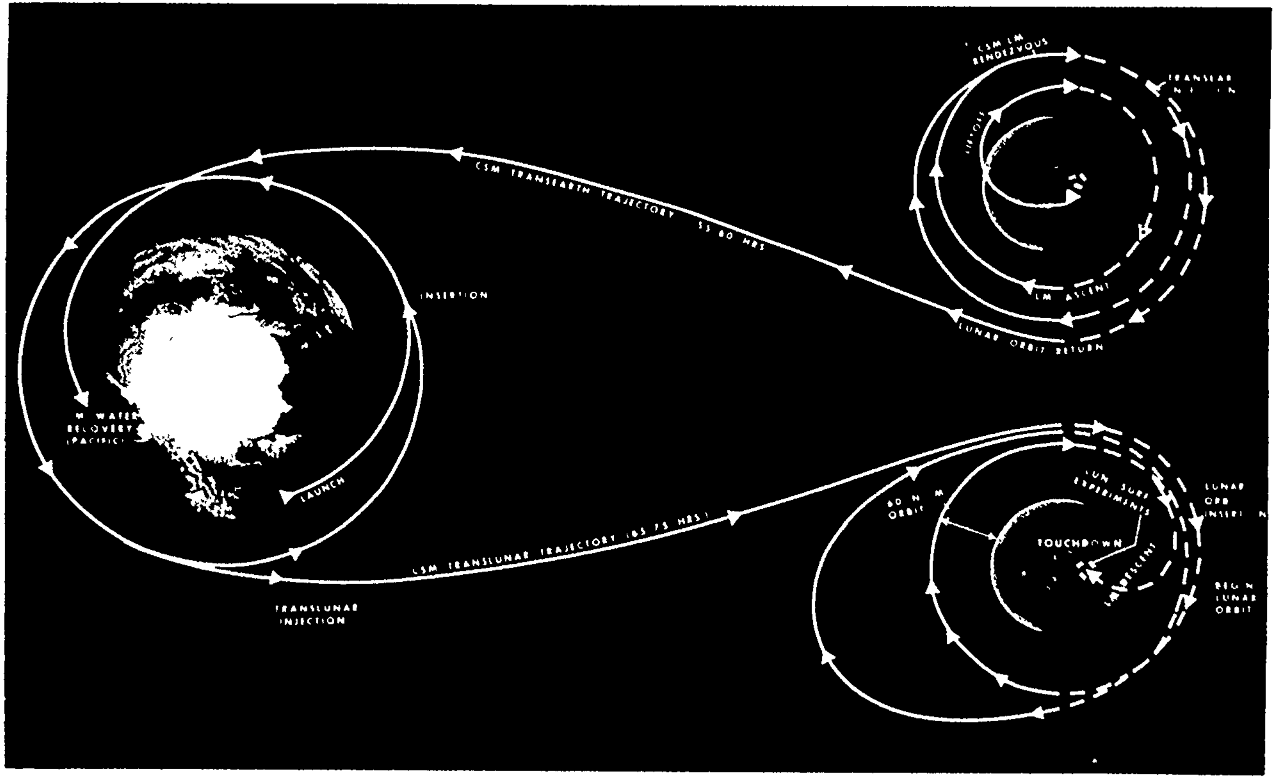


Figure 86. FLIGHT PLAN FOR AN APOLLO MOON LANDING. The trajectory for the flight out to the moon is shown below and for the trip back to the earth above. Note the parking orbit about the earth at the beginning of the flight. The plan for each Apollo moon landing varied slightly, depending upon the site selected for the landing, the amount of stay-time on the moon, and the tasks to be performed in lunar orbit.

predetermined point to send the spacecraft on the trajectory to the moon.

Early in the flight on the earth-moon trajectory, the astronauts dock the command-service modules with the lunar module, as previously described. The Apollo spacecraft in its regular flight configuration, with the lunar module in front, continues on its way to the moon. As many midcourse corrections are made as necessary to keep the spacecraft on course. Usually the trajectory is highly accurate, and one correction is adequate.

As the spacecraft approaches the moon, it is turned in orbit so that the aft end is forward and the large propulsion engine in the service module is exposed for firing to brake the spacecraft and put it into orbit around the moon. The spacecraft orbits the moon several times, allowing the astronauts to survey the **landing site** and make further checks of the lunar module. Finally the lunar module is separated, and the two astronauts take it on a trajectory toward the moon, braking it gradually until they can bring it down gently on a fairly level surface.

The kind of exploration to be done on each flight is carefully planned in advance, and the amount of stay-time is set. At the time appointed for departure, an astronaut fires the ascent engine, and the lunar module lifts off from the surface, leaving behind the lower portion of the lunar module (the descent stage). The top portion of the lunar module (the ascent stage) seeks out the main spacecraft left in lunar orbit, and the pilot of the command module docks the main spacecraft with the ascent stage of the lunar module.

After the moon-landers come back into the main spacecraft and bring with them their rock and soil samples, the remaining stage of the lunar module is jettisoned. The main spacecraft is then ready for the trip back to the earth. The large propulsion engine in the service module is fired, sending the spacecraft on the return trajectory to the earth.

On the trip back, midcourse corrections are made as necessary, just as on the journey to the moon. As the spacecraft approaches the earth, the service module is jettisoned, and the command module reenters the earth's atmosphere. The impact with the atmosphere cuts down the speed of the spacecraft. Then a drogue chute opens, and finally three large orange-and-white striped parachutes further brake the spacecraft before splashdown in the Pacific Ocean.

Although remarkably rapid progress was made during each of the Apollo flights, several preliminary flights were required before the moon landing could be scheduled.

Apollo Flights

The first six unmanned Apollo flights[1] tested equipment: the two Saturn boosters and the three flight modules. The smaller Saturn booster, the Saturn IB, was used for flights that did not carry full equipment or go to the moon. The giant Saturn V was used for the fully equipped spacecraft and the moon flights.

Plans for the manned Apollo flights were open-ended. No detailed plans were made in advance, as had been done before. The astronauts were to proceed as far as it was safe for them to go on each flight. The first Apollo manned flights tested equipment.

TESTS OF FLIGHT EQUIPMENT.—The first four manned Apollo flights, (Apollo 7, 8, 9, and 10) were made alternately in earth orbit and in orbit around the moon (Table 4). Each flight carried one or more experienced astronauts.

On the Apollo-7 flight, made in October 1968 and commanded by Wally Schirra, one of the original seven astronauts, the command module proved itself ready for flights to the moon. The heat shield worked well, and all systems operated satisfactorily. One feature of the flight was the "Wally, Walt, and Donn Show," which gave the public its first real-time television view of life in the weightless condition in a spacecraft. The other astronauts on board were Walter Cunningham and Donn Eisele.

The historic Apollo-8 flight took men to the moon for the first time. On Christmas Eve, in 1968, Astronauts Frank Borman, James A. Lovell, and William Anders (Fig. 87) read from the Bible the awesome words describing Creation as they orbited the moon and gave earth dwellers a new look at the moon and the planet earth as seen from the moon. This important flight tested navigation and midcourse corrections on the long earth-moon trajectory, and it was the first manned flight made with the Saturn V booster. The Apollo 8 carried a dummy lunar module; no landing was planned.

[1]There were six preparatory unmanned flights, but these were not numbered in sequence Changes were made in numbering and scheduling flights because of the fire on the launch pad

TABLE 4

APOLLO MANNED FLIGHTS
(October 1968 - April 1972)[a]

Flight number and names of flight modules	Astronauts[b]	Date of launch	Length of flight days	hr.	min.	Number of revolutions	Description of flight
Apollo 7	Walter R. Schirra Donn Eisele Walter Cunningham	11 Oct. 68	10	20	9	163 of earth	Tested command and service modules in earth orbit; launched by Saturn IB. Recovery in Atlantic Ocean.
Apollo 8	Frank Borman James A. Lovell William Anders	21 Dec. 68	6	3	0	10 of moon	First manned flight in lunar orbit. Tested command and service modules on earth-moon trajectory; carried dummy lunar module. First manned flight launched by Saturn V. Recovery in Pacific Ocean.
Apollo 9 (Gumdrop and Spider)[c]	James A. McDivitt David R. Scott Russell L. Schweickart	3 Mar. 69	10	1	1	151 of earth	Tests of lunar module in earth orbit; docking with command and service modules. First all-up flight; launched with Saturn V. Recovery in Atlantic Ocean.
Apollo 10 (Charlie Brown and Snoopy)	Thomas P. Stafford John W. Young Eugene A. Cernan	18 May 69	8	0	3	31 of moon	Dress rehearsal for lunar landing; separation of lunar module and descent to a point about 9 miles above prospective landing site. Recovery in Pacific Ocean.
Apollo 11 (Columbia and Eagle)	Neil A. Armstrong Michael Collins Edwin E. Aldrin	16 July 69	8	3	19	30 of moon	First lunar landing; Sea of Tranquility. One EVA, 2 hr. 31 min. Recovery in Pacific Ocean.
Apollo 12 (Yankee Clipper and Intrepid)	Charles Conrad Richard F. Gordon Alan L. Bean	14 Nov. 69	10	4	36	45 of moon	Second lunar landing; Ocean of Storms. Two EVAs, total 7 hr. 39 min. Recovery in Pacific Ocean.

TABLE 4 (Continued)

Flight number and names of flight modules	Astronauts[b]	Date of launch	Length of flight			Number of revolutions	Description of flight
Apollo 13 (Odyssey and Aquarius)	James A. Lovell Fred W. Haise John L. Swigert	11 Apr. 70	5	22	55	--	No lunar landing. Rupture of oxygen tank and explosion in service module. Recovery in Pacific Ocean.
Apollo 14 (Kitty Hawk and Antares)	Alan B. Shepard Stuart A. Roosa Edgar D. Mitchell	31 Jan. 71	9	0	42	34 of moon	Third lunar landing; Fra Mauro highland area. Two EVAs, total 9 hr. 25 min. Recovery in Pacific Ocean.
Apollo 15 (Endeavor and Falcon)	David R. Scott Alfred M. Worden James B. Irwin	26 July 71	12	7	12	75 of moon	Fourth lunar landing; beside Hadley Rill and Apennine Mountains. Three EVAs on moon totaling more than 18 hours. First EVA in deep space, 16-min. space walk by Worden. Recovery in Pacific Ocean.
Apollo-16 (Casper and Orion)	John W. Young Thomas K. Mattingly Charles M. Duke	16 April 1972	11	1	51	64 of moon	Fifth lunar landing; Descartes highland area. First exploration of interior of highlands. Three EVAs on moon totaling 20 hr 14 min. Second EVA in deep space, about 1 hr., by Mattingly. Flight cut short 1 day because of difficulties with guidance system. Recovery in Pacific Ocean.

[a]The final flight, Apollo 17, is scheduled in December 1972.

[b]The first astronaut named is the commander of the flight, the second the commander of the command module, and the third the commander of the lunar module On the flights making a lunar landing, the first and third astronauts named were the moon-landers.

[c]The first name is that of the combined command-service modules, the second that of the lunar module.

Figure 87 CREW MAKING THE FIRST FLIGHT IN LUNAR ORBIT. From left to right are Apollo Astronauts Frank Borman, William Anders, and James Lovell. These astronauts made the first trip on the lunar trajectory during the Apollo-8 flight in December 1968

On the Apollo-9 flight, in March 1969, Astronauts James McDivitt, David R Scott, and Russell (Rusty) Schweickart made a thorough test of the lunar module in earth orbit They ran through the procedures for rendezvous and docking of the Gum Drop (command-service modules) with the Spider (lunar module). The tests of the Spider (Fig 88) were especially important, as the lunar module was a new piece of flight equipment. The Apollo 9 was the first all-up flight, or flight carrying all the equipment needed for a lunar landing

Because the performance of the lunar module would be the key to a successful landing, the module was further tested during the Apollo 10 flight, this time in lunar orbit. During Apollo 10 Astronauts Thomas Stafford and Gene Cernan took Snoopy, the lunar module, on a descent trajectory to a low orbit above the site where the landing would soon be made. Astronaut John Young stayed with Charlie Brown (the command-service modules) in lunar orbit (Fig. 89). After Snoopy made a rendezvous and Charlie Brown was docked with Snoopy, the simulated landing was complete. All was in readiness for the first actual landing.

FIRST MOON LANDING. —The Apollo 11, launched from Cape Kennedy in July 1969, was scheduled to make the first moon landing. The flight was commanded by Neil Armstrong, (Fig. 90), who had brought the Gemini 8 down safely for an emergency splashdown in the Pacific Ocean. The second moon-lander was to be Astronaut Edwin Aldrin, who had specialized in celestial mechanics and practiced underwater to simulate the space work planned for his Gemini-12 flight. The third astronaut, the pilot of the command module, was Michael Collins, who had performed EVA on the Gemini-10 flight.

All went well on the trip out to the moon. Excitement

Figure 88 ASTRONAUT DURING EVA TESTING LUNAR MODULE. Astronaut Russell Schweickart is taking a sample from the outside of the lunar module (the Spider) during the Apollo-9 flight. The Spider is docked with the command-service modules (the Gumdrop). Note Schweickart's Portable Life-Support System (PLSS) and heavy EVA space suit

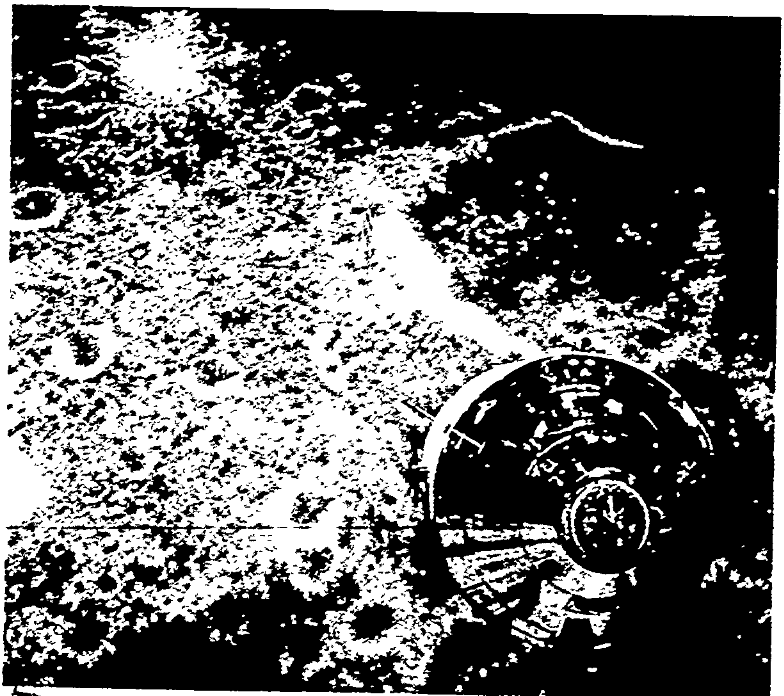


Figure 89 COMMAND SERVICE MODULES IN LUNAR ORBIT This photograph of the Apollo command service modules (Charlie Brown) was taken from the lunar module (Snoopy) during the Apollo-10 flight This flight was a dress rehearsal for the lunar landing

mounted as the spacecraft passed behind the moon, where the rocket was fired to brake the spacecraft The burn was successful and the Apollo went into orbit around the moon Armstrong and Aldrin made the final check on the lunar module, the Eagle, before it separated from the Columbia The Eagle made the descent to the moon almost exactly as had been done on the Apollo-10 flight When Armstrong and Aldrin were preparing to land the Eagle, they noticed large boulders covering the landing site Taking over partial control, Neil Armstrong fired the thrusters to take the Eagle to a smoother place at the edge of the landing site Just as the fuel was almost exhausted, Armstrong put the Eagle down with the words "Houston, Tranquility Base here The Eagle has landed" It was 4 17 pm EDT on 20 July 1969.

After venting the oxygen, from the lunar module and checking all equipment, the moon-landers prepared to climb down from the

Figure 90 CREW FOR FIRST MOON LANDING The crew of the Apollo 11 which made the first landing on the moon were left to right Astronauts Neil Armstrong Michael Collins and Edwin Aldrin Astronauts Armstrong and Aldrin made the moon landing Astronaut Collins piloted the Columbia in lunar orbit while the other two astronauts were on the moon

front porch of the Eagle and step onto the moon People all over the world shared the experience with the astronauts by means of television and radio In the eerie light Neil Armstrong made his way carefully down the steps As he put his first boot on the moon he said That's one small step for a man one giant leap for mankind For the first time in the history of the world man had put foot on another celestial body to begin firsthand exploration

To mark the historic occasion President Nixon telephoned the astronauts from the White House In his message he said For one priceless moment in the whole history of man all the people on this earth are truly one—one in their pride in what you have done and one in our prayers that you will return safely to earth." The plaque that the astronauts left on the moon stated. "We came in peace for all mankind," and they carried medals to honor Soviet Cosmonauts Gagarin and Komarov, who had died in accidents, as well as the three American astronauts who had lost their lives in the fire on the launch pad. After setting up an American flag, stiffened with wire so that it appeared to wave on the airless moon, the astronauts proceeded with the first experiments.

The EVA made the first real test of the new Apollo **moon suit** with its remarkable backpack, or **Portable Life Support System (PLSS)**. Dressed in the suit and carrying the backpack (Fig. 91), each moon-lander actually becomes an independent spacecraft, as he carries with him all the support that he needs during EVA. The system provides cooling, water, electric power, communications, and oxygen enough to last for hours outside the lunar module.

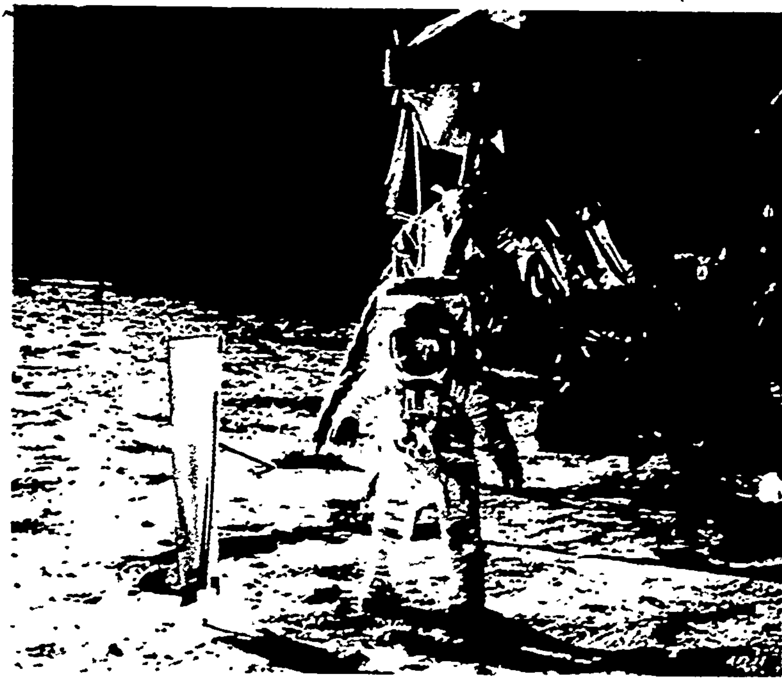


Figure 91 ASTRONAUT AT SITE OF FIRST LANDING. Astronaut Edwin Aldrin is shown standing in front of the lunar module (the Eagle) after the world's first landing on the moon on 20 July 1969 The picture was taken by Astronaut Neil Armstrong, the first man on the moon Note the moon suit and the Portable Life Support System (PLSS) that Astronaut Aldrin is carrying.

Built into the suit, which is constructed in layers somewhat like a thermos bottle, is protection against intense heat and cold, harmful radiation, and micrometeorites. The gold visor on the helmet protects the astronaut against the strong glare from the sun.

After an EVA lasting about 2½ hours, Armstrong and Aldrin returned to the Eagle, repressurized it, and powered up the systems once again. Then they settled down to eat and rest.

After remaining for 21 hours 36 minutes on the moon, the astronauts launched the Eagle into lunar orbit, leaving behind the descent stage The Eagle made a rendezvous with the Columbia, as it was being piloted by Collins on its 27th revolution of the moon. After the happy reunion in the Columbia, the astronauts stowed their rock and soil samples. Then they prepared for the trip back to the earth and a triumphant splashdown and recovery in the Pacific Ocean. President Nixon was on the recovery ship, the Hornet, to welcome the heroes. The President talked to the three astronauts as they peered from their quarantine facility. Celebrations had to wait until the quarantine period was over.

The successful flight of Apollo 11 marked the achievement of the principal goal set for Project Apollo. American astronauts had landed on the moon and returned safely to the earth. The way was now open for exploration of the moon.

LATER FLIGHTS.—On the Apollo-11 flight the astronauts had shown that they could master the difficult landing on the moon and the launch into lunar orbit. On the Apollo-12 flight, made in November of the same year, Charles Conrad and Alan Bean succeeded in bringing down the Intrepid to make a pinpoint landing in another lunar plain, the Ocean of Storms (Fig. 92).

The first two moon flights and landings were made with such success that the public was not aware of the precision required for an Apollo flight and of the many hazards that such a flight entails. Then, on the Apollo-13 flight, made in April 1970, an oxygen tank in the Apollo spacecraft exploded, and the public realized some of the dangers that astronauts face.

Astronauts James Lovell and John Swigert were preparing for the moon landing when the explosion occurred. It ripped a hole in one side of the service module, and oxygen began venting from the service module. Fortunately, the lunar module had not yet separated to make the descent to the moon, but the propulsion

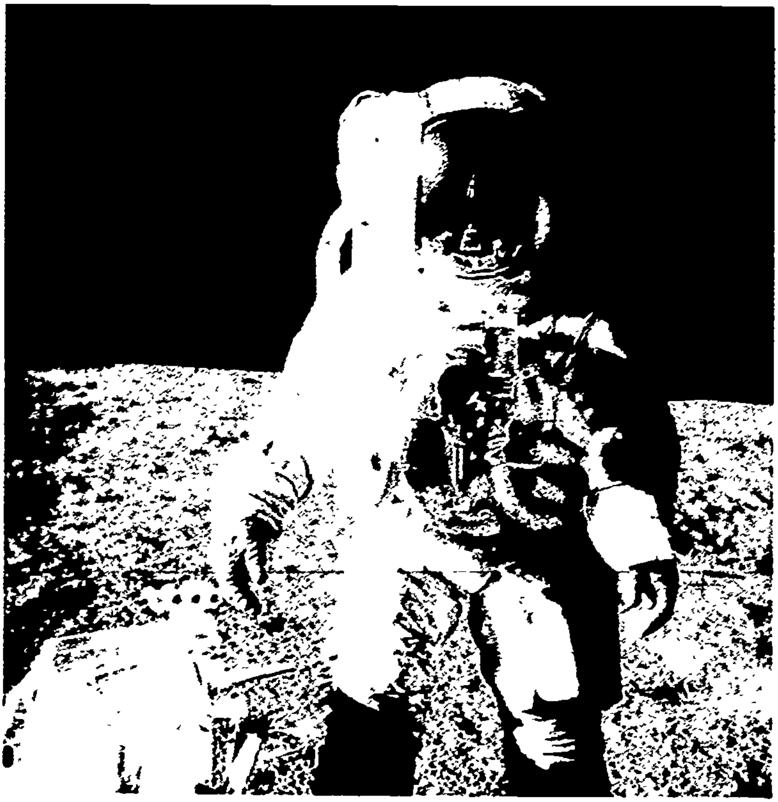


Figure 92. ASTRONAUT DURING EVA ON MOON ON APOLLO-12 FLIGHT Above is shown Astronaut Alan Bean performing scientific experiments on the moon. Note his Portable Life Support System (PLSS), helmet and moon suit, camera, and hand tools The picture was taken by his fellow moon lander, Astronaut Charles Conrad.

engine in the service module had already been fired to take the spacecraft out of the free-return trajectory.

After looping around the moon, the damaged spacecraft would go into lunar orbit unless a propulsion engine was fired to put it on a trajectory back to the earth. A serious decision had to be made What engine would be used? Since it was not safe to attempt to use the engine in the damaged service module, NASA officials decided to try using the propulsion engine in the lunar module. The astronauts fired the engine, and there was an agonizing period of waiting. All went well. The spacecraft was soon speeding back to the earth, but it was due to splash down in the

Indian Ocean, short of the recovery site. The engine would have to be fired once more to gain speed. Again there were anxious moments. The engine burn was successful, and the spacecraft headed toward its designated recovery site.

During the return flight the lunar module was used as a lifeboat. At first the astronauts used the command module for a bedroom, but the cold soon forced them to depend upon the lunar module for sleeping room also. Just before preparing for reentry, the astronauts crawled back through the connecting tunnel to the command module and powered up its systems once more. About an hour and a half before reentry, they jettisoned the lunar module (Fig. 93). Mission Control radioed, "Farewell Aquarius and we thank you." Lovell added, "She was a good ship."

Once clear of the lunar module, the Odyssey prepared for reentry and splashdown in the Pacific Ocean. The astronauts were safely recovered after one of the most accurate splashdowns ever made. The near tragedy caused modifications to be made in the

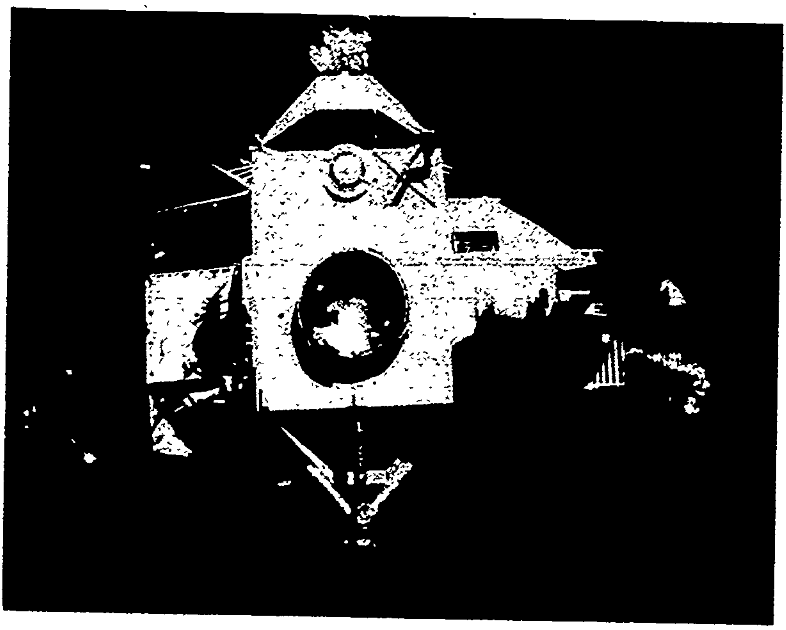


Figure 93. LUNAR MODULE LIFEBOAT. This view of the Aquarius was taken from the command module of the Apollo-13 spacecraft after the Aquarius was jettisoned. Note that the landing pads are still attached to the lunar module. The Apollo-13 astronauts were unable to make a moon landing because of an explosion in the service module.

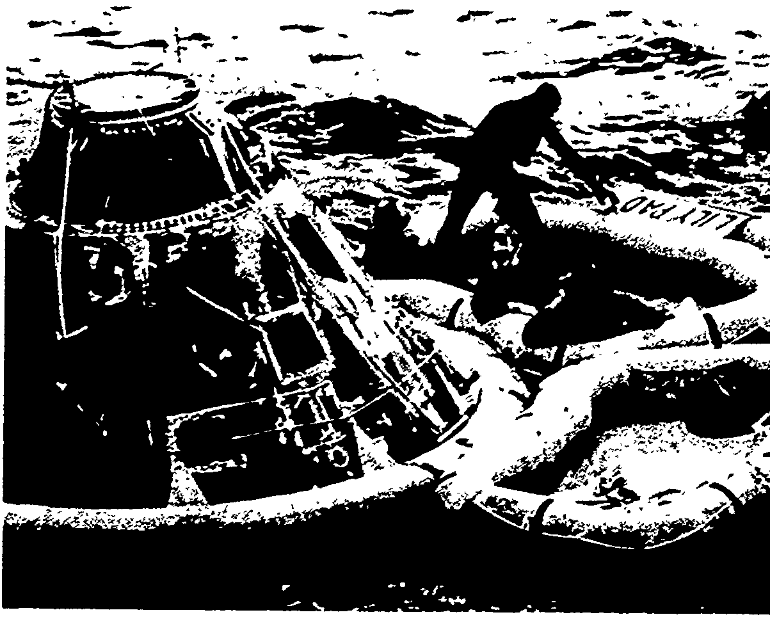


Figure 94. ASTRONAUTS RECOVERED AFTER FIRST EXPLORATION OF LUNAR HIGHLANDS. The Apollo-14 astronauts are (left to right) Edgar Mitchell, Stuart Roosa, and Alan Shepard. Shepard and Mitchell made the moon landing in the Fra Mauro highland area and explored the area around their landing site. The Apollo-14 astronauts are shown watching recovery operations in the Pacific Ocean.

service module, and another oxygen tank was added to the module.

On the Apollo-14 and the Apollo-15 flights the astronauts made pinpoint landings on the moon, as they had on the Apollo-12 flight, but the later landings were made in the more hazardous highland areas.

Apollo-14 was commanded by Alan Shepard (Fig. 94), who made the first Mercury suborbital flight. He brought the Antares lunar module down in the Fra Mauro highland area, which had originally been scheduled as the landing site for the Apollo 13. As he stepped onto the moon, Shepard said, "It's been a long time, but we are here." The words had a special personal meaning for Shepard. He had been taken off flight status after his Mercury flight because of problems with his inner ear, but he had undergone surgery which enabled him to return to flight status. Shepard was the only one of the original seven astronauts still on flight duty, and he did not mind it if well-wishers joked about his being an old man and presented him with a cane.

On the Apollo-15 flight, Astronauts David Scott and James Irwin put the Falcon down safely in an even more treacherous landing area at the edge of the Apennine Mountains and a gorge known as Hadley Rill. The Apollo 15 was the first Apollo spacecraft that carried the heavier load of scientific equipment and the jeeplike powered **lunar rover** (Fig. 95). With the added equipment and the experience gained on previous flights, Scott and Irwin were able to extend exploration. On their three EVAs on the moon they totaled more than 18 hours, or almost as much time as on the three previous landings combined.

On the Apollo-16 flight, made in April 1972, Astronauts John Young and Charles Duke put the lunar module down on a plain in the Descartes highland area. This was the first exploration made in the interior of the highlands. The lunar rover performed even better than on the previous landing, and time on the three EVAs was extended to 20 hours 14 minutes. An extra day to be spent in

Figure 95 POWERED LUNAR ROVER CARRIED ON APOLLO SPACECRAFT. To the right of the lunar module, the Falcon, is shown the lunar rover carried on the Apollo-15 flight Astronaut Irwin is saluting the flag. The Apennine Mountains of the moon are shown in the background

lunar orbit was cut because of trouble with the backup for the guidance system of the large propulsion engine in the service module.

One more Apollo flight is scheduled for December 1972. On this flight the landing is to be made in the Taurus-Littrow area, a highland area with gorges. This site, like that of all later flights, was selected for its scientific value. Scientists will continue to study the findings made on the Apollo flights long after they are completed.

While scientists are interpreting findings made during the Apollo flights, American astronauts will be working to achieve our next major goal for manned spaceflight: to put a space station into earth orbit. The Skylab will be the first experimental space station.

SKYLAB AND MODULES FOR VISITING IT

By making use of equipment developed for the Apollo flights, engineers have built the Skylab, the forerunner of our first space station. The Skylab has the Saturn Workshop, which includes a laboratory and living quarters for the astronauts, and a small observatory (Apollo Telescope Mount). The Saturn Workshop is built from the empty shell of the third stage of the Saturn V booster. The Skylab, to be launched into earth orbit in 1973, will give us a small temporary space station.

The combined Apollo command-service modules, modified for their new use, are to be launched from the earth on the smaller Saturn IB booster. The spacecraft will take three astronauts to rendezvous with the Skylab and dock with the Multiple Docking Adapter (Fig. 96). The modules will remain docked until the astronauts' tour of duty with the Skylab is over.

The first visit to the Skylab is planned to last 28 days, and the second and third visits are to be extended to 56 days. During their visits the astronauts will conduct experiments to investigate the way in which a space station would be useful to man and to tell us more about how well men can live and work in space. When their tour of duty in the Skylab is completed, the three astronauts will undock their spacecraft and return to the earth for recovery in the ocean, just as is done on the Apollo flights.

The Skylab does not look backward on the Apollo flights, however, but forward toward a new era in manned spaceflight. The expendable Apollo modules that are to be used for visits to the Skylab are forerunners of the space shuttle and the new re-

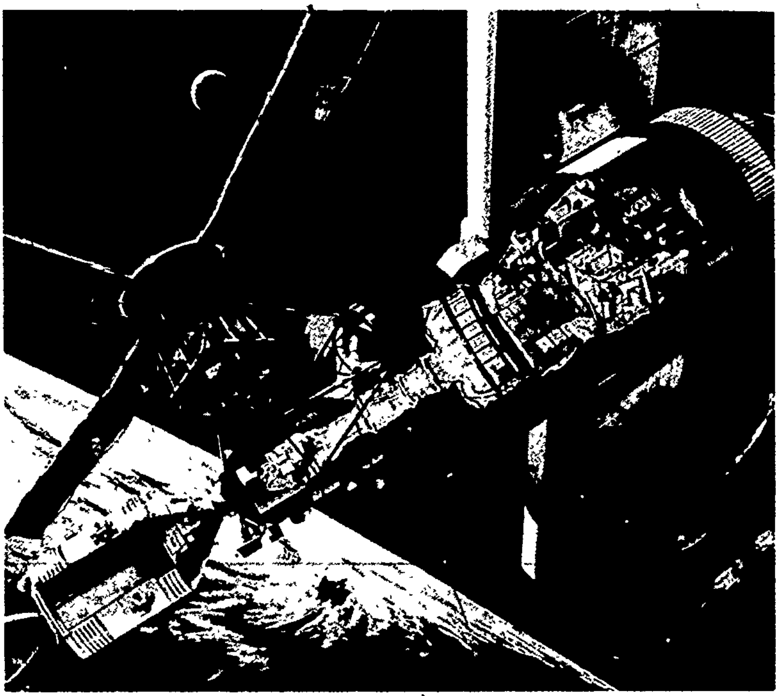


Figure 96. MODIFIED APOLLO MODULES DOCKED TO SKYLAB. The cutaway drawing shows these modules (lower left) after they have carried three astronauts to the Skylab The modules are to be launched by the Saturn IB booster. After the astronauts' tour of duty in the Skylab is over, the modules will take the astronauts back to earth. The service module will be jettisoned before reentry, and the command module will be recovered as on the Apollo flights.

usable space vehicles. We are now preparing to enter a new era of spaceflight that should bring with it many remarkable developments.

TERMS TO REMEMBER

module of a spacecraft
form-fitting couch
attitude of the spacecraft
redundant engineering
life-support system
heat shield
counterpressure
space suit
ablation
simulated spaceflights
G-forces
weightlessness
weightless trajectory
centrifuges
suborbital flight
large propulsion thrusters

rendezvous
docking
extravehicular activity (EVA)
lunar orbit rendezvous (LOR)
telemetered medical data
space coveralls
heavy space suit for EVA
maneuvering gun
depressurize the space cabin
reaction force
earth-moon trajectory
pure-oxygen atmosphere
landing site
moon suit
Portable Life Support System (PLSS)
lunar rover

NAMES OF SPACECRAFT

Mercury
Gemini (reentry module and adapter module)
Agena target vehicle
Apollo (command module, service module, and lunar module)
Skylab and command-service modules for visiting it

IDEAS TO REMEMBER

1. Man could not truly explore space until he could go into space himself to make firsthand observations.

2. The first American long-range goal for manned spaceflight was to land a man on the moon and return him safely to the earth. In reaching the first goal, the Mercury spacecraft was used for Step 1, the Gemini for Step 2, and the Apollo for Step 3, the final step.

3. During Step 1 the Mercury, a one-module spacecraft, carried a single astronaut in orbital flight. Six manned flights were made with the Mercury: two suborbital flights and four orbital flights. Astronaut Alan Shepard made the first suborbital flight, and Astronaut John Glenn made the first American orbital spaceflight. The goal of Project Mercury was to extend orbital flight to one day (24 hours). On the final Mercury flight Astronaut Gordon Cooper remained in orbit for about one day and a half, thereby exceeding the goal set. On the Mercury flights the astronauts became pilots rather than passengers in the spacecraft.

4. During Step 2 the Gemini, a spacecraft made up of two modules (reentry module and adapter module), carried two astronauts during flights in earth orbit intended to prepare for the Apollo moon flights. The principal goals of Project Gemini were (a) to extend time in orbital flight up to about two weeks, (b) to develop and practice rendezvous and docking, and (c) to develop and practice extravehicular activity (EVA): so-called space walks and space work. Ten manned flights were made in the Gemini in less than two years. All goals were met.

5. During Step 3, the Apollo, a spacecraft made up of three modules (command module, service module, and lunar module), landed American astronauts on the moon and returned them safely to the earth, thus reaching the first American long-range goal for manned spaceflight. The first landing, made by Astronauts Neil Armstrong and Edwin Aldrin on 20 July 1969, marked the first time in the history of the world that man had landed on a celestial body outside the earth. The first landing was preceded by four flights to test the Saturn boosters and the modules of the spacecraft (Apollo flights 7, 8, 9, and 10). Four more successful landings were made (Apollo flights 12, 14, 15, and 16) to continue exploration of the moon. Apollo 13 was unable to land because of an explosion in the service module. One more exploratory flight still remains to be made.

6. With equipment developed for the Apollo flights, the United States is preparing to take the first step toward reaching its second long-range goal for manned spaceflight: to put a space station into earth orbit. The Skylab, to be launched during 1973, is an experimental space station. Modified Apollo command-service modules will be used for visiting the Skylab. The first visit is to last up to 28. days, the second and third visits up to 56 days.

QUESTIONS

1. What was the first US long-range goal for manned spaceflight? What is the second such goal?
2. When was Project Apollo proposed? Why were the Gemini flights scheduled? What were the three steps that the United States took in advancing toward the moon?
3. What new flight stresses did the astronauts experience on the Mercury flights?
4. Why was the cone shape chosen for the design of the Mercury spacecraft? How did the Mercury capsule operate at reentry? What kept it from being burned up in the atmosphere?
5. What kind of life-support system was used in the Mercury spacecraft? How did the space suit tie in with the system? What changes were made in the space suit for use on the Gemini and Apollo spacecraft?
6. What special kind of training do astronauts receive?
7. What was the result of the Mercury flights? Describe the two most important Mercury flights.
8. In what ways was the Gemini an advanced spacecraft?
9. What did the Gemini astronauts use as targets for rendezvous and docking? Why was practice in rendezvous and docking needed? How would these maneuvers be used on the Apollo flights?
10. What was the longest flight made by US astronauts? Does this still hold the world record?
11. Describe the world's first rendezvous? When was docking first done? Describe the first US space walk.

12. What are the three modules of the Apollo spacecraft, and how is each used in the flight to the moon and the landing?

13. What was the purpose of the early Apollo flights? How many flights were made before the first moon landing?

14. Describe the first moon landing. When was it made and by whom? What was accomplished by the landing?

15. What was the purpose of the later Apollo flights? Were they successful?

16. What unusual use was made of the lunar module on the Apollo-13 flight?

17. Have the Apollo flights been completed? If so, what would you consider to be the most important result(s) of the flights? If the flights have not been completed, what would you consider to be the important result(s) to date?

18. How will the modified Apollo command-service modules be used for visits to the Skylab? Where will the modules be kept while the astronauts are at work in the Skylab? How will the modules be brought back to the earth?

THINGS TO DO

1 Compare the three US manned spacecraft developed for the moon journey (Mercury, Gemini, and Apollo). Consider the number of astronauts that each spacecraft carried, the number of modules, the relative size of the spacecraft, and the kinds of flights to be made. Compare also the size of the three boosters used for launching and the amount of thrust each booster produced. What would you consider to be the three most important developments made in manned spacecraft as these three series of spacecraft were flown?

2 Make a special study of the Apollo lunar module. This was the one piece of flight equipment new on the Apollo flights. The lunar module operates only in space and does not return to the earth. Secure a model of the lunar module or a good drawing of it. Describe how the module operates during lunar orbit, the descent to the moon, the landing, and the ascent and docking with the command-service modules. What special use was made of the Aquarius lunar module on the Apollo-13 flight? Can you foresee a use for a module like the lunar module when the space shuttle and the new reusable space vehicles are operating?

3. Do some research and then write a description of either the first US suborbital flight, the first US orbital flight, or the first moon landing. Tell the principal happenings during the flight. Point out the historical significance of the flight. Perhaps you can arrange with your history or English teacher to allow you to submit this essay in fulfilment of an assignment in his class.

4 Describe the main operations that take place at reentry and recovery at the end of an Apollo flight. How does the position of the command module at reentry help in braking it? What prevents the module from being burned up in the atmosphere? How are the parachutes used? Are the astronauts in danger after they splash down? Why are the Apollo astronauts no longer quarantined? How has dropping the quarantine made recovery simpler?

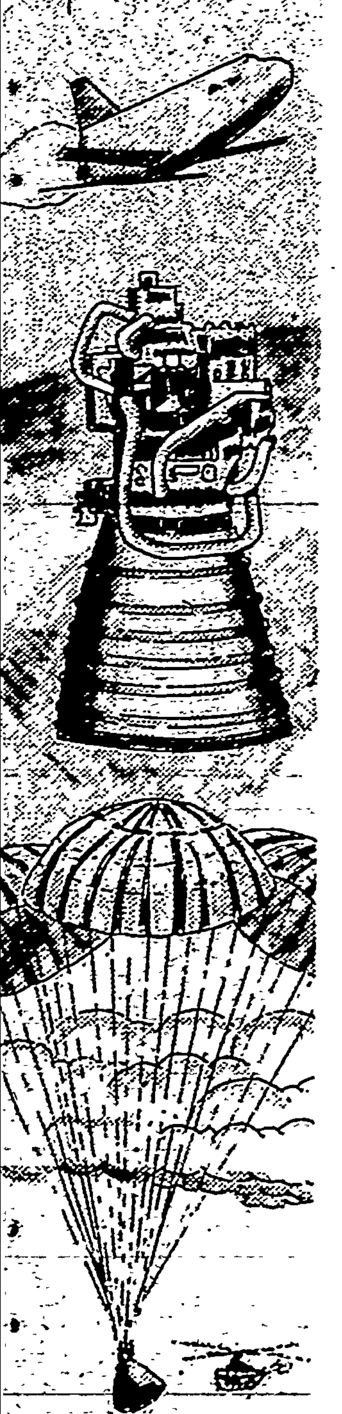
5 Select one of the Apollo astronauts who has a special interest for you. Make a study of his Apollo flight (flights) and of any earlier flights he may have made on the Mercury and Gemini spacecraft. Find out something about his qualifications for being an astronaut and about the special training he has had Perhaps your English teacher will accept your essay in fulfilment of an assignment in his class

6 Make a study of one of the Apollo flights that has special interest for you. Describe the principal events of the flight Concentrate on the operations of the spacecraft rather than on the exploration done on the moon. Explain the significance of the flight

7 If there is an Apollo flight yet to be made, make a special study of this flight. Follow closely the news releases and television broadcasts of the flight. Pick out the most important happenings on the flight and describe these. Explain the importance of the flight. Later, compare your appraisal of the flight with reports appearing in aerospace magazines

8 Prepare a report on the command-service modules to be used for visits to the Skylab See what you can find out about the modules that will be reserved for rescue operations should these become necessary. How will the reserve modules be modified? Be alert for new developments as the time approaches for the launch of the Skylab and the first visit to be made to it (1973). What spacecraft will be used in place of the command-service modules when the first permanent space station is in orbit?

Chapter 6



Spacecraft of the Future

THIS CHAPTER takes a glimpse into the future to make predictions about spacecraft of tomorrow based upon plans being drawn up by NASA. The chapter begins by describing plans for the first permanent space station and the new reusable space vehicles that will service it. It tells how these reusable vehicles, which are to be part of a new space transportation system, should cut down the cost of space launches. Emphasis is placed on the space shuttle, which has first priority. Plans for future planetary probes are then described, together with the spacecraft that are to be used for the probes. Some speculation is then presented about manned flights to the planets and the kind of spacecraft that might make such flights. When you have studied this chapter, you should be able to do the following: (1) explain how the presence of a space station in earth orbit will affect the launch and operation of future spacecraft, (2) tell about US plans for developing a space shuttle and other reusable space vehicles, (3) describe a spacecraft that might take astronauts to Mars (if you believe such a vehicle is not possible, give reasons).

AS THE APOLLO flights are being completed, the United States is planning to make a new beginning with spaceflight. Instead of making larger and more powerful boosters than the Saturn V and spacecraft that are more complex than the Apollo, engineers are now designing new kinds of reusable spacecraft. These spacecraft are to be launched into orbit much as present spacecraft are. The booster and the orbiter portions will separate after launch. At first probably the orbiter only, but ultimately both booster and orbiter, will fly back to the earth at the end of the mission and land much as aircraft do. After being refueled, checked, and given maintenance, the reusable space vehicle will be ready for another flight. With the reusuable space vehicle, engineers will be bridging the gap between aircraft and spacecraft.

During the first decade and a half of space travel the United States and the Soviet Union took a shortcut into space by using rocket boosters developed from missiles instead of waiting until experimental rocket aircraft could be orbited and advance into space. Because missiles by their very nature are expendable, our first rocket boosters were expendable also. Now we are using the experience gained with both expendable rocket boosters and with aircraft to develop **reusable space vehicles.**

When the first reusable space vehicles are ready for use, the astronauts will probably be making visits to a permanent space station (Fig. 97), which is to follow the Skylab. After the Apollo flights are completed, the astronauts will again be concentrating on

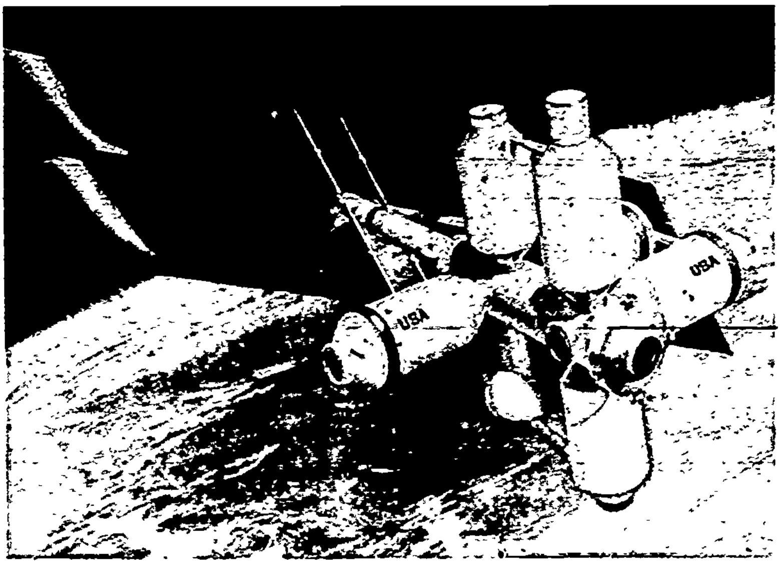


Figure 97. A DESIGN FOR A SMALL SPACE STATION. This drawing shows a proposal for using small modules to make up a six-man space station Each module would be outfitted for a particular purpose, such as for crew quarters, a control center, or a galley (dining room). Modules could be added as needed until a large space station was established in orbit.

flights in a near-earth orbit. This does not mean that the United States has lost interest in further exploration of the moon and the planets. On the contrary, by establishing a space station near the earth, this country will have a way station for later flights to the moon and the planets, as well as a means for developing the practical uses of space for earth dwellers. Our plans for a space station and for reusable space vehicles for visiting it are part of our long-range plans for the space program. They will help in developing more advanced applications satellites and in designing and developing space vehicles that will ultimately carry men to the planets.

SPACE STATION AND REUSABLE SPACE VEHICLES

When the United States has a permanent space station in earth orbit, scientists and astronauts will be able to conduct experiments in space that will advance all practical uses of spacecraft for communications, for weather observations, for navigation, and for surveying earth resources. Findings made as a result of experiments in the space station will help us improve construction of unmanned applications satellites, or will assist us in replacing these with modules in the space station or with satellites that are manned for at least part of the time. **Experiments in the life sciences** carried out in the space station, which should tell us more about man's ability to live and work in space, should give us the kind of information we need for building more advanced manned spacecraft. As Dr. Charles Berry, NASA's Director of Life Sciences, has said, manned spacecraft must now be constructed that are more like houses in which man can live rather than like the cockpits of aircraft. Constructing advanced manned spacecraft will call forth the ingenuity of both the engineer and the life scientist. The findings that life scientists make in the space station should help the engineer.

Of even more direct concern for the construction of future spacecraft are the designs that are now being drawn up for the reusable space vehicles for servicing the space station. When President Nixon asked his special Space Task Group to make plans for the space program following the Apollo flights, the Group recommended that the United States develop a series of reusable space vehicles as part of a new **space transportation system**. The first vehicle in the new system is to be the **space shuttle**, which is to be used for trips back and forth between the earth and the space station. Since the shuttle must be ready for use when the first permanent space station is orbited, the shuttle is being given first priority.

One of the main reasons for developing the space shuttle and other reusable space vehicles is to cut down the cost of orbiting payloads in space. Today the parts of the space booster that launch a spacecraft are allowed to fall into the ocean or are jettisoned in space Of all the spacecraft modules orbited, only the reentry modules of manned spacecraft are returned to the earth, and these are not refitted for another use. If space vehicles could be brought back after a spaceflight and used repeatedly, costs could be greatly reduced. It is easy to see how the costs of sea and air transportation would soar if large oceangoing vessels and jet transports were discarded after one use. Spacecraft cost far more than present-day sea and air transports and therefore represent a far greater loss when they are discarded.

Just as we have learned how to make large cost reductions for aircraft payloads, we can make even greater reductions in the cost of orbiting payloads in space. The Jupiter-C booster that orbited Explorer 1, the first American satellite weighing about 31 pounds, put a pound of payload into orbit at a cost of about $100,000. The Saturn V, which can put 280,000 pounds into a near-earth orbit, reduced costs for orbiting a pound of payload to about $500 The goal for the new reusable space vehicles is to reduce the cost even more. to about $100 per pound of payload. Some experts believe that costs can be reduced even more than this. What is important is that we develop reusable space vehicles that can bring about substantial economy in our space program.

Engineers are now at work making plans for the space shuttle. NASA obtained ideas from many sources, and President Nixon has given approval for proceeding with the development of a two-stage partially reusable space shuttle with delta wings. This vehicle, after taking off like a rocket booster, would dump its booster pods into the ocean. It would then go into orbit like a spacecraft. After discarding its major fuel tank in space, it would land as an aircraft does. The space shuttle will be able to stay in orbit up to 30 days. and it is expected to carry a crew of two plus two passengers. Anyone who can travel in a modern jet transport should be able to fly in the shuttle, as it is not expected to generate G-forces higher than 3-G The orbiter stage of the shuttle will make use of highly efficient rocket engines burning hydrogen and oxygen much like those used in the second and third stages of the Saturn V booster. One design for the space shuttle is shown in Figure 98.

With the space shuttle and the space station in operation, there will no longer be a marked difference between manned and unmanned spaceflight. Man's control over unmanned spacecraft will move from earth to a space station in earth orbit. Unmanned satellites can then be launched from the space station instead of from the earth. Satellites launched from the space station can be powered to enable them to change orbit or the plane of orbit. With a space station in orbit, this country will in effect have a large spacecraft in a permanent parking orbit around the earth, permitting scientists and astronauts to send spacecraft out in any direction from the earth.

The shuttle and other reusable vehicles in the new space transportation system are likely to be developed in steps, much as the Apollo spacecraft was. Until the development of the space shuttle is further along, it will not be possible to make accurate predictions about the other reusable vehicles that are to follow it, but it can be expected that later vehicles in the new space transportation system will be more completely reusable.

While first priority is being given to the space shuttle, some studies have also been made of a **space tug,** or what is sometimes called the orbit-to-orbit shuttle. One design for the space tug is shown in Figure 99. The space tug could be launched with a Saturn booster. Once in orbit, the space tug is not likely to return to the earth, but it would return to the space station after use. It would transport freight to satellites in other orbits rather than passengers. The only persons it would carry would be the pilot and work crew. The tug could be used for resupplying the satellites and for performing maintenance.

Other shuttles with more powerful propulsion systems will follow the first ones. The whole trend in the development of shuttles. is likely to be affected by the way the United States and other nations distribute their space stations. At the present time US plans call for developing only one space station. The size of the first space station is to be gradually increased, by the addition of more modules, until it could accommodate as many as 100 persons at one time. Indications now are that we shall first establish a

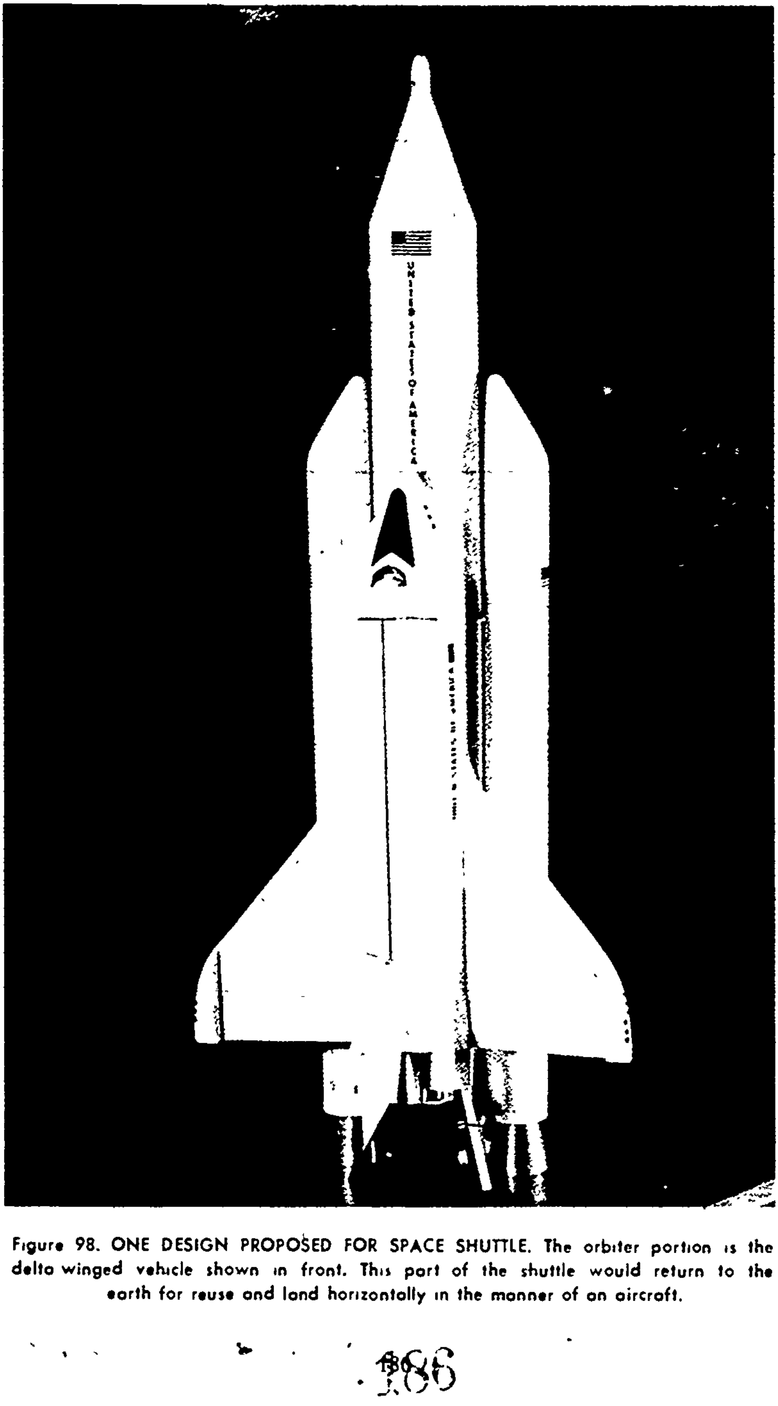


Figure 98. ONE DESIGN PROPOSED FOR SPACE SHUTTLE. The orbiter portion is the delta winged vehicle shown in front. This part of the shuttle would return to the earth for reuse and land horizontally in the manner of an aircraft.

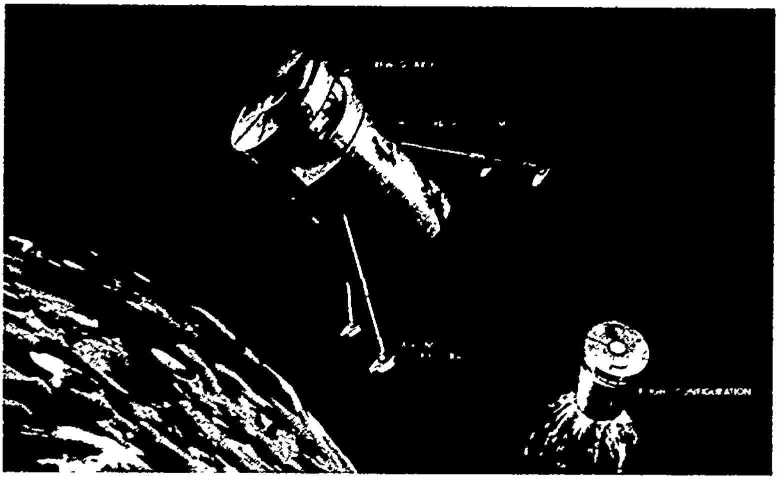


Figure 99 DESIGN PROPOSED FOR A SPACE TUG The modules shown in the drawing could be used separately or in different combinations. The space tug would be used for carrying supplies and work crews.

single large base in space in a near-earth orbit rather than several small space stations in different orbits.

Some space experts predict that there will some day be space stations in many different orbits. The next choice might be to have a space station in synchronous earth orbit. A space station placed in such an orbit would remain constantly over one area of the earth. By making use of highly acute remote sensors, scientists stationed at this position could make constant surveys of earth resources on the portion of the earth within their view. Another choice of orbit would be a polar orbit of the moon close to its surface. Scientist-astronauts stationed in such an orbit could make continuous observations of the moon. When necessary, they could use spacecraft similar to the Apollo lunar module for making a descent to the moon and an ascent to the lunar station once again Later we are likely to establish a permanent scientific station on the moon, which would be somewhat like a scientific station in Antarctica. We would need a spacecraft to service the lunar station.

Designs for reusable space vehicles are naturally being drawn to make use of present technology. While the first space shuttle and space tug are being designed and built, **breakthroughs**, or highly important new developments, are likely to be made that will change the trend of development of other vehicles in the space transportation system. Areas in which breakthroughs are most likely to occur are in (1) materials, (2) the use of oxygen from the atmosphere, and (3) **nuclear propulsion.** New materials, such as carbon and boron composites, are likely to be developed that will be stronger than steel but lighter than aluminum. If oxygen from the atmosphere could be used instead of part of the stores of liquid oxygen for an oxidizer during the early stages of flight, then the weight of propellant that a space vehicle must carry might be substantially lessened. Most important of all, nuclear engines should soon be available for use on one stage of the space shuttle. Although the large NERVA nuclear rocket has been cancelled, the technology already developed for this engine will be useful in developing smaller nuclear rocket engines. Later, the exotic forms of propulsion, which eject forms of matter other than hot gases, such as ions and photons (light rays), are apt to be used in space vehicles. Breakthroughs in propulsion will make it possible for larger space vehicles to travel to the planets.

SPACECRAFT FOR PLANETARY EXPLORATION

At the same time that the United States is working to develop a base in space near the earth, our scientists and engineers are also reaching out to explore the planets. Plans are being projected to gradually extend our probes beyond the two neighboring planets, as well as to make more thorough probes of these two planets. Spacecraft being developed for the planetary probes to be made during the 1970s will use present rocket boosters plus additional stages or solid-fueled strap-on motors now in use. The spacecraft will be developed from technology resulting from the earlier **Mariner spacecraft** that made planetary probes and from spacecraft that were designed and built for making the probes of the moon that preceded the Apollo flights. With the new 210-foot antennas being built for the **NASA Deep Space Network,** the United States should be able to receive radio signals sent from spacecraft traveling throughout the entire reaches of the solar system.

Even with the basic technology laid out for them, engineers will still face many kinds of challenges in developing and constructing spacecraft for the planetary probes scheduled during the 1970s. In March 1972 the first of two **Pioneer spacecraft** was sent to the vicinity of the giant planet Jupiter. This spacecraft is expected to begin its flyby of Jupiter in December 1973. A second Pioneer spacecraft is to be launched to Jupiter in 1973. These spacecraft must be sturdy enough to survive passage through the hazardous asteroid belt, which lies between the orbits of Mars and Jupiter, and they must be equipped to continue sending signals back to the earth for about two years. It will take this long for the spacecraft to make the journey of more than a half billion miles to Jupiter and then swing around the planet to send information about the planet back to the earth. In 1973 a Mariner spacecraft will be equipped to swing around Venus and go inward to fly by Mercury, the planet closest to the sun. This spacecraft will carry a television camera with a special lens to enable it to take pictures of the surface of Venus through the thick cloud cover that hides the planet from view. If the pictures are successful. they will give man his first views of Venus.

A combined orbiter and soft-lander, the **Viking spacecraft** (Fig. 100), is being developed for a journey to Mars in 1976. This spacecraft is to be instrumented to give us more definite answers to our questions about the existence of life on Mars.

Perhaps engineers will learn something about using a gravity assist from the Venus-Mercury probe. Such information should help in planning probes beyond Jupiter to the outer planets.

As you project your thinking into the future, you might ask: Will American astronauts visit Mars or make flybys of Mars and the outer planets? Thomas O. Paine, who was NASA Administrator at the time of the first moon landing, in July 1969, said that the Apollo moon flights were but a prelude to interplanetary flight. Present goals for the US space program are based upon an implied goal of making a manned landing on Mars at some time in the future. After accepting the recommendations of his special Space Task Group in regard to present goals, President Nixon said that the United States "will eventually send men to explore the planet Mars." But before we make preparations for interplanetary flight. we need to have a solid base of information about Mars and the other planets in the solar system and a better

Figure 100 VIKING SPACECRAFT The drawing shows how the combined orbiter lander is to operate The lander portion will be parachuted through the atmosphere of Mars The lander is expected to obtain data about possible living matter on Mars

understanding of man's ability to endure continued exposure to space.

The dreams of the first space scientists still persist, however. They are recorded in the words of Konstantin Tsiolkovsky, on a monument over his grave in the village of Kaluga:

> Man will not stay on the earth forever, but, in the pursuit of light and space, will first emerge timidly from the bounds of the atmosphere and then conquer all of the space about the sun.

Almost half a century elapsed between the time that Tsiolkovsky wrote these words and the time that the first artificial satellites were orbited. You might decide for yourself whether or not you think it is reasonable to expect that at least another half century will elapse before men land on Mars.

No plans have as yet been projected for space vehicles that will take American astronauts to Mars. Space planners predict that these vehicles will be developed by powering modules much like those now being designed for the space station. Modules for interplanetary flight are likely to look more like a house for living in space than like an aircraft cockpit or a space capsule. Any module being developed for making the journey to Mars will first be tested thoroughly in earth orbit.

How soon the vehicles for interplanetary flight will be ready depends in part upon the way in which the youth of today are inspired by the vision of the early space scientists and by the work of the practical engineers who followed them. More than three and a half centuries ago Johannes Kepler wrote to Galileo, urging him to help in preparing maps for future space travelers. He explained his request by saying:

> There will certainly be no lack of human pioneers when we have mastered the art of soaring Let us create vessels and sails adjusted to the heavenly ether, and men will present themselves who are unafraid of the boundless voids In the meantime we shall prepare, for the brave sky-travellers, maps of the celestial bodies. . . .

We have developed spacecraft that can reach the moon, and we have courageous astronauts who are eager to venture farther into space. We have prepared detailed maps of the moon, and the task of mapping Mars is progressing. We are already well on our way toward interplanetary travel.

TERMS TO REMEMBER

reusable space vehicles
experiments in life sciences
space transportation system
space shuttle
space tug (orbit-to-orbit shuttle)
breakthroughs
nuclear propulsion
NASA Deep Space Network
Mariner spacecraft
Pioneer spacecraft
Viking spacecraft

IDEAS TO REMEMBER

1. The United States is developing reusable space vehicles as part of a new space transportation system. One of the main reasons for developing the new reusable space vehicles is to reduce the cost of space operations.
2. The space shuttle is to be the first vehicle in the new space transportation system. It is being given first priority so that it will be ready for servicing the first space station.
3. Some design studies have been made of a space tug. Other space vehicles will be developed later.
4. During the 1970s the US spacecraft sent to the planets will be the expendable kind orbited by rocket boosters. Developing such spacecraft will still present great challenges to engineers because of the difficult tasks they must perform.
5. The United States will eventually send men to explore the planet Mars. Vehicles for interplanetary flights are likely to be developed from modules of a space station.

QUESTIONS

1. **How is the presence of a space station in earth orbit likely to affect the development of future applications satellites?**
2. **Why is a new space transportation system being developed? What is meant by reusable space vehicles?**
3. **What is the space shuttle? How far have plans advanced for the shuttle? How is the shuttle expected to operate?**
4. **What is the space tug?**
5. **What probes to Jupiter have been started? What spacecraft is being used?**
6. **Which planet is to be probed next? What spacecraft will be used?**
7. **What new spacecraft will be used for the next probe of Mars? How will it operate? What kind of findings is it designed to make?**
8. **Do you think astronauts will land on Mars within the present century? If you think such a landing is possible, describe the kind of spacecraft the astronauts might use. If you think such a landing is not possible, give reasons for your answer.**

THINGS TO DO

1. Make a special report on the space shuttle If a design has been approved for development. secure a drawing of the design or prepare a model Explain how the shuttle will operate What kind of propulsion engines will be used? Will the shuttle have wings? When are the flight tests scheduled to begin? When will the shuttle be ready for use? For what kind of missions will the shuttle be used?

2. Making use of the latest designs proposed. prepare a report on the first permanent space station. Emphasize the way in which it will affect the operation of spacecraft How will spacecraft dock and depart from the station? Relate what you have learned about the first US experimental space station (the Skylab) to what you know about the first permanent space station

3. Do some research and prepare a report on the spacecraft to be used for one of the future planetary probes Describe how the spacecraft will operate and the kind of measurements it will make What kind of questions is the spacecraft designed to answer?

4. Use your imagination and prepare a design for a more advanced spacecraft Apply what you have learned in this course Concentrate on one design. and prepare a model or drawing of it You might try to picture one of the following an advanced lunar module. an earth-to-moon shuttle. a large nuclear shuttle. an advanced manned applications satellite. or a Mars lander for carrying six astronauts

REFERENCES FOR FURTHER READING

ARMSTRONG. NEIL. and OTHERS *The First Lunar Landing as Told by the Astronauts* Washington. D.C. Government Printing Office. 1970

——— *First on the Moon.* Boston. Little. Brown. and Co. 1970

BEITLER. STANLEY *Rockets and Your Future* New York Harper & Bros. 1961

BERNARDO. JAMES V *Aviation and Space in the Modern World* New York E. P Dutton & Co.. 1968

BRAUN. WERNHER VON *Space Frontier* New York Holt. Rinehart. and Winston. 1967

——— and Ordway. Frederick I. III *History of Rocketry and Space Travel* New York Crowell. 1969

CAIDIN. MARTIN *Why Space? and How It Serves You in Your Daily Life* New York. Julian Messner. 1965

CLARKE. ARTHUR C *The Exploration of Space* New York Harper & Row. 1959

——— *Man and Space* Life Science Library New York Time Inc. 1964

DILLE. JOHN *Americans in Space* New York American Heritage Publishing Co 1965

EMME. EUGENE M *A History of Space Flight* Holt Library of Science Series. Vol I New York Holt. Rinehart. and Winston 1965

GRISSOM. VIRGIL *Gemini. A Personal Account of Man's Venture Into Space* New York Macmillan Co.. 1968

HAGGERTY, JAMES J *Man's Conquest of Space* New York. Scholastic Book Services. 1966

HENDRICKSON, WALTER B., JR *Satellites and What They Do* New York Bobbs-Merrill Co. 1963.

LEY, WILLY *Events in Space* New York David McKay Co. 1969.

MACMILLAN, NORMAN *Great Flights and Air Adventures From Balloons to Spacecraft* London G Bell & Sons. 1964

MISENHIMER, TED G. *Aeroscience* Culver City. Calif.. Aero Products Research. Inc.. 1970

MOORE, PATRICK *Space The Story of Man's Greatest Feat of Exploration* New York: Natural History Press. 1969

National Aerospace Education Council *Project Apollo*. Washington. D.C 1967.

NEWLON, CLARKE *Famous Pioneers in Space* New York Dodd. Mead & Co. 1963.

OBERTH, HERMANN *Man Into Space* New York. Harper and Bros.. 1967

SHELTON, WILLIAM R. *American Space Exploration, The First Decade* Boston. Little. Brown and Co. 1967

________ *Man's Conquest of Space* Washington. D C. National Geographic Society. 1968

SILCOCK, BRYAN *Pathways in Space*. Progress of Science Series New York Roy Publishers. 1964

THOMAS, SHIRLEY *Men in Space* Vols. 1. 3. and 5 New York Chilton Co. 1960. 1961. and 1962

U S News & World Report Book *U S on the Moon What It Means to Us* New York. Macmillan Co. 1969

VAETH, J. GORDON, *Weather Eyes in the Sky* New York Ronald Press Co.. 1965

WILFORD, JOHN NOBLE *We Reach the Moon* New York Times Book New York W W Norton. 1969

INDEX

A

B

C

U

V

W

X

Y

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