DOCUMENT RESUME

ED 068 294 SE 014 558

AUTHOR Coard, E. A.
TITLE Space Exploration: Manned and Unmanned Flight. Aerospace Education III.
INSTITUTION Air Univ., Maxwell AFB, Ala. Junior Reserve Office Training Corps.
SPONS AGENCY Department of Defense, Washington, D.C.
PUB DATE 71
NOTE 196p.

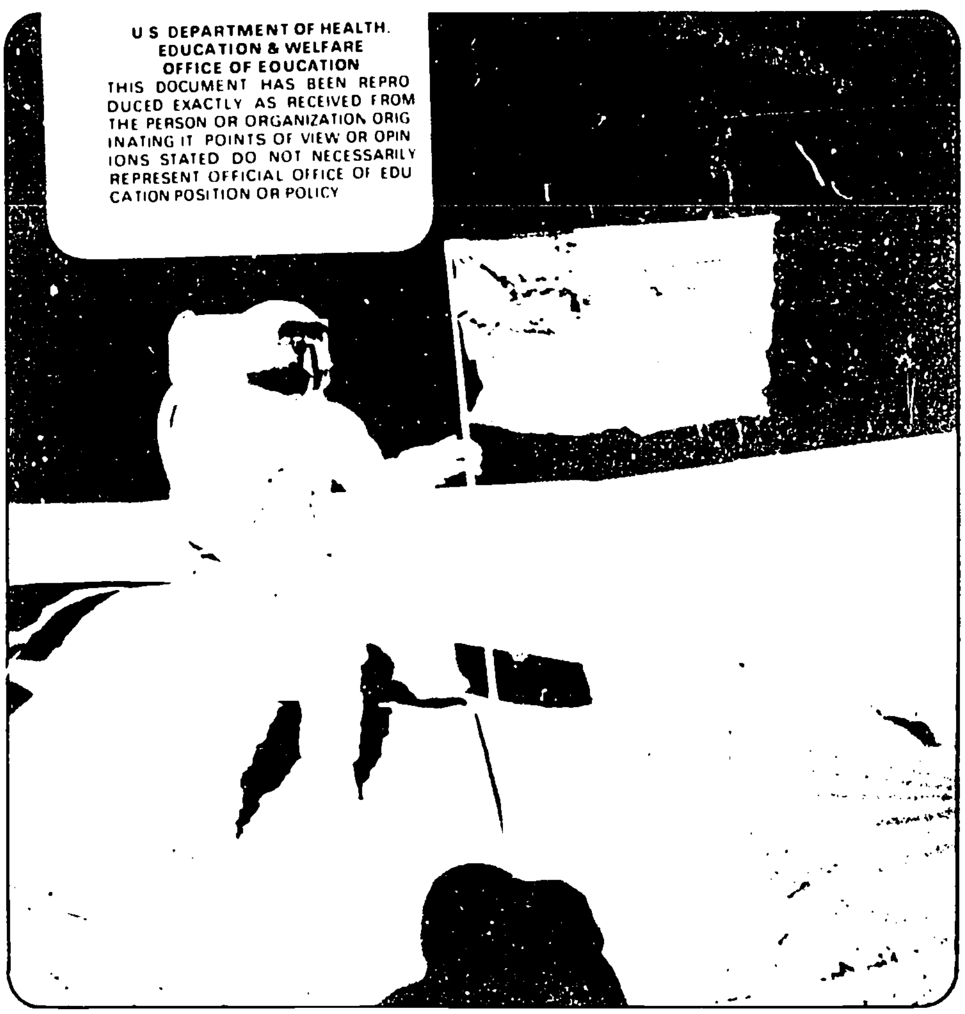
EDRS PRICE MF-$0.65 HC-$6.58
DESCRIPTORS *Aerospace Education; *Aerospace Technology; Lunar Research; National Organizations; *Programs; *Resource Materials; *Space Sciences; Supplementary Textbooks; Textbooks

ABSTRACT

This book, for use only in the Air Force ROTC training program, deals with the idea of space exploration. The possibility of going into space and subsequent moon landings have encouraged the government and scientists to formulate future plans in this field. Brief descriptions (mostly informative in nature) of these plans provide an account of future challenges and impact on life situations. The Apollo program will culminate in a Skylab meant to gather information about space and the planets. The Skylab should lead to setting up a permanent space station. Later probes of planets, especially Venus, will provide information that might prove very useful in the study of the universe. (PS)

SPACE EXPLORATION

Manned and Unmanned Flight



Aerospace Education III

Space Exploration

Manned and Unmanned Flight

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Academic Publications Division
3825th Support Group (Academic)

AIR FORCE JUNIOR ROTC
AIR UNIVERSITY
MAXWELL AIR FORCE BASE, ALABAMA

1971

This publication has been reviewed and approved by responsible personnel of the Air University in accordance with current directives on doctrine, policy, essentiality, propriety, and quality.

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

Preface

WHEN AMERICAN astronauts first landed on the moon, in July 1969, the United States had reached its first-priority goal in space exploration, and President Nixon set new goals for the program. In making a decision about what these goals should be, the President followed the recommendations of his special Space Task Group, which had drawn up a broad program for the future. This book takes a look at that program now and as projected into the remainder of the 1970s.

Until the end of 1972 our efforts will continue to center on the Apollo flights, but we shall no longer be learning how to operate the Apollo spacecraft and the Saturn boosters. Instead, our main interest will be focused on the exploration of the moon. The last Apollo flights are spaced at six-month or longer intervals to allow scientists to gain as much information as possible from the results of one landing before we make another.

In 1973, after the Apollo flights have been completed, the Skylab will be placed in earth orbit, and astronauts will make three visits to the laboratory to conduct experiments. The Skylab flights will make use of the knowledge obtained in our probes of space and will give us valuable information about constructing a permanent space station.

During the entire decade of the 1970s we shall continue with our program for exploring the planets, and we are likely to make exciting new discoveries. In

1973 a Mariner spacecraft will be modified to take pictures of the surface of the cloud-shrouded planet Venus, which astronomers have never seen. Later the Viking, a combination orbiter and soft-lander, will make a landing on Mars to obtain firsthand evidence about life on that planet. The program for exploring the planets will climax with the Grand Tours of the outer planets near the end of the decade. A like opportunity for making such Grand Tours will not present itself for another 180 years.

Taken as a whole, our program for exploring space during the 1970s promises to be even more exciting than our program for reaching the moon. Our present program, although undertaken with a reduced budget, can promise us more because we have the knowledge of the first decade of space exploration upon which to build.

In making a survey of our national space program, this volume places emphasis upon exploration and the search for scientific knowledge. You have studied about the practical applications of space technology in the first year of the course. Applications are reviewed briefly in the introductory chapter only to remind you that scientific knowledge obtained during space exploration can be put to many practical uses. In planning its long-range space program, however, our country cannot allow its goals to be tied too closely to practical applications. Our Nation must reach out boldly to explore space without attempting to predict exactly what kind of practical applications will result.

When, in 1961, President Kennedy proposed the lunar landing as a national goal, he said that space is a new kind of ocean and we must learn to sail upon it. We have learned how to travel in space, and some of the prospects that await us in the future are even more promising than the lunar landing. Now that the frontiers have disappeared from the planet earth, we are finding a new frontier in space. This frontier will remain forever as a challenge to man's desire to explore the unknown. This book describes some of our adventures on the space frontier. Later books in this year's program will tell you more about the problems we face in advancing on the space frontier and the benefits to be gained.

At the end of each chapter, you will find a list of references for further reading. These are merely suggestions. There are many other good references available at present, and new books about space are constantly being published. You will need to consult the press and television for reports on the most recent launchings, and your teacher will supply you with the latest NASA publications about the space program.

Grateful acknowledgment is made to NASA for the photographs used in this book. Except where otherwise indicated, all photographs and airbrush drawings used in this book have been provided by NASA.

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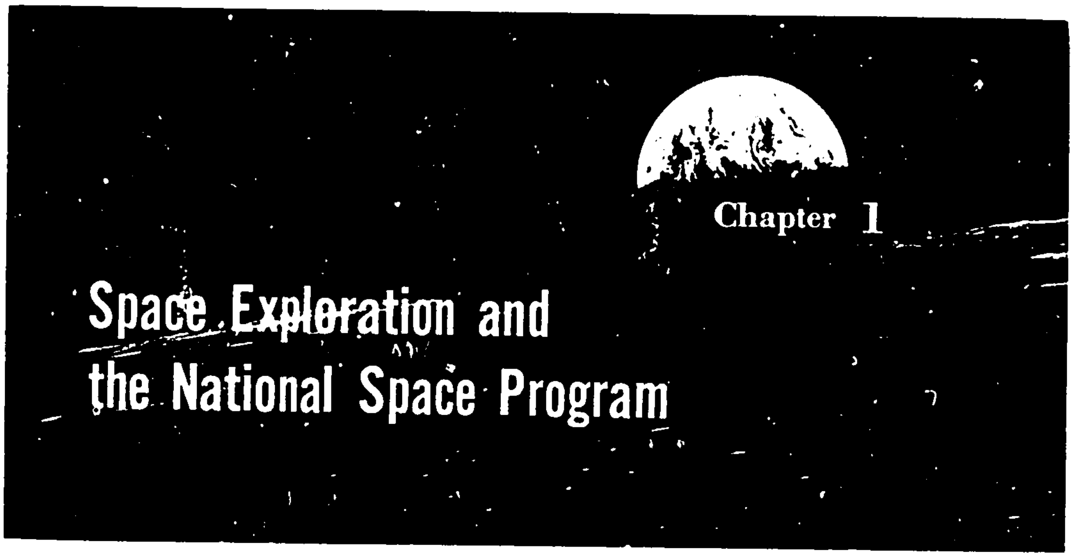


Chapter 1

Space Exploration and the National Space Program

THIS CHAPTER explains that space exploration, the search for scientific knowledge, and practical applications are the three main purposes of the national space program. It tells why the United States set new goals for the space program after the lunar landing, and it explains the six goals of our present program and tells how they relate to space exploration and the search for scientific knowledge. Finally, the chapter describes the practical ways in which some of the knowledge obtained from space exploration is being applied. After you have studied this chapter, you should be able to do the following: (1) explain four goals of the space program as they relate to space exploration and the search for scientific knowledge, (2) describe the three main purposes of the national space program, and (3) tell three principal applications made of the knowledge obtained from space exploration.

EXPLORATION is at the forefront of the national space program and determines the direction of that program. In the first decade of space exploration the United States made a long, bold stride into the future to reach the moon, to land upon it, and to return astronauts safely to the earth. Before the end of the decade our astronauts made four flights to the moon, and on two of these flights they landed on the moon to explore its surface. This exploration, unique in the history of the world, has given us a new perspective on the planet earth, the entire solar system, and the universe beyond. It has also enabled us to give new direction to our space program.

In the second decade of space exploration we are not attempting to make another long stride into the future. There are too many pressing problems that face us on the earth, and it is not necessary that our astronauts take another and longer reach into the future and attempt to land on Mars at this time. Instead we are directing exploration to realize the greatest possible benefits from the lunar landings, to experiment with a space laboratory and then develop a permanent space station that will enable us to explore space at firsthand, and finally to send probes to all the planets in the solar system. In making these planetary probes, our spacecraft will go inward toward Mercury, the planet closest to the sun, and outward beyond the last planet, tiny Pluto, more than three and a half billion miles from the sun. In their own way the present programs for space exploration are even bolder and more imaginative than our program for reaching the moon.

If our Nation is to remain great, it must continue to meet the challenge that space exploration offers. As far back as we know, man has had the desire to reach out to explore the unknown. In doing this, he has taken risks, has adapted to surprises and to new experiences, and has gone ahead without being able to predict precisely the results of his exploration. When Columbus set out on his voyage of exploration in the hope of finding a new passage to the East, he found a New World instead. Because of the wish to explore, man has advanced, and nations have made great achievements. As President Richard M. Nixon has said, "A great nation must be an exploring nation if it wishes to remain great." We must continue to explore space if we expect to keep our position of leadership among the nations of the world.

Through exploration undertaken in the course of reaching the moon and landing upon it, this country has built up a national space program.

LUNAR LANDING: A GOAL ACHIEVED

When, in May 1961, President John F. Kennedy proposed that the United States send a man to the moon before the end of the decade, he was setting a first-priority goal for our space program. This goal was to enable American astronauts to land on the moon and return them safely to the earth. It was a challenge to the American people to make a great voyage of exploration in the administration's spirit of the New Frontier. No project yet undertaken by the American people had demanded such gigantic effort. As President Kennedy pointed out: "No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."

The project to put astronauts on the moon became known as Project Apollo. The first lunar landing was to be satisfying in itself, but this was not the primary reason for undertaking the exploration. Project Apollo was to focus the national effort in making a great surge forward in obtaining knowledge about space and applying it. The project called for scientific discoveries and for a more massive management and engineering effort than this country had ever before undertaken. The Nation committed itself to this gigantic project in order to reap the benefits that would result from it.

Looking back at the proposal about a decade later, with the moon landing achieved, one finds it difficult to picture what a great challenge Project Apollo presented at the beginning. Then man had ventured into space only one time. The Soviet cosmonaut, the late Yuri Gagarin, had made the first historic journey into space, a one-orbit trip lasting somewhat less than two hours. Many doubts still persisted about man's ability to endure the rigors of space for longer periods. Unmanned satellites had shown that dangerous radiation belts exist outside the earth, and other unknown hazards were believed to await man as he ventured beyond the protective cover of the earth's atmosphere. The first orbital flights were made at 100 to 200 miles from the earth. The moon is about a quarter of a million miles away. The vast space between the earth and the moon (cislunar space) was then an almost completely unexplored region.

At the time Project Apollo was begun, the United States had yet to regain the self-confidence that it had lost in the wake of the first Soviet Sputniks. Earlier, both the Soviet Union and the United States had proposed orbiting an artificial satellite during the International Geophysical Year (IGY 1957–58). With the vast resources at its command, the United States expected to reach space first, and its first space booster had been confidently named the Vanguard. For reasons still difficult to explain, the United States did not concentrate the effort needed to reach the goal it had set. While the Vanguard booster was encountering difficulties on the launch pad, the Soviet Union surprised the world with the beeping signals from its Sputnik I, the world's first artificial satellite, orbited in October 1957. The American people, who prided themselves on their ability to advance scientific knowledge and make practical applications, were dismayed that another country had outdistanced them in space.

By May 1961, the United States had recovered from its shock, organized its resources and effort, and put its program for space exploration on a sound foundation. By the Space Act of 1958, Congress established the National Aeronautics and Space Administration (NASA). This agency was to combine aeronautical research with a greatly expanded program for exploring space for peaceful purposes. It would bring together the efforts of industry, the universities, and scientists throughout the Nation to accomplish its purposes. When Project Apollo was proposed, Project Mercury, under the direction of NASA, was underway. The preliminary unmanned flights had been completed, and Astronaut Alan Shepard had made the first suborbital flight. The United States was ready to meet the challenge of manned spaceflight. Although a flight to the moon was possible in theory, it still represented a bold undertaking. The people of the United States accepted the new and greater challenge of Project Apollo with enthusiasm. They were eager to make up for their slow start in space exploration.

With the challenging goal of a moon landing before them, the Americans progressed steadily with their space program during the 1960s. As the end of the decade approached, suspense increased. Would American astronauts be the first to land on the moon, or would the Soviets make another first? American astronauts had completed many successful maneuvers in space, and they were ready for the long-awaited trip. They did not allow their confidence to outrun them, however, and they did not slacken their efforts. Then, in July 1969, the Eagle landed on the Sea of Tranquility, and the American astronauts Neil Armstrong and Edwin Aldrin stepped onto the moon. After [illegible] of viewing the moon and wondering about it from afar, man [illegible] reached the earth's natural satellite to make firsthand observations. [illegible] event was a momentous one in man's history. Centuries may [illegible] before historians can accurately assess the significance of this [illegible]

F[illegible] United States the landing had certain immediate results. With the safe recovery of the Apollo–11 astronauts, the United States had achieved its first-priority goal in space. President Nixon took action to set new goals for the national space program.

PRESENT GOALS OF THE SPACE PROGRAM

When President Nixon considered the new goals for the space program proposed by the special Space Task Group and the Science Advisory Committee, he was aware that much had changed in this country since Project Apollo began. The first enthusiasm for the space program had disappeared. This country was beset by doubts and dissent, and many social problems demanded solution. New priorities for the space program had to be considered in the light of these problems.

Although spending for the space program has never exceeded .75 percent of the Gross National Product (value of all US products and services), or less than 1 percent of the national wealth, even at the height of spending for Project Apollo, President Nixon realized that the budget for space would be reduced in the future. Expenditures for space exploration would have to compete with those for expanded social programs. But space exploration can now be planned on a permanent basis. We no longer need to make sudden long reaches forward at a great cost in money and effort.

Our present national space program is built upon six goals, or objectives, which have no special priorities. The goals are flexible ones that can be adjusted as the needs of our country change and as we obtain new knowledge. When President Nixon announced these goals in March 1970, he arranged them in the following order:

1. We should continue to explore the moon (Project Apollo).
2. We should move ahead with bold exploration of the planets and the universe.
3. We should reduce substantially the cost of space operations (new space transportation system).
4. We should seek to extend man's capability to live and work in space (the Syklab and the space station).
5. We should hasten and expand the practical applications of space technology.
6. We should encourage greater international cooperation in space.

The programs for space exploration and the search for knowledge as described in this book relate directly to the first four goals of our national space program as stated above, and they relate indirectly to the last two goals.

The programs described in the following chapters tell about Project Apollo and the exploration of the moon, plans for the Skylab, the development of a space station from the Skylab, and the exploration of the planets. At present our efforts for reducing the cost of space operations (Goal 3) are centered on developing a new space transportation system made up of vehicles like the space shuttle and space tug.

These vehicles are being designed so that they can be adapted to many purposes and can be used over and over again. The space shuttle and the space tug are to be tested as they service our first permanent space station, and they are described in connection with the ideas that we now have for constructing this station (Chapter 4). Later on, more advanced reusable space vehicles will be built for use in exploring the moon and the planets.

In our efforts to explore space, we are seeking to work more closely with other nations of the world (Goal 6). The challenge offered by space exploration is such a gigantic one that it cannot be met by the United States and the Soviet Union alone. All nations must cooperate in exploring space, and all should share in the benefits. President Nixon has said, "Our progress will be faster and our accomplishments will be greater if nations will join together in this effort, both in contributing the resources and in enjoying the benefits." We are already cooperating with other nations in launching their unmanned scientific experiments, and they are sharing the costs with us. We are looking forward to the day when we can extend these arrangements to include more of the larger applications satellites and exchange astronauts and space crews. American astronauts have toured worldwide to explain our space program. They have visited the Soviet Union to learn more about the work of the Soviet cosmonauts, and the cosmonauts have visited the United States. At present we are discussing plans with the Soviet Union about how we might work together more closely in rescue work in space.

In explaining our national space program, which is directed toward the six goals stated, President Nixon said that the entire program has three large purposes: (1) exploration, (2) search for scientific knowledge, and (3) practical applications.

In describing our programs of exploration and the search for scientific knowledge, this book tells about the adventures of the astronauts in making the Apollo flights and in exploring the moon. But the men in space suits are not the only ones who have an important part in our national space program. Thousands of scientists and engineers at the launch and control sites and in the laboratories and offices of the Nation also play an important part in that program. They have helped to make the flights of the Apollo astronauts possible, and they are preparing the way for the unmanned flights that will continue space exploration when the Apollo flights and the flights in the Skylab are completed. It took the careful work of thousands of scientists and engineers to probe space and learn more about the radiation environment that lay between the earth and the moon before the Apollo spacecraft could be built and the Apollo flights planned. Then, as the astronauts were practicing the maneuvers that would enable them to fly to the moon, scientists were helping to plan the instruments that the astronauts would use in exploring the moon and in selecting the lunar sites that would yield the most valuable scientific information.

In the summer of 1969, shortly after the Apollo astronauts made their first landing on the moon, scientists rejoiced at receiving valuable information from the Mariner 6 and 7 probes of Mars. This information, like that obtained from the Apollo flights, has greatly expanded our store of scientific knowledge. Later in the decade of the 1970s we plan to send probes called the Grand Tours to the outer planets to learn something more about these mysterious planets. Space exploration is directed toward obtaining scientific knowledge not only for further exploration of space but, even more important, for expanding the permanent store of human knowledge. Our space program is intended to help us arrive at a greater systematic understanding of ourselves and our universe. Some of that knowledge leads to practical applications.

PRACTICAL APPLICATIONS OF SPACE TECHNOLOGY

Our country is already reaping many practical benefits from space exploration. Some of the direct findings of space research and many more of the indirect benefits, or "spinoffs," can be applied to solving social problems, such as cleaning up the polluted environment and rebuilding decayed cities.

When man sent the first small artificial satellites into orbit, he established himself in a new relation to the planet earth and to the heavenly bodies. At last man had penetrated the layer of air encircling the earth that shuts out most of the radiations from space. He had a new view of the earth and of the universe beyond. Even with the first small scientific satellites, the United States obtained a wealth of new information about the earth and its environment. When television cameras and improved instruments were installed in the unmanned satellites, their value increased, and it became clear that the satellites could themselves be put to work to perform many useful tasks for man, such as providing information for making more accurate long-range weather forecasts and for relaying communications over long distances.

Scientists and engineers soon found many ways in which to apply the knowledge they obtained from space exploration. Industrialists, teachers, doctors, city planners, government officials—in fact, the members of almost every profession and trade in American life—have in some way made use of the technology developed in the course of producing the spacecraft, boosters, and instruments for space travel.

Even with the variety of applications satellites and the many products developed as the result of space exploration, some experts do not consider these as the greatest benefits to be derived from the space program in the immediate future. They believe that this country can obtain still greater benefits from the management know-how developed during Project Apollo.

Management Know-How

In the midst of their perplexity over problems of polluted air and water and the decay of cities, some Americans found new hope when the astronauts landed on the moon. Project Apollo represented one of the largest programs of technological development ever undertaken by man. Yet Project Apollo, gigantic as it was, had not gotten out of control but had been managed successfully. It had reached its primary goal within the limits of the time and funds set for it. The success of Project Apollo pointed the way for solving such social problems as pollution and welfare problems, which also need to be managed on a massive scale.

When Project Apollo was first proposed, it was scarcely more than an idea. James E. Webb, who was Administrator of NASA at that time, said that building the Apollo spacecraft was somewhat like developing a butterfly from a caterpillar when one had never seen a butterfly before. There was no model or pattern to follow. First, NASA officials had to decide what method would be used for reaching the moon. Then they had to determine what kind of spacecraft should be built to perform the sequence of tasks derived from the method selected. As the Gemini astronauts were working out the complex maneuvers that would enable us to reach the moon, engineers were already constructing the Apollo spacecraft that would make the trip.

Project Apollo was successful because the managers of the program had the ability to analyze complex tasks. They could tell what problems would need to be solved years in advance, and they planned ways to solve these problems. It took the work of some 20,000 industrial contractors, scores of university laboratories, and the efforts of some 400,000 people to build the rockets and spacecraft for Project Apollo. This represented the management of resources amounting to some $24 billion. After the hardware was produced, another gigantic management effort was needed to check out and launch the hardware. All these efforts had to be brought together at the right time to make Project Apollo a success.

After Astronaut Aldrin had participated in the first lunar landing, he said, "I think this demonstrated that we were certainly on the right track when we took this commitment to go to the moon. I think that what this means is that many other problems perhaps can be solved in the same way by taking a commitment to solve them in a long-time fashion."

Another way that space-generated technology can be applied is to use the satellites themselves.

Applications Satellites

With the experience gained in putting satellites to practical use, the United States will be able to reap greater benefits from these satellites in the future. NASA Administrator, Dr. James C. Fletcher, has said, "Now I think we are in a position to make great strides in the applications satellites area." While the people of our Nation are working to clean up our polluted environment, they are determined to manage our natural resources more wisely in the future and find new resources to replace those we have depleted. The resources of the mines, forest, fields, and the oceans can soon be surveyed from space on a massive scale with the Earth Resources Technology Satellites (ERTS) and the Applications Technology Satellites (ATS). These make up one class of applications satellites, the survey satellites.

The survey satellites have great promise for future development. This class includes all satellites that look at the earth and gather information about the earth and its resources. The first kind of ERTS (Fig. 1) is scheduled to be launched in 1972 and the second kind in 1973. These satellites will compile information on mineral deposits, pollution, crops, forests, water, the expansion of cities, transportation patterns, and similar matters.

The survey satellites will make use of improved infrared cameras and instruments perfected for use in the early applications satellites, as well

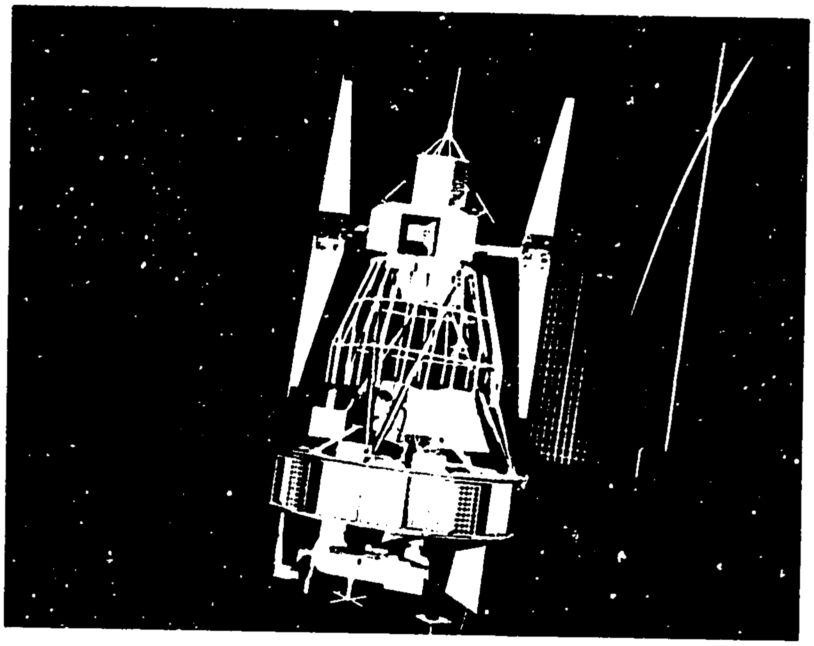


Figure 1. First kind of Earth Resources Technology Satellite (ERTS) (artist's sketch).

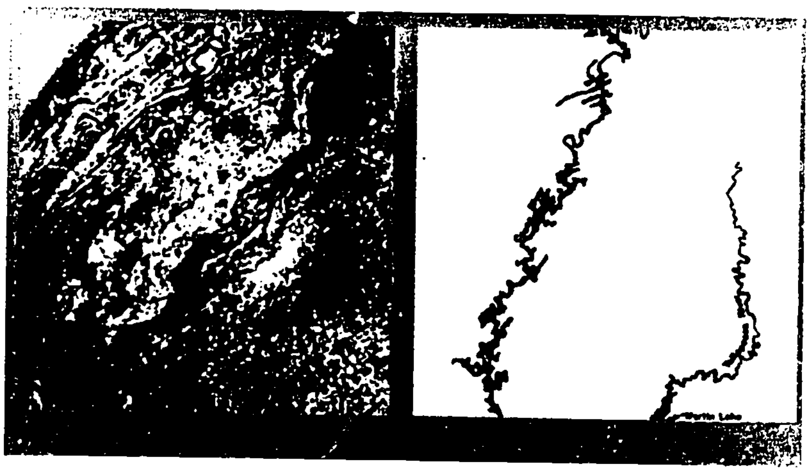


Figure 2. Automatic mapping of the distribution of surface water in Alabama by infrared photography from space (US Geologic Survey). This method will be used by the ERTS.

as the experience gained in interpreting photographs taken from space (Fig. 2). Survey satellites are launched into a polar orbit. From this position they can view every part of the earth twice daily as it turns on its axis.

Applications satellites can be conveniently divided into four classes: the survey satellites, the communication satellites, the weather satellites, and the navigation satellites.

The second class is made up of the communication satellites. Audiences who have viewed overseas television broadcasts via satellite have become acquainted with the way in which satellites can be used to take over the work done by cables and microwave towers in communication systems. Overseas communications could be further extended for radio telephone and teletype service by replacing underseas cables with satellites. Communication satellites have already been put on a partially self-supporting basis through commercial enterprises known as the US Communications Satellite Corporation (Comsat) and the International Telecommunications Satellite Consortium (Intelsat).

The United States has extended the use of satellites for continuous service by establishing three communication satellites in the synchronous orbit, the equatorial orbit at 22,300 miles above the earth. The

Figure 3. Proposed direct broadcast satellite (artist's sketch).

three satellites, spaced equal distances apart in this orbit, remain above a fixed point on the earth, following the earth as it turns on its axis. Thus communications can be relayed continuously.

Another possibility for extending the usefulness of communication satellites is to use them for direct broadcasts (Fig. 3). Under such a plan the program would originate at a television station on the earth, go through a satellite, and then be broadcast directly into people's homes. It would not be necessary to relay the program through a second television station on earth, as under the present plan. Before direct broadcast is possible, more power will be needed in the satellite, and it will be necessary to use directional antennas. The United States has signed an agreement with India to conduct an experiment with direct broadcast of an educational program. When direct broadcasts become practicable on a large scale, developing nations will be able to conduct programs of mass education through the use of satellites.

The success that the United States has already achieved with communication satellites has been matched with that obtained with the third class of applications satellites, the weather satellites. In fact, it was not until the United States sent its early weather and scientific satellites into space that we were able to get a real view of weather systems and the way they are influenced by the movement of radiations from the sun into the magnetosphere and then into the atmosphere. The early weather satellites took television pictures that showed the movement of weather fronts on a massive scale. They took pictures of cloud coverage and the formation of whirlpool shapes in the clouds, which represented newly developing hurricanes. The pictures were relayed a long enough time before the hurricanes reached land so that people who were in the path of the hurricane could be alerted. Weather satellites have been particularly useful in transmitting information about cloud formations high above the earth, and they have furnished us with information about the weather over the oceans and other regions not provided with weather stations.

Through the use of better infrared cameras in satellites, it is now possible to take pictures of all kinds of weather systems and to take these pictures at night, and daylight coverage has also been improved. The National Oceanographic and Atmospheric Administration, an agency of the Department of Commerce that includes the Weather Service, is now receiving routine information from a series of operational weather satellites, and the information is being used in making weather forecasts.

The fourth class of satellites, the navigation satellites, has not been developed to the same extent as have the communication and weather satellites. For some time, however, the US Navy has used a system of navigation based on signals received from four satellites and the use of special receiving equipment and codes for interpreting the signals. The Navy has released information on the system so that it might be of use to other ships, but the system has not yet been standardized for general use. Satellites probably hold promise for wider use in air navigation than in sea navigation. Congestion of the crowded air lanes could be relieved through the use of satellites. Such satellites would give controllers a whole new range of communication channels for their use.

Besides the direct benefits received from the applications satellites, the space program offers indirect benefits, or spinoffs.

Spinoffs

In the course of designing and building satellites and spacecraft and the rocket systems used with them, scientists, engineers, and industrialists developed a whole new technology. When discoveries were made or processes improved, NASA made the information immediately available to industry. The by-products developed from aerospace research and development are called "spinoffs."

Developing in close connection with the aerospace industry, or as a part of it, were the electronics industry and computer technology. Because of the need to miniaturize electronics equipment to make it fit into satellites and space capsules, many inventions, such as the transistor radio, were made, and the entire electronics industry has grown rapidly. The complex computations that had to be made almost instantly to guide missiles and space boosters gave impetus to the development of the computer. Today the computer is being used widely in business administration, in banking, in transportation, and in many other fields. Computers have been developed to do many kinds of tasks, and computers have been miniaturized to fit into a space capsule.

The demands made upon the aerospace industry for a high degree of precision and for quality control have led to improvements in manufacturing processes and to a higher quality of goods in industry generally. Foods are processed and packaged in many new ways because of what has been learned in research on space diets. New materials have been developed and old materials have been improved to make it possible to keep the space capsule from burning up as it reenters the atmosphere at extremely high speeds.

The whole field of medicine has undergone changes because of space research and medical procedures developed in screening and training astronauts. Medical instruments and electronic instrumentation were improved, offering opportunities to equip hospitals and clinics more efficiently. With diagnosis assisted by the computer, it will be possible to automate more of the services required in hospitals and thus help to make up for the shortage of doctors and nurses.

Thousands of benefits have resulted from applying space technology. As the needs of our country change and as new knowledge is obtained from space exploration, new applications of that knowledge will be made. What is important is that we continue a bold program of space exploration so that we can keep on advancing our knowledge. Our present program of space exploration is focused upon the Apollo flights for exploring the moon.

REVIEW QUESTIONS

1. **Why must the United States continue to explore space?**
2. **Why was it necessary to set new goals for the national space program after the lunar landing was made?**
3. **What four goals of the national space program relate directly to space exploration and the search for scieutific knowledge? What are the other two goals? How do they affect space exploration?**
4. **What kinds of practical applications have been made of knowledge gained from the space program? What are the four kinds of applications satellites?**
5. **How might space technology help in preventing pollution of the environment and in enabling us to conserve our natural resources?**

THINGS TO DO

1. Find out about the NASA budget for the present fiscal year and report to the class on your findings. You might explain how the NASA budget was developed. how it was presented to Congress. and how congressional action taken on the budget has affected present projects for space exploration. You can tie in your research with what you have already learned about the operation of the branches of the US Government.
2. Talk to your aerospace education instructor and to your science teacher about organizing an astronomy or a space club. Young people all over the United States are forming such clubs. If your school cannot sponsor such a club, perhaps some of your friends will be interested in forming a neighborhood club.

3. Start a scrapbook about the exploration of space and keep it up during the entire school year. You might select only the most important flights and events and cover the entire national space program and Soviet achievements as well. If you are especially interested in one aspect of space exploration, you might limit your collection to this one field. You might, for example, select manned lunar flights (Project Apollo), space laboratories (Skylab) and space stations, or planetary probes. Include both American and Soviet achievements.

4. Make a report on the contributions the Air Force has made to space exploration. You might include rocket boosters and the work of astronauts, or you might choose to limit your study to one field or even to selected boosters or to the work of certain astronauts.

5. Make a report to the class on the way space technology will be applied in preventing pollution of the environment, in conserving our natural resources, and in helping farmers to raise better crops. Do some research on the new Earth Resources Technology Satellites (ERTS).

SUGGESTIONS FOR FURTHER READING

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

BRAUN, WERNHER VON, and ORDWAY, FREDERICK I., III. *History of Rocketry and Space Travel.* Rev. ed. New York: Thomas Y. Crowell Co., 1969.

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

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

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

———. *Harnessing Space.* New York: Macmillan Co., 1965.

Space Task Group. *The Post-Apollo Space Program: Directions for the Future.* Report to the President. Washington, D.C.: Government Printing Office, 1969.

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

THIS CHAPTER explains the purpose of Project Apollo, and it describes the manned Apollo flights that have already been made. It outlines the plans for the lunar landing, describing the method selected for reaching the moon, the Apollo spacecraft, the Saturn boosters, and the flight plan for the lunar landing. Then it explains how Project Mercury was Step 1 and Project Gemini was Step 2 in preparing for Project Apollo (Step 3) in achieving the lunar landing. Next it describes the ground complex used for the Apollo flights and the flights themselves. It tells how Apollo 7, 8, 9, and 10 tested the Apollo spacecraft and the Saturn boosters in preparation for the lunar landings. Then it describes the flights and landings made on Apollo 11, 12, and 14 and the rescue operations on Apollo 13. After you have studied this chapter, you should be able to do the following: (1) tell the purpose of the Apollo flights, (2) explain the method used for reaching the moon and returning to the earth, (3) describe the Saturn V booster and the Apollo spacecraft, (4) explain how the early Apollo manned flights prepared for the lunar landing, (5) tell why the first lunar landing was important, and (6) explain the progress made in achieving lunar landings to date.

AS THE PRESENT SAMPLES of moon rocks and soil are being studied, there is speculation about what the remaining Apollo flights might tell us about the moon. These last flights are to be made to areas of special scientific interest. Now it is possible to direct flights to such areas because we can make pinpoint landings on the moon and additional equipment will be provided. On Apollo 15 and subsequent flights, a powered lunar rover and more supplies will be loaded into the spacecraft, enabling the astronauts to venture out farther from their landing base and to stay longer on the moon. By the time the Apollo flights are completed, the United States should have obtained valuable scientific data and have a much better idea of how to direct lunar exploration in the future. The actual exploration done during the Apollo landings is explained in the next chapter. This chapter describes the Apollo flights that made the exploration possible.

The Apollo flights represent the climax of all our earlier efforts in manned spaceflight. The giant Saturn V, which propels the Apollo to the moon, is likely to be the largest all-chemical space booster that the United States will ever stage for launching, and the Apollo spacecraft is the most complex of all US manned spacecraft built thus far. Apollo technology is to be used as the foundation for flights planned for the astronauts during the first half of the 1970s.

The Saturn V and the Apollo spacecraft were developed by using the state of the art existing in 1961 as a foundation. In this year the Mercury manned flights were just beginning. Although NASA officials knew that many short preliminary flights would have to be made before the astronauts would be ready for the actual flight to the moon and the landing, their planning had to begin with the goal set, the lunar landing, and then work backwards.

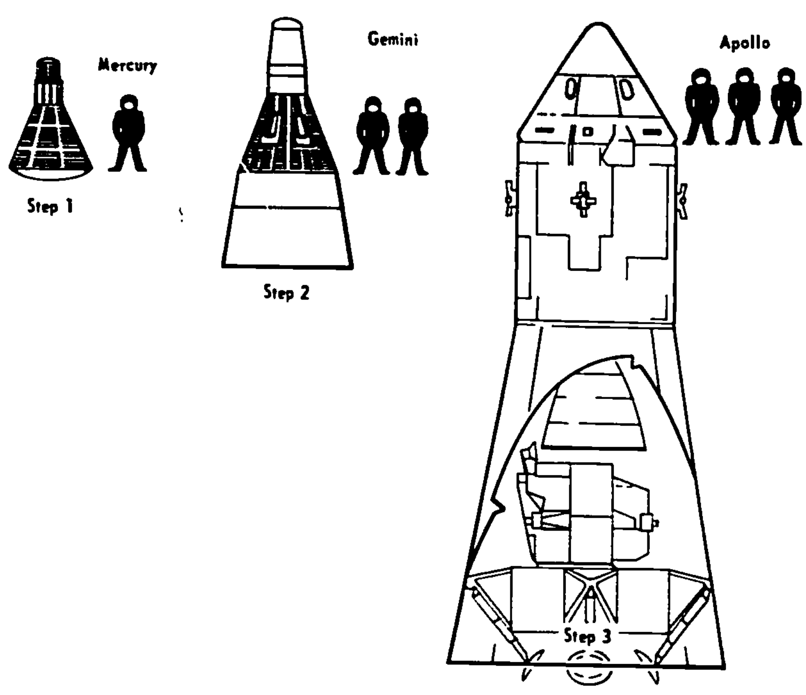


Figure 4. Three steps in the flight to the moon.

PLANS FOR THE LUNAR LANDING

With the goal for the lunar landing set, Project Mercury became Step 1 (Fig. 4) in the enlarged manned spaceflight program. The small Mercury capsule, designed to carry one man, was to orbit close to the earth and follow the trajectory set for it at launch. It was clear that another step was necessary before astronauts could leave earth orbit and go out to the moon. The Gemini, a more advanced vehicle, was built to carry two men and perform the kind of maneuvers that would be needed on the lunar flight. Project Gemini became Step 2, and the Apollo flights were to make up Step 3. Through the flights of the Mercury and the Gemini, which gradually increased in difficulty, astronauts learned the skills that would be required in piloting the Apollo spacecraft. The same kind of efficient management was used in training the astronauts and in scheduling and launching the Apollo flights as was used in designing and building the Apollo spacecraft and the Saturn boosters. At the outset, the success of the entire management effort revolved about selecting the best method for reaching the moon.

Method Selected

Even before scientists and engineers knew about the final results of the Mercury flights, or Step 1, NASA officials had to decide upon the

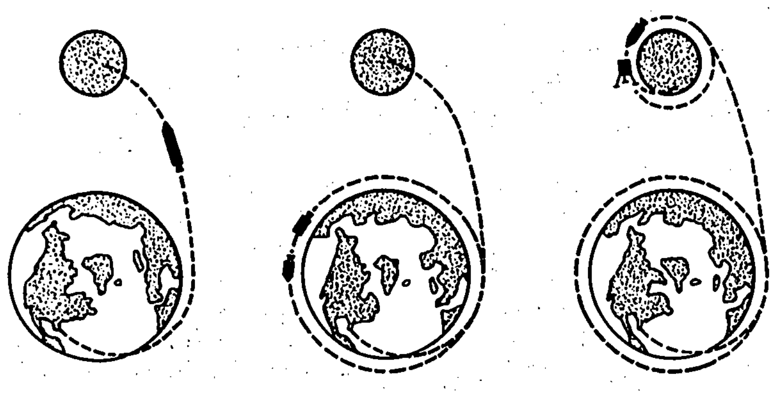


Figure 5. Three methods for reaching the moon. The United States selected the third method, lunar orbit rendezvous.

best method for making the lunar landing. This decision would determine the design for the Apollo, the butterfly that was to emerge. Then no one knew what the butterfly would look like, as NASA Administrator Webb pointed out.

After much discussion, NASA officials narrowed down the proposals for making the lunar flight to the following methods: (1) a direct flight from the earth to the moon, (2) earth orbit rendezvous, and (3) lunar orbit rendezvous. The basic flight plan for the three methods is shown in Figure 5.

Neither the United States nor the Soviet Union had enough booster power to use the first method, a direct flight.

The Soviets probably selected the second method, earth orbit rendezvous and a flight from earth orbit. They began to assemble heavy spacecraft in earth orbit, and they worked with rendezvous and docking. In 1963, during his historic speech before the International Astronomical Federation in Paris, the late Cosmonaut Yuri Gagarin described the merits of this second method of reaching the moon, but he noted that the rocket power necessary for making use of this method was not then available.

The United States selected the third method, lunar orbit rendezvous and a descent from lunar orbit. This method permitted the landing to be made with only one Saturn V booster and was believed to be as reliable as the other two methods. Before the Apollo spacecraft begins the journey to the moon, it is put into a parking orbit around the earth.

Once NASA officials had selected lunar orbit rendezvous (LOR) as the method for achieving their goal, engineers could go forward with their work of designing and constructing the Apollo spacecraft.

Three-Module Apollo Spacecraft

The Apollo spacecraft, which was to make Step 3 possible, carries three men and has three modules. The first module on the top of the stack for the moon launch is the command module, the part in which the astronauts ride during the trip from the earth to lunar orbit and back again (Fig. 6). The second module, the service module, contains the large propulsion engine and supplies. The third module is the lunar module located in the adapter section. At the very top of the stack, above the command module housing the astronauts, rests the launch escape tower. This rocket-propelled device is used to provide the as-

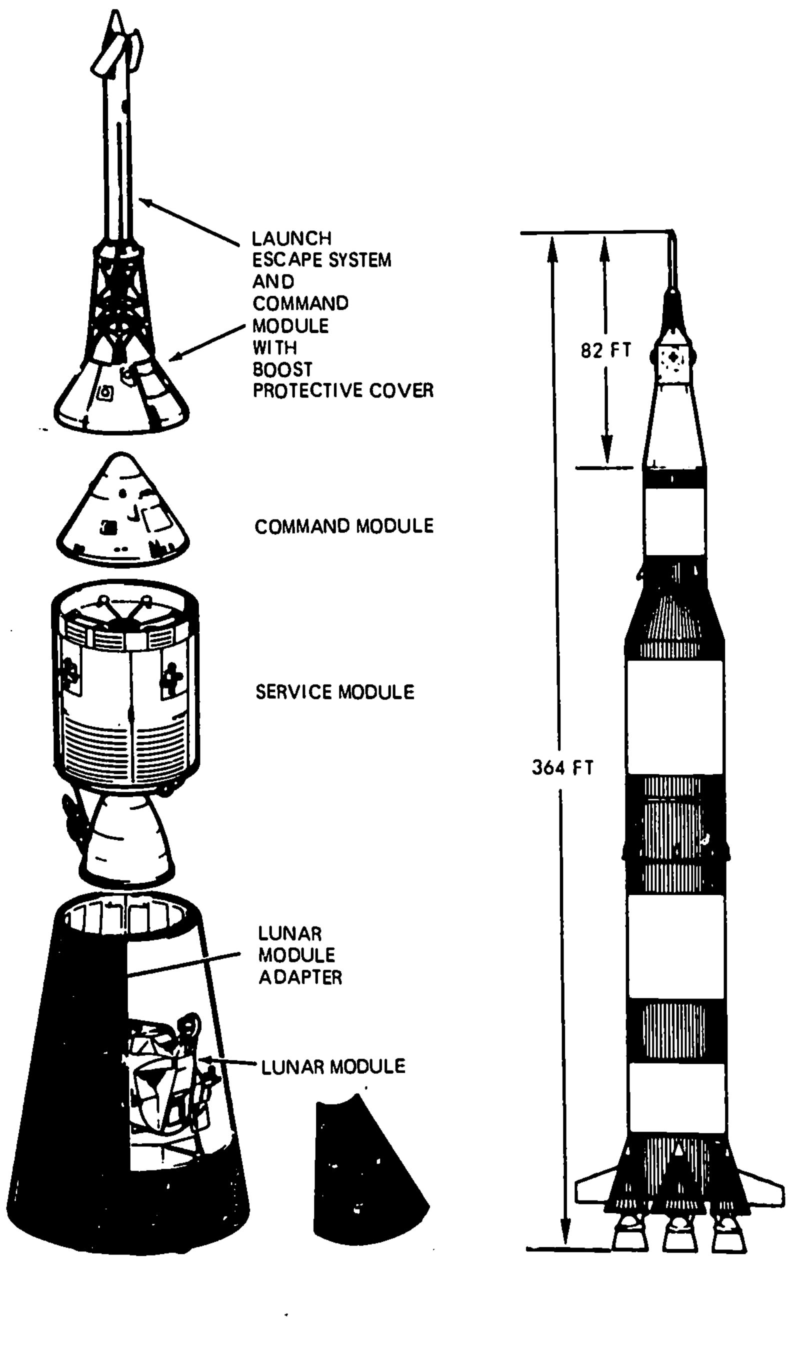


Figure 6. Modules of the Apollo spacecraft and the spacecraft assembled on the Saturn V booster ready for launch.

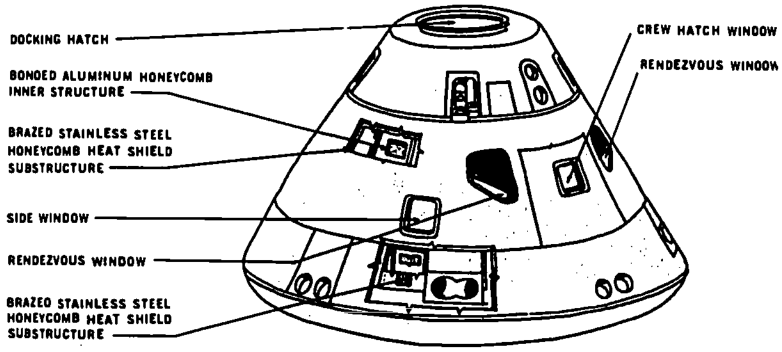


Figure 7. Structure of the Apollo command module.

tronauts with a means for propelling themselves to safety if trouble should develop in the booster at launch. It is jettisoned immediately after lift-off.

The command and service modules form one unit during the flight of the Apollo spacecraft. The command module has no primary propulsion system. Its dozen small thrusters can be used only for controlling the attitude of the spacecraft. The astronauts must depend upon the large engine in the service module to give them propulsive power to make midcourse corrections. Near the end of the flight the service module separates from the command module and is left out in space. The command module comes in for the splashdown and is recovered.

During flight the astronauts usually ride in the command module, but they can use the tunnel to pass back and forth between the command module and the lunar module. Both the command module and the lunar module are pressurized with oxygen for breathing. The service module is not pressurized.

By restricting the amount of space that must be continuously pressurized for life support and by organizing the equipment into modules, engineers have been able to save valuable space and weight in constructing the spacecraft. When a module has finished performing the tasks for which it was intended, it can be jettisoned in space, and the spacecraft is made lighter as a result. The principle of modular construction, begun with the Mercury, was further developed with the Gemini and the Apollo spacecraft.

The top module of the Apollo spacecraft, the command module, which houses the astronauts, has a double wall built with titanium alloy and with a stainless steel honeycomb sandwich construction (Fig. 7). From the outside this module appears simple enough, but when viewed from the inside, it is found to be crowded with crew couches and with many subsystems, instrument panels, wiring, displays, and other accessories. The module contains the environmental controls, the life-support system, and equipment for guidance, navigation, and computation, as well as the attitude-control engines for reentry.

The command module has a peculiar cone or bell shape, which resembles that of the Mercury capsule. Engineers had selected this shape for the Mercury from among many other designs. They believed that the bell shape had the best aerodynamic characteristics, or features that would enable it to go through the atmosphere at launch and reenter it at splashdown. When the Apollo command module is prepared for launch, the small end is placed uppermost on the booster. In this position the capsule offers the least resistance to the air as it is boosted into space. When the command module is made ready for splashdown, it is turned so that the large blunt end strikes against the atmosphere first, creating large amounts of drag to brake the spacecraft as it descends.

The plan of construction of the Apollo command module follows that of the Mercury except that on the Apollo the heat shield covers the entire vehicle, not just the large blunt end. The Apollo capsule travels at much higher speeds than the Mercury and the Gemini capsules as it reenters the atmosphere. It must therefore be better protected so that it can withstand much higher temperatures. When the Apollo module returns from the moon, it is traveling at more than 24,000 mph, the same speed at which it left the earth, and some surfaces reach a temperature as high as 5,000 degrees F.

Folded down inside the adapter at the bottom of the assembly is the lunar module, with its four cushioned legs. This is the detachable vehicle that will be used later in making the descent to the moon and in rising from it. This was the new feature of the Apollo spacecraft. The lunar module cannot make use of wings, parachutes, or sails when it descends to the moon because the moon has no atmosphere. Instead, the lunar module operates much as a helicopter does, but it has to have rocket engines instead of air-breathing engines. The lunar module is lightweight and efficient, but it is not built for comfort. There

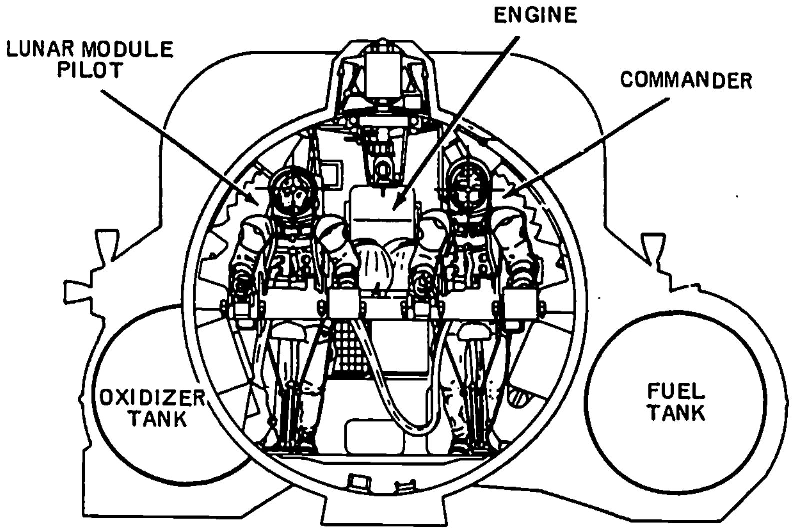


Figure 8. Commander and pilot riding in the Apollo lunar module.

are no seats in the module. The two astronauts stand up and peer through two small openings as they guide the module down for a landing (Fig. 8). The cushions on the module's four feet help to keep it from sinking into the lunar soil, and the module is constructed so that it will not topple over even on a fairly steep incline.

The complete Apollo spacecraft is a combination of three modules: the command module, the service module, and the lunar module. When the three modules are ready for the flight to the moon, they rest on top of the giant Saturn V booster.

Saturn Boosters

Actually two different Saturn boosters were used for the Apollo flights: the smaller two-stage Saturn IB, also known as the Uprated Saturn I, and the giant three-stage Saturn V. The smaller Saturn booster was generally used for the preliminary flights in earth orbit, the larger Saturn for the flights to the moon.

The Saturn V moon rocket is an awesome giant. Its great size complicated the tasks of assembling and launching it. When the Saturn V was first flight-tested, it was four times more powerful than any rocket either the Soviet Union or the United States had launched previously.

When ready for a moon launch, the Saturn V, the Apollo spacecraft, and the escape tower all together rise to a height of 364 feet, or some six stories higher than the Statue of Liberty in New York harbor. When fired at launch, the first stage of the Saturn V generates some 7.5 million pounds of thrust, or energy equal to that produced by some 600,000 automobile engines. One Saturn V could launch into orbit at one time all of the manned spacecraft launched before the Apollo flights, or it could put into earth orbit the Mercury spacecraft with its Atlas booster attached to it.

The Saturn V weighs about 200 times as much as the early German V–2 rockets brought to the United States for testing and development after World War II. But the Saturn V, developed by a team of rocket scientists under the former German rocket expert Wernher von Braun, is much more than a greatly enlarged V–2. It represents tremendous improvements in rocket technology, as you will learn later in your study of rocket engines. The second and third stages of the Saturn V burn lightweight liquid hydrogen fuel, which can generate more thrust per pound than kerosene, but the liquid hydrogen must be kept at an extremely low temperature (−423 degrees F. as compared with −297 degrees F. for liquid oxygen). The third stage of the Saturn V booster remains attached to the spacecraft in earth orbit and is fired again, as required by the flight plan.

With the Saturn V there have been improvements not only in fuel but also in ground-testing and checkout procedures. The Atlas and the Titan II, which boosted the Mercury and the Gemini spacecraft, respectively, were developed from military ballistic missiles and man-rated, but the Saturn boosters were developed from the beginning for launching a manned spacecraft. The Atlas was flown 91 times before being used for the first manned orbital flight of the Gemini, and the Saturn I and IB, 14 times before launching the Apollo 7 into earth orbit. But the Saturn V was only flight-tested twice before being used for the Apollo–8 flight.

After you have some idea of what the Apollo spacecraft and the Saturn V booster are like, you can get a better picture of the flight plan for the lunar landing.

Flight Plan for the Lunar Landing

As the Saturn V is launched, it roars into space, boosting the Apollo spacecraft into earth orbit. The first two stages of the Saturn are jetti-

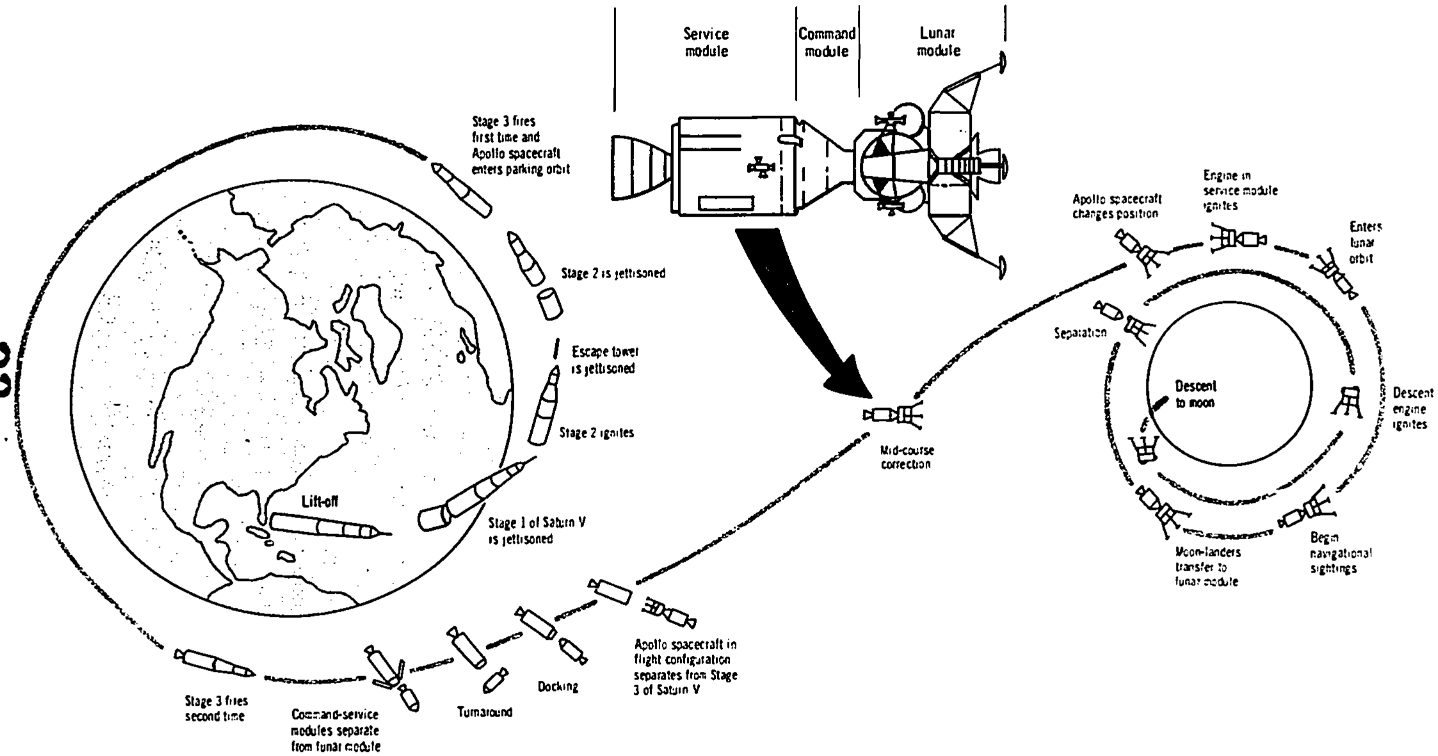


Figure 9. Flight plan for the trip from the earth to the moon and the landing on the moon.

soned as they finish their burn. The third stage, which can be refired in space, remains attached to the Apollo as it circles the earth about one-and-a-half times. The Apollo is then in its "parking orbit." During the time it is in this orbit, the astronauts are able to get up and move about in the command module. They make navigation sightings and have primary control over the spacecraft. At a predetermined point, they refire the Saturn V's third stage, pushing the speed of the Apollo up to more than 24,000 mph and putting it on a trajectory to the moon.

As the Apollo spacecraft begins its journey to the moon, the astronauts separate the combined command and service modules from the lunar module (Fig. 9). Then they turn the command-service modules through 180 degrees and dock the small end of the command module with the lunar module, which sheds its shroud. The command-service modules pull the lunar module free of the spent third stage of the Saturn V rocket, and the Apollo spacecraft is in the flight configuration.

As the Apollo spacecraft continues on its trajectory to the moon, it gradually loses speed. Finally it reaches the point in space where the gravitational force of the moon is stronger than that of the earth. The moon takes over, and the spacecraft speeds up again. Just before looping around the moon, the spacecraft is turned so that the rear faces forward. This shift exposes the large rocket engine in the service module so that it can be fired to brake the spacecraft and place it in orbit around the moon.

While the Apollo spacecraft is in lunar orbit, the two astronauts who are to make the lunar landing leave the command module, enter the tunnel, and go into the lunar module. Then they prepare the systems in the lunar module for the landing. Upon a signal, the lunar module is separated from the command-service modules, and the moon-landers fire the large descent engine in the lunar module to take them down to the moon. As they gradually descend, the astronauts use the large engine for braking. The lunar module hovers over the landing site while the pilot picks the best spot for putting it down. After the lunar module lands, the astronauts prepare for the moon walk. They leave the module one at a time.

When the astronauts have completed their exploration and are ready to go back to lunar orbit, they receive help from the earth in making the launch. They fire the ascent engine, which is in the upper stage of the lunar module. The lower stage is used as a launch pad and is left behind on the moon. After the astronauts ascend from the moon, they begin the rendezvous. When they reach the command-service modules in lunar orbit, they are docked. Then the moon-landers reenter the tunnel and go back into the command module, rejoining the third astronaut, who has remained in lunar orbit. When the three astronauts are back in the command module, they impact the remainder of the lunar module on the moon in order to obtain scientific data. (This part of the module was left in space on the Apollo-11 flight.)

As the astronauts orbit the moon, they prepare for the journey back to the earth. When ready, they fire the engine in the service module upon a command from the earth, and they begin the journey home. As the command-service modules reach a point about 34,000 miles from the moon, the earth's gravitational pull becomes dominant. Then, subject to the earth's pull, the Apollo returns at ever-increasing speed until it reaches a velocity of more than 24,000 mph, the same speed at which it left the earth.

Putting the spacecraft on the trajectory to the earth must be done with precision, as the spacecraft must reenter the atmosphere through a narrow corridor. If it were to return at too shallow an angle, it would bounce off the atmosphere and be lost in space. If it were to come back at too steep an angle, it would be burned up in the atmosphere. To insure an absolutely accurate trajectory, both on the return trip and on the trip out to the moon, the astronauts use the large engine in the service module to make midcourse corrections.

As the command-service modules approach the earth's atmosphere, the service module is jettisoned (Fig. 10). The command module is turned in orbit, placing the large blunt end forward in readiness for impacting the atmosphere. As the command module reenters, it is gradually braked by aerodynamic drag. Finally, at about 15,000 feet, the drogue chutes snap out, and then the three large orange-and-white parachutes open as the command module comes in for a splashdown in the Pacific Ocean.

The flight plan just outlined is the basic plan for a lunar landing and is essentially the one followed on the Apollo-11 flight. On each succeeding flight some slight variations were made in the plan as the mission required. The lunar flight plan represents a big jump from the simple plans for the Mercury flights in earth orbit. The astronauts were able to make this great advance because of the experience gained during Step 2, or the Gemini flights. On the Gemini flights the astronauts gradually increased the time spent in space, and they developed and practiced maneuvers, such as rendezvous and docking, which are needed for the lunar flight.

Developing and Practicing Maneuvers

Project Mercury, or Step 1 in the US manned spaceflight program, showed that man could survive orbital flight. From the vantage point of hindsight, this may seem obvious, but some medical experts had predicted that dire consequences would follow when the astronauts

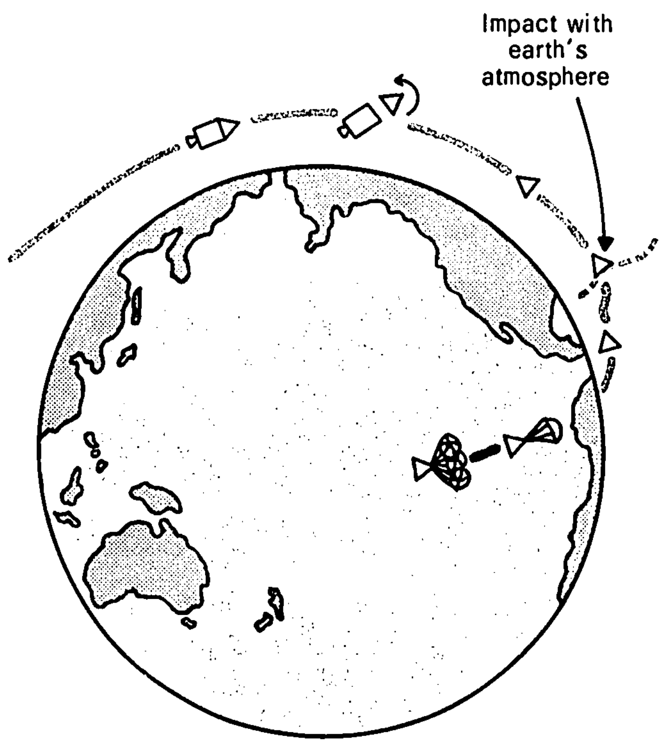


Figure 10. Return of the Apollo command and service modules to the earth and reentry of the command module.

were subjected to the extreme acceleration and deceleration of a rocket flight or when they were left weightless in orbit for hours at a time. Project Mercury logged some 53 man-hours of orbital flight. During the last Mercury flight Astronaut Gordon Cooper remained in orbit for about a day and a half. After the Mercury flights the astronauts could no longer be considered as guinea pigs in the experiment of spaceflight. They were ready to assume an active role as pilots of the spacecraft.

On the Gemini flights the astronauts had to achieve greater endurance and execute more complicated maneuvers to prepare them to go to the moon.

To achieve the necessary endurance, a flight of 14 days was set as a goal for the Gemini. If the astronauts could remain in flight for this length of time, they could survive a flight to the moon and back. The 14 days would allow enough time for the trip itself, which should not take more than 72 hours either way, and in addition clock enough time for a safety reserve and for stay time on the moon for exploration. To reach the goal of 14 days, the time in flight was increased gradually. The astronauts went from the 1.5-day record on the Mercury to 4 days on Gemini 4, and then 8 days on Gemini 5. Finally, on

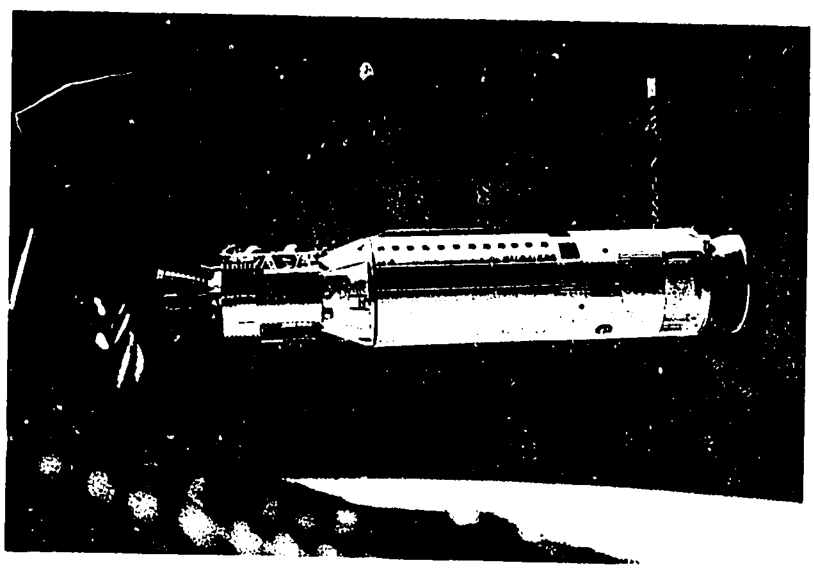


Figure 11. Agena target rocket photographed from the Gemini-8 spacecraft during rendezvous.

the Gemini–7 flight, made in December 1965, Astronauts Frank Borman and James Lovell stayed in orbit 14 days. After the record flight the astronauts were in excellent condition. They had established a world record for endurance in spaceflight that stood until June 1970, when the Soviet cosmonauts in the Soyuz 9 set a new record of almost 18 days. On Apollo 15 the mission will take 12 days, and on the last flights the time may be extended beyond 14 days.

The other goals for the Gemini flights, or Step 2, consisted of performing and perfecting key maneuvers like rendezvous, docking and making use of the engines in the target spacecraft, extravehicular activity (walking and working in space outside the vehicle), and modifying the direction of the capsule at reentry. These were the kinds of maneuvers that the Apollo astronauts would have to use on their trip to and from the moon and upon landing.

Whenever possible the Gemini astronauts practiced rendezvous, or finding a target in space and bringing about a meeting with it. On some of the flights, rendezvous was followed with docking, or the actual linking, of the Gemini with an active Agena target vehicle. The Agena target vehicle (Fig. 11) had a powerful rocket engine that could be refired in space. With the energy supplied by the Agena engine, the combined Gemini-Agena was able to go to a record height of 850 miles above the earth on the Gemini–11 flight.

At first, looking for another vehicle in space and trying to rendezvous with it was a little like looking for a needle in a haystack. Many people believed that, even with the help of advanced communications, rendezvous could never take place. If you have followed a rendezvous on television, the maneuver may have seemed to you like an automatic exercise. Rendezvous can now be made automatically, but orbits have to be calculated in advance. The astronauts are able to make a rendezvous today with apparent ease because they have practiced diligently and the calculations are made precisely. Out in space the laws of celestial mechanics take over, as you know. A space vehicle that is simply speeded up goes into a higher orbit and will never overtake the other vehicle left behind in another orbit. A space vehicle that is slowed down falls into a lower orbit.

The world's first rendezvous took place between the Gemini 6 and the Gemini 7 (Fig. 12), which established the endurance record. The meeting took place above the Pacific Ocean near Hawaii on 15 December 1965. Astronauts Walter Schirra and Thomas Stafford were flying in the Gemini 6, the spacecraft that made the rendezvous.

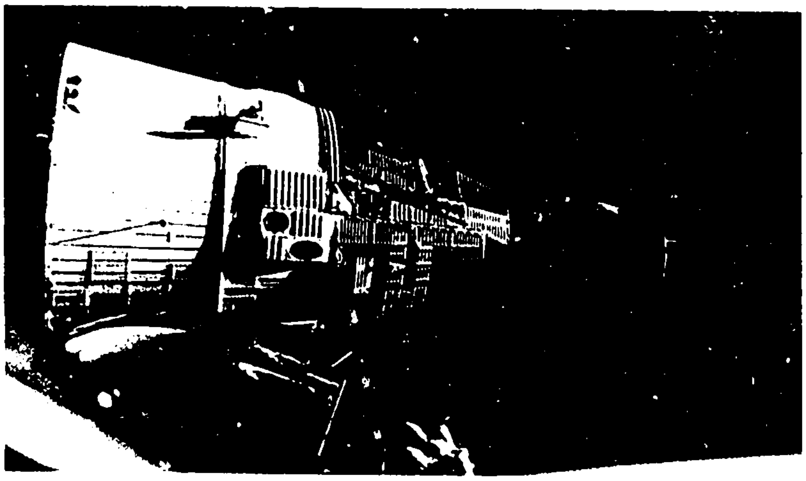


Figure 12. Gemini-7 spacecraft photographed from the Gemini-6 spacecraft during the world's first rendezvous and station keeping.

Schirra and Stafford compared their radar trackings with the ground tracks. The on-board equipment was working well, and the astronauts could have performed the entire maneuver without help from the ground. In all, eleven rendezvous maneuvers were made on the Gemini flights, and seven different ways of making a rendezvous were tried.

The first successful docking of the Gemini with the Agena target was accomplished on the Gemini–8 flight in March 1966. Astronaut Neil Armstrong carefully made the approach and linkup, but when the Gemini 8 was connected with the Agena target, the combined spacecraft began to spin wildly and threaten to go out of control. Unknown to anyone, one of the stabilization thrusters in the Gemini had short-circuited and kept firing, causing the difficulty and forcing an emergency return to the earth. On subsequent Gemini flights, eight more successful dockings were made.

Unlike rendezvous, extravehicular activity (EVA) proved to be somewhat more difficult to perform than ground tests had indicated. But the first space walk was dramatically successful. It was a 22–minute walk made by the late Astronaut Edward White on the Gemini–4 flight in June 1965. White did not fall when he stepped from the spacecraft but was supported by the same forces that held the spacecraft in orbit. Oxygen from the Gemini was supplied to White through the tube inside the tether (Fig. 13), which fastened him to the spacecraft. White experienced no disorientation, as had Soviet Cosmonaut Leonov, the world's first space walker. With the aid of a powered space gun, Astronaut White was able to maneuver successfully, but when the fuel for the gun was exhausted, he had difficulty controlling his movements. On later flights the Gemini astronauts were able to extend the time in extravehicular activity without becoming dizzy and disoriented, but they could not control their movements well enough to enable them to perform all the tasks planned for them. Finally, on the Gemini–12 flight, the last of the series, Astronaut Edwin Aldrin (Fig. 14) was able to complete all the space work planned for the Gemini flight. He had practiced the tasks beforehand by doing them underwater, where the feeling is much the same as in space. Aldrin also used

Figure 13. The first US space walk by the late Astronaut Edward H. White. Note the space gun and the tether.

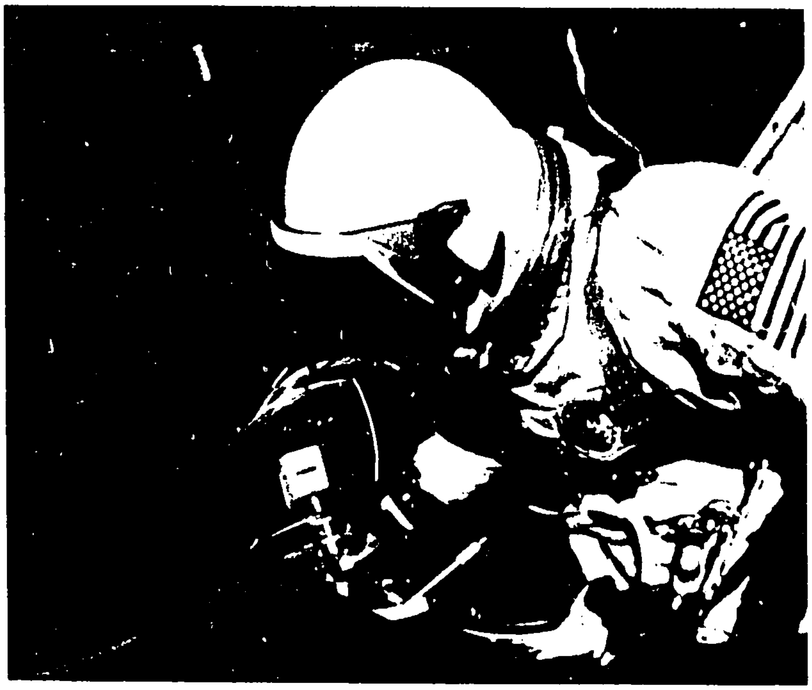


Figure 14. Standup EVA (extravehicular activity) by Astronaut Edwin Aldrin during the Gemini-12 flight. Aldrin is attaching a camera to the Gemini spacecraft.

another method for putting on the body restraints. The astronauts must use restraints, or belts, to secure them in position and keep them from floating about as they work in space.

In all, the Gemini astronauts engaged in extravehicular activity on five of their missions, totaling some twelve hours of such activity. This included space walking, standup extravehicular activity for taking photographs, and space work outside the Gemini. The Gemini astronauts showed that man can work and explore in the vacuum of space, whether just outside his spacecraft or on the surface of the moon.

While the Gemini astronauts were perfecting space maneuvers, engineers and scientists were at work completing the complex ground facilities needed for the Apollo flights.

GROUND COMPLEX

Most of the surface complex for the Apollo flights had been built up gradually since the beginning of spaceflight. Some of the facilities already in existence were modified to support the Apollo flights, and the communication network was extended to follow the astronauts into deep space. Other facilities were constructed especially for Project Apollo. The ground complex for the Apollo flights includes the worldwide operational communication and control system, the recovery system, the Manned Spacecraft Center, and the Apollo assembly and launch complex at Cape Kennedy.

The communication network for the tracking and control of the Apollo flights is made up of two groups of stations. The first group is used for controlling a flight when it is near the earth and the other when the flight goes beyond.

The first group, or network, of stations follows the Apollo spacecraft at launch, during earth orbit, and again when the trip to the moon is completed and the Apollo command module approaches the earth. This network includes fixed land stations with 30–foot antennas, a transportable station, and instrumentation ships and aircraft.

The second network includes three stations with dish-shaped antennas 85 feet in diameter, which are part of the NASA Deep Space Network. As the Apollo leaves earth orbit and starts toward the moon, the long-distance stations take over. These stations, with their powerful

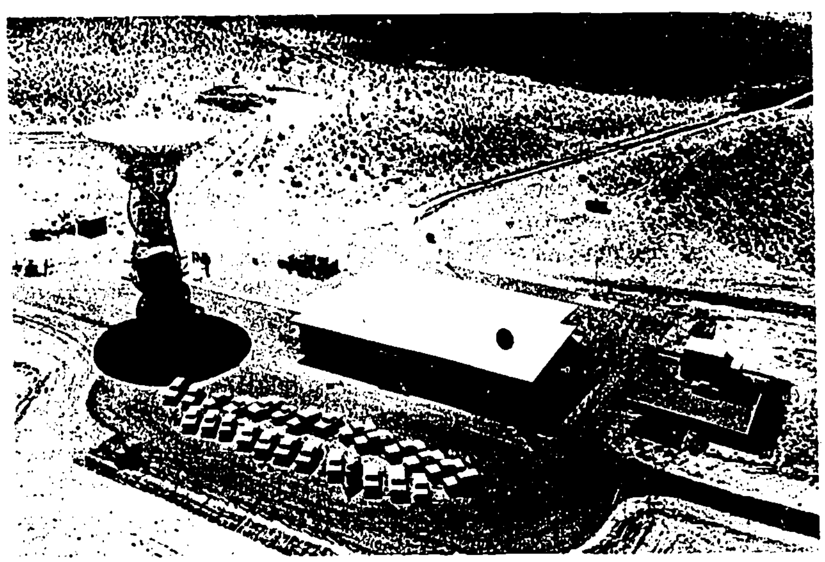


Figure 15. Large dish antenna (210 feet in diameter) at Goldstone, California. This is part of the NASA Deep Space Network.

transmitters and sensitive receivers, are dependable for communications at great distances. The stations are located at Goldstone, California; Madrid, Spain; and Canberra, Australia. They are about one-third of the earth's circumference, or 120 degrees, apart. As the rotating earth cuts off one station from contact with the Apollo, the next station rises above the horizon and takes over. Work is underway to extend the Deep Space Network by constructing a 210-foot antenna at each of the three sites. The larger antenna at Goldstone (Fig. 15) has already been completed and is being used for the Apollo moon flights. When all three of the larger antennas are ready for use sometime in 1973, the expanded Deep Space Network will provide for communications throughout the solar system.

All tracking for the Apollo flights is coordinated at the Manned Spacecraft Center at Houston. This center has operational control over all ground facilities supporting the Apollo flights. It receives tracking and telemetry data on manned flights from the ground network worldwide. The center brings all this information together, and its controllers send instructions to the astronauts during their mission. The controllers make use of a large computer complex, which can work out a whole series of alternate courses of action for the astronauts. The remarkable job that the controllers do in relaying instructions to the astronauts and in enabling them to return safely to the earth was shown during the Apollo-13 emergency.

Besides being a communication center, the Manned Spacecraft Center serves in other ways as part of the Apollo ground complex. Here the astronauts receive training, and here the Lunar Receiving Laboratory is located. This laboratory was used for quarantining the astronauts and the samples they brought back with them following the first three lunar landings. When scientists were sure the moon harbored no organisms that would spread disease on the earth, quarantine was no longer enforced. The Apollo-14 astronauts were the last ones to be quarantined. The Lunar Receiving Laboratory continues to be used for handling and distributing the rock and soil samples that the astronauts bring back from the moon.

The Apollo moon launches were made from the special assembly and launch complex (Launch Complex 39) at Cape Kennedy. Here the three stages of the Saturn V booster are brought together. The first stage came in by barge from the Mississippi test facility by way of the Gulf of Mexico, the second stage by barge from California by way of the Panama Canal, and the third stage by a giant transport aircraft.

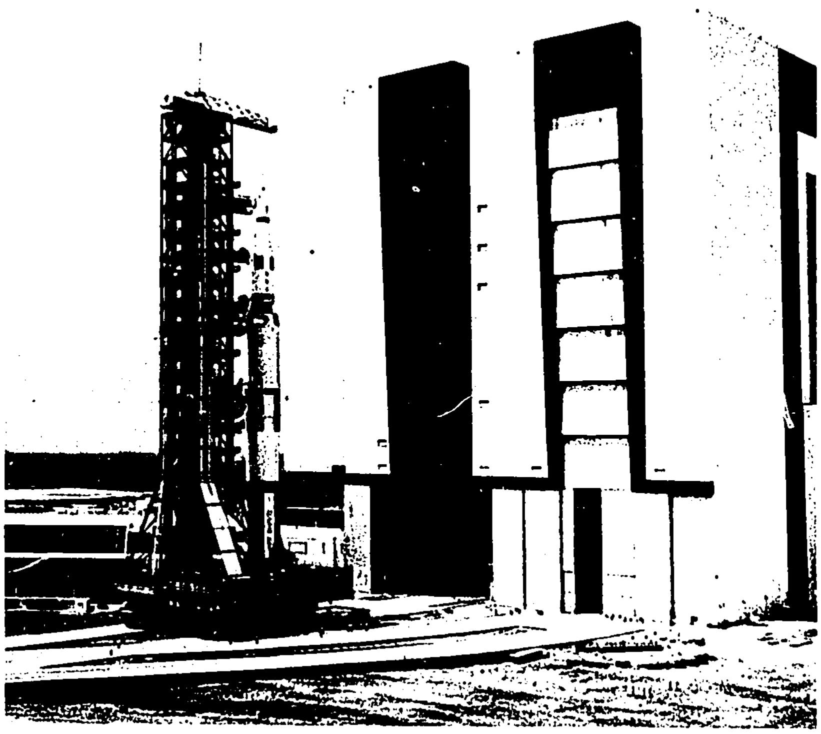


Figure 16. Vertical Assembly Building (VAB) at Cape Kennedy. Here the Apollo spacecraft and the Saturn V booster are assembled for the flight to the moon.

Within the Apollo complex at Cape Kennedy is the unique Vertical Assembly Building (VAB). This massive building (Fig. 16), the largest in the world when its construction began, is 525 feet high and has a volume of 129.5 million cubic feet. The leader of the team of architects who designed the building described it as "not so much a building to house a Moon Vehicle as a machine to build a Moon Craft." In the high bays of this building the three stages of the giant Saturn V are assembled and then mated with the Apollo spacecraft. The parts are checked separately and then together. The building, if completely outfitted, could accommodate four Saturn Vs at one time. Because of the deafening noise and the shock waves generated by the Saturn V as it roars into space about three miles away, the VAB was constructed without windows. Translucent panels of plastic were substituted, and an air-conditioning system was installed to keep clouds from forming within the vast interior.

After the Saturn V and the Apollo spacecraft are assembled in the VAB, they are transported intact to one of two launch pads. To move the assembly, a special giant crawler about the size of a baseball infield was built. This crawler operates much as a caterpillar tractor does. It transports the booster and spacecraft along a runway as wide as an eight-lane highway. The assembly, which will soon soar into space at a breathtaking speed, moves along at about one mile per hour, slowing up as it goes around the bend and then up the ramp to the pad.

When the Apollo is made ready for a launch, the whole Apollo complex at Cape Kennedy hums with activity. Preparations reached their first peak in anticipation of the flight tests of the hardware and the first manned launches.

TESTING THE APOLLO SPACECRAFT AND ITS BOOSTER

Since much of the burden of proving the Saturn V booster had been placed on ground tests, there were tense moments when the first Saturn IB boosters were test-flown with flight equipment. On their first unmanned tests, the Saturn boosters gave a magnificent performance. The engineers were also satisfied that the Apollo heat shield had proved itself and could withstand the intense heat that would be generated at reentry into the earth's atmosphere upon return from the moon. Confidence was high as preparations went forward for the first manned flight. Then, in January 1967, tragedy struck when least expected.

The three astronauts assigned to the first flight—veterans Virgil Grissom and Edward White and a new candidate for a space mission, Roger Chaffee—were testing the Apollo command module on the pad to see if there was any leakage of oxygen. Suddenly a fire broke out in the wiring. The booster was not even fueled, but the oxygen in the Apollo capsule had been increased to higher than atmospheric pressure for the test. The flames spread rapidly, and the astronauts perished before they could open the hatch to reach safety. A board of inquiry conducted an investigation and recommended that the command module be made fireproof.

During the dark days that followed, those responsible for the Apollo flights concentrated on their tasks with a new sense of dedication. Everyone was determined to show that these three brave astronauts had not died in vain and that their work would go forward. While the command module was being made fireproof, all the remaining unmanned tests of the hardware were made, including the test of the lunar module. It was almost two years before these tests were completed and the improved command module was ready for the astronauts. By this time the hatch in the command module had been redesigned to make it open more easily, and new fireproof material was used in the command module and the moon suit. In addition, a mixture of oxygen and nitrogen was to be used for testing the module on the ground.

The first manned Apollo flight, designated Apollo 7, was made in earth orbit. This was followed by three other manned flights made in rapid succession. The first four manned flights (Apollo 7, 8, 9, and 10) were made alternately in earth orbit and lunar orbit (Fig. 17).

Apollo 7 (Earth Orbit)

In October 1968, the Apollo 7, resting on the smaller Saturn IB was ready for a flight into earth orbit. Much time had been lost, but there was still enough time to make the landing before the end of 1969 if all went well. The commander of Apollo 7, Astronaut Wally Schirra (Fig. 18), then a 45-year-old Navy captain, brought to the Apollo some of the confidence built up during the flights of the Mercury and the Gemini. Schirra had flown the next to last Mercury flight, which had become known as the "textbook flight" because everything had gone according to plan. He was also pilot of the Gemini 6, which had made the world's first successful rendezvous. Schirra was ably supported by two space rookies, Astronauts Donn F. Eisele, a 38-year-old Air Force major, and Walter Cunningham, a 36-year-old civilian, who had formerly been a Marine and a research scientist.

After making a successful launch, the Apollo 7 orbited the earth twice. At just about the point where the refiring of the attached booster would take place on a lunar flight, the Apollo–7 astronauts pulled the command and service modules away from the top stage of their booster. Then the astronauts began to make tests of the systems in the command module to see if they would actually work in space. At first the astronauts were troubled with small problems, but, as the flight progressed, the situation improved markedly.

Apollo Manned Flights

(Launched October 1968 through January 1971)

Apollo Flight No.	Astronauts[a]	Date	Flight plan	Main events
7	Schirra Eisele Cunningham	11–22 Oct. 1968	Earth orbit	Tested command and service modules; 163 rev.
8	Borman Lovell Anders	21–27 Dec. 1968	Lunar orbit	Tested flight on earth-moon trajectory; 10 rev. of moon.
9 . . . . . . (Gumdrop and Spider)	McDivitt Schweickart Scott	3–13 March 1969	Earth orbit	First flight with complete Apollo spacecraft; docking command and service modules with lunar module; 151 rev.
10 . . . . . . (Charlie Brown and Snoopy)	Stafford Cernan Young	18–26 May 1969	Lunar orbit	Final preparation for lunar landing; separation and descent of lunar module to a point about 9 miles above proposed landing site; 31 rev. of moon.
11 . . . . . . (Columbia and Eagle)	Armstrong Aldrin Collins	16–24 July 1969	Lunar landing	World's first lunar landing; explored site on Sea of Tranquility, conducted first solar wind experiment, and set up a seismometer and a laser reflector. One EVA, 2 hr. 31 min.; total stay time, 21 hr. 36 min.
12 . . . . . . (Yankee Clipper and Intrepid)	Conrad Bean Gordon	14–24 Nov. 1969	Lunar landing	Explored site on Ocean of Storms, put down first complete ALSEP, and recovered parts from Surveyor 3. Two EVAs, total 7 hr. 39 min.; total stay time, 31 hr. 31 min.
13 . . . . . . (Odyssey and Aquarius)	Lovell Haise Swigert	11–17 April 1970	Lunar landing (not made)	Fire and explosion in service module; rescue operations using lunar module as lifeboat; safe recovery in Pacific Ocean.
14 ______ (Kitty Hawk and Antares)	Shepard Mitchell Roosa	31 Jan.– 9 Feb. 1971	Lunar landing	Explored Fra Mauro region, put down second ALSEP and second laser reflector, and took samples from near top of Cone Crater. Two EVAs, total 9 hr. 25 min.; total stay time, 33 hr. 31 min.

[a] On the flights making the lunar landing, the first astronaut named above (commander) and the second (pilot of the lunar module) are the two moon-landers. The third astronaut (pilot of the command module) remains with the command and service modules and orbits the moon while the other two astronauts are on the moon.

Figure 17.

One of the most important tests was to try out the powerful rocket engine in the service module. Eight firings were made, giving the Apollo 7 great bursts of power that caused it to change orbit. The tests showed that the big engine could be expected to work well on the trip to the moon. Then the astronauts would rely upon it for making mid-course corrections and for giving them the powerful boost they would need to send them on a trajectory back to the earth.

Another memorable feature of the Apollo–7 flight was the television broadcast. The program, called the "Wally, Walt, and Donn Show," gave the American public a realistic idea of what it is like to live in the weightless condition in a spacecraft. These were the first successful live telecasts from American astronauts.

Through the flight of the Apollo 7, the American public was given a new insight into spaceflight, and confidence in the Apollo flights reached a new high. After the astronauts were successfully recovered, George M. Low, then manager of the Apollo spacecraft, said that the mission had "accomplished 101 percent of the planned objectives." He

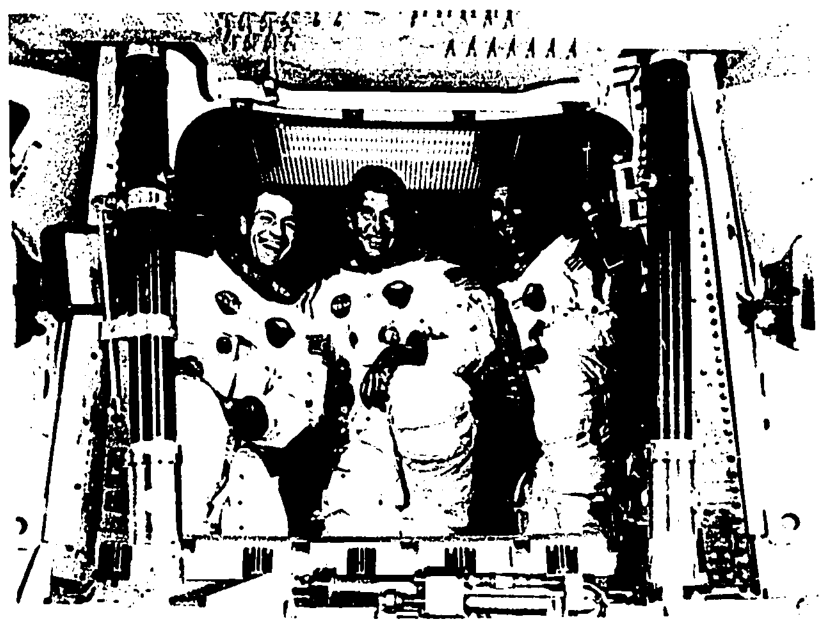


Figure 18. Apollo-7 crew during training. Astronauts on the first manned Apollo flight were (left to right) Donn F. Eisele, Walter M. Schirra, and Walter Cunningham.

chalked up the extra 1 percent because the flight controllers gave the astronauts more tests than planned.

Even before the Apollo–7 astronauts returned to the earth, a simulation was being made of the Apollo–8 flight, the first to go to lunar orbit.

Apollo 8 (Lunar Orbit)

With the flight of Apollo 8, the American astronauts were to make a giant step forward. Up to this time all manned spaceflights had been made relatively close to the earth. Even at the highest point of their highest orbit, the astronauts had not gone more than about 850 miles from the earth. These earlier flights might be thought of as coastal voyages along the planet earth. Now the astronauts were to venture out on the open ocean of space to go to the moon about a quarter of a million miles away. Also, this was to be the first manned test of the Saturn V, which had been test-flown only two times before.

Apollo 8 was commanded by Frank Borman, a 40-year-old Air Force colonel, who had commanded the Gemini–7 endurance flight. He was accompanied by James Lovell, a 40-year-old Navy captain, who had also flown on the Gemini 7. Later Lovell commanded the Gemini 12, the last Gemini mission. The third astronaut assigned, William Anders, a 35-year-old Air Force major, was a seasoned pilot, but he was new to spaceflight

The Apollo 8 began its flight on 21 December 1968. After making almost two orbits of the earth, the astronauts fired the third stage of the Saturn V, which had remained attached to the spacecraft. The burst generated power to propel the Apollo into a translunar injection, giving it a speed of more than 24,000 mph. On the third day of the flight, 23 December, when the Apollo was almost 206,000 miles from the earth, it reached the imaginary line where the gravitational pull of the earth no longer prevails and that of the moon takes over. By the time it reached this point, the spacecraft had slowed down to only somewhat more than 2,200 mph. The Apollo 8 was the first spacecraft piloted by man to come under the gravitational influence of another heavenly body.

If no further action had been taken, the Apollo 8 would have swung around the far side of the moon, aided by the lunar gravitational force, and then begun its flight back to the earth on an elongated elliptical orbit. The spacecraft was on what is called a free-return trajectory. But the Apollo–8 astronauts, like those imaginary travelers in Jules Verne's story, were not to simply loop around the moon and return to the earth. The Apollo–8 astronauts were to make repeated orbits of the moon. To bring their spacecraft into lunar orbit, they had to fire their rocket engine to change their trajectory.

Unfortunately, the astronauts had to fire the large rocket engine in the service module while they were behind the moon and out of touch with the NASA Deep Space Network and the controllers at the Manned Spacecraft Center. Great was the tension while contact with the astronauts was broken off. Had all the calculations been made correctly, and would the Apollo actually orbit the moon? The controllers waited some 20 minutes before the spacecraft emerged from behind the moon. Then Astronaut Lovell, in a matter-of-fact voice, announced the dimensions of the orbit. Its lowest point was to be about 70 miles above the moon.

As the astronauts orbited the moon, they observed the features below them and the full earth in the distance. This was indeed an auspicious moment in history. The astronauts shared their views with the world's television public through two telecasts of the moon. During the second telecast, made on Christmas Eve, the three astronauts took turns reading from the Bible the awesome words from Genesis describing Creation while the lunar scenery flashed into view below.

After completing ten orbits of the moon, the Apollo–8 astronauts fired the large rocket engine in the service module once more and headed back to earth. As the Apollo capsule reentered the earth's atmosphere, it was once more traveling at a speed of more than 24,000 mph. At this time only the command module remained. All the other parts of the Apollo had been discarded in space. The astronauts were recovered in the Pacific Ocean (Fig. 19) and later welcomed as heroes.

The lunar landing could not be far away. But first the astronauts would have to practice more of the complex maneuvers with their equipment, especially with the lunar module.

Apollo 9 (Earth Orbit)

The Apollo–9 flight, first scheduled for February 1969, was delayed until March. All the equipment had to be in first-class condition, as the Apollo 9 was to be the first flight to carry all the modules in readiness for testing the complex maneuvers that would be required for the lunar landing. Although the Apollo 8 had flown to lunar orbit, it did not carry with it an actual lunar module, only a dummy for ballast. The Apollo 9 was to launch with the first lunar module folded down inside the adapter, and this was to be tested during the flight.

Figure 19. Apollo-8 crew coming aboard recovery ship in the Pacific Ocean. Left to right are Frank Borman, James Lovell, and William Anders.

Much significance was attached to the tests of the lunar module, as this strange-looking vehicle was the only really new piece of flight equipment on the Apollo. Although much effort had been devoted to designing and building the lunar module and simulating its flight on the ground and in the earth's atmosphere, there was still some uncertainty about how it would perform in space. Difficult tasks had to be performed by the module if the lunar landing was to be successful. Further, the lunar module was not intended for long occupancy, and it was not protected with a heat shield that would enable it to return to the earth. Once the lunar module had been separated from the command module and the astronauts fired the descent engine in the lunar module to propel it away from the command module, they knew that they could survive in space for only a limited time. Then they would have to rendezvous and be docked with the command and service modules.

The Apollo 9 was under the command of Astronaut James McDivitt, a 39-year-old Air Force colonel and a veteran of the Gemini–4 flight, during which the late Astronaut Edward White had made the first US space walk. Astronaut David Scott, a 36-year-old Air Force colonel, was assigned as the pilot of the command module. Scott had made his debut in space on the troubled Gemini–8 flight along with Astronaut Neil Armstrong. Astronaut Russell (Rusty) Schweickart, a 33-year-old civilian, once an Air Force pilot, was assigned as pilot of the lunar module.

Although the Apollo 9 was to remain in earth orbit, it was launched by the giant Saturn V booster, and the launch was made from the moon port at Complex 39. The larger booster was needed because the Apollo 9 carried full flight equipment for a lunar landing, and the modules were fuelled in readiness for a series of test maneuvers.

About three hours after launch, the maneuvers began. The first was the difficult maneuver that is made early in the flight toward the moon, the turnaround and docking of the command and service modules with the lunar module. Astronaut Scott steered the command-service modules to move backward and turn around for docking with the lunar module. The two parts were linked and then locked together. The electrical systems were then connected and checked. Later Scott pressed a switch to release the third stage of the Saturn V rocket, which had remained attached to the lunar module. The propellant was dumped through the engine to shoot the stage off into space. The first crucial test had been successful.

The second day was taken up with checking the spacecraft's guidance and navigation systems.

On the third day of the flight the astronauts made the first manned test of the lunar module. They called it the Spider in order to identify it in radio communications. The combined command and service modules were nicknamed the Gumdrop. Pilot Scott remained in the Gumdrop, and McDivitt and Schweickart, who represented the moon-landers, moved through the tunnel and into the Spider. There they spent about nine hours, making a thorough check of all systems in preparation for use.

Astronaut Schweickart was to engage in extravehicular activity (EVA), a space walk to test the portable life support system (PLSS)

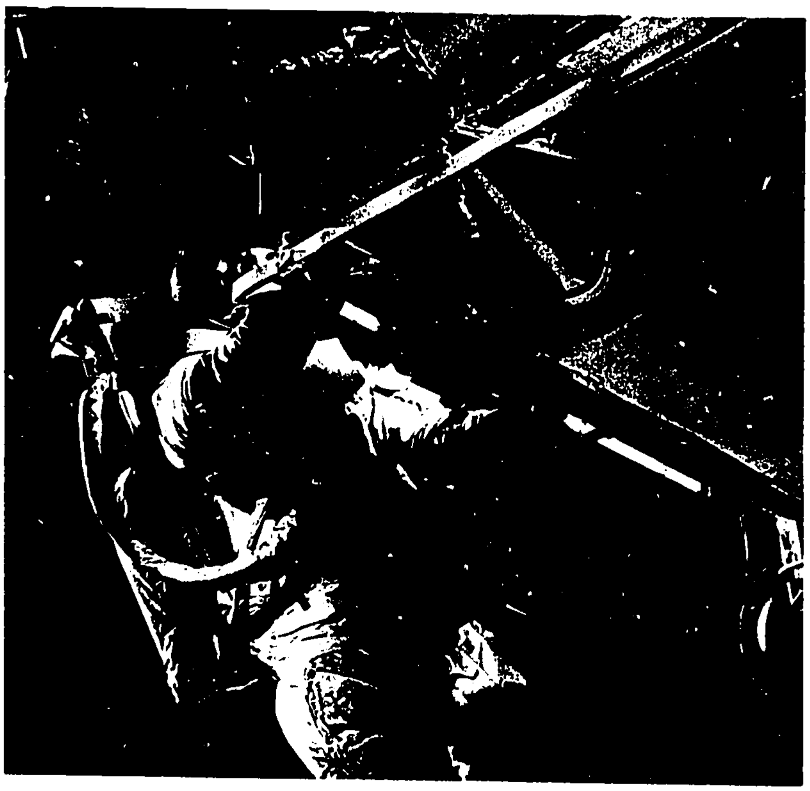


Figure 20. EVA with the Spider (lunar module) during the Apollo.9 flight. Rusty Schweickart is holding to the hand rails. Note his backpack.

that would be used on the moon. Unfortunately, Schweickart was plagued with airsickness, which developed as he moved about the spacecraft. On the fourth day, Rusty and his companions were able to get some rest, and he and the other astronauts recovered from their minor illnesses. Schweickart was then able to make a space walk to test the backpack (Fig. 20). This was the first time this equipment was tested in flight. With the backpack in use, Schweickart became a miniature spacecraft, as he was able to exist solely from the life support supplies in the backpack. No oxygen was piped th-ough a tether to supply his space suit.

On the fifth day the Gumdrop and the Spider went through what wa: probably the most difficult maneuver of all. This was a simulation of the descent to the moon and of the rendezvous and docking with the command module (Fig. 21) after the exploration had been completed. After McDivitt and Schweickart made sure that the Spider was functioning as it should, they fired the small rockets that pulled the

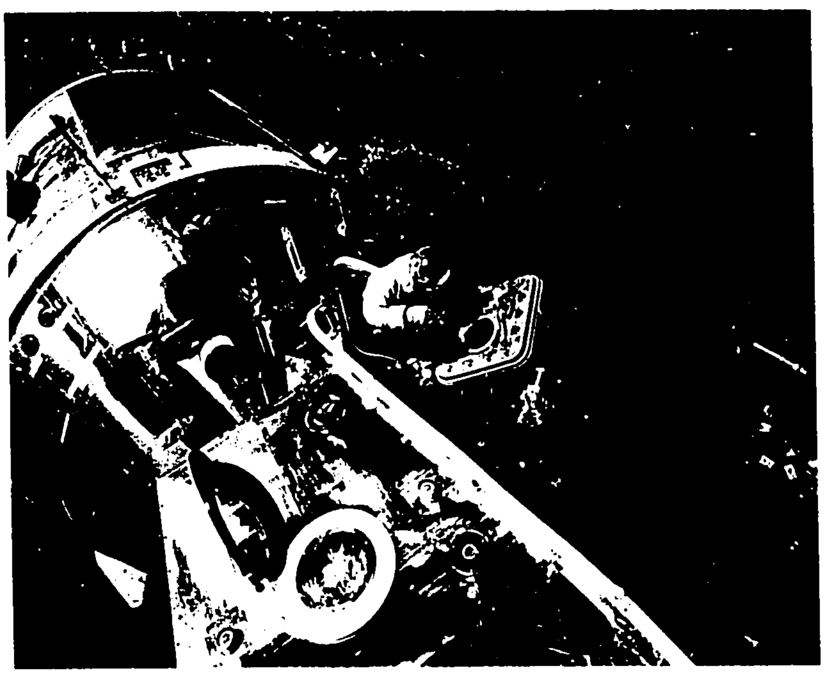


Figure 21. The Gumdrop (command module) docked with the Spider during the Apollo-9 flight. Astronaut David Scott, command module pilot, is preparing for EVA. The earth is in the background.

Spider away from the Gumdrop. Then the test began. Firing the descent engine, they propelled the Spider into a higher orbit. After they had checked the position of the Gumdrop, they fired the descent engine again. Then they released the lower stage of the Spider, which would be used as a launch platform on the moon. This action exposed the ascent rocket, allowing McDivitt and Schweickart to check it. Then the two astronauts located the Gumdrop again and practiced rendezvous. It was an elated Scott, alone in the Gumdrop, who saw the Spider coming back into view. Once the three astronauts were together in the Gumdrop again, the remaining part of the Spider was jettisoned in space. The most difficult test was over, and the results had been successful beyond expectations.

The remaining five days in orbit were spent in checking and rechecking systems and in repeating maneuvers, thus enabling the astronauts to gain additional confidence in their equipment. When the Apollo–9 astronauts were safely recovered, plans were already underway for a dress rehearsal of the lunar landing.

Apollo 10 (Lunar Orbit)

When the Apollo–10 flight was first scheduled, it was planned as the lunar landing. During the year that followed the scheduling, problems had developed which showed that one more flight was needed before the landing. The Apollo–10 flight, scheduled for May 1969, would provide a dress rehearsal for the landing. It would put together all the experience gained with the Apollo 7, 8, and 9, but, most important of all, it would allow for more practice with the lunar module. The final practice would be conducted in the vicinity of the moon, not in earth orbit.

Naturally the astronauts were disappointed when they found out that they would not make the first landing, but they bowed to necessity. All three astronauts selected for the Apollo 10—Thomas Stafford, Eugene Cernan, and John Young—had flown in the Gemini, and two of the astronauts, Stafford and Young, had made two Gemini flights. All three astronauts had been practicing for the lunar landing for over a year. The commander was the 38-year-old Stafford, an Air Force colonel. He was to fly the lunar module with Cernan, a 35-year-old Navy commander. Young, a 36-year-old Navy captain, would pilot the command module.

To identify their modules for communication, the Apollo–10 astronauts dubbed the lunar module Snoopy and the combined command-service modules, Charlie Brown after the characters in the popular "Peanuts" comic strip.

Following an almost perfect launch, the Apollo 10 orbited the earth one-and-a-half times. Then the astronauts refired the engines in the third stage of the Saturn V to send the spacecraft toward the moon at a speed of more than 24,000 mph. The turnaround by Charlie Brown and docking with Snoopy was made, and the flight out was smooth. The astronauts were not bothered by colds and nausea. When the Apollo 10 reached the vicinity of the moon, the astronauts fired the large engine in the service module, and the spacecraft went into orbit around the moon. Then the astronauts tested the color television equipment and gave the public the first view of the lunar features in color.

Early the next morning, Stafford and Cernan crawled through the tunnel into Snoopy, the lunar module. After testing the systems, they fired the descent engine to take them down to a point about 9 miles above the target area selected for the first landing. At this altitude Stafford and Cernan could get a good view of the smooth lunar plain below, and they could be reached by Young in the command module, if necessary. After the astronauts surveyed the site, Snoopy began to climb in orbit.

Stafford and Cernan were preparing for a second low pass over the proposed landing site when Snoopy began to act strangely. The astronauts had just jettisoned the lower stage of the module when the top stage went into a swift spin and began to shake violently. Stafford took over control. After some tense moments, he finally steadied the spacecraft. Then the astronauts made a second low pass over the landing site. As they looked over the scarred surface of the moon, Cernan remarked, "This moon of ours . . . had a rough beginning somewhere back there." On later flights astronauts would land to find clues about this beginning, but this flight was made only to prepare for a landing. Consequently, Stafford and Cernan fired the ascent engine and took Snoopy back to rendezvous with Charlie Brown (Fig. 22).

As the Apollo 10 completed the 31 orbits planned, the astronauts made careful observations of the lunar features coming into view below them. Then they telecast some more dramatic pictures of the moon as it receded in the distance. The astronauts ended their telecast by showing earth dwellers a new view of their planet as seen from the vicinity of the moon (Fig. 23).

Snoopy's wild behavior after the jettisoning of the lower stage was explained by the fact that a technician on the ground had left a control switch in the wrong position and the astronauts had not noticed this in checking. But there was another question raised by the Apollo-10 flight that could not be answered so easily. On both lunar flights, the Apollo 8 and the Apollo 10, the ground controllers had noted irregu-

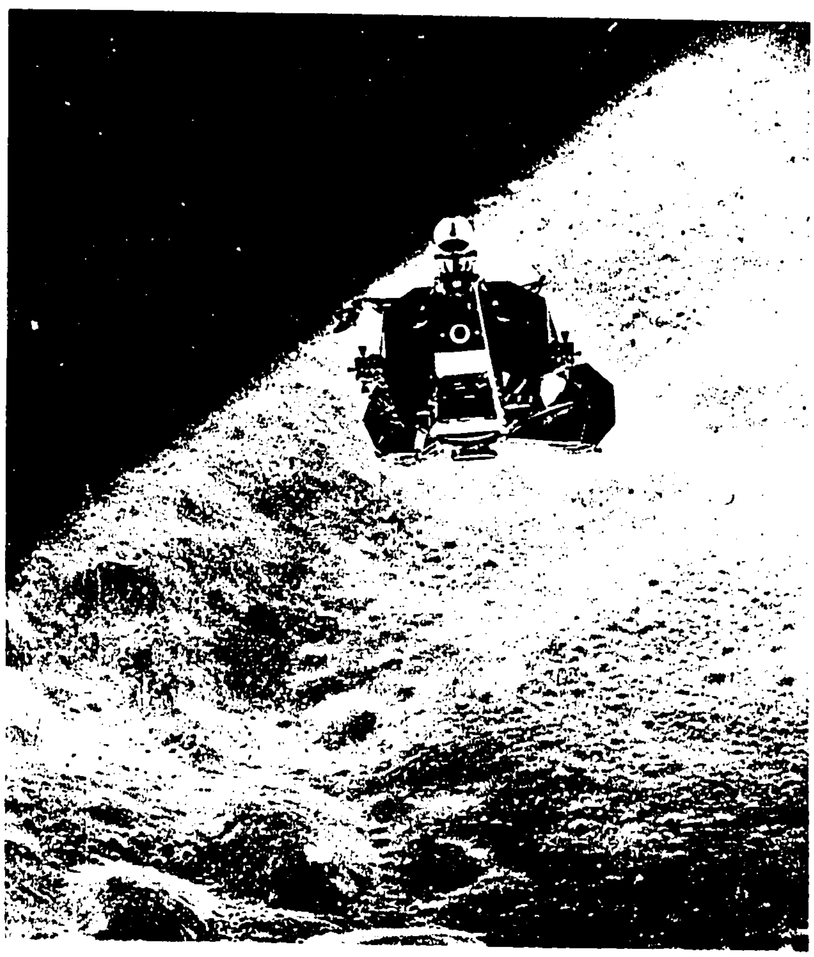


Figure 22. Snoopy (lunar module) preparing to rendezvous during the Apollo-10 flight.

Figure 23. View of the earth as seen by Astronauts Tom Stafford, John Young, and Eugene Cernan during the Apollo-10 flight. The west coast of North America is visible, but the rest of the land mass is obscured by clouds.

larities in the moon's gravitational field as the astronauts orbited the moon. When the spacecraft's flight path was traced, it showed "periwiggles," or slight deviations from the elliptical orbit. Further study revealed that there were concentrations of mass in the moon just below these points. As one lunar expert explained it, the moon is like a tremendous cake with raisins embedded in it. The "raisins," or mascons, as they are called, are associated with the large circular seas. For purposes of flight, however, it was enough to know that there were these deviations in the orbit, and the computer in the lunar module had to be programmed to take them into consideration.

After the Apollo-10 astronauts were safely recovered, NASA Administrator Thomas Paine announced that the Apollo 11, scheduled for flight in July 1969, would make the lunar landing. The announcement was made almost exactly eight years to a day after President Kennedy had first proposed the landing. Many obstacles had been overcome in the meantime, and even the Soviets were beginning to predict that the Americans would be the first men on the moon. But the astronauts knew that overconfidence could be dangerous.

LUNAR LANDINGS

After witnessing four successful Apollo flights, the American people had high hopes that the first lunar landing would be made as scheduled. Almost all the complex maneuvers that had once seemed impossible had now been made. During the Apollo flights the public had had an opportunity to become familiar with the flight plan for a lunar landing, and their expectations mounted as the launch date approached. The first lunar landing would mark the climax of a decade of hard work, and it would achieve America's Number 1 goal in space.

To the scientist, the lunar landing would not be the high point of achievement but rather the beginning of firsthand exploration of the heavenly bodies. Further, because the Apollo 11 would have to test out for the first time the complete descent to the moon and then the ascent, it would carry only the smallest amount of scientific equipment. During later landings the astronauts would be able to carry more equipment and would stay longer on the moon. But the scientists also looked to the first landing with great expectation. The first actual observations made by a man on the moon promised to give them new insight, and the first samples of lunar rocks and soil would certainly give them new clues to the moon's history. Whether from the point of view of science or of flight and technology, the first lunar landing promised to be an event to be recorded for all time.

Apollo 11

The astronauts assigned to the Apollo–11 flight, like those on the Apollo 10, had each made a flight on the Gemini. Neil Armstrong, the commander, a 38-year-old civilian, had brought the troubled Gemini 8 under control and guided it down for an emergency landing. Edwin (Buzz) Aldrin, a 39-year-old Air Force colonel, had commanded the Gemini 12. Michael Collins, a 38-year-old Air Force colonel, had walked twice in space during the Gemini–10 flight, which had also made two successful rendezvous.

The three astronauts selected for the momentous flight had trained for a long time, and each had other experiences that fitted him for the flight. Armstrong, once a Navy combat pilot, had earned a degree in aeronautical engineering and had been one of the most outstanding pilots of the X–15. Aldrin, also an Air Force combat pilot, had earned a doctor of science degree, specializing in astronautics. He had once been assigned to the Manned Spacecraft Center as an expert in orbital mechanics. Collins, who was to pilot the command module, had a reputation as an outstanding test pilot.

To identify the modules of their spacecraft, the Apollo–11 astronauts called the combined command-service modules the Columbia, another name for the United States, and the lunar module the Eagle, the bird that is a national symbol. These seemed fit names for a spacecraft destined to make a historic voyage.

As crowds of visitors thronged Cape Kennedy, the astronauts remained in isolation to avoid any contact with strange viruses. They even had to turn down an invitation to have dinner with the President of the United States on the night before their flight.

The Apollo 11 was launched on 16 July 1969 and went into a parking orbit above the earth. After orbiting one-and-a-half times, the astronauts fired the third stage of the Saturn V booster. and they were off on the translunar injection.

While the Apollo 11 was on the way to the moon, some concern was felt because an unmanned Soviet spacecraft, Luna 15, was also on the way to the moon. Would the Soviets attempt to upstage the Americans by landing a robot to collect moon samples and return them to the earth? Would Luna 15 interfere with communications with our astronauts? Astronaut Frank Borman, who had recently visited the Soviet Union on a goodwill tour, made a telephone call to the Soviets to get information about the Luna 15. The Soviets assured the American people that the Soviet spacecraft would in no way interfere with the landing. Americans breathed easily once more. The Luna 15 crashed onto the moon. It was not until a year later, when the Soviets landed a successful robot sampler (Luna 16), that Americans learned that their earlier surmise had been correct.

After the reassuring telephone message, the public relaxed, but tension built up on the ground once more as the Apollo 11 looped behind the moon. Would the engine in the Columbia fire to send the Apollo

11 into orbit around the moon? The ground controllers were once more reassured as Armstrong calmly announced a successful burn. On 20 July, Armstrong and Aldrin made the final check of the Eagle as it was in orbit with the Columbia about 70 miles above the moon.

When the spacecraft was behind the moon on its 13th orbit, the astronauts separated the Eagle from the Columbia and presented the Eagle for inspection. "The Eagle has wings," Armstrong announced.

Then the moon-landers began their descent on a trajectory almost identical with that used by the Apollo–10 astronauts. When the Eagle was hovering over the intended landing site, Armstrong and Aldrin were startled to see below them a crater strewn with rocks and boulders. Some slight errors had built up during translunar and orbital navigation. Armstrong took over partial control of the Eagle to keep it from landing while the overloaded computer signalled a warning. Finally, as the fuel was just about exhausted, Armstrong spied a suitable spot and brought the Eagle down. Then he notified Mission Control: "Houston, Tranquility Base here. The Eagle has landed." It was 4:17 P. M. EDT on 20 July 1969. Mission Control reported the landing to Collins, orbiting in the Columbia above the moon. The Eagle had landed about four miles west of the planned location but well within the landing zone. For some time, however, the ground controllers had difficulty in locating the exact site on their maps.

The flight plan called for the lunar excursion to wait until Armstrong and Aldrin had a four-hour rest period and a chance to eat and check their equipment. The astronauts had to be in top physical condition to enable them to face the hazards that might await them on the moon. Once outside the Eagle, they would have to depend entirely on their backpack, the Portable Life Support System (PLSS). The moon, as you know, has no air or water, and the temperature on its surface may reach 250 degrees F. in the sun and slightly more than the same amount below zero at night or in the shadows. Day was just beginning to dawn as the astronauts landed.

After Armstrong and Aldrin made preliminary observations from the windows of the Eagle, they were eager to get out on the moon. They asked Mission Control to advance the time for the exploration. Permission was granted. Then the world had to wait. The astronauts had difficulty venting the oxygen from the Eagle and checking their equipment.

At 10:56 P.M. EDT Armstrong slowly made his way down the ladder. At the time the lunar dawn was advancing, and the light cast eerie

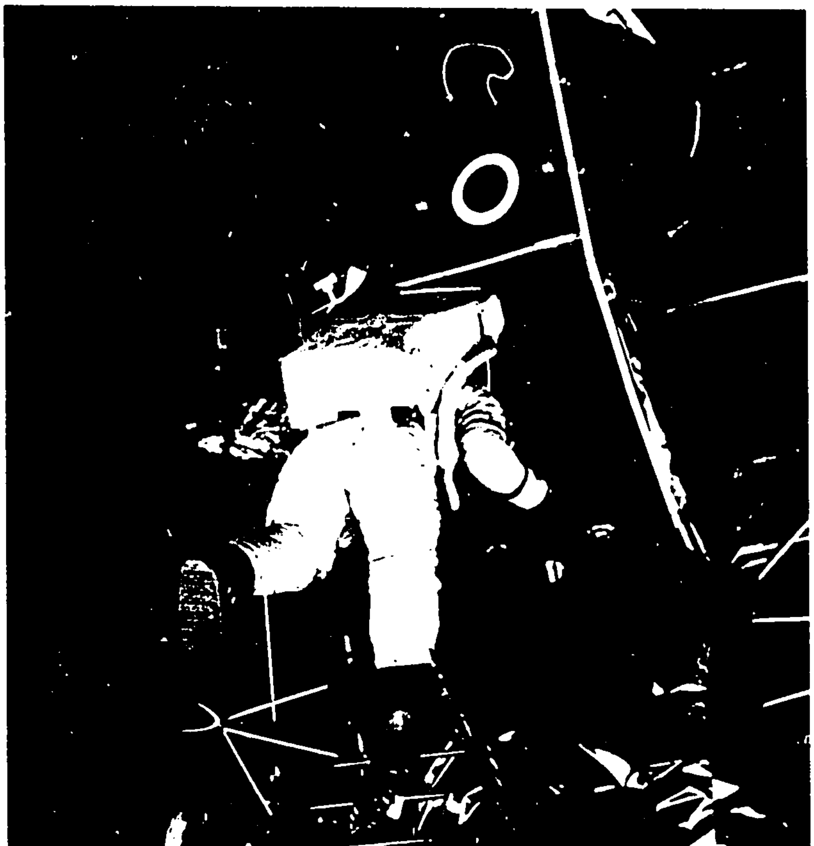


Figure 24. Astronaut Aldrin emerging from the Eagle. The photograph was taken by Astronaut Neil Armstrong, the first man to step onto the moon.

shadows. As he reached out to plant his boot on the moon, Armstrong said: "That's one small step for a man, one giant leap for mankind."

One of the first moves that Armstrong made was to plant the television camera on the surface so that the astronauts might share their experiences with people on the earth. About 20 minutes after Armstrong emerged from the Eagle, Aldrin began to make his way cautiously down the ladder to join Armstrong (Fig. 24). One of the astronauts' first jobs was to collect the contingency sample, the sample that would be assured in case the moon-landers had to make a hasty departure.

To mark the historic occasion, the astronauts planted on the moon the American flag (Fig. 25), a practice followed on later landings. The occasion was made noteworthy by a telephone call from President Nixon in the White House. The President said: "Because of what you have done, the heavens have become a part of man's world. And as you talk to us from the Sea of Tranquility, it requires us to redouble our efforts to bring peace and tranquility to earth. For one priceless moment in the whole history of man, all the people on this earth are

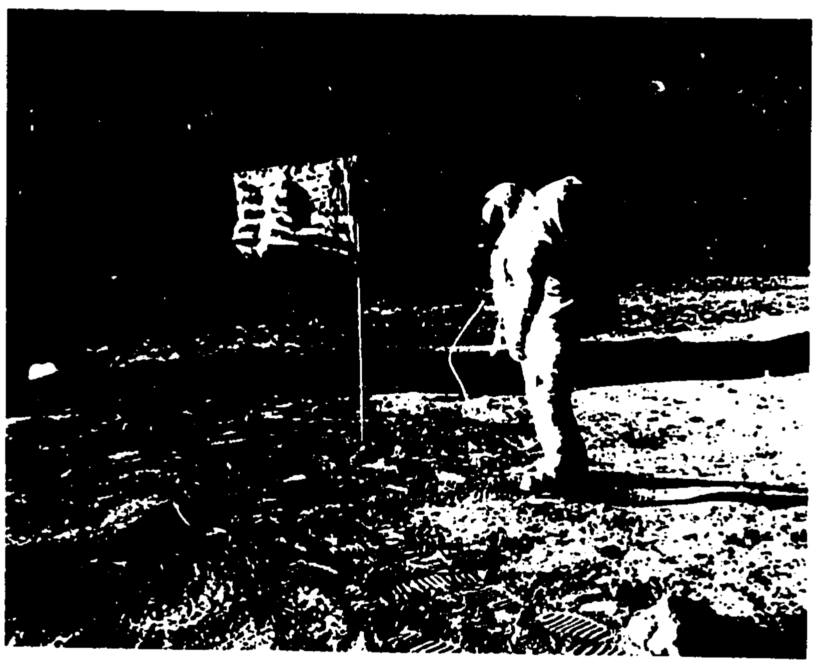


Figure 25. First American flag placed on the moon. The Eagle is to the left. The astronauts' footprints show clearly in the lunar soil.

truly one—one in their pride in what you have done and one in our prayers that you will return safely to earth."

After responding to the President's message, the astronauts continued with the tasks assigned them.

At the site where the astronauts landed, the moon was flat and relatively smooth but scarred with crater pocks. Aldrin described the moonscape as "magnificent desolation." Armstrong said that it reminded him of the high deserts of the United States, adding that it had "a stark beauty all its own." The observations made by the astronauts upon landing and the experiments they set up on the moon are described in the next chapter.

After they had completed their exploration, Armstrong and Aldrin prepared the Eagle for occupancy again. Then they ate and rested. After a stay time of 21 hours 36 minutes, the Eagle was readied for launch into lunar orbit.

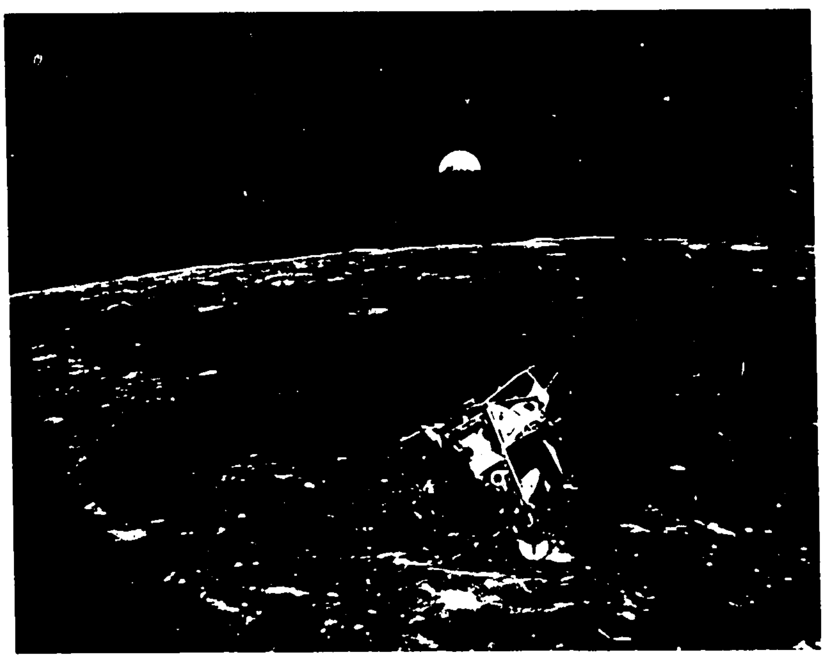


Figure 26. Eagle approaching the Columbia for rendezvous and docking after the first lunar landing. The photograph was taken from the Columbia. The earth is shown rising above the moon's horizon.

This was the first launch that the astronauts had made without the help of the complex countdown and launch facilities at Cape Kennedy. But this time they were launching with only the two stages of the Eagle, not with the complete Saturn-Apollo assembly. Besides being far lighter in weight, the Eagle had less gravitational force to resist (lunar gravity is one-sixth that of the earth). The astronauts fired the ascent engine in the upper stage of the Eagle to place this stage in a low orbit. The lower stage of the Eagle, used as a launch pad, remained behind on the moon. Then the astronauts fired the ascent engine again to circularize their orbit and place the Eagle some 13 miles below the Columbia and slightly behind it (Fig. 26). Subsequent firings of the engines in the reaction control system gradually raised the Eagle's orbit until the two spacecraft made a rendezvous and docked. Collins was then piloting the Columbia on its 27th revolution around the moon.

Some four hours after the astronauts were reunited in the Columbia, the Eagle was jettisoned. While the Columbia was behind the moon, the astronauts fired the large engine in the service module to put the spacecraft on a trajectory back to the earth. Then the astronauts settled down to sleep. The trip back was smooth. Only one of the scheduled midcourse corrections had to be made.

Although stormy weather caused NASA officials to change the recovery site in the Pacific Ocean, this shift in plans caused no problems. The astronauts splashed down about 13 miles from the USS Hornet. When they were recovered and brought aboard, the astronauts went into strict quarantine to prevent spread of any diseases they might have brought back from the moon. Peering through the window of their isolation quarters, Armstrong, Aldrin, and Collins greeted President Nixon, who was aboard the Hornet to welcome them (Fig. 27). The astronauts were flown to Houston to the Lunar Receiving Laboratory. Further celebrations had to wait more than two weeks while the astronauts remained in quarantine.

It is estimated that about 530 million people watching television around the world saw Neil Armstrong and Buzz Aldrin make the lunar landing. Many people in the United States were off from work that day, as the President had proclaimed a Day of National Participation. No other historical event was ever seen by so many people while it was in the making. Strangely enough, before the first spaceflights were made some scientists had predicted that men on a trip to the moon would become disoriented because of the sheer loneliness of

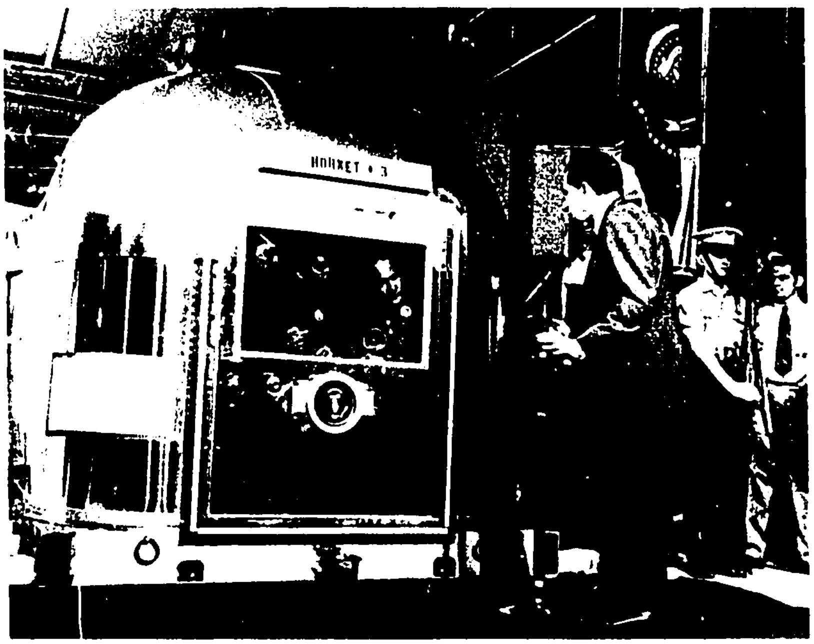


Figure 27. President Nixon welcoming the Apollo-11 astronauts on board the recovery ship. The astronauts are in the mobile quarantine facility.

spaceflight. Even the explorers of the New World had to endure long exile from their countrymen. but the astronauts, through the marvels of modern communication were in touch with the earth almost constantly throughout their journey. The world knew what was happening to them almost as it happened.

When the American astronauts landed, the race to the moon was over. Americans hoped that the end of the race might usher in a new era of cooperation in space exploration. The plaque that the astronauts implanted on the moon reads in full:

Here men from the planet Earth
first set foot upon the Moon
July 1969, A.D.
WE CAME IN PEACE FOR ALL MANKIND

Other memorials included microfilm messages of goodwill from 73 countries. Along with the medals of the three American astronauts

Figure 28. Apollo-12 crew checking out their spacecraft. Left to right are Charles Conrad, Richard Gordon, and Alan Bean.

who died in the tragic fire on the launch pad (Virgil Grissom, Edward White, and Roger Chaffee) were placed the medals of two Soviet cosmonauts (Yuri Gagarin and Vladimir Komarov) who had also lost their lives in accidents.

After reflecting on the meaning of their flight, Aldrin said, "We've come to the conclusion that this has been far more than three men on a voyage to the moon, more still than the efforts of a government and industry team, more even than the efforts of one nation. We feel that this stands as a symbol of the insatiable curiosity of all mankind to explore the unknown."

The results of the first voyage to the moon have been aptly described:

> A great problem had been resolved, marking a new era in the world's annals, and, like the discovery of America, destined to modify our history forever. Thanks to the courage and the sublime devotion of three men, the enterprise . . . instead of being put off to future ages, like other so called Quixotic projects, was now a living, accomplished fact . . . these three men shall stand forth as the representatives of an age of

> profound investigation, most pains-taking industry, and unparalleled audacity. It was only such an age that could have given birth to explorers so daring, engineers so accomplished, and lovers of abstract science so singularly pure and unselfish! . . .[1]

The age is ours, and all Americans should be proud to have a part in it. The words just quoted are those of Frenchman Jules Verne, written almost a century ago, in praising the accomplishments of three imaginary voyagers to the moon (two Americans and one Frenchman). They made the trip in a "cylindro-conical projectile" fired from a giant gun, the Columbiad. They, too, were launched from Florida. Take away the fact that their projectile was propelled to the moon by a giant gun (which would have shattered it), instead of by a mammoth rocket, there are some striking parallels between the imaginary voyage and the first lunar landing.

Once the excitement following the first lunar landing had died down, attention was focused on the samples that the astronauts brought back with them and upon what we might expect to learn from future landings.

Apollo 12

Apollo 12, which made the second lunar landing, carried the full experiment package and stayed a longer time on the moon. One task assigned to the astronauts on this excursion was to retrieve equipment from the Surveyor 3, the robot spacecraft that had landed on the moon more than two years earlier. The mission of Apollo 12 therefore called for a precision landing.

The Apollo 12 had an all-Navy crew. It was under the command of Charles Conrad, a 38-year-old Navy commander (Fig. 28). Richard Gordon, the pilot of the command module, a 38-year-old Navy commander, had teamed with Conrad on the Gemini 11. Alan Bean, a 37-year-old lieutenant commander, who was to make the lunar landing with Conrad, was new to spaceflight. The Apollo–12 astronauts called their combined command-service modules the Yankee Clipper and their lunar module the Intrepid.

Apollo 12 was launched from Cape Kennedy on 14 November 1969, a cloudy day with rain threatening. Just after Apollo 12 went up from the pad, lightning struck the Saturn V. Then it hit again. Each

[1] Jules Verne, *From the Earth to the Moon* (Philadelphia: David McK; ', 1895?), pp. 437–438. Reprinted with the permission of the publisher.

time the lightning struck, ground controllers momentarily lost contact with the booster. There were some tense moments. After the Apollo 12 went into parking orbit, a check was made of the electrical systems and computer programs on the Yankee Clipper, but these had not been damaged. While the flight was still in earth orbit, the Intrepid was also checked for possible damage from the lightning. Great was the relief when the Intrepid was found to be intact also. After the refiring of the third stage of the Saturn V and docking, the astronauts were off on a free-flight trajectory to the moon.

When the midcourse correction was made, the trajectory for the Apollo 12 was changed from a free flight to one that would allow a landing under more favorable lighting conditions. This was the first time a mixed, or hybrid, trajectory was used.

During the flight, Conrad, Bean, and Gordon shared some of their experiences with television viewers on the earth, as the other astronauts had done. One feature of the telecasts was that of the separation of the Intrepid from the Yankee Clipper.

When the Intrepid was preparing to land, its instruments showed a deviation from the data that the flight controllers had on the ground. This difference had resulted from inaccuracies developing during flight. The ground controllers, making use of new data-processing equipment, read the corrections to the astronauts. Conrad and Bean then made the adjustments in their computer. Although the astronauts landed blind in a scatter of dust, they were able to make a precision landing within sight of the Surveyor 3. The landing was made in the Ocean of Storms on 19 November 1969.

Unfortunately, when Bean started to set up the television camera, he must have aimed it into the sun momentarily. The camera would not work, and the astronauts were not able to telecast their excursions on the moon.

Conrad and Bean made two walks. While they were making these excursions, they were in buoyant spirits. They found that they could move about with relative ease in the one-sixth gravity environment in spite of their heavy moon suits and backpacks. The footing was precarious, however, and they often slipped. Once Conrad fell. The ground controllers had some anxious moments until his voice reassured them. Experts had expressed concern about what might happen if one of the explorers fell and cut his moon suit on a sharp rock. Both the moon suit and the backpack proved their efficiency, however, in giving life support on the extended excursions. After the Intrepid had been on the surface of the moon for almost 31 hours 31 minutes, Conrad and Bean departed to rendezvous with the Yankee Clipper.

While Conrad and Bean were exploring on the surface of the moon, Gordon was making observations from lunar orbit. Gordon was happy to end his lonely vigil and be reunited with his two companions. When all three astronauts were safely inside the Yankee Clipper once again, the astronauts crashed the Intrepid on the moon. They did this to get a reading on the seismometer they had left behind on the moon.

The Apollo 12 scored a success in accurate navigation and landing, and the astronauts collected many valuable samples and made extensive observations of another lunar sea. Scientists eagerly awaited the next flight, which was to go to a highland area.

Apollo 14

The Apollo 13, which was to go to the highlands near the Fra Mauro Crater, encountered difficulties when a large oxygen tank in the service module exploded. The flight, described in the next section, was turned into a fight for survival, and the moon landing could not be made. Apollo 14 took over the mission of Apollo 13. With a spacecraft modified to insure greater safety, the Apollo–14 astronauts were ready to accomplish their important scientific mission.

The Apollo 14 was commanded by 47-year-old Navy Capt. Alan Shepard, the oldest man ever to go into space. One of the original seven astronauts, Shepard had made the first US manned spaceflight, a suborbital flight in the Mercury spacecraft. Later disqualified from spaceflight because of a condition of the inner ear, Shepard underwent surgery and was returned to flight status. For some dozen years Shepard had kept up hope and prepared himself for a return to space. His efforts were to climax in this opportunity to make a lunar landing. The other astronauts were making their first spaceflight on the Apollo 14. The pilot of the command module, 37-year-old Air Force Maj. Stuart Roosa, was an accomplished test pilot. The pilot of the lunar module and the other moon-lander was Navy Capt. Edgar Mitchell, who has a doctor's degree in aeronautics and astronautics from the Massachusetts Institute of Technology and was once a research project officer. The astronauts named their combined command and service modules the Kitty Hawk and the lunar module the Antares.

Minutes before launch of the Apollo 14 on 31 January 1971, a thunderstorm moved into the area. Gloom settled over Cape Kennedy as the countdown was held. After Apollo 12 had been struck by lightning during launch, NASA officials decided to keep from launching any more flights into a thunderstorm. After some 40 minutes of holding, the front began moving away, and the Apollo 14 roared into space through a hole in the front.

The spacecraft orbited the earth and then went into translunar injection. All was going well until time came for docking. The Kitty Hawk made the turnaround to dock with the Antares. The probe entered the Antares, but the latches would not hold. This was the first time the astronauts had ever had difficulty with the docking mechanism. Even on the Gemini flights when docking was first tried, there had been no problems with the mechanism itself. Roosa tried again and again, but still the latches would not hold. For a while it seemed that the lunar landing would have to be postponed a second time. Finally, on the sixth attempt, Roosa was able to force the probe into position, and the latches snapped shut, making a successful dock. But the problem of the lunar landing was not yet solved. If the docking mechanism was faulty, the landing would have to be called off. The astronauts, with the help of Ground Control, made a careful examination of the docking mechanism. The examination showed that there had been no pilot error and that nothing was wrong with the mechanism. Evidently some foreign body, perhaps ice, had gotten into the docking mechanism and prevented the probe from locking into position. The lunar landing was possible once again.

While the Apollo spacecraft was still on the trajectory to the moon, another problem developed, this time with the computer that would supply data for the landing. The problem was a serious one because a precise landing was necessary in the rough highlands. Ground Control put experts to work, and they came up with a new routine for the computer just in time for landing.

On the Apollo–14 flight the spacecraft was put into an elliptical orbit that brought it within some 9 miles above the moon at the closest point. This position allowed the astronauts to survey the target area at close range from orbit and made it possible for the Antares to reach the landing site quickly, leaving a larger reserve of fuel for hovering. This was good insurance, as Shepard could find no smooth, flat place for bringing the Antares down. Finally he landed on an 8-degree slope (Fig. 29).

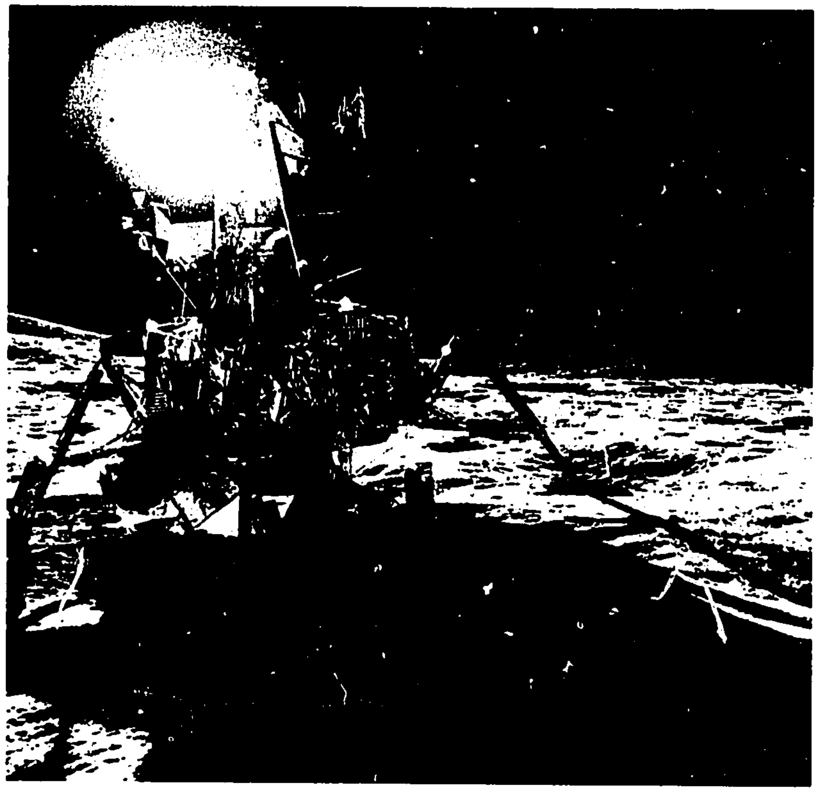


Figure 29. Antares landed on a slope in the Fra Mauro highlands during the Apollo-14 flight. The circular flare was caused by the reflection of sunlight from the lunar module.

Astronauts Shepard and Mitchell then made preparations for the extended moon walk in the Fra Mauro area, an exploration tour that scientists had long anticipated. As Shepard came down the ladder to step onto the moon he said, "It's been a long way, but we are here." The words were filled with personal meaning for Shepard and with special meaning for all the crew who had helped in solving difficult problems to make the landing possible. The mission had been "go, no go" all the way out. Even after the landing was made, problems continued. Astronaut Mitchell's moon suit showed signs of an oxygen leak, and difficulties developed with the communication system. As each new problem presented itself, the astronauts switched quickly back and forth between their roles as pilots, engineers, and scientific investigators.

The Apollo–14 mission, as planned, made the longest and best documented exploratory tour of the moon thus far. There was cause for rejoicing as the astronauts returned to the Antares to prepare for takeoff. Shepard took the handle of one of his tools and hit three golf balls to become the first golfer on the moon, where gravity is much less of a handicap than on the earth. Mitchell responded with a javelin throw.

While Shepard and Mitchell were at work on the surface of the moon, Roosa was orbiting the moon in the Kitty Hawk. He was taking special photographs for scientists and mission planners. Although he experienced some difficulties in working with a new camera, he was able to take some remarkable photographs. One of Roosa's tasks was to take detailed photographs of the Descartes Crater, which is one of the sites being considered for the landing on the Apollo–16 flight.

As Shepard and Mitchell prepared to join Roosa in orbit, those who were following the mission on earth waited breathlessly. What would happen at docking? On this flight the lunar module would make a direct ascent rendezvous; that is, the rendezvous was to be completed in one step. This would save an extra lunar orbit and some two hours of time on the journey back. The Antares fired, and the liftoff was nearly perfect. There was a "tweak" burn and then the larger one, and the Antares sought out the Kitty Hawk in lunar orbit. Insulation torn loose at liftoff dangled from the Antares, but this created no problem. The Antares found the Kitty Hawk, and docking proceeded. The probe went in, and everyone waited. Finally, Roosa said, "Okay. We captured." About 21 seconds later, "And we got a hard dock."

The flight back was smooth, and the command module of the Kitty Hawk, released from the service module, splashed down in the Pacific Ocean almost precisely on target. The successful flight of the Apollo 14 restored confidence in the Apollo spacecraft, following the Apollo–13 accident.

FIGHT FOR SURVIVAL: APOLLO 13

The Apollo 13 was launched from Cape Kennedy on 11 April 1970. The launch was an especially smooth one, and everything started out well. Although one member of the original crew had to be replaced at the last minute, because of exposure to measles, the new crew worked together like seasoned veterans. The commander of Apollo 13 was James Lovell, who had logged more hours in space than any other astronaut. He had participated in the first lunar flight

(Apollo 8), and he had two Gemini missions to his credit. The other two members of the crew were making their first spaceflight. The pilot of the command module was John Swigert, a 38-year-old civilian test pilot. The pilot of the lunar module was Fred Haise, a 36-year-old civilian, who had formerly been an Air Force combat pilot. The astronauts called their command-service modules the Odyssey and the lunar module the Aquarius. Little did they realize what an odyssey was in store for them!

The flight trajectory to the moon was precise. Only one midcourse correction was required and that only to change the landing time slightly to allow for better lighting conditions. The third stage of the Saturn V had been detached on schedule, and its trajectory had been adjusted to crash-land it on the moon as part of a scientific experiment. The crew were preparing for the lunar landing and had just signed off their television program when trouble developed. With the traditional calm of the astronauts, Swigert radioed Mission Control: "We've had a problem."

An explosion had blown out one side of the service module, and oxygen was venting into space. Fortunately the Aquarius had not yet been separated from the Odyssey. The ground controllers and the astronauts consulted about rescue operations. Chris Kraft, now Deputy Director of the Manned Spacecraft Center, was no stranger to emergencies. He was in charge of Mission Control when the warning was signalled that the heat shield had been lost on John Glenn's flight, and he had helped to bring down the Gemini 8. Kraft said: "This is as serious a situation as we've ever had in manned spaceflight." A plan was devised for bringing the crippled spacecraft back to the earth. The astronauts would keep the damaged service module attached to the command module, and they would power down the command module, reserving it for use at reentry. The Aquarius, the lunar module, was converted into a lifeboat.

As the Apollo 13 looped around the moon and began its journey back, the astronauts fired the engine in the Aquarius to speed the flight back. The burn would give the spacecraft just enough boost to allow for a splashdown in the Pacific Ocean, where the recovery team was in readiness.

For 87 hours the Aquarius provided life support for the astronauts, as well as power for the systems. A constant check was kept on reserves of oxygen and water. When carbon dioxide accumulated and threatened the lives of the astronauts, Ground Control sent up instruc-

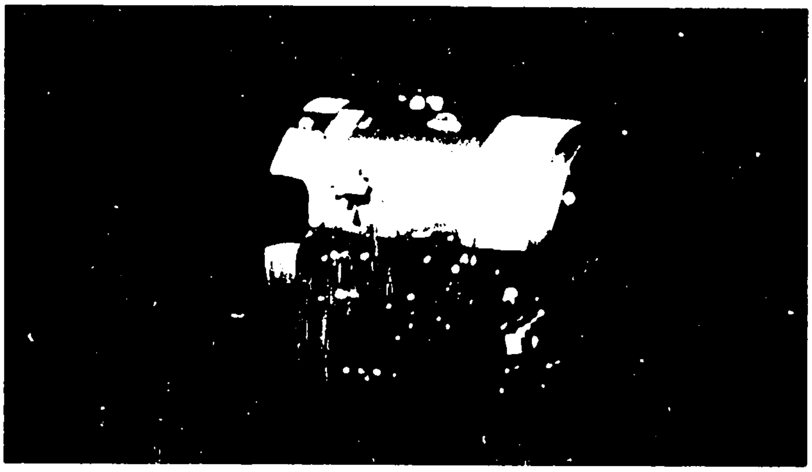


Figure 30. Service module damaged during the Apollo-13 flight. This is a view of the module after it was jettisoned.

tions, and the astronauts rigged up a canister containing lithium hydroxide that purified the atmosphere. Experienced astronauts assisted on the ground by testing instructions in simulators before Mission Control relayed them to the crew in space. The plight of the Apollo 13 brought forth a display of teamwork on a scale never before called for.

As the Apollo 13 approached the earth, all modules were still attached. The astronauts went back into the command module and prepared it for occupancy again. Then they photographed the damaged service module (Fig. 30) as they jettisoned it. The Aquarius was discarded next. It had served them well in space, but it could not take them back to the earth. The astronauts in the command module reentered the atmosphere safely and splashed down in the Pacific Ocean on 17 April after a four-day fight for survival (Fig. 31). Cheers went up from the recovery ship, and the President sent a special message of congratulations.

If the achievements of the Apollo–11 astronauts had brought the people of the world together, they were united even more in their concern over the Apollo–13 astronauts. Millions of people throughout the world, the great and the humble alike, each prayed in his own way for the safe return of the shipwrecked men.

Although the accident had prevented the Apollo–13 astronauts from landing on the moon and performing their scientific mission, the flight was highly successful from the standpoint of piloting and precise teamwork between Mission Control and the flight crew. The emergency had also afforded an opportunity for showing the potential that the lunar module has in survival operations. A tragedy had been averted, but the hazards were evident. The accident prompted the United States and the Soviet Union to make an agreement to work together in developing docking and rendezvous arrangements for rescuing stranded space crews.

An investigation of the accident showed that a fire had developed as a result of a short circuit in the wiring. This had caused the oxygen tank to explode, ripping out one side of the service module. To pre-

Figure 31. Recovery of the Apollo-13 astronauts in the Pacific Ocean. James Lovell, the commander, is leaving the spacecraft. John Swigert (back to camera) and Fred Haise (right) are on the life raft.

vent similar accidents in the future, the spacecraft was equipped with three newly designed oxygen tanks, an emergency battery, and emergency supplies of water; and the wiring was removed from contact with flammable material. The modified spacecraft proved itself on the Apollo–14 flight. Future spacecraft will be provided with additional life-support supplies to enable them to undertake extended exploration and accomplish even more exacting scientific missions.

FUTURE FLIGHTS

The next lunar landing, that of the Apollo 15, is to be made in the Hadley-Apennine area, which is about 20 degrees north of the equator and in the center of the visible face of the moon. This will be the first landing site located outside of the narrow landing zone at the equator. The site selected will allow investigation of both a mountain area with volcano-like features and a winding rill, or gorge. This type of rill has been the source of much interest because it resembles a dry riverbed. The Apennine Mountains at the proposed landing site rise about 8,000 feet above the surrounding plain. The lunar module is to land at the base of a mountain beside the Hadley Rill.

The Apollo–15 flight, which will be a 12–day mission, will allow for almost three days of stay time on the moon and for three traverses. The moon-landers will be able to venture much farther from their landing site than on previous flights because they will have the new powered lunar rover to help them.

The Apollo 15 will have an all–Air Force crew. The commander will be Col. David R. Scott, who took part in Apollo 9 and also has a Gemini mission to his credit. The other two members of the crew will make their first spaceflight on the Apollo 15. The pilot of the lunar module will be Lt. Col. James B. Irwin, and the commander of the command module will be Maj. Alfred M. Worden. The mission is scheduled for July 1971.

For the two remaining flights, Apollo 16 and 17, much thought will be given to selecting sites that will promise the greatest amount of scientific information. A large crater, perhaps the Descartes Crater, which was surveyed on the Apollo–14 flight, will be chosen. Findings made on the Apollo–15 flight and further studies of data obtained on previous flights will influence the selection of the remaining sites. After the first landing was made on the moon, the primary mission of the Apollo flights has been to explore the moon.

REVIEW QUESTIONS

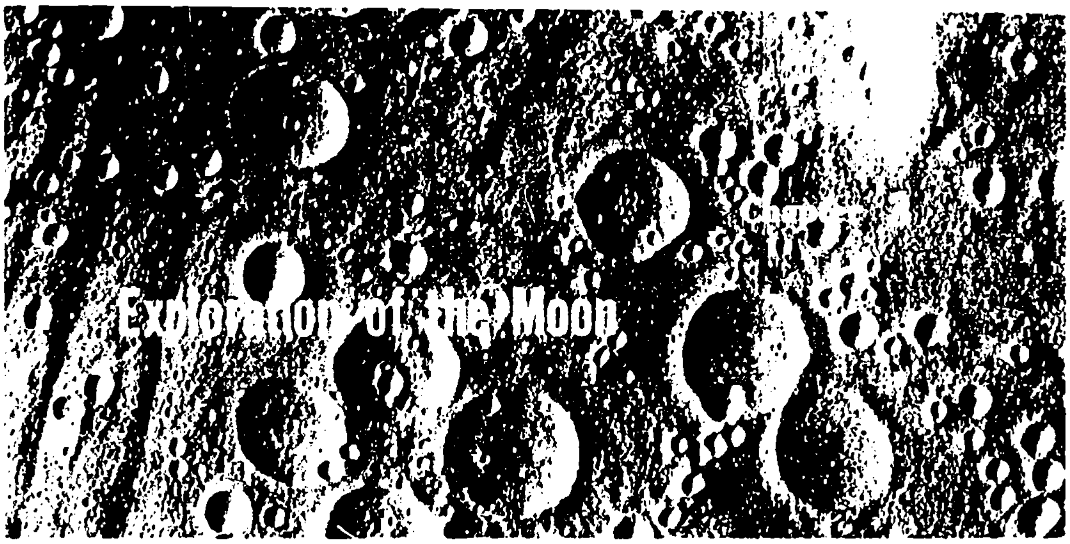
1. **Which method was selected for reaching the moon? Why was this preferred over the other two methods proposed?**
2. **What are the three large parts, or modules, of the Apollo spacecraft? What is the main purpose of each part?**
3. **Describe the giant Saturn V booster. How is the third stage used during a flight to the moon?**
4. **Explain three important maneuvers, or operations, in the flight plan for the lunar landing.**
5. **In what ways did Project Gemini (Step 2) prepare for Project Apollo (Step 3) and the lunar landing?**
6. **What are three important parts of the ground complex for Project Apollo?**
7. **How did Apollo 8 and 10 prepare for the lunar landing?**
8. **Why was Apollo 11 an important flight?**
9. **How many lunar landings have the Apollo astronauts made to date? Name three kinds of operational problems that developed on these flights.**
10. **How were the astronauts saved on Apollo 13? What were two important results of Apollo 13?**

THINGS TO DO

1. Report to the class on the most recent Apollo flight. Tell about the problems the astronauts encountered during the flight and the way in which they solved these problems. Explain the particular mission of the flight and the way in which this flight was different from the others.
2. Present a report to the class on the Saturn V booster, the Apollo spacecraft, or any one of the Apollo modules that has special interest for you. Use a prepared diagram or make one for yourself. The class might like to know more about the lunar module because this is the unique feature of the Apollo spacecraft. You could include in your report an account of the way the lunar module was used to rescue the Apollo-13 astronauts.
3. If you can make models, you might want to prepare a model of the Saturn V booster, the Apollo spacecraft, or any one of the Apollo modules that has special interest for you. Parts for some of these models can be obtained commercially. Explain to the class how the real hardware that your model represents operates and how it contributes to an Apollo flight.
4. If you are especially interested in orbits and trajectories, prepare a diagram of the lunar flight plan and explain it to the class. Pick out one or more of the most important parts of the plan to explain in greater detail. You might tell what happened on some of the flights at these points in the flight plan.
5. When the Apollo flights have been completed, make a summary report to the class on the flights. Explain the most important results of the flights. Pick out specific flights to illustrate your ideas.

SUGGESTIONS FOR FURTHER READING

ARMSTRONG, NEIL, and Others. *The First Lunar Landing as Told by the Astronauts.* Washington, D.C.: Government Printing Office, 1970.
BOOKER, P. J., FREWER, G. C., and PARDOE, G. K. C. *Project Apollo.* New York: American Elsevier Publishing Co., 1969.
BRAUN, WERNHER VON, and ORDWAY, FREDERICK I., III. *History of Rocketry and Space Travel.* Rev. ed. New York: Thomas Y. Crowell Co., 1969.
CAIDIN, MARTIN. *By Apollo to the Moon.* New York: E. P. Dutton and Co., 1963.
CLARKE, ARTHUR C. *Man and Space.* Life Science Library. New York: Time, Inc., 1964.
COBB, ROBERT T. *Mission Moon.* New York: Holt, Rinehart, and Winston, 1967.
FAGET, MAX. *Manned Space Flight.* New York: Holt, Rinehart, and Winston, 1965.
LEWIS, RICHARD S. *Appointment on the Moon: The Inside Story of America's Space Venture.* New York: Viking Press, 1968.
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.: Revised 1967.
U.S. News & World Report Book. *U.S. on the Moon: What It Means to Us.* New York: Collier Books, Macmillian Co., 1969.
WILFORD, JOHN NOBLE. *We Reach the Moon.* A New York Times Book. New York: W. W. Norton, 1969.



Exploration of the Moon

THIS CHAPTER explains why the United States is exploring the moon. First it describes the kinds of lunar features to which the investigations are being directed and tells briefly what was known about these features before space exploration began. Then it explains the key questions that are being raised about the moon as they relate to its origin, the formation of its physical features, and the nature of its interior. Next it describes the kinds of findings about the moon made by the US unmanned spacecraft that preceded the Apollo flights: the Rangers, Surveyors, and Lunar Orbiters. Then the chapter tells how the astronauts have explored the moon during the landings made on the Apollo 11, 12, and 14 flights, describing instruments used, special experiments, and the collection of rock and soil samples and giving a summary of tentative findings. Finally, the chapter tells how the United States might conduct further exploration of the moon in the future. After you have studied this chapter, you should be able to do the following: (1) explain why the United States is exploring the moon, (2) describe the principal lunar features and tell which the Apollo astronauts have investigated, (3) explain the two opposing views that scientists hold about the origin of the lunar craters and seas, (4) describe the results obtained from the US unmanned spacecraft that explored the moon, (5) explain why the astronauts set up experiments on the moon and collected rock and soil samples, and (6) name three important findings about the moon made as a result of the Apollo landings.

WHEN THE APOLLO FLIGHTS were first proposed, scientists understood that the moon is not surrounded by an atmosphere and has no water upon its surface. Because the moon has no wind, rain, or any kind of weather to bring about changes, scientists knew that the moon has not undergone erosion as the earth has. Therefore, scientists at first believed that the astronauts might be expected to find evidence of the early history of the moon upon its surface. The astronauts might, it was once thought, read the history of the moon from its surface as from an open book. At last it would be possible to determine which theory about the moon's origin is correct.

Then, as scientists obtained more and more evidence from the preliminary probes of the moon, they began to understand that the moon has undergone some changes over the billions of years. These changes have taken place much more slowly than those brought about by erosion on the earth, but the evidence of changes on the moon is significant. It indicates that the moon has had a more eventful history than was at first supposed. The evidence of events taking place during the moon's early history might still be expected to be there, but the astronauts would have to do some digging to find this evidence.

When the astronauts reached the moon, they did not find conclusive evidence for supporting any of the theories then held about the moon's origin. After the first landing, Prof. Harold Urey of the University of California at San Diego, one of the leading authorities on the moon, said, "All of us who have been talking about the origin of the moon should feel very humble at the present time. Nobody is right about it."

The early exploration of the moon, like all good experimentation in its early stages, has raised many more questions than it has answered. Nevertheless, scientists are still convinced that the moon will be a kind of Rosetta Stone for them. Evidence obtained from the moon should help them reconstruct the early history of the earth and the entire solar system, just as the Rosetta Stone enabled archeologists to reconstruct the early history of Egypt.

To help you understand what scientists want to investigate on the later Apollo flights and what findings have already been made, you need to know something about the principal theories of the moon's origin. These theories have raised key questions that scientists are now trying to answer. But before you are ready to tackle some of these questions for yourself, you need to have a better idea of what the moon is like close up.

PHYSICAL FEATURES OF THE MOON

It was only natural that man, from the time of his earliest existence on the earth, had a feeling of wonder about the moon and its physical features. The lighted sphere of the moon was clearly visible to him in the night sky, and the waxing and waning of the moon demanded an explanation. For many centuries the moon has been known to affect the tides on the earth. Its movements have also been used to mark the advance of the seasons, and its changes have been related to the rhythms of life on earth, especially to the planting season and the harvest. Man was curious to know the source of this mysterious influence that the moon exerted on earth dwellers and whether the moon harbored other beings like himself.

When man gradually changed his ideas about the universe, from that of an earth-centered system to a sun-centered system, and then to the present concept of our solar system as only one small part of an almost infinite universe, he changed many of his ideas about the moon also. He came to understand that the moon has a bleak, forbidding surface, with apparently unchanging features, and that it is unable to support life. He realized also that the mysterious force that the moon exerted on the earth is a gravitational force.

The moon's gravity is only one-sixth of the earth's gravity. The earth is able to exert more gravitational force because the mass of the earth is about 81 times that of the moon. The difference in actual size is not quite so large. The earth is just under 8,000 miles in diameter, and the moon is slightly more than 2,000 miles in diameter. The surface of the moon, if spread out on the earth's surface, would cover an area about the size of Africa.

Since the earth's pull is much stronger than that of the moon, man was able to explain why the moon is kept in orbit about the earth. He also came to understand that the moon was the one and only natural satellite of the earth. Then he compared the earth's moon with the moons of the other planets. He found that the earth's moon is much larger in relation to the size of the parent body than are the moons of the other planets. Now some scientists are suggesting that we think of the moon and the earth as double planets rather than as planet and satellite. Whether or not this new concept of the earth-moon system is a better one, we shall find out in time. Space travel has given us many new methods for studying the moon.

Before the age of space travel, man had to be content with studying the moon from afar. Although the moon is a close neighbor of the earth as compared with the planets, astronomers were handicapped in studying the moon with telescopes because it reflects only a small amount of the sunlight shining on it. Although the full moon may be a dazzling sight in the night sky, it reflects only about 7 percent of the sunlight shining on it, or about as much as a black rock. Nevertheless, after making careful observations and improving their telescopes, astronomers were able to make fairly detailed maps of the moon.

Early in the seventeenth century Galileo made the first observations of the moon with a telescope. He saw that the dark areas of the moon are lowlands and the light areas are highlands. The large light and dark areas can be distinguished even with the naked eye because of the differences made by the sunlight as it falls on them, but the actual features do not become visible until they are viewed with a low-powered telescope. Galileo was also able to distinguish some of the craters, features which cover the surface of the moon and have become familiar to us from photographs taken in the space age. After Galileo made careful observations with his telescope, he began to map the moon.

Astronomers who followed Galileo continued with the mapping. An Italian astronomer, Giovanni Riccioli, who published a map of the moon in 1651, is known for establishing the pattern for naming lunar features. Although Riccioli knew there was no water on the moon, he allowed his imagination free play. Because the lowlands looked like

Figure 32. Moon at the full phase as viewed with a 100-inch telescope (Mount Wilson Observatory).

bodies of water in his low-powered telescope, he gave them names of seas, or maria (the Latin word for seas; singular "mare"), oceans, bays, or other bodies of water. He used fanciful names like the Sea of Tranquility (Mare Tranquillitatis), the Ocean of Storms (Oceanus Procellarum), and the Bay of Rainbows (Sinus Iridum). He named the craters for astronomers, such as Tycho and Copernicus, thereby establishing the precedent of naming craters for persons responsible for significant contributions to astronomy or space exploration. The highlands were named for mountains known at the time. These are lunar Alps, Apennines, Carpathians, and the like, but these mountains are quite different from those found on the earth.

As larger telescopes were made and as photography developed, many additional features were discovered and named (Fig. 32). Besides the maria, highlands, and craters, other smaller features were observed and named, such as the rills, clefts, and rays. The rills are principally rifts in the valleys of the highlands, and the clefts are corresponding breaks in the maria, or seas. Perhaps the most mysterious features of all are the rays, which show up vividly during the full moon, fanning out from the newest craters like the spokes of a giant wheel. The rays from Tycho Crater, which is not far from the south pole of the moon, sometimes reach out over the entire full moon and make Tycho the most conspicuous crater on the moon. Copernicus Crater, located northeast of the Apollo-12 landing site, also has conspicuous rays.

The other features of the moon show up best not at the full moon but a little after the full phase, when the shadows begin to fall. By measuring the shadows, astronomers were able to determine the heights of the mountains on the moon.

All the time astronomers were studying the features of the moon, they were observing only a little more than half of the moon's sphere. Since the moon rotates on its axis at about the same rate that it revolves around the earth, the same side of the moon is always turned toward the earth. During the course of the month, this side presents a slightly different appearance each night as the moon moves into the sunlight or out of it. The moon goes through four main phases each month: the new moon (dark of the moon), the first quarter, the full moon, and the third quarter (Fig. 33). Because the orbit of the moon is elliptical and because of other irregularities, the moon undergoes what is known as libration, or an apparent swinging back and forth. As a result we are able to see about 59 percent of the moon in all, but

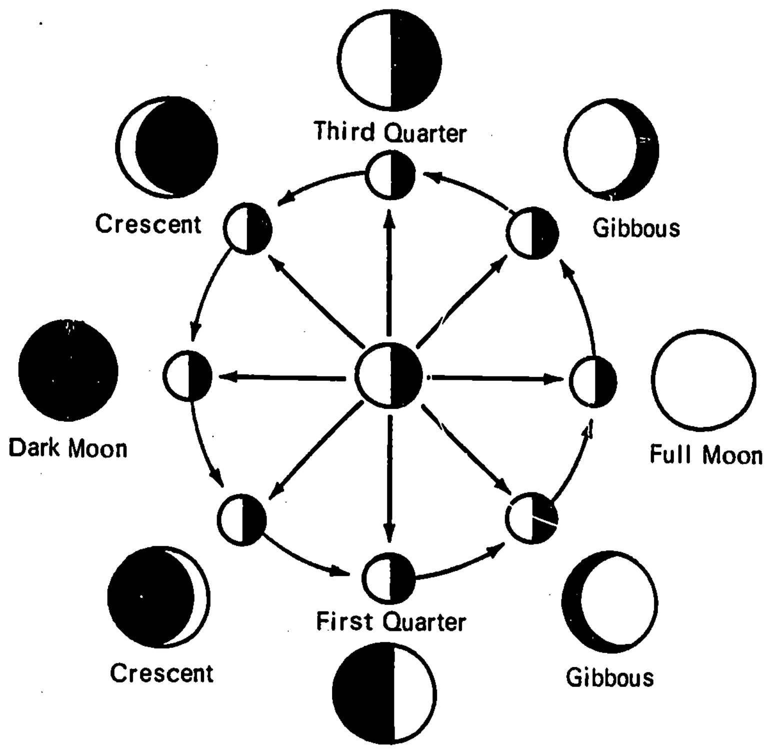


Figure 33. Phases of the moon as seen from the earth during a lunar month (about 28 days).

we can, of course, see no more than 50 percent of the sphere at any one time. For centuries astronomers wondered what the other side of the moon looked like. Now automated spacecraft and the astronauts have orbited the moon, and we have taken many photographs of the far side, such as shown in Figure 34.

For 350 years before the first lunar probes were made, astronomers working with telescopes did not observe any large changes in the moon, such as the sudden disappearance of mountains or the appearance of a large crater. To them the moon appeared to be completely lifeless. In fact, after they had observed all that they could of the seemingly changeless features of the moon with their telescopes, professional astronomers lost interest in the moon. They were willing to leave moon observations to amateurs and to direct their attention to more distant bodies.

When space travel began, scientists took a renewed interest in the moon. At a mean distance of 238,000 miles from the earth, the moon is about a hundred times closer than the nearest planet, Venus. Being relatively close to the earth, the moon was logically the first body to probe and visit. As astronomers were beginning new studies of the moon, Soviet astronomer N. A. Kozyrev, in November 1958, noted a red glow in the vicinity of Alphonsus Crater. Kozyrev's observation

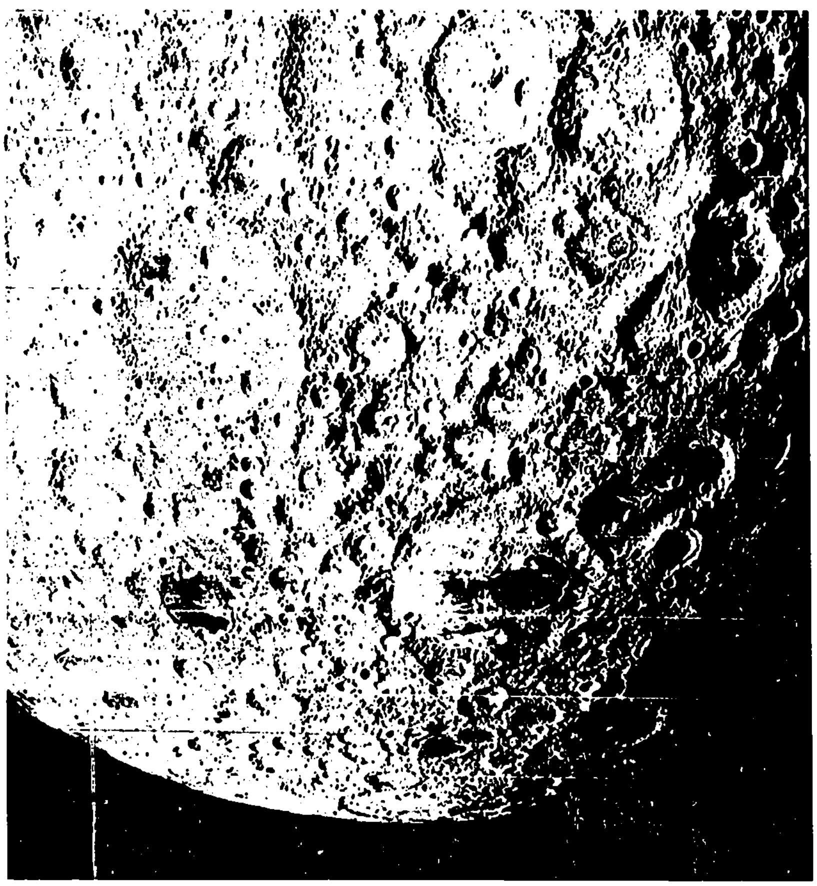


Figure 34. Far side of the moon (southern half). This photograph was taken by Lunar Orbiter 2. Note the rugged highlands.

led to an extensive study of lunar craters to detect possible volcanic activity.

Circular craters and seas are characteristic features of the moon that have become familiar to earth dwellers since the time of the first moon probes. The large circular seas appear to be very much enlarged craters. Many views of the seas show crater impacted upon crater, making the moon seem as though it had been struck with giant buckshot at different times.

Lunar craters vary greatly in size. The largest could inclose an entire state or a small country, and the smallest craterlets would hold only an astronaut's boot. One of the largest known craters on the visible face of the moon is Bailly Crater, which is more than 180 miles in diameter. It would include some 400 Grand Canyons or cover most of England.

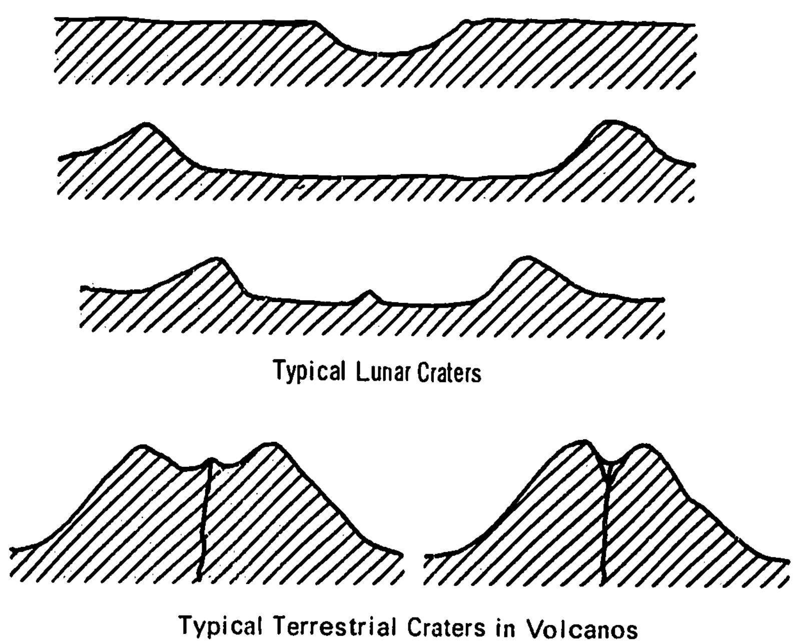


Figure 35. Cross sections of typical lunar craters and of the craters of typical terrestrial volcanos like Vesuvius. Most large lunar craters have a flat bed.

Typical lunar craters are circular depressions. Many of the largest are shaped like giant saucers with a smooth floor and a piled-up wall, or rim (Fig. 35). An astronaut could stand on the floor of one of these giant craters and not be able to realize it, as the crater walls might be out of view over the moon's horizon. Some of the large craters have one or more central peaks. No matter how high these peaks are, they have not been found to rise above the crater walls. Some of the smaller craters that appear to be more recently formed are shaped more like a bowl than a saucer. Most lunar craters appear to have been formed by impact, but no evidence has as yet been found to support this. The subject is the focus of much interest, as lunar craters and seas are believed to hold clues that will help scientists answer key questions about the moon.

KEY QUESTIONS ABOUT THE MOON

The bleak moonscape, as shown by thousands of photographs taken since space exploration began, presents quite a different sight from most of the earth's landscape. But one cannot judge from appearances only. Scientists continue to ask: Is the moon basically unlike the earth, or is it like the earth would have been if it had lost its atmosphere early in its history?

Because the moon is much less massive than the earth, its gravitational force was not strong enough to maintain an atmosphere if it did have one. Without an atmosphere to protect it, the moon was subject to bombardment by meteorites from space. Also, because the moon is devoid of an atmosphere, it has had no shield to protect it against the sudden drastic changes in temperature that occur as the moon moves into or out of the sunlight. Since the surface of the moon reaches temperatures around 250 degrees F. in the sunlight, any water that might once have been present on the surface would have boiled away. Even if the moon was basically like the earth at one time, it would have undergone quite different processes from those on the earth. What changes did take place on the moon? After making observations of the moon, scientists are trying to reconstruct its history. Fundamental questions raised about the moon focus upon its origin.

Origin of the Moon

To understand the theories about the origin of the moon, you have to stretch your imagination to take in a vast period of time. You are considering hundreds of million or billions of years, not the centuries of recorded human history. The earliest event recorded in history dates back some 6,000 years. Scientists, from a careful study of meteorites found on earth, have long speculated that the earth, the moon, and the rest of the solar system are about 4.6 billion years old. However, they have not found rocks on the earth that are more than about 3.5 billion years old.

What happened during the first billion years of the earth's existence was, and continues to be, a mystery. Scientists speculated that the moon would offer them clues to the lost record of the earth's past, and Prof. Harold Urey became interested in these speculations. At present a consultant to NASA on the study of lunar samples, he is also a chemist known for the discovery of heavy hydrogen and for contributions to the atom bomb. Realizing the opportunity that the moon offered for interpreting the history of the earth, Professor Urey encouraged scientists to renew their lunar studies, and he has made important contributions to these studies. Consequently, he is known as the father of modern lunar science.

With their renewed interest in the study of the moon, scientists took a fresh look at the theories of the moon's origin. Samples of rocks and soil taken from the moon would give them a chance to test these theories. There were three principal theories of the moon's origin held at the time of the first lunar landing.

The first theory holds that the moon was formed somewhere out in space. For some reason it wandered into the earth's gravitational field and was captured by the earth.

The second theory states that the moon was once part of the earth but that it broke loose and became an independent body. The hole that it left in the earth is probably the great bed of the Pacific Ocean. This theory was proposed by Sir George Darwin, son of the famous naturalist Charles Darwin. It gained little support at the time it was first advanced (1898), but the findings from the first lunar probes caused renewed interest in this theory.

A third theory is that the moon was formed at the same time as the earth from the same kind of planetary matter.

The second and the third theories support the speculation that the moon is the same age as the earth. They simply propose different lines of development. The theories are simple enough to understand, but each demands further explanations, which, in turn, raise a whole series of complex questions.

The first theory assumes that the moon is basically unlike the earth, the second that it is basically like the earth. The third theory would assume that the two bodies are fundamentally alike, but it would allow for some differences.

One of the first questions proposed for investigation was to determine whether samples of rocks and soil taken from the moon showed fundamental chemical differences from those on the earth. Samples taken thus far do not give full support to any of the three theories outlined, and debate continues. It centers on the ways in which the physical features of the moon were formed and on the nature of the moon's interior.

Formation of the Physical Features

Even if the moon has undergone relatively little change since it was first formed, scientists have a big task in reconstructing what happened during the 4.6 billion years that the moon is believed to have existed. They hope to make a concentrated study of the features of the moon as they now exist and establish their age. This will assist them in reconstructing the events that have contributed to making the moon what it is today. Since the study of the moon, selenology (named from the Greek moon goddess, Selene), is relatively new, it must borrow much from geology, the study of the earth's history. This explains why astronauts scheduled to make flights to the moon are given special instructions in geology and training in the methods of geological research. As scientists reconstruct events on the moon, they try to determine how such events would have affected the earth. Again, in making these comparisons, they are helped by the geologists and the students of other earth sciences. This method of comparison assumes that the earth and the moon were near neighbors throughout most or all of their history. Findings from the study of the lunar seas and craters may or may not support this assumption.

The origin of the lunar seas is believed to be closely linked with that of the lunar craters. The large maria, or seas, are thought to have been formed of molten material that spread out over the original surface, filling in the cracks and crevasses and lapping up against the highlands. The crucial question is: What caused this immense flow of molten material? Did it occur at one time or in stages? Was it brought about by tremendous eruptions from the interior of the moon, much like volcanic action on the earth, or did it result from melting as the

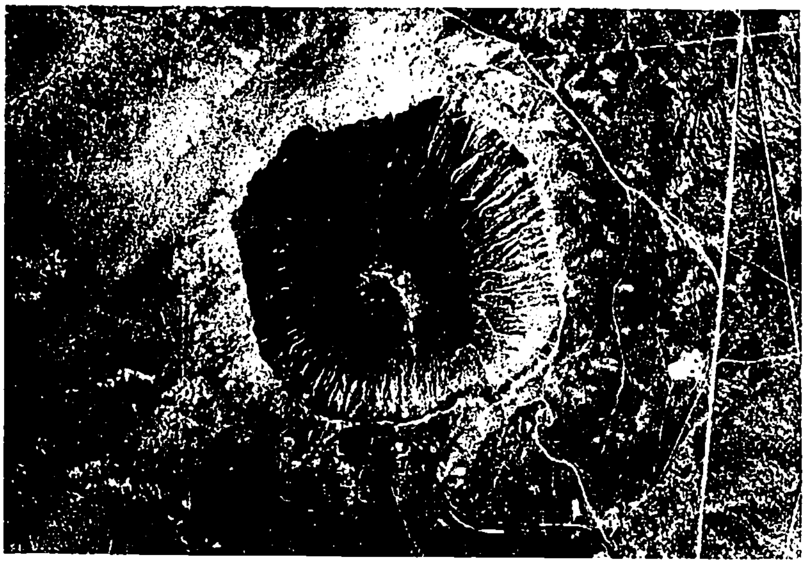


Figure 36. Aerial view of the Barringer crater in Arizona (US Geological Survey). This crater was produced by the impact of a meteorite. The crater is about 600 feet deep and about three-fourths mile across.

result of bombardment by meteorites? To explain the existence of the moon's craters and seas, scientists propose either one of two theories: volcanic eruption or bombardment by meteorites.

If the moon was bombarded by meteorites, would there not be some similar record of events on the earth? The earth is, of course, protected by an atmosphere, which would cause most of the meteors to be burned up before they reached the surface. If meteorites did impact the earth and dig craters, these would have been obliterated in time because of the action of wind and water. Although meteorites were not discovered on earth by the scientific community until early in the nineteenth century, many instances of meteorites entering the earth's atmosphere have been recorded, and many more have gone unrecorded because they are difficult to detect. The Barringer Crater in Arizona (Fig. 36), the first meteorite crater recognized on the earth, is not the largest. There is ample evidence of other larger meteorite craters scattered over the earth.

At present it is not possible to draw a direct comparison between the lunar craters and evidence of meteorite bombardment on the earth. But scientists who believe that the lunar craters were formed by meteorites have found the evidence of meteorite bombardment on the earth most useful in reconstructing what might have happened on the moon. Craters made by nuclear explosions have also been helpful in understanding meteorite bombardment. It appears that a meteorite coming to the earth from outer space strikes the earth with gigantic force, burying itself beneath the surface and traveling for some distance in the instant before being brought to rest. The terrific friction generated causes such intense heat that the earth around the area becomes vaporized. As the gases attempt to escape, there is a terrific explosion, and material is ejected, resulting in a circular crater.

Besides the maria and craters, other lunar features to be investigated are the highlands. The Apollo–14 astronauts explored a highland area, and the Apollo–15 astronauts are to land at the base of the Apennine Mountains. The highlands that have been photographed in detail appear to be extremely rugged. They have steep crags and are covered with giant boulders. The mountains are believed to be the oldest features on the moon. It is speculated that the same rock formations that make up the highlands extend out to form the bedrock under the lunar maria. Some of the highlands, such as the Apennines, have what appear to be chains of volcanos. When we know how the lunar seas were formed, we shall have clues to understanding the highlands.

Another key question concerns the presence of water on the moon. The astronauts did not, of course, find any water on the moon. They often described the soil as appearing to be moist. They did not mean that it was actually moist, however, but rather that the soil adhered as if it were moist. Their observations agree with findings made on the earth; that is, materials in a vacuum tend to be bound together. Although the astronauts found no evidence that water once existed on the surface of the moon, some scientists still believe that water was once present and might still be found frozen beneath the surface. They speculate that some of the rills were once riverbeds. Their speculation has been encouraged by the fact that some rills are winding and some appear to have branched, much as rivers have done on the earth. The Apollo–15 astronauts are to land beside Hadley Rill, which resembles a dry riverbed. The presence of underground water on the moon would be significant in explaining volcanic action, as it is the steam generated from the underground water on the earth that provides the force to eject the lava from the volcanos. All questions about the formation of the lunar features naturally go back to the question about the nature of the moon's interior.

Nature of the Moon's Interior

If the large lunar maria were formed by volcanic action similar to that on the earth, then the moon might be expected to have a molten nickel-iron core similar to that of the earth. If, on the other hand, the lunar maria were formed by meteorite bombardment, then the heat was generated at the surface of the moon, and the moon is likely to be an inert body with a cold interior. In the past scientists have assembled the findings, interpreted them, and drawn one or the other conclusion. There have been those who believed that the moon has, or once had, a hot core and those who have speculated a cold core. Professor Urey, who said that all present theories about the moon's origin are inadequate, was a cold-moon theorist. He is now looking with new interest at the possibilities of vulcanism and a hot core, but there are serious objections to the hot-core theory also.

If the moon still has a molten nickel-iron core similar to that of the earth, then the moon might be expected to have a magnetic field. This would be produced by the electric currents caused by turbulence within the fluid metal. It is now clear, however, that the moon does not have a magnetosphere similar to that of the earth. If the moon once had a molten core that has cooled and hardened, there should still be some evidence that the hot core once existed. The moon might still display a small amount of magnetism in some of its rocks, or it might have a magnetic field so weak that it would have to be measured by specially devised instruments.

Any description of the moon's interior must take into account the mascons, the mass concentrations of matter, that affected the orbital path of the Apollo spacecraft. These mascons are found under the large circular seas, such as the Sea of Tranquility and the Ocean of Storms. They are massive enough to exert a considerable gravitational pull on the spacecraft as it flies over them. We do not as yet know what kind of material makes up the concentrations of matter although there has been much speculation about this subject. If the concentration of material is nickel-iron, as some scientists believe, then there is no way to explain why this material did not melt and settle at the moon's center if the moon has, or once had, a molten core.

From this brief outline of the major questions that scientists are asking about the moon, it becomes clear that no single explanation of any one feature of the moon would provide an adequate explanation of the moon's origin. Any meaningful explanation of one part of the evidence must fit in with other findings to adequately reconstruct the moon's history (and the history of the earth and the solar system), much as the parts of a jigsaw puzzle must fit together to make a complete picture. It is likely that many important parts to the puzzle about the moon are still missing. That is why scientists are eagerly awaiting any clues that might be brought to light on the remaining Apollo flights.

You will gain a better understanding of what astronauts might investigate on the remaining Apollo flights if you can see how our knowledge about the moon was gradually extended by automated spacecraft and then by the first Apollo flights. Imagine, if you can, that you are an astronomer awaiting reports on the first lunar probes. You have a good understanding of the information obtained about the moon from three-and-a-half centuries of study through telescopes, but you are certain that close-up studies will bring some surprises.

PRELIMINARY UNMANNED EXPLORATION

When the Apollo program was announced in May 1961, more exact information was needed about actual conditions on the moon and near it. Scientists decided what information was needed and then engineers constructed lunar probes and robot explorers that could go to the moon, obtain the necessary information, and relay it back to the earth. To blaze the trail to the moon, both the United States and the Soviet Union devised ingenious probes and robot explorers. The US automated spacecraft had significance for the Apollo program in two ways: for the technological advancements they brought about, helping to make the Saturn V and the Apollo spacecraft possible; and for the scientific information they obtained, thus making the journey safer for the astronauts.

The first step was to get a much closer and more detailed view of the moon than telescope pictures had given. The first US close-up pictures were obtained by the Ranger probes. The second step was to send a soft-lander (the Surveyor) to the moon to find out what kind of bearing surfaces the moon had. The third step was to put a satellite into orbit (the Lunar Orbiter) to survey the moon from above at close range and to take detailed pictures of the moon's surface. The early

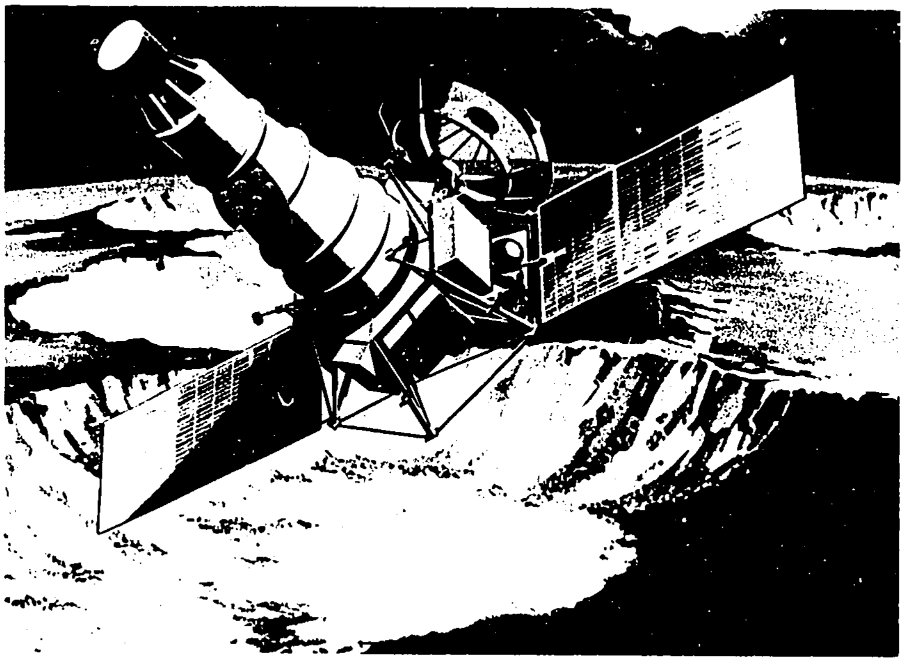


Figure 37. Ranger 9 before impacting on the moon (artist's sketch). This spacecraft took some 6,000 photographs of the area near Alphonsus Crater. For a photograph taken by Ranger 9 see Figure 38.

Pioneer satellites and some of the more advanced Explorer satellites also made probes of the moon, but this chapter considers only those spacecraft launched under the Ranger, Surveyor, and Lunar Orbiter programs.

Ranger Probes

The Ranger probes, placed into the earth-moon trajectory by the Atlas-Agena booster, were designed to make a hard landing on the moon (Fig. 37). In the last minutes before landing, as it was traveling at about 6,000 mph, the Ranger took close-up pictures of the moon. It did not start taking these pictures until it was about 8,000 feet above the moon. Then, as it traveled toward the moon, with its television cameras pointed straight down, it took pictures that were transmitted to the earth before impact. The Ranger probes weighed anywhere from 300 to 800 pounds. At first the engineers tried to eject an instrument package from the Ranger as it landed, but no package, however well protected, could survive the landing. The moon has no atmosphere for braking a spacecraft.

The Ranger program, begun in 1959, originally was to consist of five probes. The first two Ranger shots were to test the equipment, and the last three were to actually collect information. None of the first five Rangers succeeded in transmitting data. Ranger 4 made the trip to the moon, but it landed on the far side of the moon and consequently was unable to send back pictures. By this time the Soviet Luna 2 had already made an impact on the moon, and Luna 3 had orbited the moon, transmitting photographs showing 70 percent of the far side. The US Ranger program was falling behind.

Both the Soviet Union and the United States had difficulty in getting the first moon probes on the correct trajectory. Since the earth and the moon are turning on their own axes at the same time that they are revolving around the sun, complex computations had to be made to aim the probes. They had to be aimed slightly ahead of the moon, or in the spot where the moon would be when the probe reached it. Then, too, the gravitational force of the sun, as well as that of the moon and the earth, had to be taken into consideration in figuring the trajectory. Although this was a complex problem, it could be solved with a high degree of accuracy through the use of computers. But even when the correct trajectory was known, it was not always possible to get the exact amount of thrust, the precise direction, or the other factors that would put the spacecraft exactly on the calculated trajectory. For this reason an adjustment in the trajectory, a midcourse correction, had to be made by automatically firing a rocket engine in the Ranger upon command from the earth. In the Ranger program the United States solved some of the complex problems in putting a spacecraft on an accurate earth-moon trajectory, thus marking out the path to be followed on the Apollo flights.

As the United States extended the Ranger program, scientists and engineers were able to make midcourse corrections and aim the probes accurately. The Rangers did not send back photographs, however, until Ranger 7, which was launched in July 1964. There were two other successful probes, Rangers 8 and 9.

During the last three launches of the Ranger, the United States received about 17,400 close-up pictures of the moon. These were made of three sites; each picture in a group was taken at successively closer range as the spacecraft rushed toward the moon. The Ranger pictures clearly showed that the moon had undergone change. They revealed maria that had accumulated boulders and other debris that had moved from the highlands over billions of years. These early pictures did not, of course, have the fine resolution of the later pictures, but they represented a remarkable achievement at the time. It was estimated that the Ranger photographs of the moon had about 2,000 times better definition than those obtained by the best earth-based telescopes.

Ranger 7 landed in the Sea That Is Known (Mare Cognitum), named in honor of the occasion. Ranger 8 impacted in the Sea of Tranquility, where the Apollo–11 astronauts were to make the first landing. Ranger 9 crashed in the Alphonsus Crater, in which the Soviet astronomer Kozyrev had recently noted a red glow. Photographs of the floor of crater Alphonsus showed among other things a small darkened crater, from which gas might have been escaping, and a rill system (Fig. 38). The photographs also indicated that a large, smooth crater floor might make a suitable landing place for astronauts. Of the

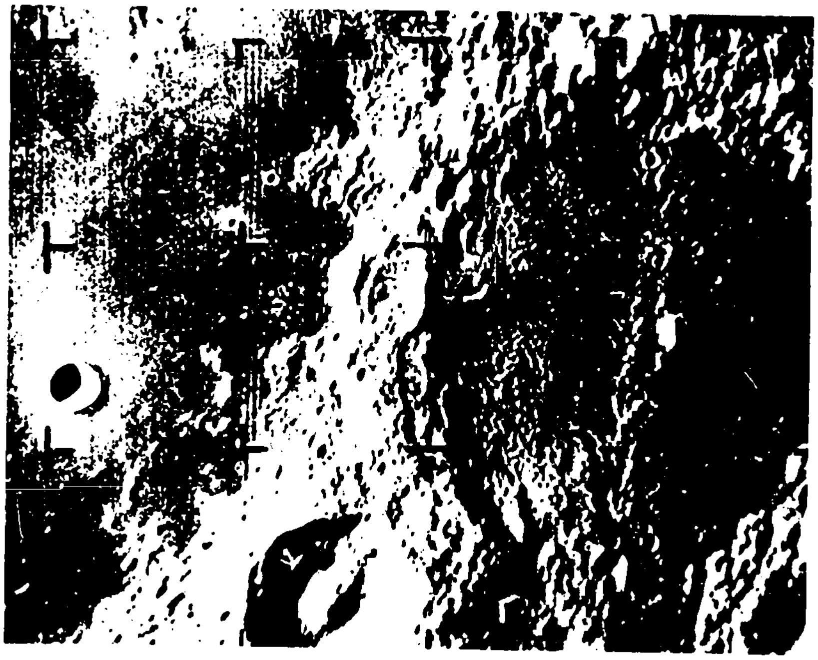


Figure 38. Photograph of Alphonsus Crater (right) taken by Ranger 9. Note the intricate pattern of ridges and rills on the crater floor. Also observe the smaller craters on the floor and walls of Alphonsus.

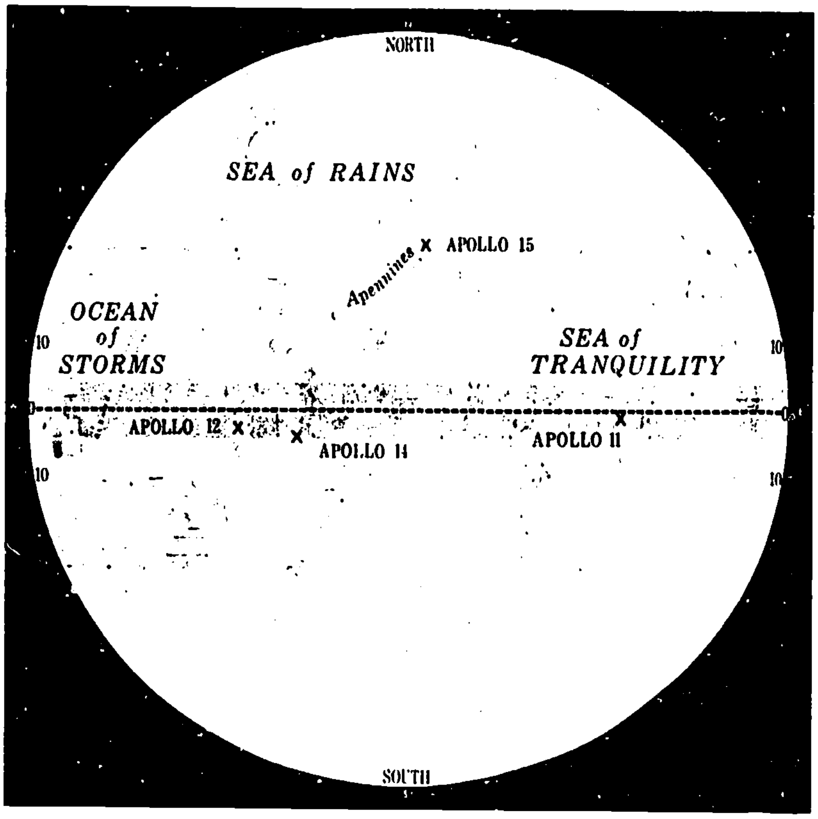


Figure 39. Lunar landing zone and the landing sites of the Apollo 11, 12, and 14 lunar modules. Note that the site selected for the Apollo-15 landing is the first one located outside the zone.

three successful Rangers, only Ranger 8 took photographs within the zone chosen for the Apollo landings. The landing zone was given more extensive reconnaissance on the ground by Surveyor soft-landers.

Surveyor Soft-Landers

The original Apollo landing zone stretches 1,800 miles along the equator of the moon on the side facing the earth. The zone extends 5 degrees north and 5 degrees south of the equator, making it about 200 miles in width (Fig. 39). Four Surveyor soft-landers transmitted data that helped NASA officials mark out the landing zone and select the best landing sites within it.

The Surveyor spacecraft, boosted by the Atlas-Centaur, weighed about 600 pounds (about 100 pounds on the moon). The exact weight of each Surveyor varied somewhat, depending upon the load of instruments carried. There were seven Surveyors launched, each instrumented for its special mission. The spacecraft was designed so that it could carry stereo-panoramic television cameras, a surface sampler, and a scoop for digging. The landing struts were equipped with gauges that could transmit information about the touchdown.

One of the first questions that the Surveyor answered was: Would smooth lunar seas like those shown in the Ranger photographs be strong enough to support the Apollo lunar module? Now that astronauts have landed on the plains and have walked upon them, we know the answer to the question. There were many doubts about the answer at the time of the Surveyor missions. Prof. Thomas Gold, an astronomer at Cornell University, had concluded from his observations that the lunar plains were covered with a deep layer of dust. Prophets of doom began to predict that the Apollo astronauts would be buried in a sea of dust when they attempted to come down on the moon. This gloomy prediction was exploded when the Soviet Union landed its Luna 9 in February 1966. This first successful soft-lander, was a robot observatory weighing 220 pounds. It was contained in a ball thrown clear of the rocket. When the ball touched the surface, it was not swallowed up in a sea of dust. Instead, the ball opened like the petals of a flower, and the television cameras inside began transmitting pictures of the landing area. The pictures showed a surface consisting of loose, crumbly material littered with pebbles.

About three months after Luna 9 landed, the U.S. Surveyor 1, launched on 30 May 1966, had a remarkably successful trip. One midcourse correction was made, and Surveyor 1 came down almost exactly on target in the Ocean of Storms, the lunar plain on which the Apollo–12 astronauts were to land later. The spiderlike legs of the spacecraft sank only about an inch into the surface. Immediately upon landing, Surveyor 1 began to transmit pictures of the surface, showing loose soil littered with pebbles, rocks, and boulders, the largest a little less than a foot across. Before its cameras were closed down at the beginning of the two-week lunar night, the spacecraft had transmitted more than 10,000 pictures. As a further experiment, a gas jet was turned on to study surface materials.

Before Surveyor 1 was left to the long lunar night, its solar panels and an antenna were placed in a nearly vertical position so that they could be photographed later by a Lunar Orbiter. Then the scientists waited to see if the delicate instruments would survive the −250 degree F. freeze of the long lunar night. Imagine their jubilation when the spacecraft came to life again as the lunar day dawned. Pictures continued to be transmitted for six more days.

Surveyor 1 gave great encouragement to all those who were trying to make the Apollo lunar flights possible. Soft-landing a spacecraft required overcoming formidable obstacles. Since the moon has no atmosphere, the Surveyor could not be landed by parachute; it had to be braked by firing small rocket engines. Once the Surveyor was successfully landed, similar techniques could be applied to the Apollo lunar module. The Surveyor rockets had to be fired by means of commands from the ground. The astronauts fire their own rockets while landing the lunar module, and they are able to hover to select a suitable spot for landing.

Unfortunately, the performance of Surveyor 1 was not duplicated by Surveyors 2 and 4, which were lost. The four other Surveyors were

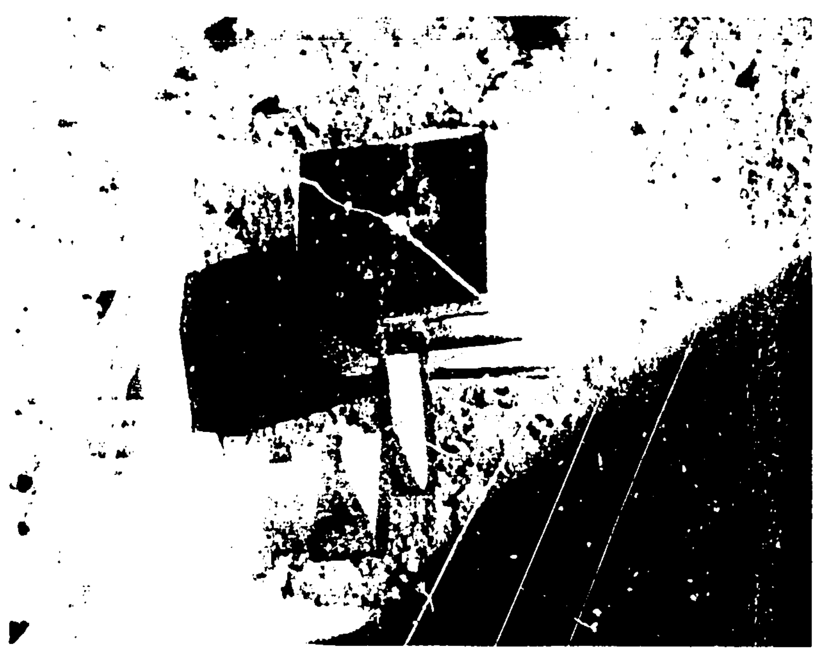


Figure 40. Photograph of lunar soil sampler taken by Surveyor 5. The ribbon-like cable connected the sampler with the spacecraft. It carried power and transmitted data from the sampler to the telemetry system in the Surveyor.

successful, making their collective achievements a truly remarkable feat.

Surveyor 5 made findings of special significance to science. This was the first Surveyor to carry the soil sampler (Fig. 40). This consisted of a gold box with radioactive material and instruments to measure the chemical composition of the landing site. After some difficulties in flight, Surveyor 5 eased down gently in the Sea of Tranquility, where the first lunar landing was later made. The first pictures sent back to the earth were of excellent quality. They showed a surface littered with small rocks. As the box was lowered, it sent out alpha particles to bombard the surface of the moon. Signals sent back to the earth recorded what happened when these alpha particles interacted with surface materials, thus providing a clue to the chemical composition of this material. After studying the signals, NASA officials announced that the surface was made up of basalt. This hard, heavy, dark volcanic rock is quite common on the earth. In fact, it makes up the mantle, or middle layer, of the earth. Basalt, formed from molten material (lava), is porous. It contains many tiny cavities in which gases are present. The findings made by Surveyor 1 had shown that 60 percent of the rock sampled was made up of oxygen. Findings made by Surveyor 5 were confirmed by Surveyor 6, also landed on a lunar plain, the Central Bay, almost in the center of the visible face of the moon.

After the Surveyors had made reconnaissance of four Apollo landing sites, their primary objective had been accomplished. Surveyor 7, the last spacecraft in the series, could be used for a purely scientific mission. It took pictures and made soil samples of an extremely rugged highland area near Tycho Crater, which is not far from the moon's south pole and is especially conspicuous because of its rays. Surveyor 7 reported the presence of basalt, as well as granite. It showed by far the roughest moonscape photographed by the Surveyors. Pictures of the area revealed jagged ridges, boulders the size of a three-story house, and craters of all sizes.

If the lunar plains (and highlands) are made up of volcanic lava like that found on the earth, then the moon could be assumed to be much like the earth and to have been formed in much the same way. The earth went through a period of cooling as the igneous, or volcanic, rocks took form. Soviet scientists, after studying the findings made by their robot explorers Luna 9 and Luna 10, came to this general conclusion. American scientists deferred their reports, however, because they wanted to wait until the Apollo astronauts brought back rock and soil samples from the moon. Analysis of the first samples was to disclose surprising information that justified waiting.

With Surveyor 7 ended one of the most successful space ventures that the United States had entered up to this time. Experience gained with the Surveyors, beside helping to make the Apollo flights possible, should be valuable in future lunar and planetary exploration. The success met with by the Surveyors was matched by the Lunar Orbiters.

Lunar Orbiters

The Lunar Orbiter (Fig. 41), an 350-pound flying laboratory, was designed to survey the moon at distances as close as 26 miles above the surface. The newly developed cameras in this orbiter took some medium-resolution pictures of larger areas and some highly detailed pictures of smaller areas. These pictures provided excellent coverage of prospective Apollo landing sites and areas of particular scientific interest, such as the floors of craters. The cameras on the Lunar Orbi-

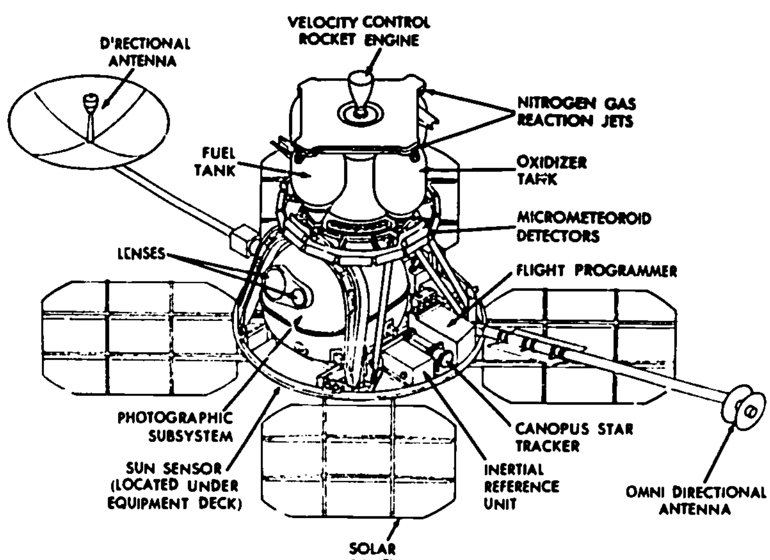


Figure 41. Diagram of the Lunar Orbiter. Note the photographic equipment and the solar panels that supplied power for transmitting the photographs of the moon to the earth.

ters were designed to operate for about 30 days. After each spacecraft had completed its mission, it was crash-landed on the moon so that it would in no way interfere with the forthcoming Apollo flights.

In one year (August 1966 to August 1967) five Lunar Orbiters were flown with phenomenal success, providing almost complete photographic coverage of the moon. The spacecraft could transmit such remarkably detailed pictures of the moon because it orbited close to the surface and used a new system of photography. The cameras on the Lunar Orbiters, unlike those on the Rangers and the Surveyors, did not merely take pictures and transmit them to the earth. The Lunar Orbiter took the pictures directly on film and developed the film in its own laboratory. Then it stored the pictures and transmitted them to the earth upon command. In this way it was possible to get pictures of a much higher quality, and the pictures could be transmitted when the receiving station on the earth faced the moon and someone was on duty at the station to receive them. The pictures transmit-

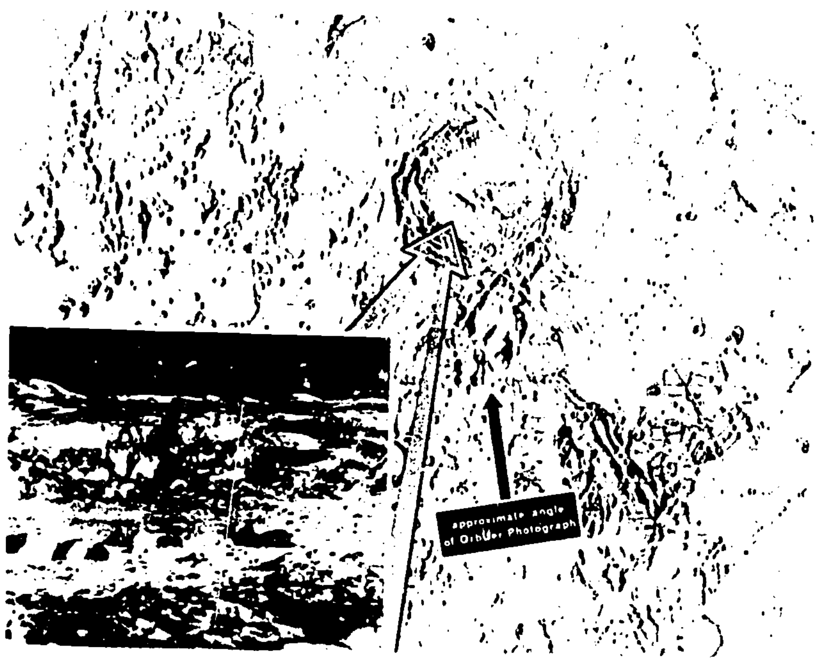


Figure 42. Lunar map of Copernicus Crater (US Geological Survey) with inset showing photograph taken by Lunar Orbiter 2. This famous Orbiter photograph shows the central peaks of the crater and parts of the crater walls. The peaks rise 1,000 to 3,000 feet above the crater floor. The total height of the crater walls is about 10,000 feet.

ted from the Lunar Orbiters could thus be systematically processed and arranged for use in making moon maps and in charting the prospective Apollo landing sites.

Each Lunar Orbiter was assigned some special area to investigate and photograph. For example, Lunar Orbiter 2 took a remarkable picture of Copernicus Crater (Fig. 42), one of the two large craters with conspicuous rays. The picture shows details of the central peaks. Lunar Orbiter 3 pinpointed Surveyor 1 and photographed it. Lunar Orbiter 5, turning its telephoto lens on the earth, gave earth dwellers a new view of their spinning planet.

Photographs taken by the Lunar Orbiters will continue to be useful even after the Apollo flights are completed. Scientists are continuing to study the pictures. It has been estimated that these photographs gave astronomers more information about the moon than they had obtained in the last 50 years of observations with the best earth-based telescopes. To extend and verify the records made by the Lunar Orbiters, the Apollo astronauts are taking many photographs as they orbit the moon and make observations of specific sites. Photographs of the lunar surface taken from orbit will continue to have great value for scientists. The Surveyors and the Apollo astronauts have been able to photograph on the ground only a small part of the moon. We shall have to depend upon photographs taken from orbit for firsthand knowledge about the rest of the moon.

Probably the most eagerly awaited findings from the Lunar Orbiters were the detailed views they gave of the hidden side of the moon. The US orbiters were not the first to give the world a view of the far side of the moon. The Soviet Luna 3 had orbited the moon and photographed the far side as early as October 1959, a remarkable feat at the time. The photographs taken by Luna 3 did not show much detail, however, as the photographs were taken in full sunlight, the probe was farther from the surface, and the cameras were not so advanced. Later photographs taken by the Soviet Zond 3 showed more detail.

After scientists had a good view of pictures of the far side of the moon, they were surprised to note only one large mare, or sea. Maria cover about half of the visible side of the moon, but highlands predominate on the far side. The features found on both sides of the moon are nevertheless fundamentally the same, and both sides of the moon's sphere have equal periods of daylight and darkness. At present there is no satisfactory explanation for the difference in the distribution of physical features on the two sides of the moon. Probably the moon has been affected in some way by the strong gravitational pull of the earth on the side constantly facing the earth.

By August 1967, the US Air Force had produced a detailed chart of the far side of the moon by making use of pictures taken by the Lunar Orbiters and filling in with photographs obtained by Zond 3. The chart was prepared for the 1967 meeting of the International Astronomical Union in Prague, Czechoslovakia.

The Lunar Orbiters were not intended to provide data for mapping and photographic coverage alone. They also made measurements of the moon's environment, sending back information on the moon's gravitational field, micrometeoroids, and radiation. The Soviets, after studying the findings of their early Luna probes, concluded that the moon has no magnetic field. American scientists, on the other hand, have obtained evidence that the moon has a very weak magnetic field. The Apollo astronauts are using highly sensitive instruments to make further measurements of magnetism.

The Lunar Orbiters also gave practice in using the Apollo communication network and in tracking spacecraft in orbit around the moon. It was in tracking the Lunar Orbiters that controllers first observed the irregularities in the moon's gravitational field. These irregularities became a more serious problem when the Apollo astronauts prepared to navigate the lunar module to descend for a landing. After checking all their observations on lunar orbits, scientists discovered the lunar mascons.

Through the findings made by unmanned spacecraft, the United States had obtained much new information about the moon, but for each question answered many more questions were raised. Soon the astronauts were to follow, and it was hoped they would provide some answers to these questions.

EARLY MANNED EXPLORATION

While unmanned exploration of the moon was going forward, a group of outstanding American scientists from the American Academy of Sciences met at Woods Hole, Massachusetts, in 1965, to propose questions about the moon that the Apollo astronauts should try to answer. They suggested fifteen major questions, which revolved around the key questions outlined earlier in this chapter. They wanted to know, among other things, about the moon's age, its surface composition, the nature of its interior, the processes that were responsible for its present structure, any evidence of volcanic activity, the effects of solar radiation, and the presence of any magnetic fields in the lunar rocks.

To answer their questions, the scientists proposed that NASA use instruments that were as simple as possible but could still report data accurately and survive under the rigorous conditions on the moon. The astronauts would set up the instruments on the moon, and these instruments should be able to send back data for at least a year after the astronauts left. To make comparisons possible, the same instruments were to be used at each succeeding site rather than trying to increase the complexity of the instruments with each flight. The result of the scientists' recommendations was the package of instruments known as the Apollo Lunar Surface Experiments Package (ALSEP).

Besides taking instruments to the moon, the astronauts were to make observations and to collect samples of rocks and soil, which would later be studied by renowned experts worldwide. The astronauts would visit different kinds of areas so that the samples from these areas could be compared. Through the use of television cameras on the moon, scientists would be able to look over the shoulders of the astronauts and make observations with them, as it were. Scientists could even relay advice and suggestions to the astronauts through the flight controllers. By the time that the last Apollo flights are being made and operational and navigation problems are under control, it is hoped that at least one scientist-astronaut can be included with the moon-landers. The Apollo exploration flights, with their lines of communication reaching back to the earth and with their follow-ups in the scientific laboratories of the world, make up a truly unique experience in the history of scientific investigation.

The attention of scientists and laymen alike has naturally been focused on the results obtained from the analyses of the lunar samples. These samples are distributed in small amounts to many experts, and the experts inspect, examine, pound, heat, melt, powder, expose to radioactive materials, and submit these samples to other tests in order to extract as much information from them as possible. The experts arrive at their conclusions independently. Then they meet each year in January at the Manned Spacecraft Center in Houston. Here they talk over their ideas and try to reconcile differences so that they can make a meaningful consolidated report.

Although the same general plan of sampling and basically the same instruments are to be used on each Apollo flight, the exploration will gradually become more thorough and exact. With each flight the astronauts will stay longer on the surface of the moon, probe more deeply below its surface, and venture out farther from their landing point. On the Apollo–14 flight, for example, the astronauts used powered drills to penetrate below the surface of the moon and made use of a hand cart. On the Apollo–15 flight, the lunar module is to carry with it a powered lunar rover. This jeep-like vehicle, with a motor on each wheel, will advance cautiously over the surface of the moon. The rover will make it possible for the astronauts to cover much more ground, make more observations, and collect a larger load of samples. They will be kept from falling on the slippery surface or from dropping into a crevasse. While each succeeding Apollo flight promises fuller data, the later flights cannot duplicate the excitement and expectancy with which scientists awaited the first landing.

Apollo–11 Exploration

After the Apollo–11 lunar module, the Eagle, landed in the Sea of Tranquility, Astronauts Neil Armstrong and Buzz Aldrin observed the moonscape through the windows of their module. They were already familiar with the view through pictures of the track taken during the Apollo–8 and the Apollo–10 flights, and they had carefully observed the site as they descended for a landing. An astronaut depends upon observations made in flight, as he has a somewhat limited view once he lands on the moon. Since the moon is much smaller than the earth, the moon's horizon drops away at a much closer range. For an astronaut on the moon the horizon is only about two miles away when he is standing on a flat plain. When the Eagle landed in the Sea of Tranquility, the astronauts' vision was further limited because the lunar day was just dawning.

The Eagle landed near the terminator (imaginary line separating nighttime from daytime), and the light of the rising sun cast weird shadows. Since both Armstrong and Aldrin had made previous spaceflights, they were not surprised at the strange effects brought about because the moon is surrounded by the vacuum of space. Because there is no atmosphere on the moon, they heard no sound, and there was no wind or blue sky. Instead the sky was inky black, but the astronauts could not see the stars because of the glare caused by the sunlight. Later, inside the Eagle, they had a chance to get a good view of the earth in their telescope. Because the earth is much larger than the moon and reflects about seven times as much light, the full earth, with its water and atmosphere, looked like a great mottled blue-and-gold globe glowing against the blackness of space.

You may have thought that the descriptions of the moon as given by Armstrong and Aldrin did not agree exactly with those given earlier by other Apollo astronauts. Although the moon does not, of course, have sunrises and sunsets like the earth, it does present different aspects, depending upon the time of the lunar day and the angle from which it is viewed. When the sun is low in the sky at dawn, the moon has a harsh, forbidding look and is predominantly gray. The moonscape tends to soften gradually as the day advances. At lunar noon, when the sun is directly overhead, the moon appears warm and brown. As the sun descends in the sky and dusk approaches, the moon gradually becomes stark once again. The Apollo–11 astronauts were describing the moonscape at the lunar dawn.

As the astronauts began their exploration, they proceeded slowly and cautiously. They were testing the moon suit and the backpack for the first time under actual conditions. They knew that a bad fall might tear the moon suit and threaten decompression. They checked all of their equipment carefully because they could not waste valuable oxygen. Once on the moon, they had to depend upon the limited quantities of life-support supplies in the Eagle. These would have to last them until they could rejoin Astronaut Collins and the Columbia in lunar orbit.

On this first traverse of the moon, the astronauts did not take the full Apollo experiment package (the ALSEP), but they had some of the basic instruments and made a good beginning at this new kind of exploration. In all they spent 2 hours 31 minutes outside the Eagle, and they went as far as 300 feet from the Eagle. They collected about 48 pounds of rock samples and soil samples as well, and they set up three experiments: the aluminum foil screen for detecting solar wind, a seismometer (moonquake detector), and a laser reflector. They brought the rock and soil samples and the foil screen back with them. They left the seismometer and the laser reflector on the moon.

You may have watched the astronauts pound the pole into the soil and set the aluminum foil screen upright on the moon (Fig. 43). This was an experiment devised by a Swiss astronomer at Bern University. The foil was especially treated so that it would capture low-energy ionized particles, called the solar wind, which stream onto the moon from the sun. Scientists reasoned that since the moon has virtually no at-

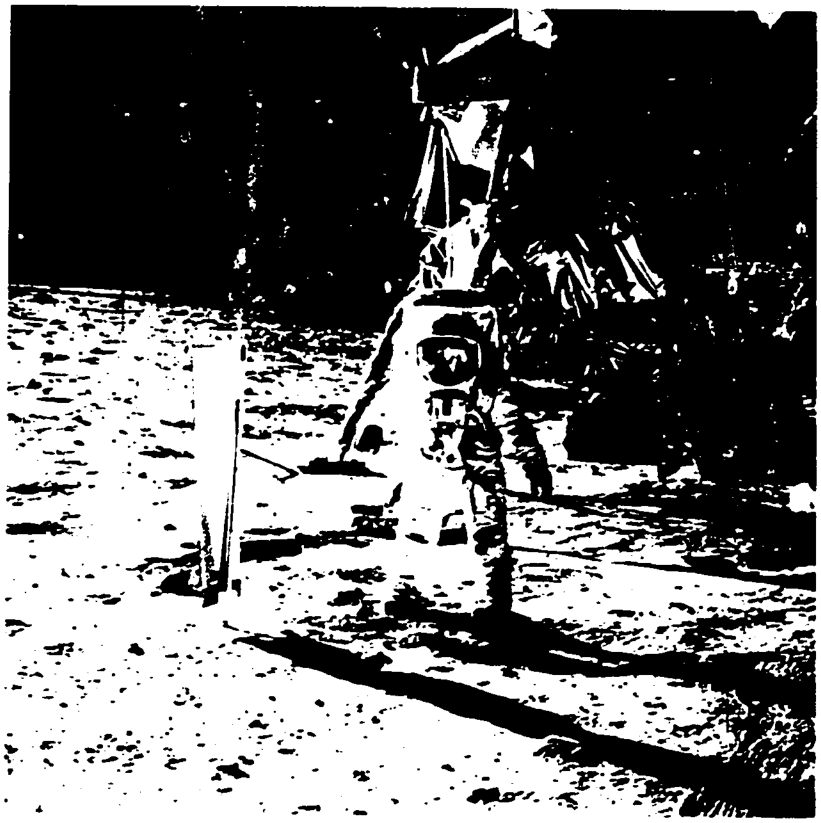


Figure 43. Solar wind experiment deployed on Apollo-11 landing.

mosphere or magnetic field, it does not repel the solar wind, as the earth does. Since the solar wind should reach the surface of the moon without hindrance, the moon should provide us with a good opportunity for studying these minute particles of solar matter. When the astronauts brought the screen back to the earth, it was sent to Switzerland to have its contents analyzed. Similar solar wind experiments were made on later flights.

The lunar seismometer (Fig. 44), or moonquake detector, was designed to operate like seismometers used on the earth except that it was made one hundred times more sensitive. Since there is no traffic, no loud explosions, no roar of water, or similar disturbances on the moon, the lunar seismometer could be made much more sensitive than those used on the earth. The lunar seismometer recorded, for example, the sound made as the astronauts walked on the moon and the impact of a rock they tossed into a crater. Scientists were not surprised, therefore, that the lunar seismometer recorded a loud echo when spacecraft were later crash-landed on the moon. What they were surprised about was the length of time the echo lasted and the pattern of sound waves returned. Even when the instruments were first shut down for the lunar night (in August 1969), the seismometer had recorded some mild surprises. It showed three presumed moonquakes and more than two hundred landslides. The record indicated that the surface of the moon is acted upon by interior forces so that the moon may not be the inert body that some scientists formerly believed. The record also showed that materials tend to move about on the moon much more than had been formerly believed. Although there is no erosion of the kind experienced on the earth, there is what geologists call mass wasting. Even the relatively weak lunar gravity produces landslides. For example, it causes rocks and boulders to drop from a crater wall and slide to the center of a crater.

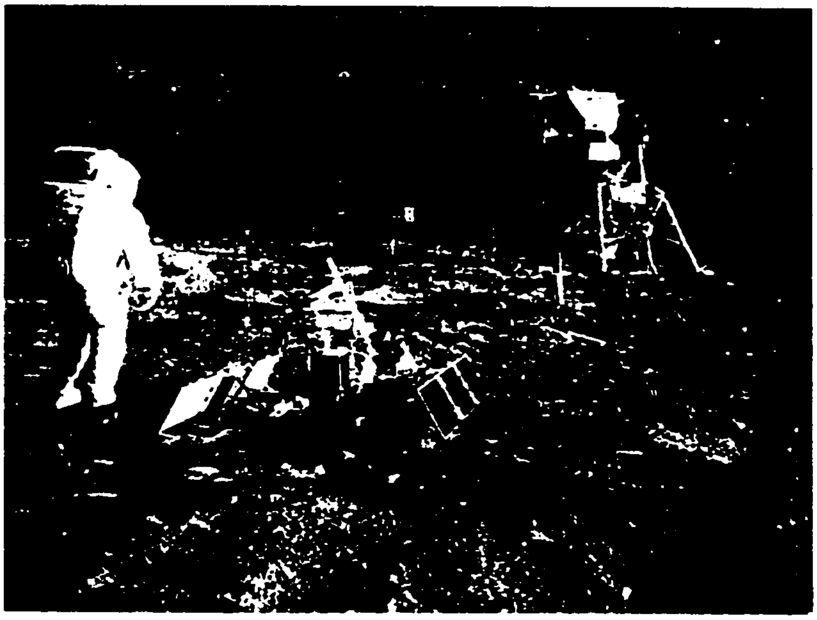


Figure 44. Placing the seismometer and the other experiments in the Early Apollo Scientific Experiments Package (EASEP). The seismometer is in the foreground. The laser reflector is behind it.

On the earth, scientists have set up a series of seismometer stations all over the globe to make recordings and check findings. From data obtained by these stations we have learned almost everything we know about the earth's interior: its molten core, its heavy medium layer (mantle) made up of basaltic rock, and its relatively light covering of crystalline rocks. Scientists hope that in time they can have a similar series of stations on the moon that will give them information about the moon's interior. A seismometer will be set up at each Apollo landing site.

The laser reflector that Armstrong and Aldrin placed on the moon is made up of pieces of polished quartz. These are arranged so that they return a laser (highly concentrated light) beam in exactly the same direction in which it was sent from the earth. Astronomers on the earth can send out a laser beam to the moon, hit the reflector, and then measure the length of time it takes to get an echo. When astronomers first sent laser beams to the moon, they were not able to get an echo because they could not locate the reflector. But as soon as astronomers knew the precise spot where the Eagle had landed, they were able to get a return. Through use of the reflector, scientists have been able to compute the distance between the earth and the moon to a degree of accuracy within six inches. Using the principle of triangulation, they can now measure distances on the earth with a corresponding degree of accuracy. Now scientists can check out theories, such as the drift of continents, which they could not verify before. They also have more information about the wobbles of the earth's axis, which is important in understanding earthquakes.

The Apollo–14 astronauts put down a second reflector, and a third one will be emplaced on a later flight. NASA has set up a special observatory in Arizona to study the laser reflectors and the information that can be obtained by using them. Other observatories are assigned to make studies with these reflectors, and scientists throughout the world have been invited to make use of them.

While astronomers were working with the reflector, more than 140 specialists throughout the world were analyzing the rock and soil samples that the first astronauts had brought back with them from the moon. All lunar samples were first taken to the Lunar Receiving Laboratory at the Manned Spacecraft Center in Houston for quarantine, just as the astronauts themselves were. Before the samples were released, scientists wanted to be sure they would not carry organisms that would spread disease. No evidence of life of any kind was found in the lunar samples. On the way from the moon the rock samples became covered with a dark dust although the vacuum seal was preserved. When samples were later exposed to the earth's atmosphere, they did not undergo a further change. No one has been able to explain why some materials on the moon seem to have darkened. Scientists continue to study the samples, but they have already reported some of their findings.

Through a special system of dating, which determines the proportion of radioactive materials in the rock (such as titanium) to their respective products of decay (lead in the case of titanium), scientists have been able to establish the age of the samples. They dated the samples found in the Sea of Tranquility at about 3.7 billion years. This was a great surprise to most scientists, since they thought that the great flow of molten material, which is presumed to have caused the lunar seas, occurred in relatively recent times. Instead, these seas seem to have developed at roughly the same time as the very oldest rocks on the earth.

There are three large classes of lunar rocks: the igneous rocks like basalt, which solidified after melting; the breccia, or chunks of rock and soil cemented together by temperature and pressure; and the clods, or fines, which are made up of small fragments of material much like the soil and break up easily.

The basaltic rocks were the most common at the site where the Apollo–11 astronauts landed. The lunar basalt is similar to that found on the earth, but it has a different chemical composition. Chemical studies of the basalt samples brought back by the astronauts generally agreed with the findings of Surveyor 6. Refined studies have shown that lunar basalt has a much higher proportion of titanium and other radioactive materials. Analyses of other lunar materials revealed the same findings. This fact has led American scientists to believe that the moon is probably different from the earth and developed separately.

Another surprise was the abundance of glassy material on the moon. From computations made from the first samples, scientists have estimated that this glassy material makes up a fourth to a half of the lunar surface. Scientists expected to find such glazed material on the moon, but they did not expect to find it in such abundance. The glass appears in the form of rounded beads which vary in size. Some of these beads are so small that they can be seen only with a microscope. Others are large enough to be seen with the naked eye. The glass varies in color from a clear glass through the cream and yellow colors all the way to brown. Some scientists speculate that the glazing of silicate and other materials occurred at the time of meteoritic bombardment, which vaporized the lunar surface materials. The drops rained back on the moon and later hardened. The only drawback to this theory is that it is difficult to explain why, with the moon's weak gravitational pull, the drops did not go off into space.

In the midst of all the speculation that followed the analyses of samples from the Apollo–11 landing, scientists kept asking if this site was typical of the lunar seas. Would other findings produce contrary facts about the nature of the seas? The voyage of Apollo 12 provided some answers.

Apollo–12 Exploration

In the Apollo–12 lunar module, the Intrepid, Astronauts Charles Conrad and Alan Bean landed in the Ocean of Storms (Oceanus Procellarum), another large circular lunar sea. This site is about 950 miles away from the site where the first astronauts landed. During the 31 hours 31 minutes that Conrad and Bean spent on the moon, they made two walks, each lasting more than three-and-a-half hours. The first walk was devoted principally to setting up a miniature scientific station from the instruments contained in the Apollo Lunar Surface Experiments Package (ALSEP), and the second was a kind of geological field trip during which they also recovered parts from the Surveyor 3, which they found still intact on the moon (Fig. 45). Besides the parts from the Surveyor, the astronauts took back to the earth with them about 75 pounds of lunar rock samples and soil samples as well.

Unfortunately, Conrad and Bean were unable to get their television camera to work. They had no telecast to enable them to share their observations with scientists on the earth, but they helped to make up for this by giving careful descriptions of their observations by radio as they proceeded. Their landing site, which was near a crater of some size, Head Crater, looked quite different from that observed by the first astronauts. The surface was covered with a somewhat deeper layer of dust, which caused the Intrepid to make its landing in a shower of dust. Although the Apollo–12 astronauts are believed to have seen some bedrock, they did not observe predominantly basaltic rock, as the first moon-landers did. There appeared to be more crystalline rocks and a greater variety of rocks in the vicinity of the second landing site. The area showed the same abundance of glassy material,

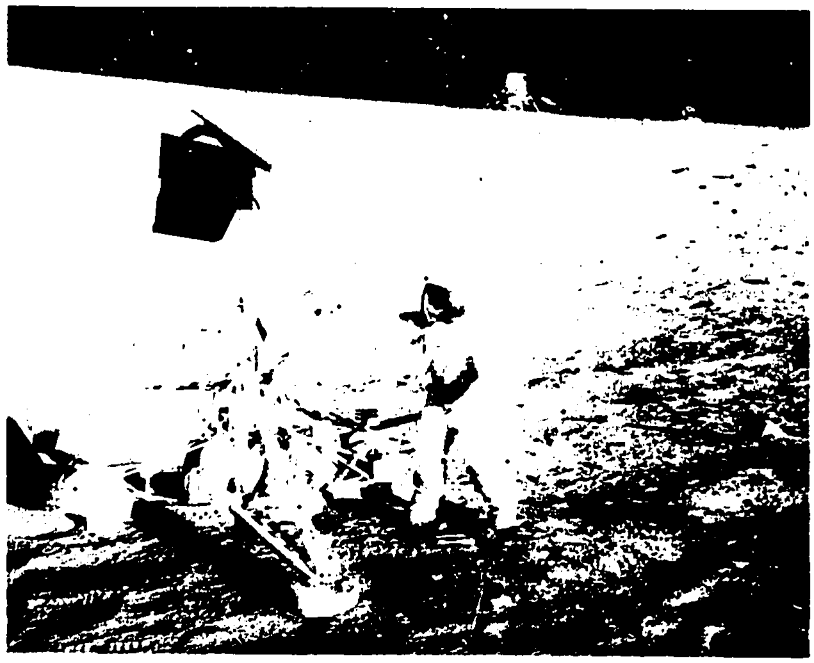


Figure 45. Surveyor 3 being examined by Apollo-12 astronaut. The lunar module is in the background.

however, and the astronauts observed glazed rock in the bottom of a crater, a natural place for a heat trap.

To back up their observations, Conrad and Bean put down the first tiny experiment station on the moon. They took the instruments from the ALSEP and deployed them as they had practiced on the earth. The experiment station consists of a central station, a nuclear generator, and four kinds of instruments: a seismometer, a spectrometer, a magnetometer, and lunar ionosphere and atmosphere detectors. The station was designed to operate for a year after the astronauts left, but the generator has proved so efficient that the station will probably operate much longer. The central station, which is about the size of a steamer trunk, receives information from the various experiments and transmits this to the earth. It also receives commands from the earth and relays these to the instruments.

The four instruments deployed on the Apollo–12 flight are more complex and specialized than those left behind after the first landing. The second set of instruments is intended to give the same type of information but in a more precise way and to transmit information for a much longer time. There was no laser reflector left on this second landing. All the instruments left in the miniature station are highly sensitive and have worked well.

The seismometer produced what was probably the greatest surprise of the Apollo–12 findings. When the Intrepid was crash-landed on the moon after Conrad and Bean were safe inside the Columbia again, the seismometer recorded a ring for about an hour. This echo might be compared with a continuing echo made after a bell is struck one time. The pattern of the sound waves was unlike anything recorded after an earthquake. The findings indicate that the moon is made of layers of different kinds of rock or that its interior is quite unstable.

Although the Apollo 13 was unable to land on the moon, it did contribute some findings by crash-landing the spent upper stage of its Saturn V rocket. When this much heavier structure hit the moon, the seismometer recorded an echo for four hours, thus reinforcing the findings of the Apollo–12 flight. Astronauts on the Apollo–14 flight also crash-landed their spent rocket stage onto the moon with similar results.

After the Apollo–12 flight was over, the seismometer continued to record a series of moonquakes about the time when the moon was closest to the earth in its monthly cycle. Gary Latham, chief Apollo seismologist, believes that these moonquakes can be linked with the red glow that astronomers have observed. He explains that the moon does not undergo tides as the earth does because the moon has no water. The gravitational pull of the larger earth on the smaller moon is much greater than the reverse, however. When the moon reaches the point closest to the earth each month, its solid surface is pulled out in the direction of the earth. The moon "pops" under the pull, and gases trapped under the surface are released, probably causing the red glow.

The second instrument in the ALSEP, the spectrometer, like the simple aluminum foil screen, will tell scientists something about the interaction of the solar wind with the moon. The spectrometer will give more precise information, however. It will chart the strength, speed, and direction of the solar wind.

The third instrument, the magnetometer, detects magnetism. The importance of detecting even small amounts of magnetism has been explained. If the moon once had a molten core and the core has cooled, some evidence of magnetism should have been left behind on the moon. The moon may have an extremely weak magnetic field, or it should show some local or transient magnetism. The magnetometer has detected only very small amounts of magnetism, but these amounts were larger than those recorded up to this time.

Just as in the case of magnetism, the moon is not expected to show any appreciable atmosphere and no significant ionosphere. Therefore, the atmosphere and ionosphere detectors, the fourth set of instruments in the ALSEP, have been designed to make them extremely sensitive, and any recordings are worthy of attention. The atmosphere detector is so sensitive that it recorded gas escaping from the astronauts' backpacks. The ionosphere detector showed some evidence of charged particles at the surface of the moon, suggesting the possibility of an ionosphere, but other evidence has been to the contrary. The solar wind does not appear to be disturbed as it approaches the moon. Therefore, the moon can have no charged particle layers around it similar to the earth's ionosphere.

When the Apollo–12 astronauts made their walk (Fig. 46) to collect specimens and to make extended observations of the moonscape,

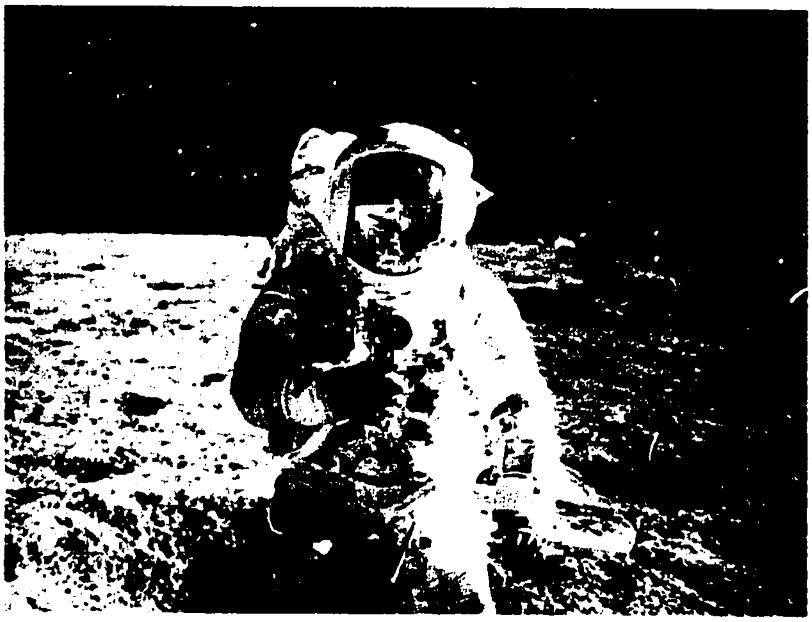


Figure 46. Astronaut Conrad prepared for collecting samples of rock and soil. Note the checklist on his wrist and the core sampler in one hand. The other hand is on the trigger of the camera used for documenting rock samples.

they were guided by experience gained during the first landing, and they had more time. Therefore, they were able to make a more systematic record of the places from which they took specimens. They also brought back a larger number of rock specimens and a greater variety. Again, the specimens were covered with a dark dust when uncovered in the laboratory, and the samples showed no evidence of life. But scientists made a surprising observation after studying many hundreds of different kinds of plant specimens grown on the lunar soil. When plants were put in the lifeless soil, they fared remarkably well —much better than in earth soil. Now scientists are trying to find the reason for that.

When the first rock samples were analyzed, they showed that the second sea was considerably younger than the first, about a billion years. Then later samples pushed this age back, and now it appears that the Ocean of Storms, like the Sea of Tranquility, dates back about 3.7 billion years.

In the summer of 1970 a surprising find was made. One small rock returned by the Apollo–12 astronauts showed a radioactive dating of 4.6 billion years. This rock may have been part of the surface of the lunar sea, or it may be an ancient rock from below the surface that was ejected from a crater. Further studies will show whether this rock represents a chance find or whether the Ocean of Storms is actually older than 3.7 billion years. While scientists were continuing their studies of the samples, astronauts made a third exploration of the moon on Apollo 14.

Apollo–14 Exploration

After Astronauts Alan Shepard and Edgar Mitchell landed the Apollo–14 lunar module, the Antares, in the Fra Mauro region, they began the third exploration of the moon. This was the longest and the most completely documented tour made up to that time. As planned, both the stay time on the moon and the time spent outside the lunar module were increased during the Apollo–14 flight. What was even more important than the extended time, however, was the fact that on the Apollo–14 flight the astronauts were exploring a new kind of area, a highland region. On the two earlier landings the astronauts had explored lunar seas. The Fra Mauro formation is a rugged highland area which is believed to contain some of the most primitive material to be found on the moon. Scientists selected this area to explore because they believe that it is blanketed with material ejected from the bottom of the Mare Imbrium (Sea of Rains) far to the north. Here in the Fra Mauro region the astronauts were able to find on the surface of the moon materials that may date back to the beginning of the moon. As Shepard and Mitchell reported their observations, the scientists were pleased to have many of their assumptions confirmed.

Even before they landed, Shepard and Mitchell had been able to see that the area they were to explore was quite different from the smooth lunar plains. As they orbited the moon before the Antares was separated from the Kitty Hawk, they could see clearly that the surface of the moon at this point was made up of almost constant hills and valleys and that there were many large boulders strewn about. This survey of the region helped the astronauts later when they had to identify the features they were to investigate during their traverse to Cone Crater and back to the Antares again. Once on the undulating surface of the moon, the astronauts found it difficult to get a clear vision ahead of them.

During the 9 hours and 25 minutes that they spent outside the Antares, Shepard and Mitchell divided their time almost equally between two moon walks. During the first one they put down the solar wind experiment, the laser-beam reflector, and the ALSEP (Apollo Lunar Surface Experiments Package), which contained essentially the same instruments as were in the package emplaced by the Apollo–12 astronauts. They also performed special experiments assigned to their flight. On the second walk they made the geological tour, which climaxed in the dramatic climb of Cone Crater. During both moon walks Shepard and Mitchell had the television camera operating. Scientists could watch them as they made their moon walks, and they could relay directions to them through the flight controllers.

The instruments in the ALSEP placed on the moon during the Apollo–14 flight have functioned well. They had their first test shortly after the landing when the temperature dropped below −150 degrees F. during an eclipse. The third seismometer, which was put down on the flight, is close enough to that left by the Apollo–12 astronauts so that readings can be compared.

A special experiment included on the Apollo–14 flight was the so-called active seismic experiment. As the first part of the experiment Mitchell set off charges to cause the Thumper device (Fig. 47) to impact on the moon, creating a man-made moonquake. As the seismometer recorded the moonquake, scientists on the earth obtained infor-

Figure 47. Thumper device carried by Astronaut Mitchell (left). Astronaut Shepard is in the background with the deployed instruments from the Apollo Lunar Surface Experiments Package (ALSEP).

mation on the physical structure and the strength of the moon's surface at this site. As the second part of the experiment, the astronauts set up grenades, which were to be fired later upon a radio command from the earth. This second man-made moonquake could be recorded by the seismometer when there were no astronauts present on the moon to affect the readings.

The high point of the exploration was the expedition to the rim of the 400-foot-high Cone Crater, which was about a half mile away from the Antares landing site. On the way to and from the crater the astronauts visited other smaller craters, and they took samples whenever they paused to rest. The going was rough at times, but the astronauts were assisted by their cart (Fig. 48). It held their tools and samples and allowed them more freedom in making their investigations. A movie and a still camera helped them in recording the descriptions of the places from which they obtained rock samples. On the walk Shepard and Mitchell also took core samples of lunar soil at a depth of about 4 feet, and they dug a trench, which disclosed three distinct layers of material under the surface.

Figure 48. Astronaut Shepard preparing hand tools for the walk to Cone Crater. He is standing beside the cart known as the Modularized Equipment Transporter (MET).

As Shepard and Mitchell neared Cone Crater the boulders seemed larger. Finally the astronauts reached the crater and began the long climb up the crater wall. When it appeared that at any moment they would reach the top, another ridge would loom up. Their time was extended. Still the top did not come into view. When they were within 50 feet of the top, the extra time was used up also, and they had to call a halt. From their position on a ridge they took samples of rocks that appeared to have been ejected from the crater. Naturally the astronauts were disappointed because they did not reach the rim of Cone Crater, but their scientific mission was accomplished nevertheless. The rock samples that they obtained lay close enough to the top to provide the evidence needed.

Scientists were highly pleased with the first findings from an exploration of a highland area. Shepard and Mitchell had carefully documented their samples, and they collected a load of 95 pounds of valuable rock samples. These included the larger samples that the scientists had requested (Fig. 49). The rocks at the Apollo–14 site appeared not only much larger than those found at the two previous sites but also of a different type. Many of the rocks picked up from the Fra Mauro formation were clodlike. They were made up of tiny particles

Figure 49. Astronauts Mitchell and Shepard examining some of the large rock samples collected during the Apollo-14 landing. They are in the Lunar Receiving Laboratory at Houston, Texas.

and crumbled easily. Tentative examination has shown the rock samples from the Apollo–14 flight to be much higher in radioactive materials, and the field magnetometer registered much more magnetism in the Fra Mauro region than at the two previous sites. Scientists expected to find more radioactivity and magnetism in the highland areas of the moon, where the rocks are believed to be made up of primitive materials. Findings from the Apollo–14 exploration cannot be established until the rock samples are tested and the results of the tests are studied. Samples obtained during the exploration will be distributed for study worldwide, just as was done with the samples obtained on the two previous landings.

Summary of Tentative Findings

You may wonder where the findings made on the three Apollo lunar landings are leading us. So far the Apollo astronauts have explored three sites on the moon: two in the lunar seas (Sea of Tranquility and the Ocean of Storms) and one in a highland area, the Fra Mauro formation. The Apollo–15 flight should produce samples from both a highland area and a winding rill. On the last Apollo flights the astronauts are likely to bring back samples from the floor of at least one large crater. After the Apollo flights are completed, we can expect to have scientific data on four kinds of features on the moon: seas, highlands, a rill, and craters. When scientists are able to compare these features, they should have a better understanding of the moon and its relation to the earth and the solar system, and they should be able to make more realistic recommendations about how to proceed with the exploration of the moon in the future.

When scientists met for the Lunar Conference in January 1971, the Apollo–14 flight had not yet been made. Findings from this and the Apollo–15 flight will be discussed at the 1972 conference. To date, scientists have been able to study returns from only the first two Apollo landings, those made on the lunar seas. Soviet scientists have reported on samples brought back by their automatic sampler, Luna 16, from the Sea of Fertility. All findings are essentially in agreement.

Although Soviet scientists agree with American scientists about the nature of the findings, they have not reached the same tentative conclusions. Some American scientists think that the difference between moon and earth basaltic rock is slight, but they believe that this difference is significant. Because moon rocks seem to have more radioactive materials in them than earth rocks, they believe that the earth and the moon may have had a different history. Therefore, we might not be justified in concluding that the moon basalt was produced by volcanic action. Soviet scientists, on the other hand, believe that the presence of basalt on the moon suggests that volcanic action produced the lunar seas.

Actually what we have at present are two sets of conflicting evidence. The crater-marked surface of the moon tells the story of violent and continuous bombardment by meteorites, and suggests that heat from this bombardment produced the molten rock which cooled and hardened to become the lunar seas. The chemical evidence, on the other hand, if interpreted as some scientists suggest, indicates that volcanic action, which took place very early in the moon's history, produced the molten rock from which the lunar seas were formed.

What is becoming clearer now is that the moon was, and is being, acted upon by forces from both within and without. When scientists come upon new clues, they will be able to reconcile what now appear to be two sets of conflicting data.

What has already been made clear is that the moon is very ancient, at least about 4.6 billion years old, and that it will give us clues about the beginning of the earth and the rest of the solar system. If later rock samples from the moon are dated farther back than 4.6 billion years, then scientists will have to change their ideas about the age of the earth and the solar system. Another fact that is evident now is that the large lunar seas are quite ancient also, having been formed at or near the beginning of the moon's history. If we cannot conclude much more than these two facts at present, it is evident that scientists will soon be able to answer more of the questions now being raised about the moon.

Questions, doubts, and debate have marked the beginning of most great scientific discoveries. We are living in an age when man is reaching out to find new answers to questions about the origin of the moon, the earth, and the entire solar system. The challenge is for you to learn more about the moon so that you can understand what the Apollo astronauts are trying to do as they perform new experiments and explore new sites on the moon. The Apollo astronauts are taking part in a great scientific undertaking, one that can be even more exciting for you than the adventures they had in reaching the moon and landing. As the Apollo flights are nearing completion, you are probably wondering what the United States plans to do to explore the moon in the future.

FUTURE EXPLORATION OF THE MOON

One of the results that the United States hopes to obtain from the Apollo flights is to learn how best to direct our efforts in exploring the moon in the future. Although no further moon missions have as yet been budgeted, the United States plans to continue exploration of the moon at some time in the future.

Your study of the observations made by the Apollo astronauts and the experiments they set up on the moon has shown how the United States was able to press forward with the exploration of the moon once man had orbited the moon and landed upon it. Further, your study of the unmanned spacecraft that preceded the Apollo astronauts—the Ranger, Surveyor, and Lunar Orbiter—have indicated the potentials of automatic spacecraft for further exploration of the moon. Although the United States made a slow start with the Surveyor, this spacecraft produced remarkable results once the first set of technical problems had been solved. The Lunar Orbiters moved forward quickly in the task of mapping the moon and taking detailed photographs of important lunar features and prospective landing sites. The Soviet Union has concentrated its efforts upon developing its earlier robot explorers into more advanced robots, and the automatic sampler (Luna 16) and the automatic rover (Lunokhod 1 landed by Luna 17) have resulted.

Both manned and unmanned spacecraft have potentialities for exploring the moon in the future. US planners should draw upon the benefits we have obtained from our experience with both kinds of spacecraft for further exploration of the moon.

As plans are now projected, the next large step that the United States is likely to take in lunar exploration would be to place a scientific station in orbit around the moon. This station should be much more than a manned Lunar Orbiter. It would be more like the space station that the United States is developing for use in earth orbit, described in Chapter 4. When men are at work in this orbital station, they could control all kinds of robot explorers operating on the moon. As it became necessary to make repairs or adjustments to the robot explorers or to instruments on the moon, an astronaut could descend to the moon in a vehicle similar to the Apollo lunar module.

Whether the next large step in lunar exploration should be a semipermanent station on the moon, we cannot tell at present. Scientists hope the United States will one day have such a station on the moon. It could be operated somewhat like the scientific stations in Antarctica. The benefits that the United States might derive from having a station on the moon should suggest themselves to you as you study present methods of exploration. The moon, the only natural satellite of the earth, provides an ideal place for an astronomical observatory. Telescopes would have a stable position there, and the viewers could look at the heavens from the moon without being hampered by the veiling effects of an atmosphere.

If you are enthusiastic about the possibilities of lunar exploration, you may foresee potentials for mining, industry, and eventual colonization. The possibilities may seem exciting to you, but today scientists are not interested in the moon for its practical value. Their chief interest is to obtain additional scientific knowledge through further exploration of the moon.

Because of what we have already accomplished in exploring the moon, we have made the first step forward in exploring the planets, and we have learned much about the space environment. Once the

Apollo flights are over, our efforts will not be directed immediately toward further lunar exploration but rather toward developing some of the possibilities that lunar exploration has opened for us. We shall continue to explore the planets and develop a space station in earth orbit.

REVIEW QUESTIONS

1. **Describe three principal features of the moon. What kind of features have the Apollo astronauts investigated?**
2. **How were astronomers able to make maps of the moon before the days of space exploration? Were these maps accurate?**
3. **What are the three principal theories about the origin of the moon?**
4. **What are the two opposing views held about the origin of the moon's craters and seas?**
5. **What special tasks were performed by the Rangers? the Surveyors? the Lunar Orbiters?**
6. **How have we been able to map the hidden side of the moon? How is the hidden side different from the visible side?**
7. **What is the purpose of the ALSEP (Apollo Lunar Surface Experiments Package)? How was it developed? What does the lunar seismometer measure?**
8. **What is done with the rock and soil samples returned to the earth by the astronauts? How are the rock samples dated?**
9. **What do you consider to be the three most important findings about the moon made as a result of the Apollo flights? Give reasons for your answer.**
10. **What might scientists and astronauts do to explore the moon further after the Apollo flights are completed?**

THINGS TO DO

1. If you have access to a low-powered telescope, make some systematic observations of the large lunar features. Check your observations against the description of these features given in a good reference book. Insofar as possible, relate your observations to the sites visited by the Apollo astronauts. Using a map of the moon or a diagram, make a report to the class on your observations. In the past, amateur astronomers have made important contributions to the study of the moon. For many years they kept up an interest in the moon when the interest of professional astronomers lagged, and they helped in making maps of the moon before the time of space exploration.

2. Demonstrate to the class the reason why we see only one side of the moon. Use the simple method of walking around a chair in a circle, turning your body as you walk, or make use of a diagram. Be sure you know how to explain what you are demonstrating. Be ready to answer questions. Tell the class what we have found out about the far side of the moon.

3. Read Jules Verne's *From the Earth to the Moon* or Konstantin E. Tsiolkovsky's *Beyond the Planet Earth*. Remember that Jules Verne was a talented story teller. Tsiolkovsky, known as the Father of Astronautics, was a scientist, not primarily a fiction writer. Note that Jules Verne predicted that the trip to the moon would be launched from Florida. What other similarities to actual events are to be found in the story? Perhaps your English teacher will let you use one of these readings for a book report. Another choice would be H. G. Wells's *The First Men in the Moon*.

4. Make a report on a lunar site explored on one of the later Apollo flights. Do some research to find out why the site has special scientific interest. Tell what some of the findings were that the astronauts made at the site. If reports have been received on the rock and soil samples collected at the site, tell something about these reports. Try to relate these reports to your description of the site.

5. Make a model or a drawing of the powered lunar rover. Explain to the class how the rover operates and how it helps the astronauts move about on the moon. You might point out how the powered rover helped the astronauts on the Apollo 15 (16 or 17) flight explore their landing site.

6. Make a report on the ALSEP (Apollo Lunar Surface Experiments Package). What are the principal instruments in the package? What is the purpose of each? Tell how the astronauts set up the experiment package on the moon and how the instruments continue to relay information to the earth long after the astronauts have left. If you are studying physics, you might be interested in giving a more detailed report on one of the special experiments, such as the solar wind experiment or the active and passive seismic experiments, rather than on the ALSEP. Insofar as you can, relate the experiment or the instruments you describe to some of the key questions about the moon that scientists are trying to answer.

SUGGESTIONS FOR FURTHER READING

BALDWIN, RALPH B. *A Fundamental Survey of the Moon*. McGraw-Hill Series in Undergraduate Astronomy. New York: McGraw-Hill Book Co., 1965.

BRAUN, WERNHER VON, and ORDWAY, FREDERICK I., III. *History of Rocketry and Space Travel*. Rev. ed. New York: Thomas Y. Crowell Co., 1969.

GLASSTONE, SAMUEL. *Sourcebook on the Space Sciences*. Princeton, N.J.: D. Van Nostrand Co., 1965.

KOPAL, ZDENEK. *Exploration of the Moon by Spacecraft*. London: Oliver and Boyd, 1968.

LEWIS, RICHARD S. *Appointment on the Moon*. New York: Viking Press, 1968.

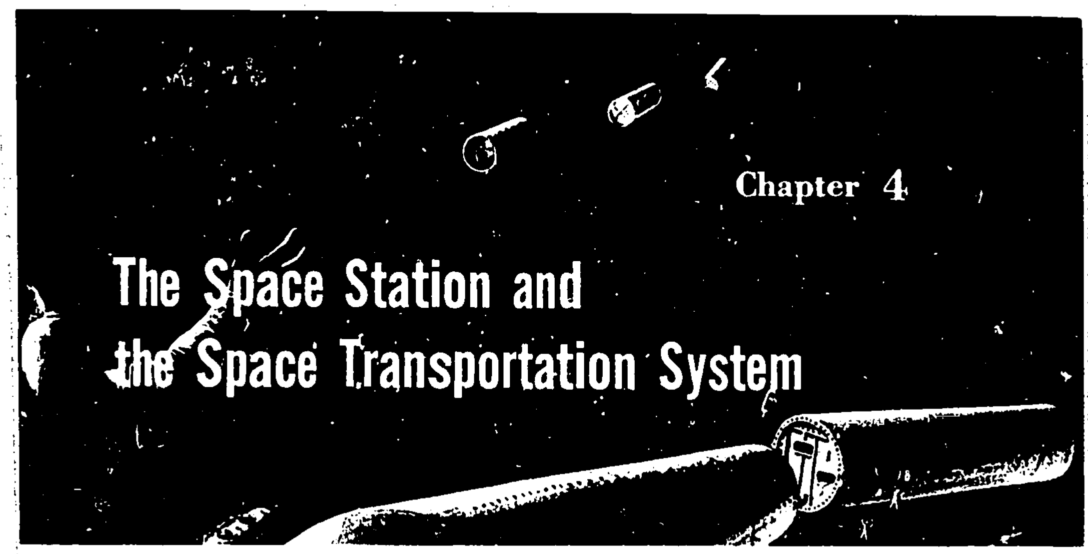
MALONEY, TERRY. *Stars, Sun and Planets*. New York: Castle Books, 1960.

MOORE, PATRICK. *Moon Flight Atlas*. Chicago: Rand McNally Co., 1969.

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

SPACE EXPLORATION

NAUGLE, JOHN E. *Unmanned Space Flight*. Holt Library of Science Series, Vol. III. New York: Holt, Rinehart, and Winston, 1965.
RUZIC, NEIL P. *Where the Winds Sleep*. Garden City, N.Y.: Doubleday, 1970.
STERN, PHILLIP D. *Our Space Environment*. Holt Library of Science Series, Vol. IV. New York: Holt, Rinehart, and Winston, 1965.
WHIPPLE, FRED L. *Earth, Moon, and Planets*, 3d ed. Cambridge, Mass.: Harvard University Press, 1968.



Chapter 4

The Space Station and the Space Transportation System

THIS CHAPTER describes the space station and the new space transportation system, which are in the idea or design stage. First it tells about some of the ideas that early space scientists had about building a large wheel-shaped space station and about surviving for long periods of time in space. Then it explains what our present ideas about a space station are and how the Skylab, the first US experimental space station, will lead to the development of a small permanent space station. Next it tells how this station will be serviced by the space shuttle and the space tug, the first vehicles in the new reusable space transportation system. Finally, the chapter tells how a large space station might be developed from the first small station. After you have studied this chapter, you should be able to do the following: (1) outline the Skylab program, (2) explain how a large space station will be developed from the first small station, (3) tell the purpose of the new space transportation system, and (4) describe the plans for the space shuttle.

AFTER THE APOLLO FLIGHTS are completed, the United States hopes to concentrate its efforts on developing a space station and a series of reusable vehicles for going to and from the station. In this way we plan to put space exploration on a more economical and efficient basis, making it possible to continue a vigorous space program even under reduced budgets.

The space station is the next logical step to having complex automated satellites in earth orbit. When men are placed in a satellite they can adjust telescopes and instruments, as well as repair and maintain them, thus increasing the period of usefulness. In a space station in earth orbit scientists could conduct all kinds of experiments. From the station they could launch the unmanned satellites that have to be orbited in another plane. Experiments that present special problems of stabilization or temperature control could be detached from the main station and orbited separately nearby. The great advantage to be gained from a space station would be to have computers, instruments, resupply, and other services available in one place.

Both the United States and the Soviet Union recognize that establishing a permanent space station is one of the steps in progressing to a more advanced space program, and both countries plan to develop such a station within the decade. Each country is going about developing this station in a slightly different way, however. As in the past, the Americans and the Soviets are progressing through essentially the same steps, but they are taking these steps in a slightly different order and are following somewhat different methods.

The Soviets have made significant advances that give foundation to their claims that they will soon have a space station. They have developed a procedure for making rendezvous and docking automatically, and they have transferred cosmonauts from one space ship to another in earth orbit. Continuing the experiments with their Soyuz space ships, which in Russian means union (docking), they orbited three modules (Soyuz 6, 7, and 8) at one time as early as October 1969. The three ships were orbited independently and approached each other, but they did not dock. Evidently some difficulties arose that prevented docking. In April 1971, the Soviets successfully docked the Soyuz 10, which carried three cosmonauts, with the unmanned Salute laboratory. The maneuver tested the docking collar and rendezvous procedures. The cosmonauts did not enter the laboratory, however, but returned to earth. On 7 June 1971 the Soviets docked the Soyuz 11 with the Salute laboratory, and three cosmonauts entered the laboratory to perform experiments. By this time the orbit of the heavy spacecraft was decaying, and the cosmonauts used rocket power to put it into a higher orbit. After spending 24 days in space and establishing a new world record for endurance in spaceflight, the Soyuz–11 cosmonauts returned to earth. They died upon reentry when a leak developed in their life-support system. The tragic death of the three cosmonauts will make it necessary to correct the engineering of the life-support system. Up until the time of the accident the Soviets were making steady progress toward developing a permanent space station.

The United States also has plans to develop a space station in earth orbit, as well as vehicles to support it, but this country has first concentrated on putting astronauts on the moon. In preparation for the lunar landing, unmanned satellites were launched to probe the moon and explore the regions of space between the earth and the moon. From experience gained with these and other research satellites, scientists have reached a new understanding of the radiation environment that surrounds the earth and of the space environment beyond. Then, too, in building the Saturn V booster and the Apollo spacecraft, American engineers and astronauts have developed vast amounts of engineering knowledge and skills in piloting spacecraft. American planners believe that all this knowledge and experience will be of inestimable value in building a space station and the vehicles to support it. The Skylab, which is being constructed from Saturn-Apollo hardware, will prepare the way for the first US space station, and designers are at work drawing up plans for this space station and for the space shuttle that is to service it.

Before considering these efforts to put US space research on a more permanent basis, it would be helpful to go back to some of the theories that early space scientists had about building space stations and about living for long periods of time in space. A brief survey of these theories will give you a better view of what the United States has already accomplished toward developing a space station and what is likely to be achieved in the future.

EARLY IDEAS ABOUT A SPACE STATION

One of the first men to describe a space station from the point of view of a scientist rather than a fiction writer was Hermann Oberth, a Hungarian, who in 1923 published the book entitled *The Rocket Into Interplanetary Space*. Oberth believed that the first small satellites, or "artificial moons," as he called them, would ultimately develop into manned space stations. Because Oberth, like other early space scientists, could not foresee the difficulties that engineers would experience in constructing spacecraft and the small ways in which we would actually begin construction, he pictured the space station on a grand scale.

Oberth's early ideas of a space station were expanded by Hermann Noordung in a book published in 1928. Noordung was the pen name of Captain Potočnik, an officer in the Austrian Army. Potočnik established the basic wheel shape that a large space station would take. The station, as described by him, has three parts: a wheel spinning on its axis to provide artificial gravity with crew accommodations in the wheel's rim, a solar power plant, and an astronomical observatory.

These parts would float in space near each other and would be connected with cables. From this basic idea, Potočnik worked out details for facilities needed for living and working in space. His ideas were further expanded by another Austrian engineer, Count von Pirquet.

Hermann Oberth, who worked with the German rocket engineers, later enlarged upon his original idea of the space station. As ferry rockets were developed, it would be possible to carry material from the earth to a position in orbit. Here men working in space suits would assemble the material to construct a space station, which would then be supplied by the ferry rockets. As men worked in space, they would have to learn how to anchor themselves in order to overcome the lack of gravity, but the weightless condition would also have advantages. Large structures like solar mirrors and high antennas could be built much more easily because they would not sag or topple over as they would on the earth. From their vantage position in space, men could more easily launch ships for voyages to the moon and the planets because these ships would not have to fight their way through the earth's atmosphere, and they would have a smaller part of the earth's gravitational force to overcome. Oberth pointed out the possibilities of putting a manned station in different kinds of orbits to serve different purposes. One of these was what he termed the "strategic orbit." This is a polar orbit at an altitude of about 375 miles. With a space station placed in this position, man could make observations of every point of the earth's surface at least twice a day.

One feature of the space station that particularly interested Oberth was a gigantic space mirror some 60 miles in diameter that could be used to collect energy from the sun. By focusing the sun's rays with such a mirror, man could melt icebergs on the earth, prevent a killing frost, or heat and light whole cities.

Wernher von Braun, the German space scientist who became an American citizen and directed development of the Saturn boosters, proposed other versions of the space station in his book called *Mars Project* (1953). One version was a circular station with a 100-foot radius, which was to be assembled in cylindrical segments. When finished, the space station would resemble a gigantic doughnut. As the station was revolved to create artificial gravity, the strongest gravity force would be found near the rim of the wheel, where man would place his living quarters. Connecting the hub with the rim would be two large arms where ferry spacecraft could dock and depart. Von Braun pointed out that a space station could be useful for many pur-

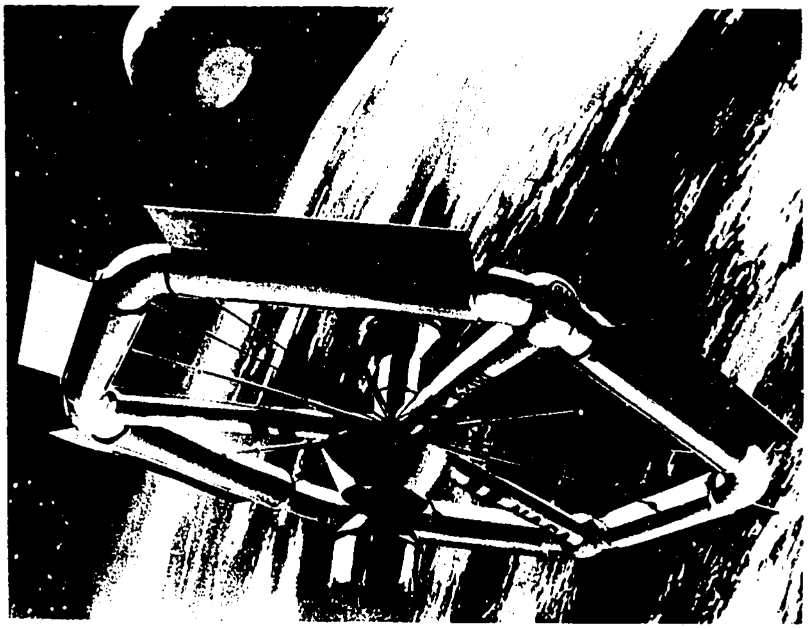


Figure 50. Early design for a wheel-shaped space station. Newer designs make use of a cluster of cylinders. The cylinders could also be rotated to create artificial gravity for living quarters.

poses, which he grouped under surveillance. This meant far more than military surveillance. It included a weather watch, patrol of icebergs, searches for lost aircraft or drifting ships, and even search for natural resources.

Other versions of the wheel-shaped space station were proposed, such as that shown in Figure 50. Such designs have interest today because of the scientific principles involved and because of what they tell us about the form that space stations might eventually take.

In attempting to look into the future, it is also profitable to go back to consider some of the early ideas that the Russian Konstantin Tsiolkovsky, the Father of Astronautics, had about space stations. Some of these ideas were described in fiction and others in scientific essays.

As early as 1914, in a novel called *Beyond the Planet Earth,* Tsiolkovsky described a space station that did not remain in earth orbit but traveled to the moon. This station had a truly international crew—a Frenchman, an Englishman, an American, an Italian, and a Russian. In this station the crew harnessed pure sunlight to produce energy for factory processes. Food was obtained from plants grown on board. These plants, through the process of photosynthesis, changed carbon dioxide into oxygen for breathing.

Tsiolkovsky drew another picture of space stations powered by pure sunlight. In an essay he pointed out that only a small fraction (about 220 millionths) of the energy radiated by the sun is received by the planets. If man were able to make use of some of the vast amount of energy that is present in interplanetary space, Tsiolkovsky pointed out, he could go out into space and establish colonies. In towns and cities built in orbit, the homes would be truly mobile, floating by in a seemingly endless chain. But these homes would not be simple boxlike structures. People could live in great comfort and luxury in homes supplied by an environment made possible by the sun's energy. The air in the homes would be healthful, as the amounts of oxygen used and the temperature would be carefully controlled. Because of the absence of gravity, there would be a pervading feeling of comfort and rest, and muscles would not sag. As an inhabitant of this orbital world left his home, he would join other beings dressed in space suits, and they would fly along definite routes between the towns built in the ether. It was a fanciful picture, to be sure, but most of the principles upon which it was based are valid.

As extravagant as some of the early predictions about space stations seemed to people about four or five decades ago, and may seem to some people today, some of the principles underlying these predictions have already been put into practice. Astronauts in their space suits, without any visible means of support, "walk" through space, and we are harnessing energy from the sun in small amounts by means of the solar cells. American astronauts have taken space modules to the moon and back. Thus we could go on enumerating other predictions that have already come to pass although in somewhat different forms than anticipated. The question naturally arises: How far have we advanced in producing a space station? The answer depends upon your definition of a space station.

WHAT IS A SPACE STATION?

The term "space station" is used to mean almost anything from a small laboratory that will remain in orbit for a matter of months to a large station that houses 50 to 100 men and will orbit for the lifetime of its structural materials. Most authorities agree in considering a space station as a satellite that can support life, permitting men to live and work in it at intervals, if not continuously.

NASA has called the first US effort to produce a space station the Skylab. This laboratory was designed for use in orbit for about one year. Present plans call for following the Skylab with a small space station that would remain in orbit for about 10 years and that would accommodate as many as 12 men. This second effort, which is now only in the idea stage, would be considered as a true space station. The Skylab is the forerunner of this space station.

SKYLAB: FORERUNNER OF THE SPACE STATION

Although the first US space station is still in the idea stage, Skylab, the laboratory that is to precede it, is to be delivered to Cape Kennedy during 1972. Launch of the Skylab nd the first visit to it are scheduled for the spring of 1973. The launch of the Skylab is awaited with much interest by scientists. Ever since the beginning of spaceflight they have looked forward to the time when we would be able to place a laboratory in orbit in which men could conduct experiments for an extended period of time under carefully controlled conditions. During the Mercury, Gemini, and Apollo flights the astronauts did conduct some experiments that told about man's ability to live and work in space. The astronauts on the Gemini–7 flight, for example, the flight that made the 14–day endurance record, took part in an extended medical experiment. This experiment was designed to show how the mineral content of the bones is affected by zero gravity. But during most of the flights an emergency developed, and piloting and meeting the emergency had to take precedence over the experiments. The Skylab is to be launched into orbit and is to remain there. The astronauts manning the laboratory will have few routine piloting and navigation duties. They can devote much more of their time to tending the experiments.

The Skylab is made up of the laboratory itself, or the Saturn Workshop, which has been built from the empty shell of the third stage of the Saturn V rocket. The Workshop is to be launched dry, that is, without the propellant, and it has been completely outfitted with living quarters and experimental equipment. Previous plans called for launching the workshop wet, or with the propellant in it, but these plans were changed. It is much safer to launch the dry laboratory, and

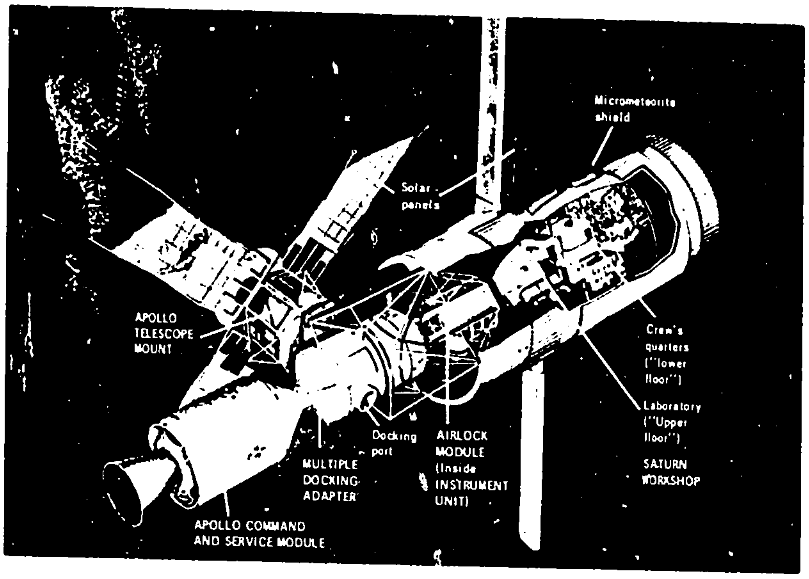


Figure 51. Skylab cluster with the docked Apollo command and service modules (artist's sketch). The Skylab module to the left side with the solar panels is the Apollo Telescope Mount. In the main cluster (left to right) are the docked Apollo command and service modules, the Docking Adapter, the Airlock Module, and the Saturn Workshop.

there is a much better chance that the experiments will be carried out successfully if instruments are in place before launch.

The Saturn Workshop will be orbited as a unit with the Apollo Telescope Mount, a Docking Adapter, and an Airlock Module (Fig. 51). The last module named will do far more than supply airlocks for experiments. It is the nerve center for the Skylab, and in it are stored the gases for breathing and the equipment for distributing them, as well as instruments, electrical power sources, and other equipment. Large "wings," or solar panels, will collect sunlight to be used for generating electrical power. The complete assembly, known as the Skylab, will be boosted into orbit by the two bottom stages of the Saturn V booster. The Skylab will be put into an orbit about 235 miles above the earth and in a plane inclined about 50 degrees to the equator. In this position the Skylab will fly over the most heavily populated areas of the world, and the astronauts can make observations of these areas. The flight launching the Saturn Workshop will be designated as Skylab 1.

The day after the Workshop, or laboratory, is put into orbit, a crew of three astronauts will follow in the combined Apollo command and service modules. The modules will be changed slightly from those used for the Apollo flights. The astronauts' flight (Skylab 2) will be launched by a Saturn IB, or the smaller Saturn booster. After the astronauts dock, they will enter the Saturn Workshop and activate the life-support systems. The Skylab is to make use of an atmosphere consisting of a mixture of nitrogen and oxygen. This will be the first time American astronauts use a mixture of gases rather than pure oxygen as a stabilized atmosphere for breathing during spaceflight. The first crew will remain in the laboratory for 28 days, establishing a new endurance record for American astronauts in space. There will be a second visit to the Skylab (Skylab 3) and a third visit (Skylab 4) made at three-month intervals. The second and third crews, also consisting of three men, will stay in the Skylab for 56 days. Each crew will include at least one scientist-astronaut.

While the Skylab is in orbit, some 50 experiments are to be conducted in it in three fields: biomedicine; solar astronony; and applications, or the observation of earth resources, weather, communications, and material processing. The first visit will emphasize the biomedical experiments; the second, experiments in solar astronomy; and the third, applications.

The biomedical experiments should tell us much more about the way the human body reacts to zero gravity. Each crew of astronauts will be part of a medical experiment, since the Skylab astronauts will be staying considerably longer periods of time in space than other US astronauts before them. Information will be obtained on the way man reacts when breathing a mixture of nitrogen and oxygen gases in space. Engineers will also have a chance to find out more about the kind of facilities that man needs to live and work in space.

The experiments in solar astronomy conducted in the Skylab, which will make use of the new equipment provided by the Apollo Telescope Mount, will be unique. The Skylab will give astronauts the first chance to work with telescopes in space. This is an opportunity that astronomers have long awaited. For a long time they have wanted to have a platform in space from which they could view the heavens with their telescopes, freed from the obscuring effects of the atmosphere. In the Skylab the images in the telescopes should not appear to seethe and boil, as they often do when viewed on earth, and all the rays in the electromagnetic spectrum should reach the telescopes. The Skylab, with its series of powerful telescopes that can be directed by man, will provide a valuable supplement to the work being done by the Orbiting

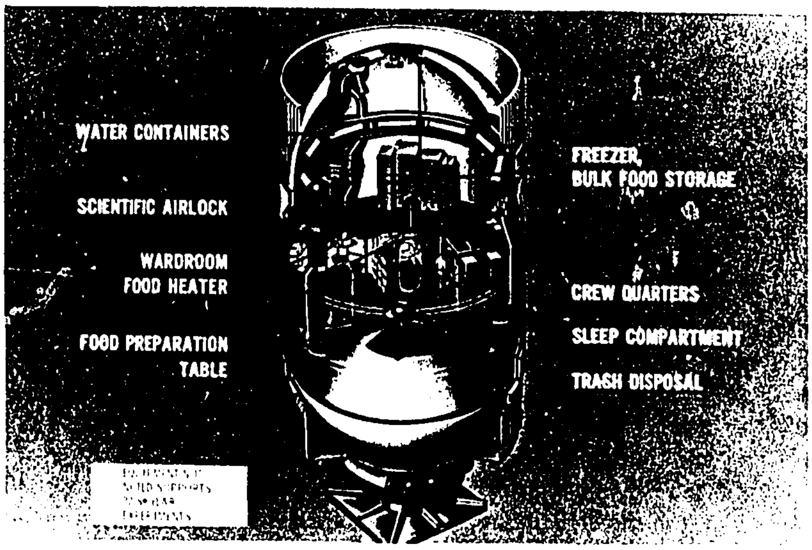


Figure 52. Saturn Workshop for the Skylab. This cutaway sketch shows the living and working areas. The Workshop was constructed from the empty shell of the third stage of the Saturn V booster.

Solar Observatory, in which telescopes are operated remotely from the ground. As an astronaut directs the telescopes in the Skylab toward the sun, the images can be photographed by television cameras. One set of cameras will take pictures to be transmitted to the scientist-as-tronaut sitting by the monitor in the Skylab, and another set of cameras will take pictures to send to scientists on the earth.

The first set of experiments in solar astronomy conducted in the Skylab will study activity in the sun but especially in the corona, or halo, from which the solar wind escapes into interplanetary space. The sun will first be viewed in the far-ultraviolet and X-ray portions of the electromagnetic spectrum, parts of the spectrum that never penetrate to the earth. After astronauts in the Skylab study the sun during solar flares and other kinds of heightened activity for extended periods, they should be able to provide astronomers with more information about the sun and the solar wind.

A third set of experiments will cover the observations now being made by automated applications satellites. Data obtained by astronauts making observations in the Skylab should enable us to assess the value of space observations in such fields as agriculture, geography, forestry, geology, ocean studies, and map making. It will tell us, for example, how well men in a space station could perform such tasks as spotting air and water pollution, identifying crops and measuring growth rates, spotting diseases in crops, mapping snow cover, measuring water runoff, and mapping shifting shorelines.

Astronauts who tend experiments in the Skylab will find living conditions much different from those on board the Apollo spacecraft. There will be much more room to move about in the Skylab, and facilities will be provided to make everyday living more like that on the earth (Fig. 52). The Saturn Workshop is about 30 times larger than the combined Apollo command and service modules. The Apollo modules that are used in the Skylab program will be occupied only when taking the crews to and from the laboratory. Once the astronauts have docked, they will live in the Skylab. The laboratory contains about 10,000 cubic feet of usable space, or about as much as is found in a medium-sized house. For the first time astronauts living in space will have a dining room (wardroom), bedrooms (sleep compartments), and a bathroom (waste compartment). They will also have a much greater variety of food on their menus than the Apollo astronauts, a larger supply of fresh water, enough storage closets to make any housewife happy, and a voluminous trash disposal bin.

At present only one Skylab has been authorized. Others may follow later when funds are available, or the experimental work may be continued under another program. Experience obtained from the Skylab should help in developing the first space station and the new transportation system that is to be used with it.

PLANS FOR THE SPACE STATION

Even before the first Apollo astronauts landed on the moon, engineers were at work to define the shape that the first US space station would take and the form of the space vehicles that would be used after Project Apollo. As the last Apollo flights are being completed and experiments are being conducted in the Skylab, NASA officials will select the designs that will be used for the first space station module, which is to house as many as 12 men, and for the space shuttle that will take passengers and supplies to and from the station. Later, decisions will be made about other kinds of modules to be added to the first one until we finally have a large space station, or a base in space. The space shuttle will be followed by a space tug and then by other vehicles until we have a whole space transportation system. This system will be used first in servicing the space station in earth orbit. Later the vehicles will range farther out into space.

The space shuttle, the space tug, and the other vehicles in the space transportation system will be designed and built so that they can be used over and over again and so that each is flexible enough to be adapted to many kinds of uses. After more than a decade of space exploration, we are ready to begin building a space station and permanent type space vehicles. The United States, like the Soviet Union, had to begin spaceflight by boosting satellites and spacecraft into orbit with staged rocket boosters. After they have served their purpose, the parts of the rocket burn up during reentry or fall into the ocean, and the largest part of the spacecraft is left behind in space. All that we have been able to recover were the space capsules with the astronauts in them and some space capsules with experiments that we managed to catch on a hook suspended from aircraft. We had to get the first satellites and spacecraft into space to learn about traveling and living in space. We could not afford to sit back and wait until there was time for the airplane to develop into a spaceplane. Now that our astronauts have spent some time in space, we are ready to design and build our first true spaceplane, the space shuttle, and to develop a permanent space base in earth orbit.

Small Space Station

Plans for the first space station, or for the first module for a larger station, originally called for a large cylinder that would house as many as 12 men. Designs now being considered provide for smaller modules that can be launched separately and be assembled in orbit (Fig. 53). Such designs are more flexible. They would enable us to launch a station for housing a smaller crew, and the station could be put into operation sooner.

The space station, growing out of experience gained from the Skylab, will present some highly significant developments. It will be run as a facility rather than as a space ship, and the facility will be considered permanent. If the first module or modules are no longer usable at the end of their design life, they can be replaced. By this time there should be additional modules in the space-station cluster. The space station, a kind of permanent base in space, can be compared with the bases established at Antarctica or with ships that conduct long-term studies of the world's oceans.

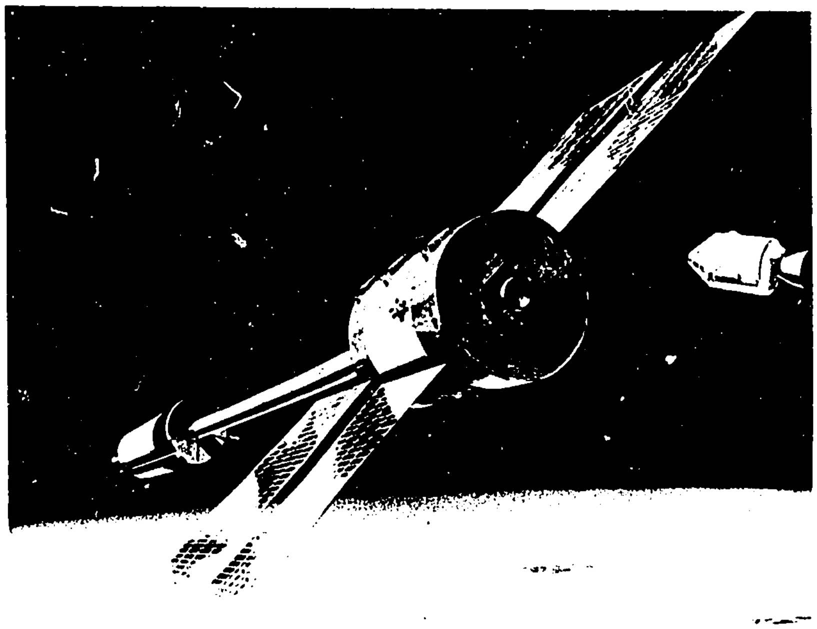


Figure 53. A design for a small space station. Modules could be added to increase the size of the station. The Apollo command and service modules are coming in to dock.

With long-term operation in view, the space station can provide many different kinds of services on a continuing basis, such as weather observations, navigational assistance, pollution control, and survey of earth resources. We expect to find out more about what these services will be from conclusions reached as the result of experiments conducted in the Skylab. The space station will also be used for stocking fuel, supplies, spare parts, and food, as well as different kinds of scientific instruments and computer data-processing equipment. From the space station the astronauts will go out to the satellites in orbit to make adjustments and repairs or to add fuels or replenish power sources. Parts that cannot be repaired in orbit can be brought back to the station for further work. Those parts that require factory service can be accumulated at the station and returned to the earth. The astronauts can also bring back from the satellites photographs and other data that has accumulated there. They would probably process and interpret this information in the space station and take reports back to the earth. On return trips to the space station, the shuttle could bring back supplies, or it could take to the station other satellites that were to be put into orbit. If the satellite was not to be launched into the same orbit as the space station, it would have to be provided with a rocket propulsion system. Such activities as these will make the space station a busy place. The men there should not feel isolated.

Another significant development with the space station will be that experiments will no longer have to be conducted by astronauts only. Men with special talents and long experience in a field can carry out experiments in space without meeting requirements as astronauts. The space shuttle will be designed and built to carry as passengers those who are able to travel by ordinary commercial airlines. Of the 12 men who might make up the regular crew of the first small space station, 4 men could be astronauts and the remainder could be scientists without special astronaut qualifications. The regular members of the station crews would have to be physically and mentally qualified to live for at least 90 days in an environment much like that in commercial aircraft.

Scientists in the space station will carry out experiments in about the same fields as in the Skylab, but the experiments will be greatly expanded. Plans are to cover the following areas: astronomy, biology, physics, aerospace medicine, space manufacturing, advanced technology, and engineering operations. Representatives from the National Academy of Sciences have met to recommend experiments to include in the space station, just as they recommended experiments to be conducted during the lunar landings.

One engineer has suggested that the United States pause halfway in the development work and build a station of half the size originally planned in order to commemorate the 200th anniversary of the Declaration of Independence. Other nations could be invited to participate in the event by supplying experiments for the station. We can expect this country to plan some noteworthy event in space for 1976, and a small space station is a possibility. We could not operate our first space station as planned, however, unless we had transportation provided by the space shuttle.

Transportation for the Space Station

From the plans outlined above, it is easy to see that much of the activity at the space station will depend upon the operation of the space shuttle. This shuttle is also the key to the new space transportation system and the focus of most of the effort in developing this system. Engineers are doing some work in defining the form that the space tug will take, but the tug is not to be ready until after the shuttle is in operation. Only after the first space shuttle and space tug are developed will engineers be able to see more clearly what the requirements will be for other vehicles in the transportation system.

Plans are to eventually build a more powerful shuttle, probably one powered by nuclear engines, for use in going to and from the moon, and a larger tug for taking loads to lunar orbit and from lunar orbit down to the moon. These later plans are as yet indefinite, but design work is being done on the first space shuttle and space tug.

SPACE SHUTTLE.—The space shuttle presents engineers with as much of a challenge as the Saturn V booster or the Apollo spacecraft, but the problems to be solved are quite different. One engineer has compared the development of the space shuttle to putting wings on the Saturn V booster and making it fly. Such a comparison is helpful in understanding the enormity of the development involved, but it does not indicate the direction that this development will take.

Some engineers, after making studies, have concluded that it is better to go at once from what they call throw-away vehicles like the Saturn V booster and the Apollo spacecraft to completely reusable vehicles. They believe that it would not be advisable to try to launch a reusable orbiter from a throw-away booster like the Saturn V. When engineers were developing the second manned spacecraft, the Gemini, they tried at first to put wings on the Gemini so that it could fly back to the earth and be recovered on land, but such efforts were not successful. Then NASA continued on the path of development begun with the Mercury spacecraft. Now the United States is planning to make a complete changeover from throw-away vehicles to reusable vehicles. In the course of developing the shuttle, engineers may find that it is better to make the changeover more gradually. They may begin, for example, by using a throw-away rocket booster like a Saturn booster for launching a new reusable orbiting spacecraft.

Whatever designs are finally accepted for development, the space shuttle will make use of what is best from both aircraft and spacecraft. The shuttle will have engines so that it can travel in powered flight through the atmosphere and into space, and it will be able to coast in orbit as a spacecraft does.

NASA has proposed that the space shuttle be made up of two parts: the booster and the orbiter. After the booster has launched the top stage, the two parts are to separate, and the booster is to turn around and fly back to the earth (Fig. 54), landing at a spaceport of choice,

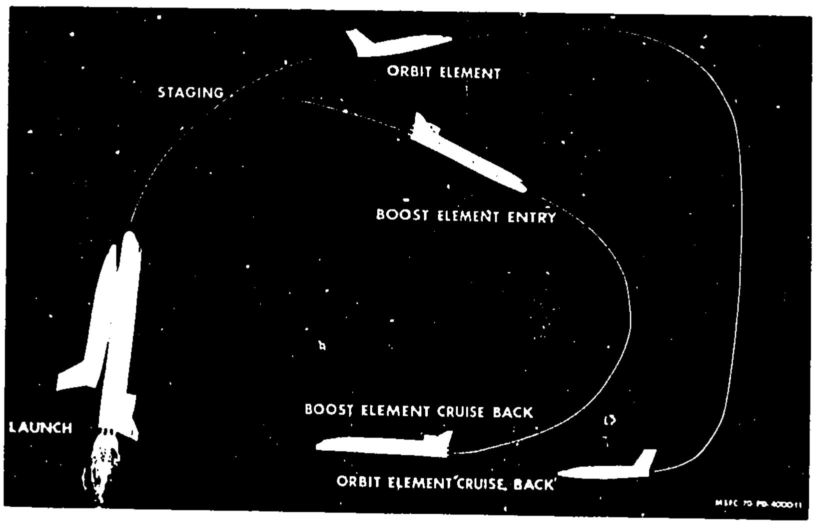


Figure 54. Launch and recovery of the two parts of the space shuttle.

much as an aircraft lands. The top stage is to continue on to an orbit in space. After the second part, the orbiter, has completed its mission in space, it would come back to the earth and fly through the atmosphere, landing at a spaceport of choice, also in the manner of an aircraft.

After the space shuttle is ready for use, spaceflights carrying both passengers and freight can be made much as aircraft flights now are. Some of the facilities like those used in the present Apollo ground complex for ground control and recovery of the astronauts would be used for testing the shuttle. After the shuttle becomes operational, the ground complex would be further simplified, but some facilities like those now used at Cape Kennedy would be needed for launching the shuttle and for enabling it to land. The shuttle would, however, eliminate almost the whole family of boosters that NASA now uses for launching different kinds of satellites and spacecraft into orbit. After the space shuttle is flying, NASA plans to keep only the largest and the smallest of its boosters, the Saturn and the Scout.

Although NASA had recommended that the space shuttle be made up of two parts, booster and orbiter, it has not stated how these parts are to be shaped. NASA wants to get the best possible ideas about designs from both US engineers and those abroad. NASA has suggested several possible shapes for the space shuttle (Fig. 55). One design shows a space shuttle with three parts. The orbiter could be divided into two parts and staged, much as a rocket booster is. Whether the shuttle finally has two parts or three, the parts must be designed and constructed so that they can return to the earth and be used over and over again.

A design now being considered for the orbiter part of the space shuttle makes use of the delta wing. Much of the design for the orbiter part of the shuttle depends upon the angle at which this part must reenter the atmosphere. If the orbiter must come back at a very steep angle, then it must be built so that it can withstand tremendous aerodynamic forces, and it would need to be wingless, as a space capsule is. If the orbiter can reenter gradually, then it might make use of wings, somewhat as a glider does.

No matter what angle is set as the limits for landing, engineers would have to shield the spacecraft against the extremely high temperatures encountered during reentry. Like the Mercury and Gemini capsule that orbited above the earth, the shuttle's orbiter would reenter the atmosphere at the speed at which it left the earth (about 18,000 mph). At such speed, intense heat would be generated on the skin of the orbiter. Engineers could use ablation, or the melting of materials, for cooling the surface and keeping the structure from melting. The orbiter would have to be kept intact so that it could be reassembled with the booster and be made ready for the next flight.

To give engineers more definite ideas about the form that the space shuttle might take, NASA has described the way the shuttle is to operate. It is to take off vertically, just as a rocket does, but it is to return to earth horizontally in the manner of an aircraft. Once the second

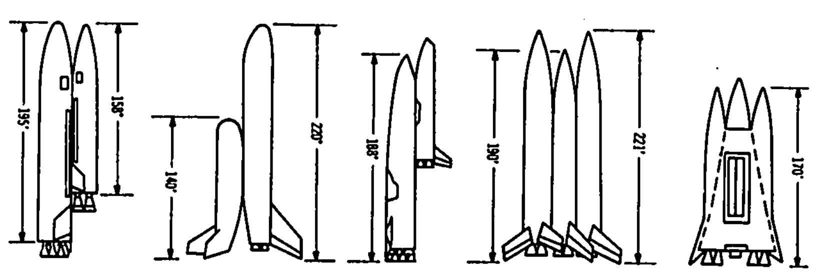


Figure 55. Possible configurations of the two-stage space shuttle.

stage of the shuttle has orbited, it should be able to remain in flight for at least a week. Some experiments are to be conducted in the space shuttle, and it must be able to make extended flights in orbit. When the shuttle returns to earth, it should be able to land and be ready for its next flight within two to three weeks. As the shuttle goes into orbit, it should not generate acceleration forces of more than 3 G, or three times the force of gravity, so that it can carry as passengers anyone who can fly in commercial aircraft. Two highly skilled astronauts are to act as the crew of the shuttle. The instruments and controls in the shuttle must be designed so that a two-man crew can pilot and navigate it. The engines for the space shuttle are to make use of liquid hydrogen and liquid oxygen, and they are to be similar to engines used in the Saturn V.

The orbiter stage of the shuttle is to have a compartment about 15 feet in diameter and about 60 feet long. No figures have been set for the payload of passengers and freight. These figures will be worked out when the characteristics of the shuttle are better known. The booster and the orbiter would each be about the size of a jumbo jet aircraft.

The space shuttle will have to be developed from scratch, but there are many sources that the engineers have to draw upon. Although the shuttle will be an entirely new development, the idea of developing a spaceplane is not new.

Even as early as World War II, Dr. Eugene Sänger, an Austrian pioneer rocket researcher, had developed plans for a kind of space bomber. This was known as the "skip bomber" or the "antipodal bomber." These two names are significant, as they tell us something about the way the bomber was to operate. It was to be taken by the pilot into a steep climb up to a very high altitude. Then the power would go out, and the plane would arc downward and skip over the top of the atmosphere, much as a flat rock can be made to skip over the top of the water. The bomber could in this way glide halfway around the world in about three-quarters of an hour.

Later the US Air Force was much interested in Sänger's plans as it began work on the follow-on to the X–15 research aircraft, the Dynasoar bomber. Much work was done on the Dynasoar, but its development had not been completed before the much lighter weight Gemini capsule was carrying two men in orbital flight. The Dynasoar project was cancelled. Then the Air Force and NASA began experiments with wingless bodies, called lifting bodies, to study what effects heating and aerodynamic forces might have on a spaceplane as it returns to the atmosphere. Information obtained from the research for developing a spaceplane, together with that gathered in the course of developing the most advanced aircraft, will help engineers in designing the space shuttle.

Although engineers have much information upon which to base their work, it will take some time to put all this information together and add the new elements that will make the space shuttle a success. NASA intends to test and prove the shuttle in much the same way that aircraft are tested. The space shuttle is not to be orbited in space on the first test, as the Apollo spacecraft was. The space shuttle is scheduled to be tested first in the atmosphere and then in space. The first test flights within the atmosphere are to be made in 1975 and the orbital test flights in 1976. The first operational flights are planned for 1977. With design work already underway, it might be possible to speed up work on the shuttle to put it into operation by 1976, the 200th anniversary of the Declaration of Independence. This would give us another choice of a space event commemorating the birth of the Nation. While design work for the shuttle is in an advanced stage, that for the space tug has only begun.

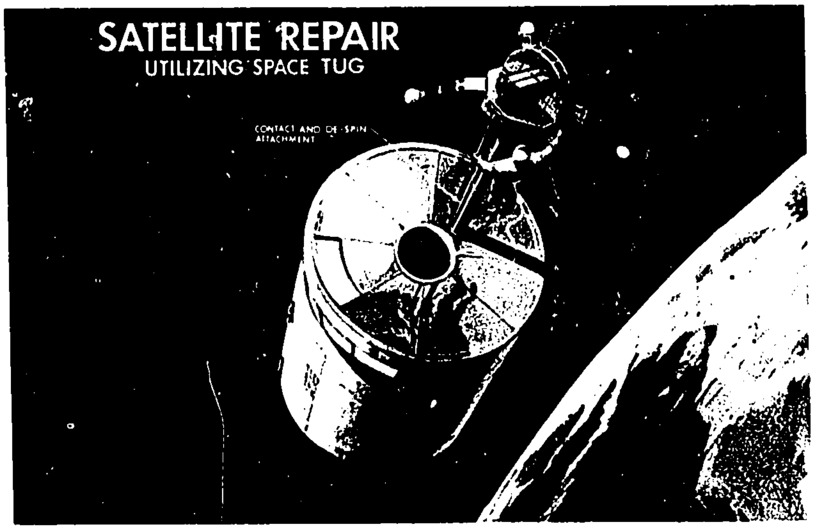


Figure 56. A design for the space tug. The crewman from the tug is shown repairing a satellite.

SPACE TUG.—The space tug, like its prototype on the earth—the small boat that tows large oceangoing vessels through shallow water to the harbor—is to pull passengers and freight in space. The tug will probably operate only in space. Once launched, it may not return to the earth. The tug will, however, be fully reusable, just as the shuttle is, and it is to be powered so that it can return to the space station for the next trip. The tug is likely to be made up of modules, which can be brought up to the space station one at a time, or the whole set of modules could be launched into orbit as the fourth stage on a Saturn V booster. Plans are to use the tug for such missions as taking passengers and supplies from the space station to satellites in orbit, returning men and material from the satellites to the space station, or taking passengers and freight from lower to higher earth orbits. Preliminary designs for the tug are being drawn up in the United States and in Western Europe. The space tug might look something like the design shown in Figure 56.

When the design for the first space tug has been selected, engineers will be ready to begin work on designs for the larger tug. Preliminary designs for the larger tug will be made at about the same time as those for the larger space station.

Large Space Station

Engineers preparing plans for a larger space station are thinking in terms of a 50–man base, which can be ready by about 1984, and of a 100–man base, which could be operating by 1990. It is challenging to the imagination to try to picture what these larger stations will look like and the kinds of activities they will support. Soon we shall have some definite ideas of what the larger space stations will be like because these are to grow from the first small station. We do not intend to start from the beginning with the larger station. This is to be built up from the module or modules used for the first small station. Other specialized modules are to be added and assembled much in the way that a child builds structures with an erector set (Fig. 57).

One of the first questions that must be answered in developing the larger space station is whether or not artificial gravity must be provided to make it possible for men to live and work for longer periods in space. If experiments in the Skylab and in the small space station show that man could suffer harmful effects from living for longer periods in zero gravity, then it will be necessary to rotate the living quart-

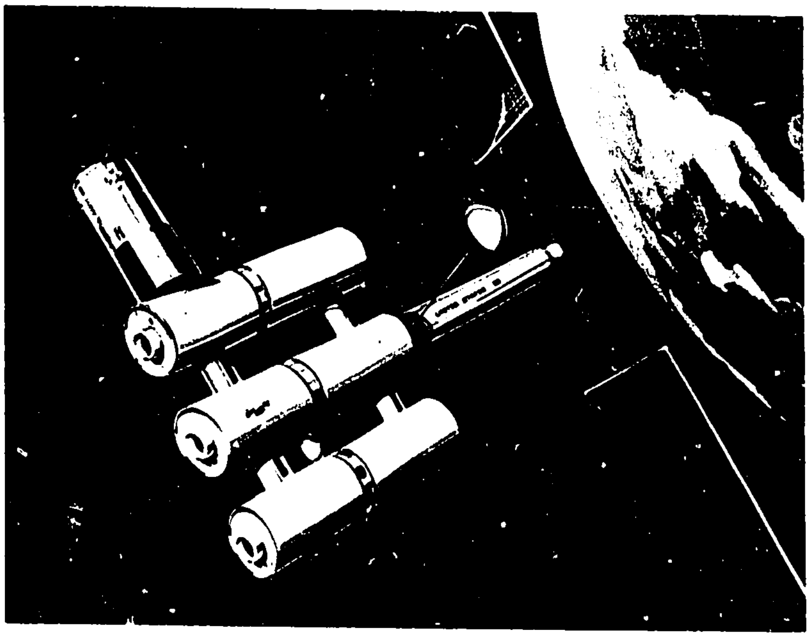


Figure 57. A design for a large space station. The large station is made up of modules. Other modules could be added. The winglike structures are solar panels used for generating electricity for the station.

ers to provide centrifugal force, or artificial gravity. If living quarters must be provided with artificial gravity, they must be placed on the outside of the space station cluster so that they can be rotated. Other modules that are to be occupied for only brief periods at a time can remain stationary. Besides living quarters, the large space station is to have an exercise and recreation area, a medical facility, scientific and medical experiment areas, and docking ports for the shuttle and for the separate experiment modules.

Men assigned to the large space station are to work there for a certain period of time and then return to the earth. Engineers are not planning to build quarters to enable the men to bring their families with them and settle at the base. At present we do not look upon the space base as a colony, such as that described by Tsiolkovsky. A colony may come later. Now we are interested only in learning how to make the most of the opportunities provided by the space environment, much as we have learned to sail upon the sea and fly in the skies. Scientists want to come to a better understanding of how well man can live and work in space, and they want to get a better idea of the missions that can best be performed by man and those that should be carried out by unmanned satellites.

At the same time that efforts in the space station are being concentrated on finding out more about the space environment, preparation can be made to train men for longer flights in space. A space station module, with some modifications, could be made into a space ship for planetary flights. After the Apollo flights are completed, our main effort will be directed toward operations in earth orbit, but we shall continue to devote considerable attention to efforts in the other direction —to going beyond the moon and exploring the planets.

REVIEW QUESTIONS

1. **Why did the early space scientists propose the wheel shape for a space station? Where were the living quarters to be located? Why?**
2. **What is a space station? What advantages would the United States gain from having a space station?**
3. **From what kind of modules is the Skylab formed? How will it operate?**
4. **How many visits will be made to the Skylab? What kind of experiments will be performed in the laboratory? How long will the astronauts stay in the Skylab?**
5. **What two parts will the space shuttle have? How will these parts operate? What other vehicles might be part of the new space transportation system? How will these vehicles be different from the earlier spacecraft and boosters?**
6. **How might a large space station be developed from the first small station?**

THINGS TO DO

1. Make a model or diagram of the Skylab. Include the principal parts: the laboratory (Saturn Workshop), the Apollo Telescope Mount, the Docking Adapter, and the Airlock Module. Explain the model or diagram to the class. Tell how each part of the Skylab is to be used. If there have been any recent developments in the Skylab project, report these to the class.
2. If the Skylab flights are in progress, report to the class on the present visit to the Skylab or on the last visit made. Describe some of the experiences the astronauts have had in going to or from the Skylab in the Apollo modules. Tell about the kinds of experiments the astronauts have been conducting in the Skylab and about any special instruments being used for the experiments. If any results of the experiments have been announced, report on the findings. What kind of atmosphere are the astronauts breathing? Describe their living quarters.

3. Prepare a science project on the first permanent US space station. Make a model or diagram of a recent design for that station. Explain how it will be assembled, if it is more than one module. Describe the progress made in either designing or building the station to date, and estimate when the station will be ready for use.

4. Prepare a science project on the space shuttle. Make a simple model of the parts of the shuttle, or prepare a diagram of a design for the shuttle. Explain how the parts will operate. Tell the progress made to date in either designing or building the space shuttle. If some progress has been made on the space tug, you may choose to base your science project on this vehicle rather than the space shuttle. Whether your project is based on the space shuttle or the space tug, explain to the class the purpose of the new space transportation system of which your vehicle is a part. Describe how the new space vehicles will be different from the early space boosters and spacecraft.

5. Make a model or diagram of a cluster of modules that might be used for a large space station. Tell what the principal parts of the space station will be. Where will the living quarters be located? Do some research so that your model or diagram will be based upon sound scientific principles. Explain your model or diagram to the class.

SUGGESTIONS FOR FURTHER READING

BONO, PHILIP, and GATLAND, KENNETH. *Frontiers of Space.* New York: Macmillan Co., 1969.

BRAUN, WERNHER VON. *Space Frontier* (Ch. 4, "Stations in Space"). New York: Holt, Rinehart, and Winston, 1967.

——— and ORDWAY, FREDERICK I., III. *History of Rocketry and Space Travel.* Rev. ed. New York: Thomas Y. Crowell Co., 1969.

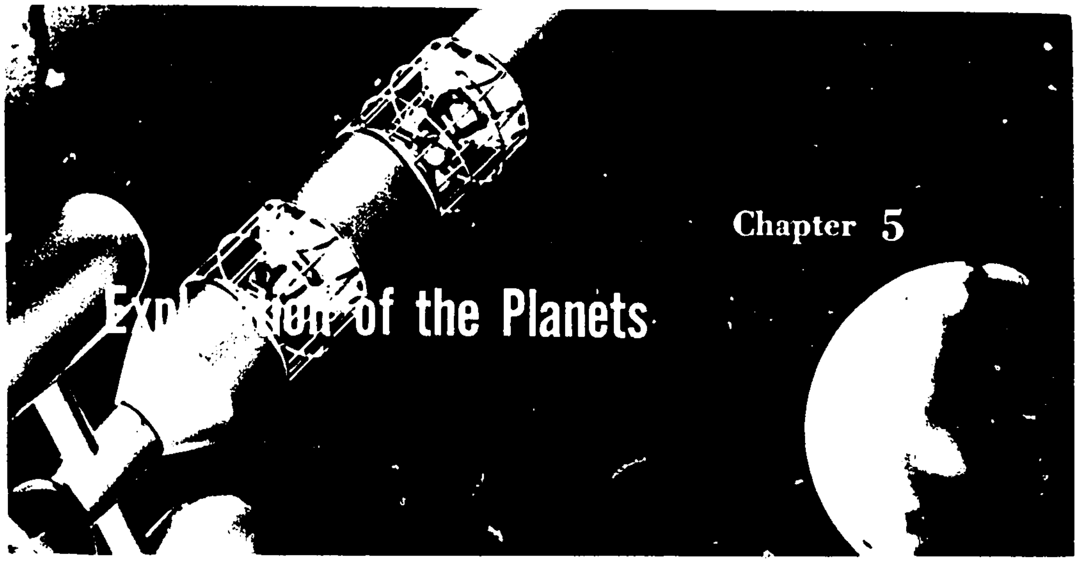
BUCHHEIM, ROBERT W. *New Space Handbook: Astronautics and Its Applications.* New York: Random House, 1963.

CLARKE, ARTHUR C. *Interplanetary Flight.* New York: Harper and Bros., 1960.

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

THOMAS, SHIRLEY. *Men of Space,* Vol. I. Philadelphia: Chilton Co., 1960.

WALTERS, H. B. *Hermann Oberth: Father of Space Travel.* New York: Macmillan Co., 1962.



Chapter 5

Exploration of the Planets

THIS CHAPTER explains the program for probing all of the planets in the solar system within the decade. It describes the solar system and outlines some of the key questions about the planets that scientists are trying to answer and some of the methods used in attempting to answer these questions. Next it outlines the information about the two neighboring planets, Mars and Venus, that has been obtained from earlier studies and from recent probes. Then the chapter summarizes information already obtained about the remaining planets and the trend of future study of the planets. Finally, the chapter tells about the probes of the planets that the United States plans to make in the future, including the Grand Tours. It describes the Mariner, Viking, and TOPS (Tour of the Outer Planets Spacecraft), which are to be used for these probes and the schedule planned. After you have studied this chapter, you should be able to do the following: (1) Name the nine planets and tell which planets belong to each of the two principal classes of planets, (2) outline two key questions about the planets that scientists are trying to answer, (3) tell what new methods of studying the planets have been used since space travel began, (4) describe some of the information obtained about Mars and Venus during recent probes, (5) explain the advantage of probing all the planets instead of concentrating on the two neighboring planets, and (6) tell what is meant by the Grand Tours of the planets.

ALMOST EVERYTHING that the United States is doing to explore space is in some way leading to the exploration of the planets. Although other programs are receiving more attention now, planetary exploration will become increasingly important as the space program advances. When the large space station is developed, it can be used to train astronauts for much longer journeys and provide way stations for voyages into deep space. Research satellites and planetary probes are furnishing us with more information about interplanetary space, enabling us to mark out trajectories between the planet earth and the other planets. Techniques that we have been using to explore the moon can be adapted to planetary exploration. The Apollo flights to the moon are actually one step forward in planetary exploration.

The Apollo lunar landings have shown planners what kind of preparations would be needed before astronauts would be ready to fly to Mars. The Apollo landings have brought manned flights to Mars closer to realization, but such flights are still not likely to take place until the 1980s or even later. In the meantime US scientists will be building up a background of information about not only Mars and the other neighboring planet, Venus, but the other planets as well. Trips to several of the outer planets at one time, referred to as the Grand Tours, are possible at the end of the decade because of the way these outer planets will be lined up with the earth at that time. By taking advantage of the unique opportunity of the late 1970s, the United States hopes to make a survey of all the planets during the decade. This goal is as ambitious in its own way as was that of making a lunar landing during the decade of the 1960s.

Only after we have obtained some solid information about each of the planets will we be able to make meaningful comparisons. Ever since the time of Galileo, it has been known that the planets are unlike each other in some respects and alike in others. By comparing the planets it is possible to reach a better understanding of each planet and of the solar system as a whole. The US program for planetary exploration has set out to compare the earth with each of the planets and to study the relationship of all of the planets with the sun and with each other. By comparing the earth with other planets we shall be able to reach a fuller understanding of earth phenomena, such as the auroral disturbances and magnetic storms, mountain building, and earthquakes. Fortunately, in recent years, through knowledge obtained as the result of space exploration, scientists have gained a better understanding of the magnetosphere, which surrounds the earth and diverts the solar wind from our planet. With this fuller knowledge of the earth, scientists are better equipped to conduct probes of the other planets. They have sought to find out if the other planets have magnetic fields and how the solar wind reacts when it comes into contact with other planets. In a similar way, as scientists obtain more information about each of the other planets in turn, they will be better able to investigate the solar system as a whole.

In the search for more information about the planets, one question is basic. Does life exist outside the earth? At the bottom of all planetary research is the desire to find out if life exists elsewhere. The search has narrowed down to the planets closest to the earth, but the interest continues. Even up to comparatively recent times some astronomers thought that the planet Venus was a lush tropical paradise and Mars was inhabited by intelligent beings who constructed a complex system of canals. Even through observations made on the earth, astronomers exploded such theories. Probes made with spacecraft have pointed out further errors, but some scientists still believe that lower forms of life exist on other planets. If life is found outside the earth, this might well prove to be the greatest scientific discovery of the century.

When Columbus and other explorers crossed the ocean barrier and went from the Old World to the New World, they found strange tribes of men and new kinds of plants and animal life. But all these forms of life were basically like those in the Old World. The water, air, and sur-

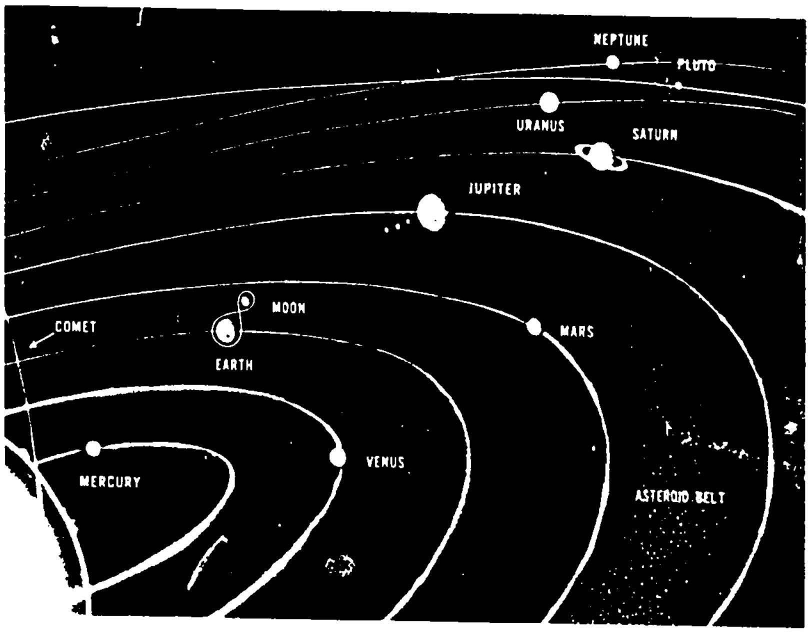


Figure 58. Solar system. The nine planets revolve in nearly circular orbits around the sun. Except for Pluto, all revolve in about the same plane. This diagram is not made to scale. For the relative sizes of the planets, see Figure 59.

face features in the New World were also much the same as those in the Old World. If man crosses the barriers of the space ocean, either in person or by sending probes or soft-landers, and discovers life on another planet, he can expect to find that life fundamentally different from life on earth. On Mars, for example, there is no known surface water, and the temperatures and the atmosphere are quite different from those on the earth. Life would probably have to assume different forms to adapt itself to Mars.

Even if expectations are not realized and no forms of life are found on other planets, it is still likely that the other planets will yield valuable clues about the origin and development of life on the earth. Many scientists believe that Jupiter rather than Mars will provide the most surprising discoveries within the decade. Jupiter, the giant of the solar system, because of its great gravitational force, is believed to retain gases from the original clouds from which the planet was formed. The planetary probes made in the next decade should provide some exciting discoveries. To foresee some of the discoveries that might be made as the result of planetary probes, it is first necessary to understand something of what we already know about the solar system.

THE SOLAR SYSTEM

Ever since ancient times man has observed the five planets visible to the naked eye from the earth: Mercury, Venus, Mars, Jupiter, and Saturn. Venus, the brightest object in the sky except for the sun and moon, appears as both an evening and a morning "star," and for this reason was given two names by the ancient Greeks. The light from Venus is sometimes so bright on a clear, calm night that it casts a shadow, as moonlight does. Mercury is difficult to observe because it appears low in the sky.

Astronomers now recognize the existence of three other planets that cannot be seen with the naked eye: Uranus, Neptune, and Pluto. These, together with the earth and the visible planets, make nine planets in all with 32 known moons. The planets revolve in orbits around the sun (Fig. 58), following the laws of Newton and Kepler, as you learned earlier in this course. The first four planets in order from the sun are known as earthlike planets because they have a density about the same as that of the earth and are of a size more like that of the earth than that of the giant planets. The first four earthlike planets are Mercury, Venus, the earth, and Mars. Next in order are the four giant planets: Jupiter, Saturn, Uranus, and Neptune. Beyond Neptune is Pluto, which is an earthlike planet with a diameter about half that of the earth.

The three outermost planets became known only in comparatively recent times. The Englishman Sir William Herschel discovered Uranus in 1781; the German astronomer J. G. Galle verified the existence of Neptune in 1846; and the American astronomer Clyde W. Tombaugh discovered Pluto in 1930.

Pluto, the outermost planet, is a small planet among the giants. It is a lone planet in other respects. It does not follow a nearly circular orbit, as the other planets do, and its plane of orbit it tipped much more than that of the other planets. Some astronomers believe that Pluto may be a moon that escaped from Neptune. Other astronomers surmise that Pluto's orbit is influenced by the gravity pull of another as yet unknown planet beyond. Pluto was not discovered until 1930, and the tenth moon of Saturn, still disputed by some astronomers, was not found until 1967. It is possible that additional planets and moons will be discovered.

The outermost planets are difficult to observe from the earth. Although the American astronomer Percival Lowell predicted the existence of Pluto and began a search for it as early as 1905, it was not discovered until 25 years later. Observing all the planets from the earth, or from any one position, gives rise to some problems because the planets reflect very little light in comparison with the dazzling light of the sun, and the planets are quite small in relation to the vast distances between them.

We tend to think of the solar system as a compact group of heavenly bodies revolving around a point called the sun. Each planet, even the smallest, does exert some gravitational pull, and the whole system is held together through the mutual pull of gravity. But the sun, not the planets themselves, exerts most of the gravitational pull within the system. The sun also contains almost all of the mass within the system. Even the giant planet Jupiter is dwarfed beside the sun.

The planets are, speaking relatively, only specks of matter revolving in orbits within the vastness of space. If the sun were represented as an orange 3 inches in diameter, the earth would shrink to the size of a pinhead 27 feet away. On the same scale, Jupiter, the largest planet, would be the size of a marble some 140 feet from the orange representing the sun. Pluto, the outermost planet, would be another pinhead like the earth some 1,100 feet from the orange (the sun). As you can see, there is not enough space on the page of your book to present a chart of the solar system to scale. It is convenient to use a second chart to show the relative sizes of the planets (Fig. 59).

To measure the vast distances between the planets, astronomers use the astronomical unit. One astronomical unit is the measure of the mean, or average, distance between the earth and the sun. In terms of this unit, the planets are spaced from the sun as follows:

	Astronomical unit		*Astronomical unit*
Mercury	0.39	Saturn	9.53
Venus	.72	Uranus	19.2
Earth	1.00	Neptune	30.0
Mars	1.52	Pluto	39.5
Jupiter	5.20		

Note the large gap between Mars and Jupiter. Within this space is the belt of asteroids, or small planetlike bodies (Fig. 58). Since all the planets except Mars and Jupiter are rather evenly spaced, it does seem that the asteroids were intended to form another planet or were part of a planet that broke up. There are thousands of asteroids in the solar system, most of which are found within this belt beyond Mars.

Although man has studied the visible planets in our solar system since ancient times, he was not able to view the more distant planets until telescopes were perfected. Planetary exploration took another big step forward when space probes were begun. Now American scientists are making plans to probe the entire solar system. In their study of the solar system they are trying to answer certain questions.

KEY QUESTIONS ABOUT THE PLANETS

Much of our interest in the planets arises from the desire to know whether we are alone in the universe, or more specifically in the solar system. In the vast reaches of space surrounding the sun are conditions favorable for harboring life to be found only on the earth? Or is some form of life to be found on at least the two neighboring planets, Venus and Mars? If life is not present on these planets now, is there evidence that it once existed there or that it is likely to burst forth soon? If life does exist, was it carried to the planet from the earth? Can spores carrying life survive in interplanetary space?

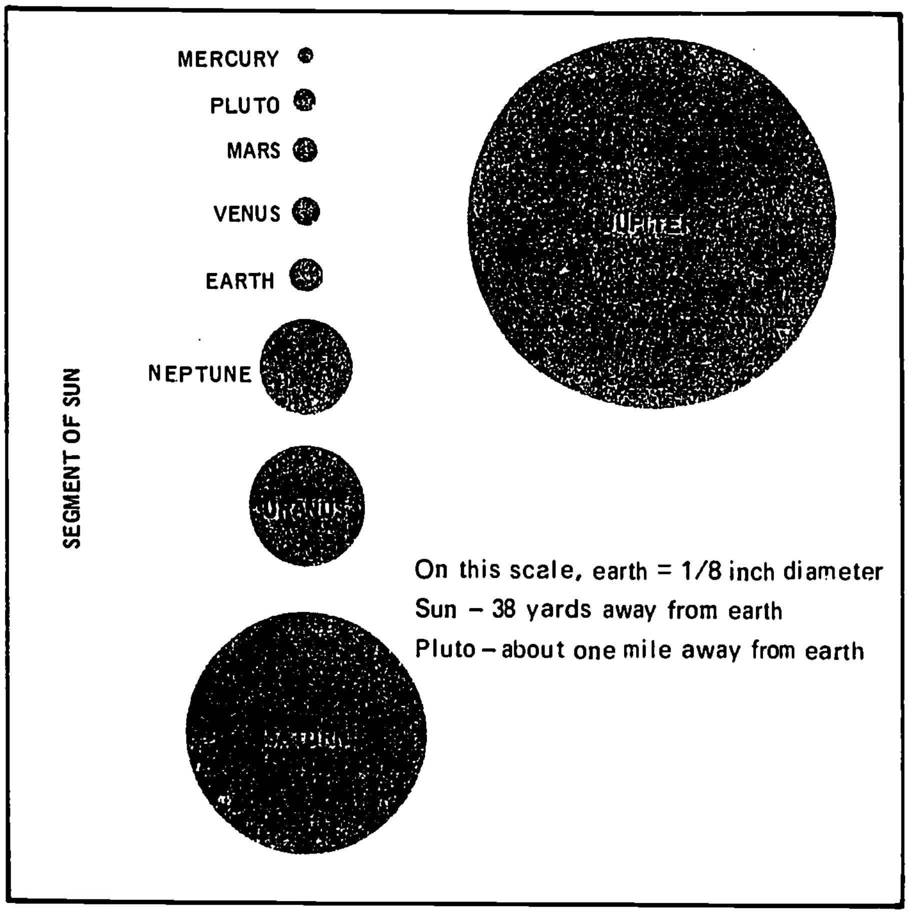


Figure 59. Relative sizes of the planets as compared with the sun.

Man is continually struck with wonder at the way in which life persists on the earth. It is only natural to surmise that life struggles to survive in interplanetary space and on other planets as well. You have probably been amazed to find plants growing in tiny crevices in rocks. Scientists have found living matter in such diverse places as the inside of a glacier or the pavement of a parking lot.

Interest in life outside the earth has led to the development of space biology. This science may open up a whole new field of knowledge. If we find some forms of living matter on another planet, we can compare these with living matter on the earth. In making comparisons, we are likely to gain valuable new insights into the study of biology. The discovery of life outside the earth should give the same kind of impetus to the study of biology as space exploration has given to the study of physics and chemistry. The space environment has provided us with a wonderful opportunity for checking laboratory findings and theories developed in the study of physics and chemistry.

A new interest in space biology was aroused in December 1970, when NASA scientists announced that amino acids had been discovered on a meteorite found in Australia the previous year. Amino acids are one of the basic constituents of living cells. The discovery gave new support to those scientists who believe that we shall find life on Mars. Most meteorites are believed to come from the asteroid belt, which is close to Mars.

To find out whether there is life on another planet, scientists need to know about the kind of atmosphere that exists there, about the presence of water, and about the range of temperatures to be found at the surface. But we are also interested in conditions on planets other than those that may support life. Although the search for life is a strong motive for planetary exploration, it is not the only one.

The United States has been exploring the moon for some time, although scientists knew at the outset that there was only the slightest chance that life would be found there. We are exploring the moon to find clues to the history of the earth and the entire solar system, and we are exploring the planets for the same reason. The development of living matter is a very important episode in that history, but the period during which life has existed probably covers only a very small part of the entire history of the solar system.

We shall be making probes of planets upon which there is little likelihood that life exists. Perhaps these probes will give us valuable clues about the origin of life on the earth. Scientists are asking whether other planets represent stages of evolution that the earth has already gone through or will go through in billions of years from now? Over the ages did life gradually move inward from one planet to another until it finally reached the earth as the sun gradually lost energy and began to cool?

In exploring the planets, scientists ask the same kinds of questions they are asking about the moon. Does the planet have an atmosphere, or is there evidence that it once had an atmosphere? Does it have a magnetic field like the earth or even a very faint one? Is water vapor present in the atmosphere? What is the range of temperatures in the atmosphere? How does the sun affect the planet's environment?

Scientists will later attempt to find out about surface conditions on the planets. What is the chemical composition of surface materials? Is water present on the surface? Are there marked temperature variations at the surface? Does the solar wind interact with surface materials?

Although scientists studying the planets will use techniques similar to those used on the moon, they could not sit back and wait until the results from the lunar probes were in and the first astronauts had landed on the moon. Because the exploration of the planets presents such a great challenge, probes of the planets were begun just as soon as spacecraft and boosters could be developed to fly to them. Because man has insatiable curiosity, he will find means to answer his questions about the planets.

MEANS FOR ANSWERING THE QUESTIONS

There are three ways in which to conduct exploration of the planets: by using men and instruments on the earth, by keeping men on the earth but sending instruments into space or to the planets, and by sending both men and instruments to the planets or to the vicinity of the planets. Astronomers in their observatories have made use of the first method for centuries as they conducted studies of the planets from the earth. Soon after the first artificial satellites were orbited, we made use of the second method. We sent out probes to make flybys of the neighboring planets. We shall not attempt to use the third method, manned exploration of the planets, until we have first obtained a solid background of information about the solar system and detailed information about the planet to be visited. Since we shall not be ready to use the third method within the decade, we shall concentrate our attention on the first two methods of planetary exploration.

Men and Instruments on Earth

With the crude telescope that he devised at the beginning of the seventeenth century, Galileo was able to make remarkable observations of the planets. When viewed through a telescope, a planet appears to be a steady disk as distinct from the blazing and seething mass of a star. The two innermost planets, Mercury and Venus, which are closer

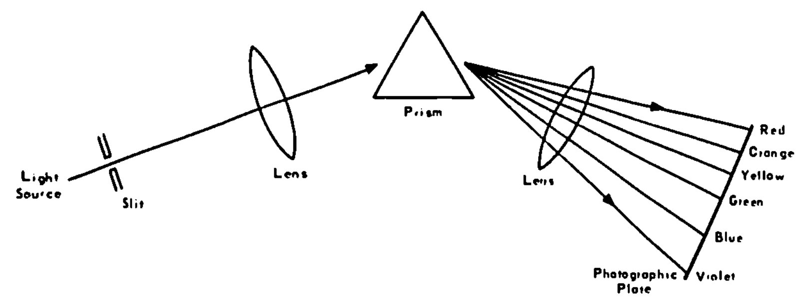


Figure 60. Diagram of a spectrograph. This instrument records the characteristic spectrum of gases present on a planet or star.

to the sun than the earth, show distinct phases, just as the moon does. The planets, shine with light reflected from the sun, which is the nearest star and, like the other stars, shines with its own light. The "planets," as the term indicates, are wanderers in the heavens. They follow a different path from the stars in the apparent revolution of the celestial sphere each night.

As telescopes were improved and astronomers had knowledge of definite laws that govern the movement of the heavenly bodies, man could add to his knowledge about the planets. Gradually he made better lens and constructed more powerful optical telescopes. These telescopes were placed on the tops of mountains or in high areas, where the conditions of seeing were much better than at sea level.

Another great step forward in the study of the planets was possible with the development of photography and the spectrograph. By exposing a photographic plate for some time, astronomers can collect the faint light from distant bodies that would not otherwise be visible through a telescope. With the aid of the spectrograph, developed in 1859, astronomers could analyze the composition of gases on the planets.

You have probably read about spectral analysis. This is essentially how information is obtained for making such an analysis: Light from the planet passes through a slit in a spectrograph and is focused by a lens onto a prism. The prism breaks the light into its component rays (red, orange, yellow, green, blue, and violet), as shown in Figure 60. A second lens focuses the component rays and spreads them out on a photographic plate to produce a spectrum. The spectrum shows the chemicals present in the gas. Each chemical element has its own characteristic spectrum, which is not duplicated by that of any other element.

When, for example, astronomers wanted to find out whether there was water vapor present in the atmosphere of Venus, they made use of the spectrograph to look for the characteristic spectrum of hydrogen and oxygen. Since they were observing Venus through the earth's atmosphere, they did not know whether the water vapor that showed up in the spectrograph represented water vapor present in the earth's atmosphere or in that of Venus. For this reason they took the spectrograph up to a high altitude in a balloon and made readings. When they still found water vapor, they were convinced that this was actually present in the Venusian atmosphere.

Further studies of the planets were made possible by the radio telescope, which was developed after World War II. Any body in space that is not at a temperature of absolute zero will emit radiation. The moon and the planets all send out radio waves that are received on the earth, but radio waves are not emitted in a steady fashion, as light waves are. The strength of the radio waves sent out varies greatly from time to time and from one planet to another. Therefore, there is great variation in the kind of information that can be obtained about the planets from the radio telescope.

Radio waves are used in other ways to study the planets. By using radar to bounce radio waves off the planets, astronomers have obtained much valuable information. They have learned about the period of rotation of certain planets in this way, and they use radio waves for obtaining information about the surface of a planet.

As instruments and techniques were improved for studying the planets from the earth, astronomers were able to fill in more information about the planets. They came to believe that through careful observations made on the earth, supplemented with educated guesses, man could in time find out all that he needed to know about the planets. Then the first successful probes of the planets were made. They showed wide gaps between information obtained by instruments on the earth and those in space. Information obtained from probes made during the first decade of space exploration has caused astronomers to change many of their ideas about the planets.

Instruments in Space

When artificial satellites were orbited, scientists had a new way to study the planets. From that time on it was possible to "see" the planets from observatories orbiting outside of the earth's atmosphere and to send probes to the planets.

The US program for probing the planets began with the Pioneer satellites. The earliest Pioneers were not intended to reach the planets but investigated the space between the earth and the moon. Pioneers 6, 7, 8, and 9 were launched into orbits between the earth and Mars. The next two Pioneers scheduled, which are to go through the asteroid belt to investigate the environment of Jupiter, are included at the end of the chapter in the descriptions of future planetary flights. Except for these two Pioneer probes, this chapter concentrates on programs intended specifically to investigate the planets: the Mariner, Viking, and TOPS (Tour of the Outer Planets Spacecraft) programs.

The Mariner spacecraft, which has been the only spacecraft used so far to probe the planets, has proved to be remarkably versatile. It is equipped with different instruments according to the planet it is to visit and the kind of information that it is to return to the earth. The early Mariner spacecraft were fitted out to make a flyby of a planet, sending back data about a planet from closer range and taking photographs of a planet from some distance. The early Mariners were roughly similar

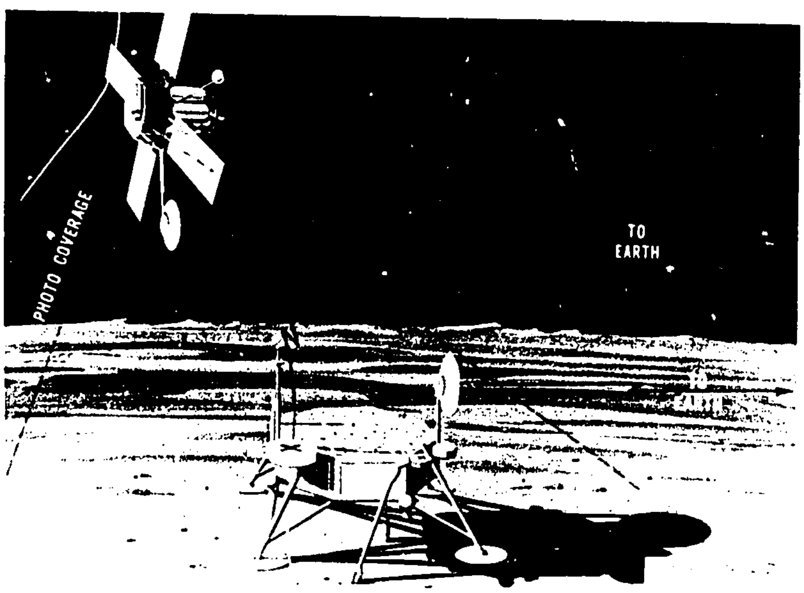


Figure 61. Viking orbiter and soft-lander (artist's sketch).

to the Ranger spacecraft, which took pictures of a small portion of the moon's surface from a distance and telemetered data about the moon before impacting. One of the most recent Mariner spacecraft was modified to orbit Mars. Another Mariner is being outfitted to go beyond Venus and swing around Mercury.

The Viking, a follow-on to the Mariner, will be a combination orbiter and lander (Fig. 61). It will thus have features similar to both the Lunar Orbiter and the Surveyor, which helped to map the moon and did reconnaissance of the landing sites. The first Viking spacecraft is to be equipped to go to Mars. When the Viking approaches Mars, the two parts will separate. The orbiter capsule will begin its journey around Mars, and the soft-lander will enter the atmosphere of the planet and begin its descent. The soft-lander will be braked by means of retrorockets and a parachute. Instruments in the soft-lander will return information on the chemical and biological conditions at the surface.

The third spacecraft for investigating the planets, what is now known as TOPS, is only in the idea stage. This spacecraft, which is to go to Jupiter and the giant planets beyond and even out to tiny Pluto, will test the ingenuity of engineers. It must keep functioning for 15 years or more, and it must survive passage through the hazardous asteroid belt. As it swings past the outermost planet of its particular Grand Tour, it must still be able to send data back to the earth over billions of miles. Present plans call for launching the TOPS with the giant Air Force–developed Titan IIID space booster, combined with the Centaur and with a third stage called Burner II.

The Grand Tours and all flights to the planets have to be scheduled when the planets to be visited are so aligned with the earth that the spacecraft can reach them with the rocket power available. A launch to a planet must await a favorable opportunity. If the launch is not made within certain time limits, the opportunity is lost, and the flight must be delayed until the next opportunity develops. Flights to Venus, for example, are scheduled at intervals of about 19 months, and flights to Mars at intervals of about 24 months.

The Soviet Union seems to have taken advantage of almost every favorable opportunity for sending probes to the neighboring planets. That country has launched dozens of planetary probes; the exact number cannot be determined. The United States has pursued a less ambitious program and has missed some opportunities. We seem to have achieved much better results with our planetary probes, however, in terms of numbers of probes returning data in relation to the total number launched. By early 1971 the United States had made two successful probes of Venus and three of Mars. During the same time the Soviet Union made four successful probes of Venus with the Venera, but no data was returned from Mars.

The Soviet Venera contained capsules for making a soft-landing on Venus. Venera 4, 5, and 6 transmitted data while going through the atmosphere of Venus but did not send back signals after landing. Venera 7, which soft-landed on Venus on 15 December 1970, sent back signals for a total of 23 minutes, part of this time being from the surface of the planet. The signals from the surface gave only the temperature readings, not both temperature and atmospheric pressure readings as intended. The achievement was remarkable nevertheless. Venera 7 was the world's first soft-lander to transmit data from the surface of another planet.

It is impossible to evaluate accurately the success that the Soviets have achieved with their probes of the planets. They have not published a complete report of their findings, and they have not explained their goals. The Soviets are known to have sent a probe to Mars (Mars 1) in November 1962, but they lost radio contact with it shortly before it reached the planet. In May 1971 the Soviets announced that they had launched Mars 2 and later Mars 3. These large advanced spacecraft are expected to reach the planet sometime in November. It is difficult to understand why the Soviets have not already made successful probes of Mars, especially in view of the fact that they have sent advanced automated spacecraft to both the moon and Venus.

By June 1971 neither the Soviet Union nor the United States had as yet probed planets beyond Venus and Mars. In 1972 the United States is to push out farther into space with the Pioneer probes of Jupiter. The next planet to be probed after Jupiter is to be Mercury. As we reach out farther, we expect to make more discoveries, but we have already added greatly to our knowledge from information obtained from probes of the neighboring planets.

THE NEIGHBORING PLANETS

In directing probes to answer their questions, scientists first turned their attention to the neighboring planets, Mars and Venus. These were the planets that could be reached by spacecraft first, and they

DATA ON THE SUN AND THE PLANETS

Body	Mean distance from sun		Diameter in miles	Period of rotation	Period of orbit	Number of moons
	Millions of miles	Astronomical unit				
Sun	—	—	865,000	25 days	—	—
Mercury	36	0.39	3,025	59 days (approx.)	88 days	0
Venus	67	0.72	7,526	247 days (approx.)	224.7 days	0
Earth	93	1.00	7,926	23 hr. 56 min.	365.3 days	1
Mars	142	1.52	4,200	24 hr. 37 min.	687 days	2
Jupiter	483	5.20	88,700	9 hr. 55 min.	11.9 yr.	12
Saturn	886	9.53	75,000	10 hr. 30 min.	29.5 yr.	10
Uranus	1,783	19.2	29,600	10 hr. 50 min.	84.0 yr.	5
Neptune	2,793	30.0	27,600	16 hr.	164.8 yr.	2
Pluto	3,666	39.5	3,600?	6.4 days	248.4 yr.	0

Figure 62.

were the planets most likely to harbor life. After the first probes of Venus revealed excessively high temperatures, US scientists became even more interested in Mars, but the Soviet Union seems to have kept up its interest in Venus. Of the two neighboring planets, Venus is the nearer to the earth (Fig. 62), but Mars is more likely to harbor living matter.

Mars

Even when Mars is at the closest approach to the earth, it is still some 35 million miles away, or about 145 times as far away as the mean distance to the moon. When probes are sent to Mars on the long curving trajectory required to conserve power, Mars is about 60 million miles away. The vast distance has made it much more difficult to effect a flyby of Mars than of the moon, and it has been more of a problem to get telemetered data from the Mars probe. It is not unreasonable to expect, however, that man will bridge the vast distance and that astronauts will someday make both flybys of Mars and landings upon its surface, just as they have done in the case of the moon. Manned planetary flights have not been planned as yet, however. Our immediate goal is to obtain more accurate information about Mars, especially about its surface features.

Of all the planets in the solar system, Mars is the one that has been the most closely observed, since our nearer neighbor, Venus, is constantly obscured by a cloud cover. For centuries astronomers have studied the features of Mars and have made detailed maps of the planet. Because the markings could be followed as the planet rotated, accurate measurements could be made of the rotation period. Mars was found to have a day-night period of 24 hours 37 minutes, or one just slightly longer than that of earth, but its year lasts 687 days, or almost twice as long as an earth year.

With a mean diameter of 4,200 miles, Mars has a diameter about half that of the earth (Fig. 62) and a volume about one-eighth as large.

Mars has two moons, Deimos (Terror) and Phobos (Fear), apt names for the moons of a planet named for the god of war. Both of the Martian moons are extremely small. Deimos, the outer moon, has a diameter of only 5 miles, and Phobos, the inner moon, a diameter of about 10 miles. These small satellites may some day be useful as bases for observing the planet.

When Mars is viewed in the evening sky with the naked eye, it appears to glow with a reddish light. Hence it is known as the Red Planet. In a telescope Mars appears as a predominantly reddish and ochre colored disk with distinct markings.

The surface features of Mars, once the subject of much controversy, were at last identified with assurance. Then the probes by the US Mariner spacecraft were made, and astronomers had to take a new look at Mars. The conspicuous reddish and ochre areas are still thought to be deserts, but not hot, sandy deserts like the earth's Sahara. The Mars deserts are most likely cold, dry, featureless plains. The reddish-ochre color may be caused by a mineral deposit, or it may simply be the result of the reflections of the sunlight on the haze in the thin Martian atmosphere. The conspicuous dark areas, variously described as blue-green or dark gray, were once thought to represent vegetation. The theory was an attractive one, as a wave of darkening seems to advance from the polar areas to the equator as the summer advances in one hemisphere or the other. When summer comes, the conspicuous ice cap gradually becomes smaller, and the one at the south pole may disappear. When winter returns, the polar ice cap forms again.

The white areas seen in telescope views of Mars have actually been identified by probes as polar caps formed of carbon dioxide ice, or dry ice. Some water vapor is almost sure to be present in the caps also. The dark areas are no longer thought to be vegetation. The kind of lower plant life that might be found on Mars could not be identified at the distance that the flybys were made, and certainly could not be seen in a telescope. The dark areas are now associated with the surface features, but these have not as yet been positively identified. No theory has as yet been proposed that can explain the wave of darkening that seems to advance with the summer season.

The dark-line markings on Mars are the features that have created the most interest and controversy. In 1877, an Italian astronomer named Schiaparelli observed the presence of distinct dark lines and called them *canali*, the Italian word for channels. Astronomers in other lands, fascinated with Schiaparelli's observations, began to refer to the markings as canals. As the so-called canals were studied further, they showed remarkable regularities. Some astronomers saw in them a regular network of canals constructed by intelligent beings. Other astronomers thought the whole idea was ridiculous and said so. The dark-line markings existed just at the limits of visibility, and there was at the time no way to check on what the telescope showed.

Today's astronomers know more about conditions on Mars. They believe that no intelligent beings could survive on this planet, let alone construct canals. There is in fact no evidence of any bodies of water or of enough oxygen in the atmosphere for supporting human life. Later probes will help scientists relate more exactly the color markings and lines observed in the telescope with what the probes reveal. On the second and third probes the dark-line markings were identified as a series of dark patches that are closely aligned with each other.

Even when astronomers found that there could be no means to support human life on Mars, their interest in the planet has persisted because they believe lower forms of life may eventually be found there. For this reason much excitement has attended the successful Mariner probes of the planet.

Mariner 3, the first probe of Mars, launched early in November 1964, failed to respond to signals, and contact with it was finally lost.

Mariner 4, launched later in the same month, sent back dramatic and significant results. The probe passed within about 5,400 miles of Mars on 14 July 1965. This was the first successful probe ever made of Mars. As the probe approached the planet, the sunlight reflected from its surface triggered the television camera in the Mariner, and it began taking pictures. These were stored aboard the Mariner for later transmittal to the earth. As the spacecraft passed behind the planet and then came back again, the radio waves passed through the Martian atmosphere, and valuable data about the atmosphere was obtained as a result.

The pictures from Mars were not transmitted until the next morning. Imagine the surprise of scientists when Mars was seen to have a surface more like the moon than the earth (Fig. 63). Mariner 4 took 21 photographs of Mars at distances ranging from 7,000 to 10,000 miles. The pictures covered only about 1 percent of the surface, but they included both crater and desert areas.

The second and third probes of Mars, Mariner 6 and 7, launched as a pair of probes in 1969, together took over 200 photographs, which covered about 20 percent of the surface. These are believed to have included samples of every kind of feature. The pictures showed much finer details, as one of the probes came as close as 2,130 miles from the planet. The close-up cameras were concentrated on the south pole of the planet. These later probes revealed that Mars is neither like the moon or the earth. As might be expected, Mars has its own characteristic surface features.

Figure 63. Portion of a photograph of Mars taken by Mariner 4. Note the two large craters in the lower left. The 21 pictures of Mars taken by Mariner 4 showed a cratered surface.

Since Mars is a close neighbor to the asteroid belt (source of the meteoroids) and since it has only a thin atmosphere to protect it against strikes, this planet might be expected to have more meteorite craters than are found in the earth-moon system. Some of these craters may, however, have been completely erased by erosion over billions of years. Mariner 6 and 7 indicated that most of the craters on Mars are shallower than those on the moon and show evidence of erosion, but there are also some small bowl-shaped craters on Mars that look freshly made and resemble some of the lunar craters. The presence of these two types of craters on Mars suggests that there have been at least two distinct episodes in the history of that planet.

One of the major surprises of the Mariner 6 and 7 probes was the discovery of two new kinds of areas on Mars: the featureless desert area and the chaotic, or jumbled, area (Fig. 64). The featureless desert contains no craters or any kind of surface marking. The chaotic area consists of a jumble of ridges and valleys with only a few craters. Such chaotic areas exist on the earth, such as in Alaska where the slumps were formed from recent earthquakes, but these areas on the earth are quite restricted in size. The chaotic area pictured by the recent Mariner probe covers an area about the size of the state of Texas.

No water has been found on the surface of Mars and no evidence that oceans once existed. The names suggesting bodies of water that appear on Martian maps are given them by astronomers in the same

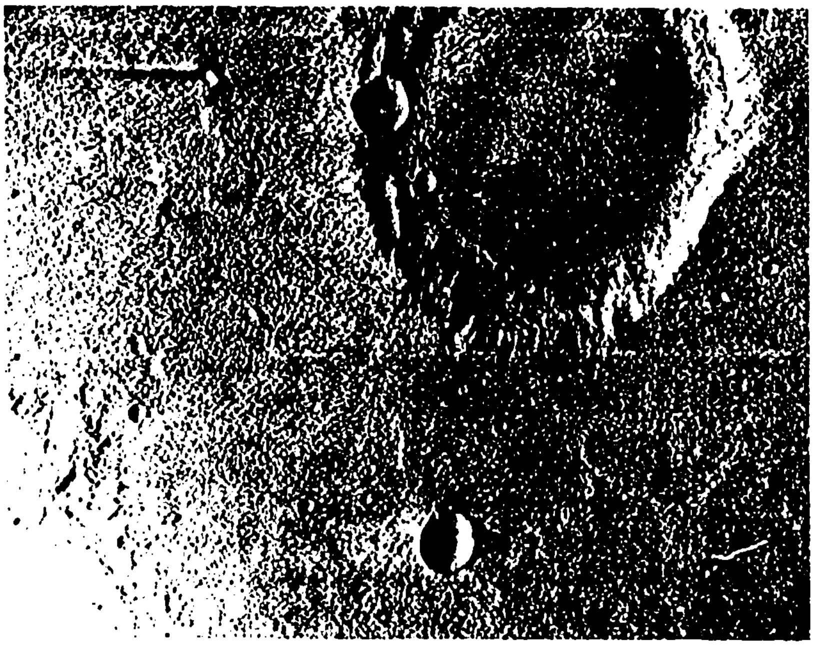


Figure 64. Chaotic area on Mars photographed by Mariner 6. The large crater is about 24 miles across. It has several slump terraces and gullies along the crater walls. Note also the smaller crater on the west wall of the big crater.

traditional manner that such names are given to features on the moon. Some scientists believe that Mars once had bodies of water and that frozen water will be found beneath the surface. As on the moon, such water would be important to support man if he were to establish a scientific station on the surface.

The Mariner 6 and 7 probes showed the atmosphere of Mars to be somewhat more hostile to life forms than the earlier probe. The Martian atmosphere is now believed to be extremely thin, about 1 percent as dense as that of the earth. One of the recent probes, upon sampling the atmosphere at the south polar cap (Fig. 65), detected carbon dioxide, water ice, fog, water vapor, and some carbon monoxide. The Martian atmosphere is made up largely of carbon dioxide. Although the probe revealed no nitrogen gas, a very small amount of free nitrogen and oxygen is believed to be present in the Martian atmosphere. Both nitrogen and oxygen are required to support life as we know it on the earth. If later probes do not confirm the presence of free nitrogen in the atmosphere of Mars, this does not rule out the possibility of life on the planet. Some living things on the earth take the nitrogen they need from the soil rather than from the atmosphere.

Mariner 6 and 7 found no temperature on the surface above 60 degrees F., but Mariner 4 recorded temperatures as high as 85 degrees F. at the equator during the daytime. In the nighttime temperatures at the equator fell to −100 degrees F. Mars might be expected to be quite cold generally because this planet is much farther away from the sun than the earth is, and the thin Martian atmosphere would not hold in much heat after the sun had gone down.

Thus scientists continue to sift the evidence to find out what the chances are that we shall find life on Mars. Results from the Mariner 9 probe, launched during May 1971, are being awaited with great interest. They may verify or disprove some of the findings of the 1969 probes. But no first hand evidence about living forms on Mars can be expected until we have put soft-landers on the planet.

In the meantime a few scientists still have hopes that torrid Venus might shelter some forms of life somewhere.

Figure 65. Mars with south polar cap. This photograph was taken by Mariner 7 when it was still about a million miles from Mars. The bright area in the northern hemisphere is a desert. The black spot in the bright area is a reference mark on the camera, not a feature of Mars.

Venus

Because water vapor was found to exist in the Venusian atmosphere, scientists took a new interest in Venus. They reasoned that perhaps, after all, Venus harbored life, and since Venus is closer to the earth than Mars, it should be visited first.

Venus, the second planet from the sun, lies inward towards the sun from the earth. It is often referred to as the sister planet of the earth

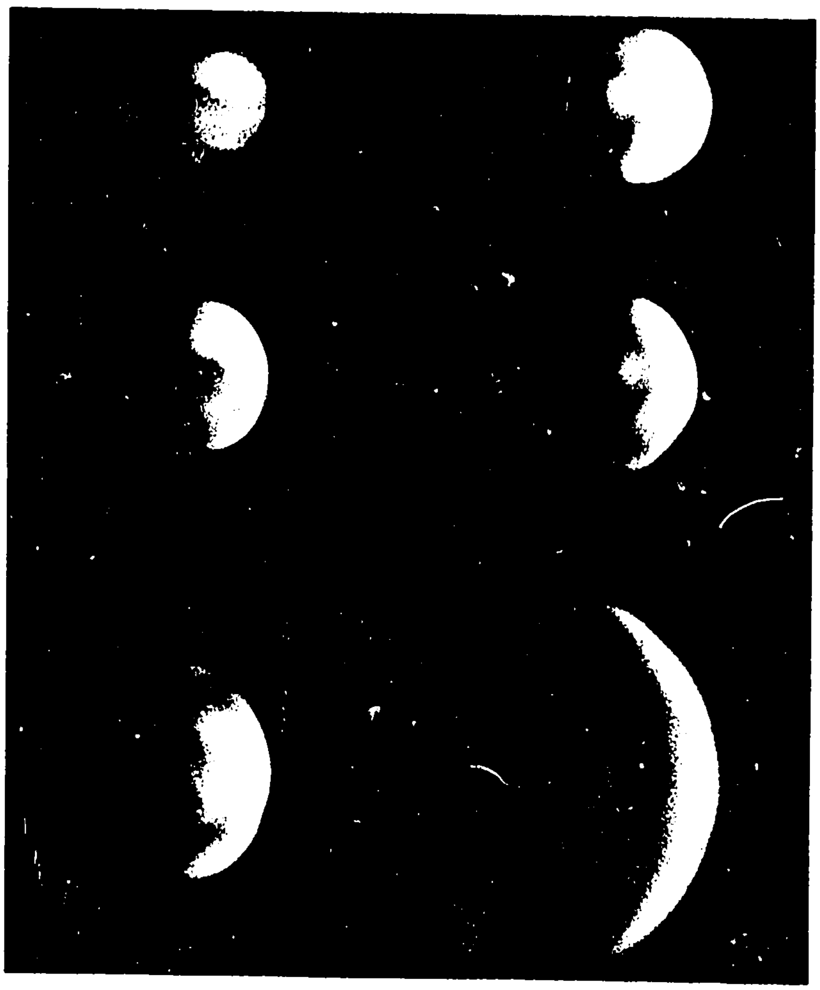


Figure 66. Phases of Venus between March and July 1967. These photographs were taken with a 61-inch telescope in a near ultraviolet light. Note the faint cloud markings.

because its size and mass are about the same as those of the earth. The diameter of Venus is 7,526 miles, just a little less than that of the earth. Venus comes within 24 million miles of the earth at its closest approach. Opportunities for making probes of Venus occur about every 19 months.

Even though Venus is the closest planet to the earth, it has remained shrouded in mystery. Dense layers of clouds constantly hide its surface, even when the planet is viewed with the most powerful telescopes. Venus has been under observation with the telescope since the time of Galileo some three and a half centuries ago, but the clouds have never cleared so that the surface can be observed. The movements of the enshrouded planet are known and have been studied with precision, however. Venus, like the moon, shows phases (Fig. 66), but the full orb of Venus is never seen from the earth because the sun obscures it. The planet is best seen in its crescent phase. The cloud cover of Venus reflects some 60 percent of the sunlight falling upon it, making it a brilliant sight in the evening sky.

Ultraviolet photographs of Venus made with a telescope show great turbulence in the dense cloud cover. This atmospheric cover continues to remain an enigma, however. Being a twin sister of the earth in size and mass, Venus would be expected to have an atmosphere slightly less dense than that of the earth. Since Venus is nearer to the sun than the earth is, it receives more heat from the sun. This should cause the atmosphere of Venus to retain more heat and therefore expand more. As the expanding gases rise, they would be expected to escape more readily from Venus than from the earth. On the contrary, a thick blanket of atmosphere remains.

Another puzzle about Venus is the fact that it appears to have little or no magnetic field. Being a twin planet to the earth, it might be expected to have a similar magnetic field.

Before 1962, when a successful Mariner probe was sent to Venus, all information about the planet had been obtained by astronomers by means of instruments placed on the earth. Spectroscopic measurement of the Venusian atmosphere revealed that its content is largely carbon dioxide, and estimates placed the pressure of this atmosphere to be all the way from five to several hundred times that of the density of the earth's atmosphere. With carbon dioxide and water vapor known to be present in the atmosphere, scientists believed that some kind of plant life could exist on Venus. They knew that temperatures could be expected to be higher than those on the earth, since Venus is much nearer to the sun than the earth is, but the surface of Venus could be expected to cool as it was turned away from the sun. Therefore, investigators were surprised at the high surface temperature readings obtained from Mariner 2, the first successful probe of Venus, or of any planet.

Data returned by Mariner 2 indicated that the temperature at the surface of Venus was somewhere between 600 and 800 degrees F. Recent readings obtained from Soviet Venera 7 gave temperatures as high as 1,000 degrees F. With such temperatures, which are well above the melting point of lead, no life could exist at the surface of the planet. Surprisingly enough, the surface readings obtained from Mariner 2 appeared to be the same on the dark side as on the sunlit side of Venus. But at the top of the cloud cover, which is some 20 miles to 30 miles thick, the temperature dropped to as low as −30 degrees F. If the data was correctly interpreted, the cloud cover permits the heat to penetrate to the surface of Venus. Then when the heat is radiated from the surface, the carbon dioxide acts as blanket, inclosing the heat and creating a so-called greenhouse effect. This effect is much more pronounced with a carbon dioxide atmosphere than with the oxygen-nitrogen atmosphere of the earth. Temperature changes are not likely to be made rapidly, since Venus appears to turn slowly on its axis. From radar data received at several stations on the earth, Venus is believed to take about 247 earth days to rotate on its axis.

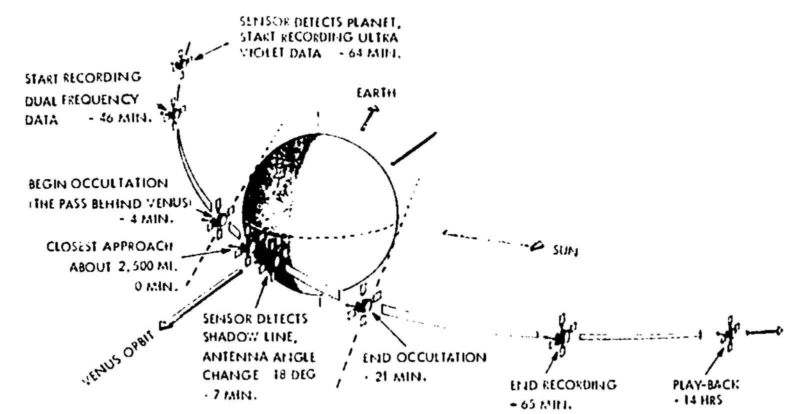


Figure 67. Flyby of Venus by Mariner 5. As the spacecraft passed behind the planet, radio signals went through its atmosphere. As a result, scientists were able to learn more about the Venusian atmosphere.

To get more information about temperatures on Venus and more clues as to the nature of the mysterious cloud cover, Mariner 5 was sent to Venus in June 1967 (Fig. 67). The spacecraft, which was originally constructed to probe Mars, was modified to fly by Venus. The television cameras were removed, as they would not be able to penetrate the cloud cover of Venus. Astronomers would naturally like to get some close-up pictures of the cloud cover and of the surface. The next Mariner probe will have a television camera equipped with a special telescope to take such pictures.

The findings of Mariner 5 were compared with those of Soviet Venera 4, which reached Venus at about the same time. The findings were generally in agreement. Both spacecraft found that carbon dioxide was the principal constituent of the Venusian atmosphere and that some water vapor was present. Also, both spacecraft reported hydrogen coronas around the planet and excessively high temperatures (above 900 degrees F.) at the surface. Neither spacecraft found evidence of any radiation belts like the Van Allen belts.

There were some discrepancies between the two sets of data. Readings obtained by the US Mariner 5, just as those gathered by Mariner 2, showed slight magnetic activity. This could indicate the presence of an extremely weak magnetic field about Venus, or it might simply be the result of the interaction between the solar wind and the Venusian atmosphere. Soviet readings obtained from the Venera 4 showed Venusian atmospheric pressure to be only 20 times heavier than that of the earth, whereas readings from the Mariner spacecraft indicated it to be 75 to 100 times heavier than the earth's atmosphere at the surface of the planet. Later Soviet calculations, made on the basis of data returned by Venera 7, confirmed the earlier American findings.

The fact that both the Soviet and the US probe detected water vapor in the atmosphere supports the theory that the upper clouds of Venus are formed of ice crystals. Even though water vapor is present in the atmosphere, it seems evident now that life cannot exist on the dry and searingly hot plains of Venus. Some scientists still believe, however, that some lower forms of life might be found on mountains or even somewhere in the middle reaches of the atmosphere, where the temperatures might be more moderate.

Soviet scientists may expect to find life on Venus, as they have continued to send advanced Venera probes to the planet. Sir Bernard Lovell of the Jodrell Bank Observatory in England has cooperated with the Soviets in monitoring signals from the Venera probes, and the

Soviets are now releasing more information about their findings. If the Soviets make significant discoveries concerning the existence of life on Venus, they can be expected to report their findings.

If life is not found on Venus, then Mars and finally Jupiter offer the last hope for finding life on other planets. Some scientists believe that Jupiter will reveal some surprising findings once probes have penetrated the cloud cover.

THE OTHER PLANETS

The National Academy of Sciences and the President's scientific advisors have recommended that the planets be one of the major goals for US space exploration in the 1970s. In making this recommendation, these scientists have pointed out that our investigations of the planets should not be concentrated on Mars and Venus but should include all the planets. Only by accumulating information on all the planets will scientists be able to arrive at a better understanding of the solar system as a whole and of each planet within it.

The next planet that is to be probed with Pioneer satellites is Jupiter, the fifth planet from the sun and the next beyond Mars. Jupiter, the largest planet by far, has a mean diameter of 88,700 miles and a volume 1,300 times that of the earth. Although Jupiter has a density roughly equal to that of water, its mass is about 318 times that of the earth and represents 70 percent of the combined mass of all the planets. In spite of its great mass, Jupiter rotates very rapidly, once in about every 10 hours. As a result of this rapid rotation, this giant planet has become flattened at the poles and bulges at the equator. Jupiter has 12 moons. Several of the outer moons rotate in a direction opposite to that of the inner ones and of the planet itself.

The surface of Jupiter has never been seen because it is covered with dense cloud belts many thousands of miles thick. The many-colored cloud belts form parallel to the equator and constantly move about, changing their shapes. Conspicuous among the clouds is the great Red Spot (Fig. 68), which remains fixed in latitude and changes only slightly in longitude. The mysterious Red Spot, discovered about 300 years ago, has revolved around the planet only three times in the last 200 years.

In the atmosphere of Jupiter scientists have detected hydrogen and small amounts of methane (marsh gas) and ammonia. Helium is probably present as well. Hydrogen and helium are the fundamental ele-

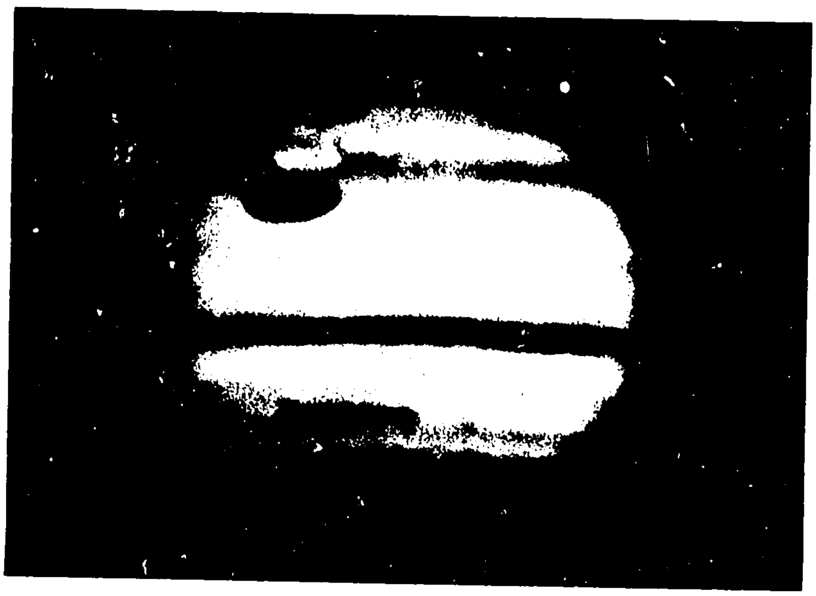


Figure 68. Jupiter as viewed through a 200-inch telescope in blue light. Note the large Red Spot to the left. The smaller dark spot above it is a shadow. Above the planet to the right is Ganymede, one of the moons of Jupiter.

ments found in the sun, and they are believed to have made up the original clouds of gases from which the planets were formed. Because Jupiter has such great mass, and therefore such tremendous gravitational force, the original gases from which the planet was formed may still be present. Probes showing the proportions of hydrogen and helium present in the Jovian atmosphere should throw new light on the evolution of the solar system.

Jupiter, like the other giant planets, is believed to have no solid surfaces but to be made up of frigid compressed gases formed around a small dense core encased in a layer of ice.

The temperature on top of Jupiter's cloud tops has been found to be about −230 degrees F. Even this frigid temperature is not quite so low as the temperature computed according to the distance from the sun (a mean distance of 483 million miles). Measurements of infrared radiation made in 1965 showed that Jupiter is radiating about 2.5 times as much heat as it receives from the sun. Recently scientists have advanced the theory that Jupiter might not be a planet but a dying star that is emitting some heat of its own. This exciting possibility adds new interest to a probe of Jupiter.

Another mystery about Jupiter concerns its magnetic field. Jupiter, unlike Mars and Venus, is known to be surrounded by highly active radiation belts. In fact, electromagnetic radiation appears to be emitted from the planet, and this radiation seems to be focused upon two of the Jovian moons. Actually it is not known whether this radiation comes from the planet or whether it is being captured from the solar wind. The great size of the radiation belts surrounding Jupiter, however, seems to indicate that the radiation comes from the planet itself. A probe of Jupiter should throw some light on the nature of its magnetic field and tell us more about the earth's magnetic field as well.

After scientists make a successful probe of Jupiter, they should have clues to enable them to investigate the other giant planets. But before sending probes beyond Jupiter, on the so-called Grand Tours, the United States plans to send a probe inward to Mercury, the other planet twice removed from the earth.

Mercury, the planet closest to the sun, is also the smallest of the planets. It is only somewhat larger than the earth's moon, but it is very dense. The high density of Mercury may be caused by large concentrations of iron or by the fact that much of the lighter, volatile substances from the interior of the planet have been lost because of the strong gravitational pull of the sun. Although Mercury can be seen even with the naked eye, it is difficult to observe the planet with the most powerful telescopes because of its nearness to the sun. Although astronomers have observed Mercury for centuries, their maps of the planet show only some gross shadings and no surface features. The rotation period of Mercury is now believed to be about 59 days. Scientists used to believe that Mercury took about the same period of time to rotate that it did to orbit the sun. They thought that the dark side of the planet, constantly shut out from the sun's rays, would register temperatures near absolute zero. Recently a radio telescope in New South Wales, Australia, received indications of a balmy 60 degrees F. on the night side of the planet. If this temperature reading is accurate, then Mercury must have an atmosphere to hold in the sun's heat. Scientists have not yet been able to detect an atmosphere on Mercury. Because so little is known about this planet and because it is so near to the sun, scientists are awaiting the first probe with great interest.

Going back to the giant planets we find that the next one beyond Jupiter and the next in size is Saturn. This is the outermost planet visible to the naked eye. Saturn, like Jupiter, is covered with clouds, and its surface has never been seen. The unique feature of Saturn is its ring system. The rings surrounding Saturn at the equator are about 41,500 miles wide, but they are quite thin. Stars have been observed shining through the rings. Saturn's ring system is believed to have been formed when one of the planet's moons approached too close and was broken apart by tidal forces. Beyond Saturn are two smaller giants, Uranus and Neptune. Like Jupiter, the other three giant planets have low density and rotate rapidly. They, too, are believed to have small, dense rocky cores surrounded by thick shells of ice. The planets themselves are believed to be composed of compressed hydrogen and helium with some methane and ammonia. The temperature of the outermost giant, Neptune, is believed to be about −300 degrees F. Neptune is so far from the sun and its orbit is so large that it takes about 165 earth years to make a complete revolution around the sun.

Beyond the giant planets is lone Pluto, the outermost planet. It is believed to be a solid body like the earth and of similar density. Since Pluto is only about half the size of the earth, it might be more accurate to think of it as a kind of frozen asteroid.

Knowledge about the planets beyond Saturn is filled with gaps. The Grand Tours, which will enable us to probe these planets, should provide a whole new range of knowledge for astronomers. Spacecraft for making these flights are to be launched near the end of the decade. Earlier flights will concentrate on the nearer planets.

FUTURE PLANETARY FLIGHTS

The planetary flights to be launched during the remainder of the decade are part of a program that includes flights to each of the planets. The flights will include probes made with the present Mariner and Pioneer spacecraft, as well as with the new combined orbiter and soft-lander, called Viking, and with TOPS.

Mariner Probes

The United States scheduled the launch of the first pair of Mariners to orbit Mars, Mariner 8 and 9, for May 1971. Mariner 8, launched on 8 May, failed to orbit. The launch of Mariner 9 was delayed until the cause of the failure could be determined and modifications made. Mariner 9, which should orbit Mars at an altitude of about 1,000 miles, is to take over the task of mapping the planet. It is to view a large part of the surface of the planet. The television pictures should show seasonal changes and surface features, and they should help in identifying potential landing sites for the Viking capsule. Instruments on the orbiter should tell us more about the atmosphere of the planet.

The third Mariner spacecraft, to be launched singly in the fall of 1973, will swing inward to probe both Venus and Mercury. It will make a flyby of Venus at a distance of about 3,300 miles in February 1974 and then reach within 625 miles of Mercury during the following month. The top priority will be Mercury. This will be the first probe of Mercury and the first probe to visit more than one planet. Using a gravity assist obtained by looping around Venus, the Mariner will gain velocity to escape and go inward toward Mercury. When the Mariner approaches Mercury, its television cameras will take photographs of the planet's surface, check the temperature at the surface, and search for signs of an atmosphere and a magnetic field. An analysis of the spacecraft's trajectory should indicate something about the nature of the planet's interior.

As the spacecraft makes its flyby of Venus, it should be able to take pictures of the planet's surface through the heavy cloud cover, as the television cameras are equipped with a special kind of telescope. The first pictures ever to be taken of the surface of Venus should make some exciting revelations.

Pioneer Probes

Two modified Pioneers are to be launched to Jupiter, one in 1972 and the other in 1973. These probes represent an exciting new phase in planetary exploration, as they are to reach out beyond the orbit of Mars. The probes will be steered through the treacherous asteroid belt and on to the vicinity of Jupiter. Each spacecraft will take about two years to make the journey of more than a half billion miles, spending about six months in the asteroid belt. When the Pioneer probe nears Jupiter, it will swing around the planet, coming within about 100,000 miles of the planet at the closest point. The two Pioneer spacecraft that are to make a flyby of Jupiter will be equipped to transmit television photographs of the planet and to return data on the planet's environment, including measures of the helium content and of electromagnetic radiation from the planet.

Viking Orbiter and Soft-Lander

If scientists are successful in receiving returns from the Mariner–9 probe of Mars, they should be ready to launch the first Viking spacecraft, the combined orbiter and soft-lander (Fig. 61). This will bring to a climax all of the earlier probes of Mars made with the Mariner and should at last provide an answer to the question of whether or not life exists on Mars. The Viking spacecraft, now under construction, will be launched in 1975.

After the Viking has reached the vicinity of Mars, the orbiter portion of the spacecraft will give the lander information about the best sites for landing. The lander will then separate from the parent spacecraft and begin its descent. As the lander gradually descends, it will telemeter to the earth information about the Martian atmosphere through which it is passing. After touchdown two cameras on the lander will take pictures of the landing site. These pictures will aid in selecting the samples of surface materials to be analyzed for organic material, water, and biological activity. The chemical sampling will be done in a somewhat different way than with the lunar Surveyor. The Viking soft-lander will put emphasis on the search for life. The biological part of the sampling will attempt to find indications of photosynthesis, respiration, and metabolism or growth.

While the soft-lander is performing its tasks on the surface of Mars, the orbiter will be giving the lander directions from overhead. The orbiter will alert the lander as to the best times for taking samples, such as during the passage of the wave of darkening, and it will present scientists on the earth with information that will enable them to relate the findings of the soft-lander with the local weather and with other conditions on Mars at the time the samples are being taken. When not engaged in directing the movements of the soft-lander, the orbiter will map the surface of the planet and fill in information about surface features. The Viking will represent the peak of US achievement with automated soft-landers. The Grand Tours, planned for the end of the decade, should present the climax of US efforts in the navigation of automated spacecraft.

Grand Tours

The prospect of the Grand Tours to the outer planets has probably excited more interest among astronomers and the general public than plans for any previous planetary probes. To be sure, there was much rejoicing among US space scientists in December 1961, when Mariner 2 made the first successful planetary probe, sending back data about Venus. Excitement mounted again in July 1965 when Mariner 4 returned the first television pictures of another planet, those of Mars showing the cratered surface.

Now scientists are hopeful that in less than two decades after the first successful planetary probe was made, we shall be launching a probe to Pluto at the farthest reaches of the solar system. The vast scope of the undertaking strikes awe in those who consider it. Another source of awe is the fact that such an opportunity for making multiple probes of the outer planets will not exist again for another 180 years, or for six generations. Scientists proposed to the President that the United States concentrate on a program for probing all the planets in the decade of the 1970s, and the planets have presented a favorable opportunity for completing the program. The TOPS is being designed for making the Grand Tours, and a booster has been designated for it. By 1973 NASA's new expanded Deep Space Network should be completed, providing 24-hour-a-day communication coverage out to the limits of the solar system.

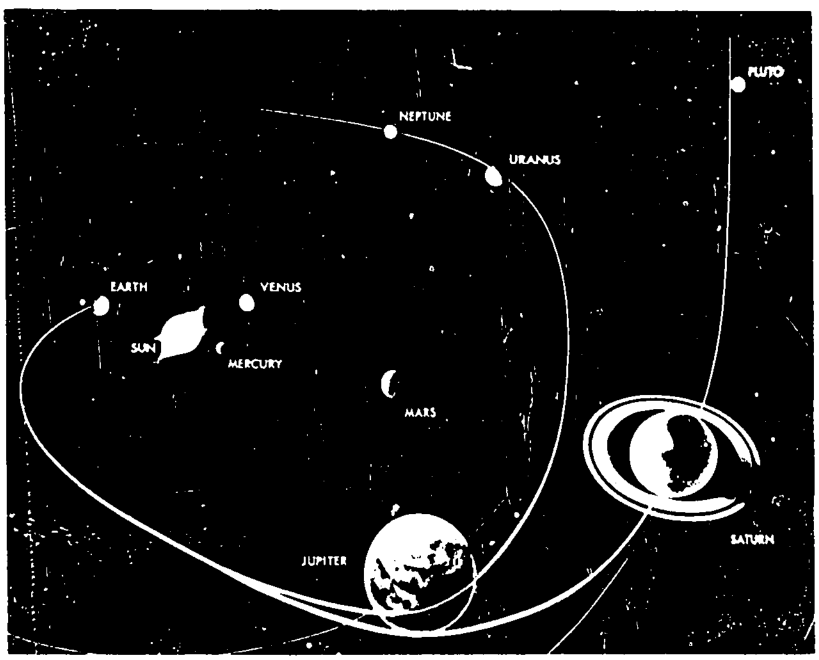


Figure 69. Grand Tours of the outer planets. Each Grand Tour is to include flybys of three planets. Each spacecraft making a Grand Tour will get a gravity assist by flying by Jupiter.

When the Grand Tour was first proposed, it was to include a four-in-one probe of the giant planets to be launched sometime between 1977 and 1979. The spacecraft would make use of a gravity assist from Jupiter, according to the principle being tested with the Mercury-Venus probe to be launched in 1973. With the gravity assist from Jupiter, the spacecraft would swing out to Saturn. Uranus, and Neptune. This would leave out Pluto, the last planet, and it would then be extremely difficult to make a probe of this planet and complete the study of the solar system. For this reason scientists proposed that the tour be split to include Pluto.

Because of the unique opportunities offered to explore the outer planets in this decade, NASA has suggested the possibility of making four gravity-assist Grand Tours, each including flybys of three planets. The first two flights might be Jupiter-Saturn-Pluto flybys, and the other two flights might be Jupiter-Uranus-Neptune flights (Fig. 69). These Grand Tours must be launched between 1975 and 1979. Each tour might be expected to take 12 to 15 years to complete. It would take about 2 years for a probe to get to Jupiter. After probing the outermost planet on each tour, the spacecraft will probably escape from the solar system into intergalactic space to orbit among the stars.

After you have stretched your imagination to picture the Grand Tours, you may wish to take a glimpse even farther into the future. You might ask: Will astronauts fly to Mars before the end of the century? If they do, will they find life? Will astronauts make a flyby of Venus? What surprises will we find upon probing Jupiter and the other giant planets? Will men eventually leave the cradle of the earth and travel in all of the regions about the sun, as Tsiolkovsky once predicted?

The interest that you and other young people have in questions like the above indicates what this country will do in the way of exploring space in the future. Whatever course our country may follow, we cannot ignore the challenge that space offers. Man has opened all the windows upon the universe, and he is not likely to close them again.

REVIEW QUESTIONS

1. **Name the nine planets in order from the sun. Which planets belong to each of the two principal classes of planets?**
2. **Why is it difficult to study all of the planets from the earth?**

3. **What methods did astronomers use for studying the planets before the age of space travel began? What instruments did they use?**
4. **Which are the two planets closest to the earth? Why is each of special interest to scientists? What kind of information about each of these planets do scientists hope to obtain from their next probes?**
5. **What two planets are to be investigated next? What special interest does each of these planets have for scientists?**
6. **In what ways are the giant planets alike?**
7. **How are the Mariner, Viking, and TOPS different? What is the purpose of each spacecraft?**
8. **What are the Pioneer probes to be launched in 1972 and 1973 supposed to do?**
9. **What is meant by the Grand Tours? When will the opportunity for making such Grand Tours occur again?**
10. **What advantage is there in probing all of the planets instead of concentrating all effort on probes of the two neighboring planets?**

THINGS TO DO

1. Observe the planets in the heavens visible to the naked eye. Check a star chart to find out which planets will be visible during the month and their location. (Star charts appear regularly in *Natural History*, the journal of the American Museum of Natural History, and in *Sky and Telescope*.) Use a low-powered telescope for making your observations if one is available to you. Why do planets appear to move among the stars? Compare your observations in the telescope with those made by astronomers with the aid of high-powered telescopes. Report to the class on your findings.
2. Make a study of the relative size of the planets. Draw a chart to scale and arrange the planets in order according to size. Compare the diameters of all the planets. Determine the volume of the earth and of the four closest planets: Venus, Mars, Mercury, and Jupiter. For computing the volume of a sphere, use the following formula:

$$V = \frac{4\pi r^3}{3}$$

In the formula $\pi = 3.1416$ and $r =$ radius.

3. Study the relative distances of the planets from the sun. The solar system extends out about 3.6 billion miles from the sun, and the planets are small in relation to this vast distance. To help you understand the distances between the planets, draw the orbits of the planets to scale on the map of the world. Use Washington, D.C., or your home town to represent the position of the sun. Where will Mercury fall? Venus? the earth, etc.?
4. Develop a science project on Mars. Summarize the studies that astronomers had made of the planet before the age of space travel. Explain what the most recent probe of Mars has told us, and what we will try to find out from the next probe. Do you believe that scientists will or will not find life on Mars? Give reasons for your answer.

5. Develop a science project on Venus. Summarize the studies astronomers had made of the planet before the age of space travel. Explain what the most recent probe of Venus has told us, and what we will try to find out from the next probe. Describe the Soviet Venera probes and the most recent findings made. Why do you believe the Soviets are especially interested in probing Venus?

6. Develop a science project on Jupiter. Why is this planet of special interest to scientists? What kind of information might we expect to obtain from the Pioneer probes of this planet? What part will Jupiter have in the Grand Tours? Do you believe that the additional information we obtain about Jupiter will help us understand the planet earth better?

7. Report to the class on the Grand Tours, or the multiple probes of the outer planets. Use a diagram showing the relative position of the outer planets during the late 1970s to help you explain. Why will these probes be possible at that time? When will the opportunity for making such probes present itself again? Why are these three-in-one "tours" possible? What is meant by a gravity assist? How will the Grand Tours help us reach our objective for the exploration of the planets during the present decade? About how long will it take after launch before the first flyby is made on each Grand Tour? the last flyby? If information is available, tell the class something more about TOPS (Tour of the Outer Planets Spacecraft) and the booster that will be used to launch it.

SUGGESTIONS FOR FURTHER READING

BRAUN, WERNHER VON and ORDWAY, FREDRICK I., III. *History of Rocketry and Space Travel*. Rev. ed. New York: Thomas Y. Crowell Co., 1969.

CLARKE, ARTHUR C. *The Exploration of Space*. New York: Harper and Rowe Pub., 1959.

________. *Man and Space*. Life Science Library. New York: Time Inc., 1964.

GLASSTONE, SAMUEL. *Sourcebook on the Space Sciences*. Princeton, N.J.: D. Van Nostrand Co., 1965.

LEY, WILLY. *Mariner IV to Mars*. A Signet Science Library Book. New York: American Library, 1966.

MALONEY, TERRY. *Stars, Sun and Planets*. New York: Castle Books, 1960.

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

NAUGLE, JOHN E. *Unmanned Space Flight*. Holt Library of Science Series, Vol. III. New York: Holt, Rinehart, and Winston, 1965.

SAGAN, CARL. *Planets*. Liege Science Library Series. New York: Time Inc., 1966.

STERN, PHILLIP D. *Our Space Environment*. Holt Library of Science Series, Vol. IV. New York: Holt, Rinehart, and Winston, 1965.

TRINKLEIN, FREDERICK, and HUFFER, CHARLES M. *Modern Space Science*, 3d ed. New York: Holt, Rinehart and Winston, 1961.

WATSON, F. G. *Between the Planets*. Philadelphia: Blakiston Co., 1945.

WHIPPLE, FRED L. *Earth, Moon, and Planets*. 3d ed. Cambridge, Mass.: Harvard University Press, 1968.

Glossary

A

ablation—the process of carrying away heat by removing the substance that acquires heat, especially by letting the substance melt or vaporize.

Agena target vehicle—upper stage of the Atlas-Agena booster modified for use as a target for docking with the Gemini spacecraft.

airlock—a coupling device that provides a hermetically sealed passageway, allowing astronauts to transfer from one spacecraft to another under controlled pressure conditions.

alpha particles—high-speed, positively charged nuclear particles identical to the nucleus of a helium atom; used on the Surveyor to make chemical tests of lunar surface materials.

Apollo—US project for making a manned landing on the moon and a return trip to the earth.

Apollo Lunar Surface Experiments Package (ALSEP)—an instrument package that the Apollo astronauts placed on the moon.

Apollo Telescope Mount—a modified ascent stage of the Apollo lunar module equipped with a telescope; to be used for the Skylab.

Applications Technology Satellites (ATS)—satellites to be placed in a synchronous (stationary) orbit to investigate and flight-test technology for a number of different kinds of applications.

artificial gravity—simulated gravity produced within a space vehicle by centrifugal force generated by rotating the vehicle around its longitudinal axis.

artificial satellite—a manmade satellite, or body that revolves around the earth or another celestial body, as distinguished from a natural satellite of that body.

asteroid—any of thousands of small planetlike bodies that revolve about the sun between the orbits of Mars and Jupiter.

astronaut—a pilot who is selected and trained to ride in, and help to control the operation of, a space vehicle; the title was also given to a pilot who flew a rocket research aircraft to an altitude of 50 miles or more.

astronomical unit—a unit of length equal to the earth's mean distance from the sun's center (about 93 million miles).

astronomy—the science of the heavenly bodies and of their size, motions, and the materials of which they are composed.

atmosphere—the body of air that surrounds the earth or the body of gas that envelops or comprises any heavenly body.

B

basalt—a fine-grained gray to greenish-black igneous rock.

breccia—a rock consisting of sharp fragments of broken rock firmly embedded in fine-grained material.

C

cislunar space—space between the earth and the moon.

cleft—a crack, or fissure, in a sea, or lowland area, on the moon.

comet—a luminous and nebulous body of the solar system composed of a head with a hazy coma, and often having a gaseous tail.

command module—the module of the Apollo spacecraft that contains the guidance and navigation system, environmental control equipment, and the main communication equipment; it is the reentry capsule.

Comsat—Communications Satellite Corporation, a part Government and part commercial organization for launching and maintaining communication satellites.

corona—a circle or crown (usually colored) seen around the sun, moon, or other luminous body.

crater—the depression caused by the impact of a meteorite or the depression around the opening of a volcano.

D

Deep Space Network—the NASA communication and tracking network for spacecraft traveling in the vicinity of the moon and beyond; to be extended to allow for communication throughout the solar system.

docking—procedure for coupling, or joining, one orbiting object with another.

E

Early Apollo Scientific Experiments Package (EASEP)—experiment package placed on the moon by the first moon-landers (Apollo-11 flight).

Earth Resources Technology Satellites (ERTS)—a series of spacecraft for conducting a variety of experiments for studying earth resources for such purposes as agriculture, oceanography, and forestry, and for developing a ground system for handling data.

extravehicular activity (EVA)—activity taking place outside the spacecraft (in open space or on the moon) with the astronaut relying on his space suit for life support and protection.

G

Gemini—second US project for manned spaceflight; program consisting of flights lasting up to two weeks and practice of extravehicular activity, rendezvous, and docking.

geology—a study of the history or of the life of the earth or other heavenly body (moon) made especially from the rocks or from other solid matter.

gibbous—pertaining to a phase of the moon (or planet) when it is seen with more than half but not all of the visible disk lighted.

Grand Tour—name given to any of a series of multiple probes of the outer planets to be made late in the 1970s.

gravitation—the mutual attraction between masses which is directly proportional to the product of the masses and inversely proportional to the square of the distance between them.

gravity assist—a boost in the velocity of a spacecraft produced by swinging it around a massive body (planet).

greenhouse effect—effect produced by heat from the sun absorbed by water and earth (surface of a planet) and later reflected to heat the atmosphere.

I

igneous rock—rock formed by the solidification of magma, or molten material.

infrared radiation—electromagnetic radiation consisting of waves found between the red end of the visible spectrum and waves used in radar.

Intelsat—International Telecommunications Satellite Consortium, an extension of the US Communications Satellite Corporation to give international service.

International Geophysical Year (IGY)—a period, beginning 1 July 1957 and ending 31 December 1958, during which the scientists of some 55 nations cooperated in advancing scientific knowledge about the earth and the effects of the sun on the earth's environment.

interplanetary space—that part of space viewed from the standpoint of the earth as having its limits just beyond the orbit of the moon and extending inward to the sun and outward to the orbit of Pluto.

ionosphere detector—an instrument for sensing the presence of an atmosphere with charged particles.

L

laser (light amplification by stimulated emission of radiation)—a device that amplifies a beam of light by using high-energy atoms.

Launch Complex 39—the large complex of facilities at Cape Kennedy, Florida, where the complete Apollo spacecraft is assembled and launched.

libration—slight oscillation, or swinging back and forth, of the apparent aspect of a satellite (moon) as viewed from the parent body (earth).

lunar module—the module of the Apollo spacecraft designed to separate from the combined command and service modules and land on the moon.

lunar orbit rendezvous (LOR)—method for reaching the moon by assembling modules in lunar orbit and making the descent to the moon from this orbit.

Lunar Orbiter—any of a series of unmanned spacecraft that orbited the moon for the purpose of obtaining more information about the nature of the moon and photographic coverage for more complete and accurate mapping.

Lunar Receiving Laboratory—special laboratory at the Manned Spacecraft Center at Houston, Texas where the rock and soil samples from the moon are received and where the astronauts were quarantined.

lunar roving vehicle (LRV)—a powered jeeplike vehicle scheduled for use by the astronauts in traversing the moon during Apollo 15, 16, and 17.

M

magnetic field—any space or region near a magnetic body or one carrying a current in which the force due to the body or current can be detected.

magnetic tail of the earth—a cometlike tail, made up of trapped particles, which extends out from the night side of the earth to a distance of about 3.5 million miles.

magnetometer—an instrument for measuring the intensity of a magnetic field.

magnetosphere—the region of space surrounding the earth that is influenced by the earth's magnetic field.

Manned Spacecraft Center—communication and control center for US manned spaceflights; located at Houston, Texas.

mare—a sea, or lowland area, on the moon or Mars (plural, maria).

Mariner—any of a series of unmanned spacecraft designed to probe the planets and their environment.

mascons—mass concentrations of matter discovered to exist in the large circular seas on the moon; nature and cause of the concentrations unknown.

Mercury—first US project for manned spaceflight; objective was to place a man in orbit around the earth.

meteor—a body from outer space that enters the earth's atmosphere with such velocity as to become incandescent and appear as a shooting "star."

meteorite—one of the countless small bodies encountered by a satellite probe or a metallic or stony body fallen to earth from outer space.

meteoroid—one of the countless small bodies existing in space outside the earth's atmosphere, known as a meteorite after it comes into contact with a spacecraft or survives descent through the atmosphere to the earth.

Modularized Equipment Transporter (MET)—hand cart used by the Apollo astronauts.

P

Pioneer—any one of a number of satellites designed primarily to explore interplanetary space.

planet—a body (excluding comets, meteors, and satellites) that revolves around the sun or other star.

Portable Life Support System (PLSS)—self-contained life-support system used by Apollo astronauts during moon walks.

R

radio telescope—a radio receiver-antenna combination for detecting radio waves sent out by heavenly bodies or by space probes.

radioactive dating—method of determining the age of lunar rock samples by finding out the proportion of certain radioactive elements in the rock to their products of decay, thus establishing the time period during which the radioactive change has taken place.

Ranger—any of a series of unmanned spacecraft that photographed the moon and telemetered the pictures to the earth before making a hard landing on the moon.

rays—long, light-colored streaks that radiate from relatively new lunar craters during the full moon; believed to be rays of light but cause unknown.

rendezvous—the meeting of two or more objects in space at a previously planned time and place.

rill—a crack, or fissure, in the valley of a mountain on the moon.

S

Saturn IB—booster used for the early earth-orbit flights of the Apollo spacecraft; also known as the Uprated Saturn I.

Saturn V—gigantic booster for the Apollo moon craft.

Saturn Workshop—laboratory built from the empty casing of the third stage of the Saturn V for use with the Skylab.

seismometer—a highly sensitive instrument for measuring the actual movements of the earth's crust or of the surface of the moon.

selenology—a branch of astronomy that deals with the study of the moon.

service module—the cylindrical module of the Apollo spacecraft that contains the service supplies and the large rocket engine for providing power to boost velocity and make midcourse corrections.

Skylab—a flight configuration consisting of the Apollo Telescope Mount, the Docking Adapter, the Airlock Module, and the Saturn Workshop, together with the docked Apollo command and service modules modified for the program; also the name given to the project for launching the flight configuration.

solar cell—a cell that converts sunlight into electrical energy.

solar system—the sun with the group of celestial bodies that are held by its attraction and revolve around it.

solar wind—a thin, ionized gas flowing continuously outward in all directions from the sun.

space capsule—a capsule for carrying out an operation or experiment in space.

space shuttle—a reusable space vehicle being designed with an orbiter and a booster component for use in making flights between the earth and space.

space station—a large satellite that can support life, permitting men to live and work in it continuously or at intervals.

space tug—a reusable space vehicle being designed for carrying loads in space.

spectrograph—a device for breaking up radiation into the component waves of the color spectrum and then photographing the spectrum to permit analysis.

spinoff—a byproduct of space research and development.

Sputnik—any of the series of the first Soviet artificial satellites; also, the Russian term for artificial satellite.

star—a gaseous heavenly body of great mass that shines by its own light (the sun), as distinguished from the planets, which shine by reflected light.

stereo-panoramic television camera—a television camera designed for showing three dimensions and giving an unobstructed view of a region.

Surveyor—any of a series of unmanned spacecraft that made a soft landing on the moon and sent back detailed photographs of prospective landing sites and information about the nature of surface materials.

T

telemetering—transmission of physical data and presentation of the data at a distance from their source.

telescope—an instrument for viewing distant objects by the reflection or refraction of light rays (optical telescope) or by receiving radio waves from the object (radio telescope).

Tour of the Outer Planets Spacecraft (TOPS)—a spacecraft being designed for making the Grand Tours.

tracking—observing and plotting the movement of a rocket or satellite by means of radar, radio, or cameras.

U

ultraviolet radiation—electromagnetic radiation shorter in wave length than visible radiation but longer than X-rays.

V

Van Allen radiation belts—zones of intense ionized radiation surrounding the earth.

Vanguard—any of an early series of three artificial satellites launched by the United States.

Vertical Assembly Building (VAB)—the 525-foot-high building at Cape Kennedy, Florida, where the Apollo spacecraft is assembled and mated with the Saturn V booster.

Viking—the combined orbiter-lander designed for probing Mars and determining whether life exists there.

volcano—a vent in the earth's crust from which molten or hot rock and steam issue.

vulcanism—volcanic power or action.

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