The third stage's single J-2 engine ignites at separation and burns for about 2 minutes to increase speed to about 16,500 miles an hour and put it and the Apollo spacecraft into a near-circular earth orbit at about 115 statute miles.

During ascent, the crew monitors the launch vehicle displays to be prepared for an abort, if necessary; relays information about boost and the spacecraft to the ground; and monitors critical subsystem displays.

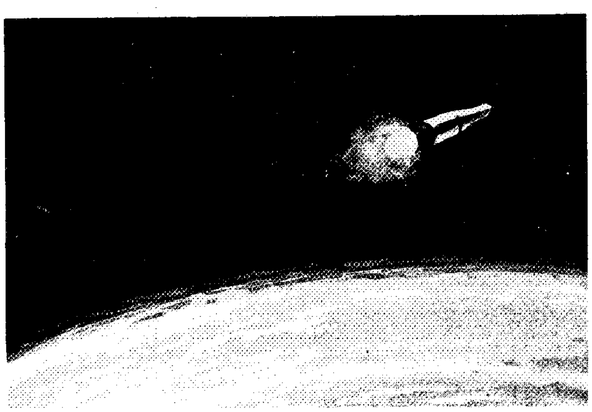
## EARTH PARKING ORBIT

The spacecraft is inserted into an earth parking orbit to permit checkout of subsystems before it is committed to lunar flight, and to allow for more than one opportunity for translunar injection (instead of a single one in a direct launch).

The mission allows the spacecraft, with the third stage attached, to orbit the earth up to three times (for 4-1/2 hours) before injection into translunar flight. Because injection is desirable as soon as possible after checkout, the translunar injection maneuver probably will be performed during the second orbit. To inject the spacecraft into translunar flight, the crew reignites the third-stage engine.

## TRANSLUNAR INJECTION

The translunar injection parameters are computed with the guidance system in the Saturn V's third-stage instrumentation unit. Thus, the third stage is commanded to fire at the proper moment and for the precise length of time necessary to put the spacecraft into a trajectory toward the moon.



P-19

*Third stage fires again for translunar injection*

This trajectory is nominally one that provides a "free return" to earth; that is, if for any reason the spacecraft is not inserted into an orbit around the moon, the spacecraft will return to earth.

The third-stage engine burns for about 5-1/2 minutes and cuts off at an altitude of about 190 miles and at a velocity of about 24,300 statute miles an hour.

During the engine thrusting, the crewmen remain in their couches and monitor the main display console.

## INITIAL TRANSLUNAR COAST

The manned space flight network tracks the spacecraft for about 10 minutes after third-stage engine cutoff to determine whether to proceed with transposition and docking. During the same period, the third stage maneuvers the spacecraft to the attitude programmed for the transposition, docking, and LM-withdrawal maneuvers.

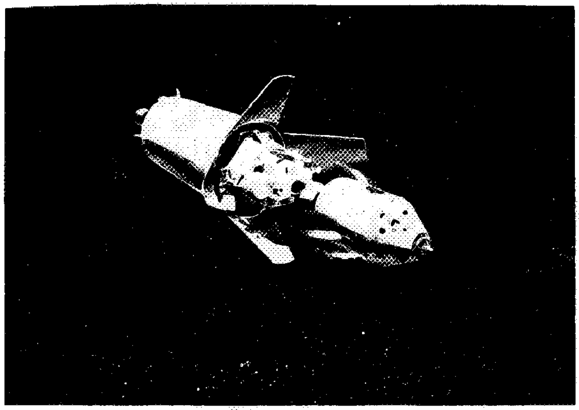
The crewmen position their couches to see out of the docking windows. The commander begins the transposition and docking maneuver by firing the service module reaction control engines. A signal is sent almost simultaneously to deploy and jettison the SLA panels, separate the CSM from the SLA, and deploy the CSM's high-gain antenna. The lunar module remains attached to the adapter.

The commander stops the CSM 50 to 75 feet away from the third stage, turns 180 degrees with a pitch maneuver so the docking windows are facing the LM, rolls the CSM for proper alignment with the LM, closes with the LM, and docks.

After the CSM and LM have docked, the pressure between the CM and the LM is equalized and the CM forward hatch is removed. A check is made to determine that all docking latches are engaged, the CSM-LM electrical umbilicals are connected, and the CM forward hatch is reinstalled. The LM's four connections to the SLA are severed by small explosive charges, and the spacecraft is separated from the SLA and third stage by spring thrusters.

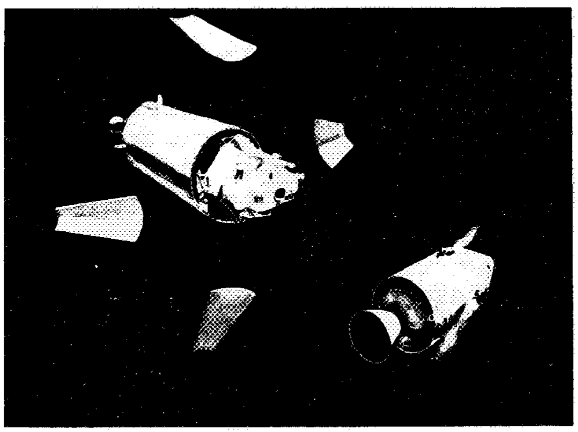
## TRANSLUNAR COAST

Now the long journey to the moon begins. It has been three to six hours since liftoff from Kennedy Space Center, depending on the number of earth



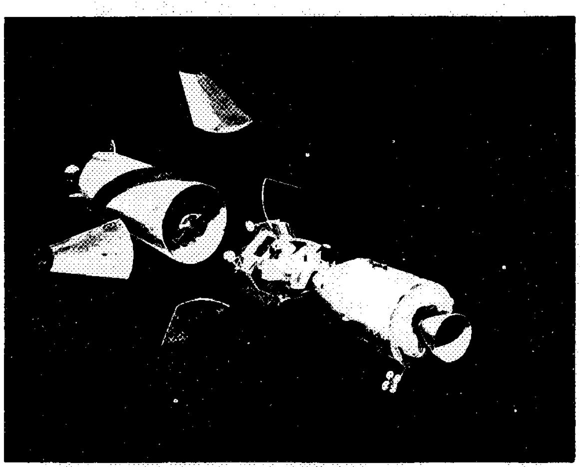
P-20

*SLA panels jettison and the CSM pulls away*



P-21

*Commander turns CSM around for docking maneuver*



P-22

*After docking, spring thrusters separate two craft*

parking orbits, and the crew settles down for the 2-1/2- to 3-1/2-day flight.

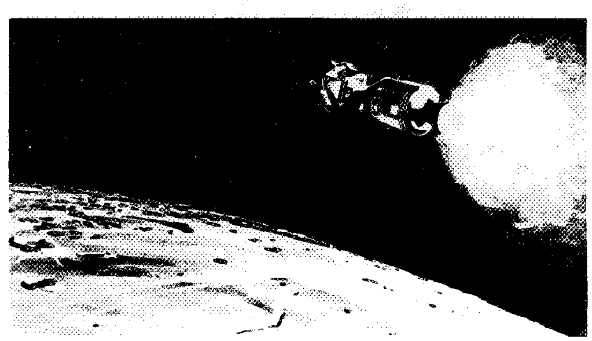
In this phase of the flight, the spacecraft is coasting. At the time of injection into the translunar trajectory, the spacecraft is traveling almost 24,300 miles per hour with respect to the earth. It begins slowing almost immediately because of the pull of earth's gravity. The speed drops until the spacecraft enters the moon's sphere of influence where it again increases due to the moon's gravitational pull.

Shortly after the coast period begins, the spacecraft is oriented for navigation sightings of stars and earth landmarks. The spacecraft is then put into a slow roll (about 2 revolutions an hour) to provide uniform solar heating. This thermal control rolling is stopped for inertial measurement unit alignment and for course corrections.

If tracking from the ground indicates a course correction is needed during the translunar coast, the correction is made with the service propulsion engine when a large change is indicated or with the SM reaction control engines when the change required is small.

The crew has a number of subsystem duties. Electrical power and environmental control subsystem status checks are conducted. The service propulsion and SM reaction control subsystems are checked. Hydrogen and oxygen purges of the fuel cells are conducted, the lithium hydroxide canisters exchanged and communication with the ground is maintained.

The three astronauts eat in shifts but sleep at the same time. The ground monitors the spacecraft performance continuously and can awaken the crew. Biomedical data is sent to the ground continuously.



P-23

*Engine retro-fires to put spacecraft in lunar orbit*

## LUNAR ORBIT INSERTION

Insertion of the spacecraft into lunar orbit is essentially a braking maneuver in which the spacecraft is transferred from the ellipse of the lunar approach to an orbit around the moon.

The insertion maneuver involves the longest firing of the service propulsion engine and results in a reduction in the craft's velocity with respect to the moon from about 5600 to 3600 miles per hour. The insertion may be a two-stage firing of the service propulsion engine, the first to put the CSM in an elliptical orbit of approximately 70-by-195 statute miles and the second to put the CSM in a circular orbit of about 70 miles. The precise timing of the firing and the exact length of the burn or burns are determined by the Mission Control Center in Houston and are programmed into the CM computer, which automatically fires the engine.

During the firing the spacecraft is out of communication with the ground since it will be passing behind the moon. Communications, which require line-of-sight to earth, are lost for about 45 minutes on each 2-hour lunar orbit.

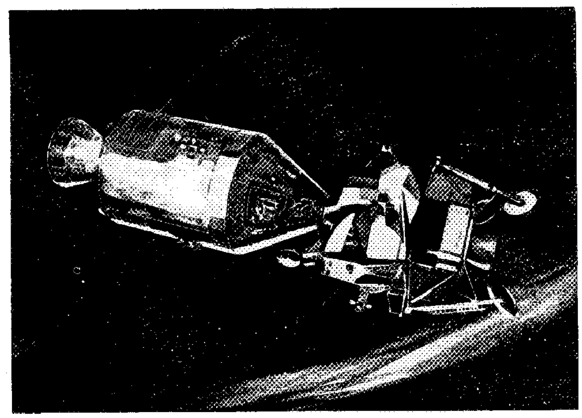
During the maneuver, the crew monitors the display of the velocity change required, the digital event timer, the flight director attitude indicators, and subsystem status displays.

## LUNAR ORBIT COAST

The docked CSM and LM orbit the moon until the LM is checked out for descent to the lunar surface. During this time coarse and fine alignments are made of the CSM inertial measurement unit, as is a series of sightings of landmarks on the lunar surface. These operations, each involving changes in spacecraft attitude, are compared with tracking data from the manned space flight network to determine the spacecraft's precise location in orbit with respect to the landing site on the moon.

The CM-LM tunnel and the LM are pressurized, and the CM hatch, the probe, and drogue are removed. The LM hatch is opened to clear the way into the LM. First to transfer to the LM is the LM pilot, who activates the LM's environmental control, electrical power and communications subsystems.

After the commander has transferred to the LM, he and the LM pilot perform a lengthy series of checks

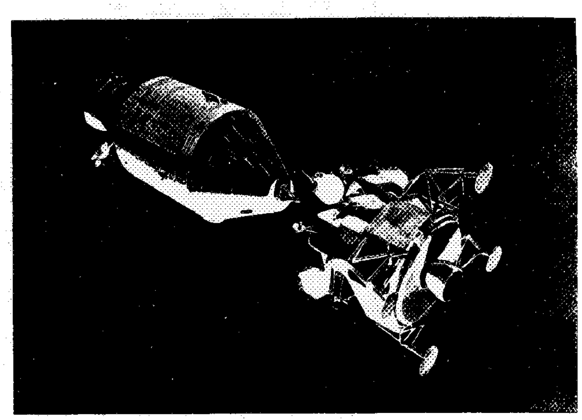


P-24

*Two crewmen transfer to LM to prepare for separation*

of the LM subsystems. While they do this, the CM pilot is performing another series of alignments and landmark sightings. The CM controls the attitude of the spacecraft during the lunar orbits and during the coarse alignments of the LM inertial measurement unit. (The fine aligning of the LM inertial measurement unit is done after the CSM and LM have separated.)

The probe and drogue are installed, the 12 docking latches are unlatched, the LM hatch is closed, the CM hatch is installed, the LM landing gear is deployed, and guidance computations are made in the final minutes before separation. Then the CM pilot activates the probe extend/release switch which undocks the LM from the CSM. The LM reaction control system moves the LM away from the CSM a short distance and is oriented so the CM pilot can inspect the LM landing gear. The LM's reaction control system then fires again to separate further the LM and CSM.



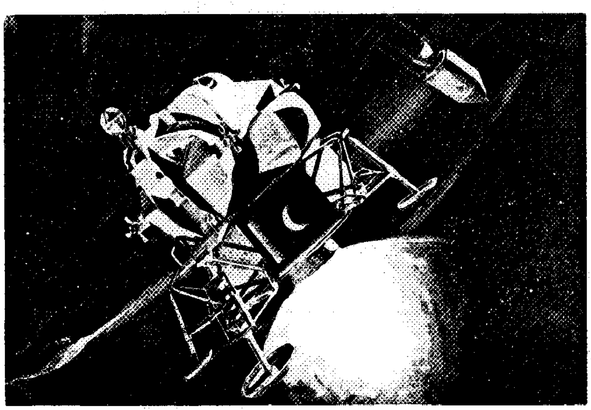
P-25

*LM with two men separates from CSM*

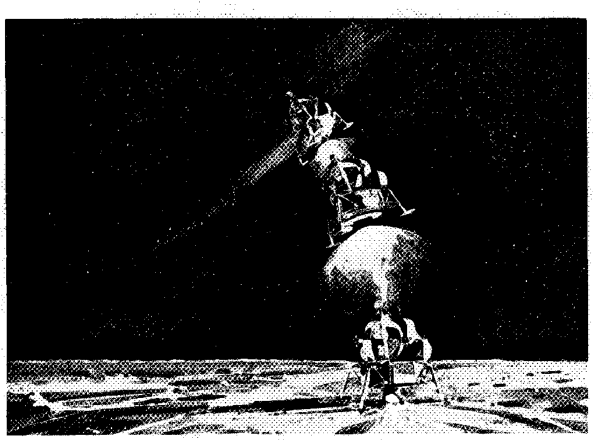
## CSM LUNAR ORBIT

The CSM remains in the 70-mile lunar orbit for about a day and a half, until the LM returns from its moon landing. The CM pilot has many duties during this time and is particularly busy during two periods: LM descent to the moon and LM ascent to rendezvous and docking. His principal jobs during these periods are to monitor the performance of the LM (requiring changes in CSM attitude to keep it in sight), communicate with the LM and with earth, and activate or operate equipment to aid in both the landing and the rendezvous and docking procedures. The CM pilot will have a period to sleep while the LM is on the lunar surface.

After separation, the CSM and LM pass behind the moon, and communications with earth are cut off. During this period, the LM telemeters its data to the CSM, where it is stored and relayed to earth after the CSM emerges from behind the moon.



P-26 *LM descends and CSM stays in orbit*



P-27 *LM's descent engine fires as craft comes in for landing*

## LM DESCENT

The descent to the moon takes an hour of complex maneuvering that taxes the skills of the astronauts and the capabilities of the lunar module.

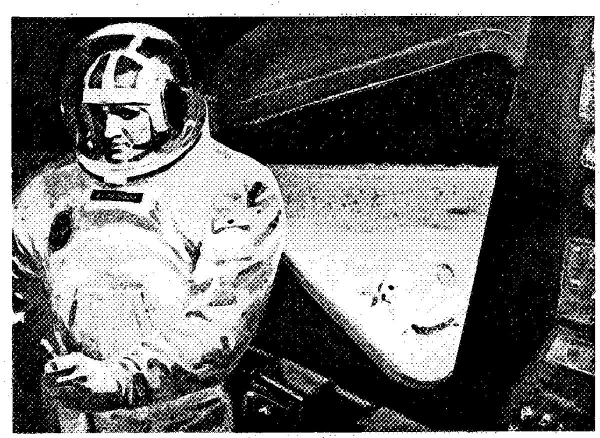
Briefly, the descent will follow this course. The LM fires its descent engine to put it into an elliptical orbit that reaches from about 70 miles to within 50,000 feet of the moon's surface. Near the 50,000 foot altitude at a preselected surface range from the landing site, the engine is fired again in a braking maneuver to reduce the module's speed.

The LM's two-man crew is busy with position and velocity checks, subsystem checks, landing radar test, attitude maneuvering, and preparation of the LM computer or the braking maneuver.

The final approach begins at approximately 9000 feet altitude with a maneuver to bring the landing site into the view of the LM crew. The firing is controlled automatically until the craft reaches an altitude of about 500 feet. When the commander takes over, the LM is pitched at an angle which permits the crewmen to assess the landing site. At about 65 feet altitude, the LM is re-oriented and descends vertically to the surface at about 3 feet per second. The commander shuts off the descent engine as soon as the landing gear touches the moon.

## LUNAR STAY

It will be about 4-1/2 hours after landing before the first American steps foot on the moon. Upon landing, the commander and LM pilot first spend



P-28 *One astronaut checks LM, other stays inside at first*

P-29
*Two astronauts set up scientific equipment on moon*

about two hours checking out the LM ascent stage. Any remaining propellant for the descent engine is vented and the inertial measurement unit is aligned and placed in standby operation. It takes 2 hours for the extravehicular mobility units to be checked out and prepared for use.

Finally, the LM cabin is depressurized, and one of the LM crewmen emerges from the lunar module, descends its ladder, and walks on the moon. He remains alone on the lunar surface for about 20 minutes while he gathers a sample of surface material and transfers it to the crewman in the ascent stage, who has been recording this activity on still and motion picture film.

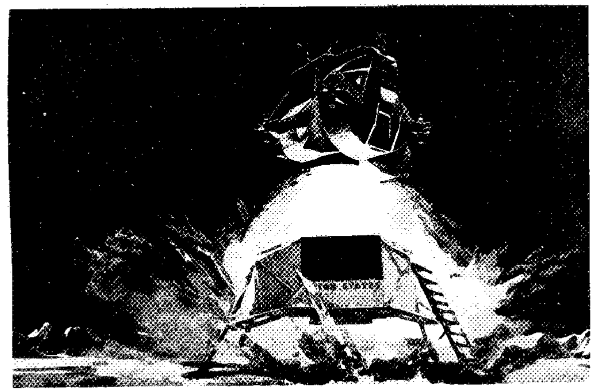
Following a period of equipment transfer between the astronaut in LM cabin, and the astronaut on the lunar surface, the second crewman descends to the surface and the two inspect the LM to determine the effects of the lunar touchdown on the vehicle. The rest of the time in the first surface excursion is consumed by erecting the S-band surface antenna, collecting a preliminary set of geological samples, and making a TV scan of the landing site.

A second lunar exploration period lasts about three hours, with both astronauts on the surface. They have many tasks to perform, including sample collections, photography, exploration of the lunar surface up to about a quarter-mile from the LM, and erection of a station that will continue to send scientific data to earth after the astronauts leave.

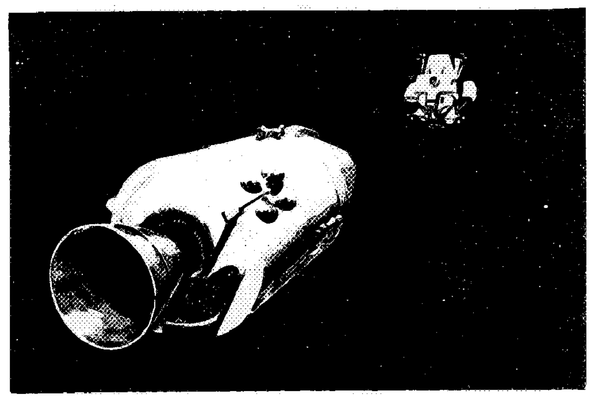
Between the two exploratory periods, the astronauts will have a sleep period. Then, after about 24 to 26 hours on the moon, the astronauts prepare for their return to the CSM.

## LM ASCENT

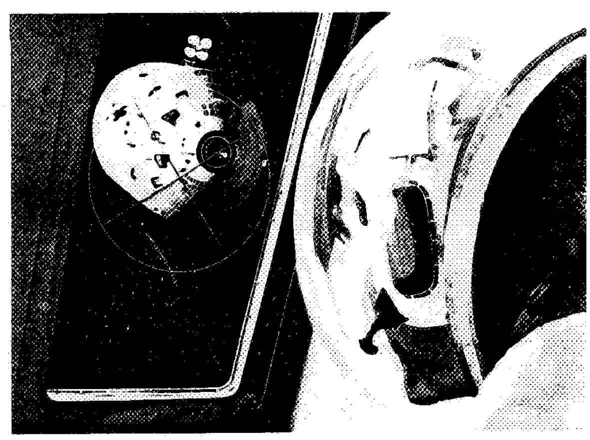
Ascent of the LM from the moon and rendezvous and docking with the orbiting CSM takes three hours.



P-30
*Astronaut fires ascent stage engine to leave moon*



P-31
*LM's ascent stage in rendezvous with orbiting CSM*



P-32
*Commander in LM guides craft to docking with CSM*

When the ascent engine ignites, the ascent stage of the LM separates from the descent stage, using the latter as a launching platform. The engine boosts the ascent stage off the moon into an elliptical orbit of an estimated 60,000 feet by about 11.4 by 34.5 miles.

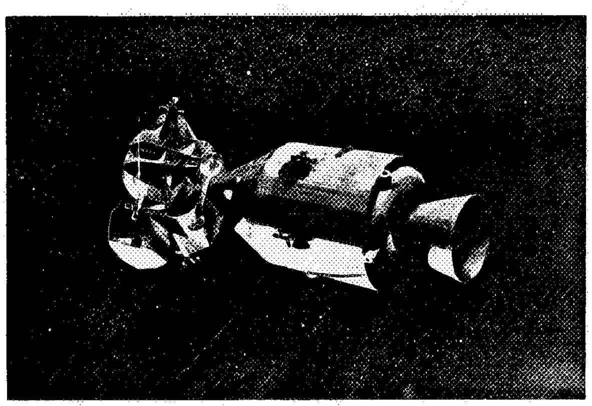
The next maneuver places the LM in a circular orbit which has a constant altitude distance from that of the CSM. When the LM's orbit is in the proper phase with the CSM orbit, the LM reaction control engines are fired to raise the LM orbit to that of the CSM, about 70 miles. During these maneuvers the CM pilot tracks the LM.

The LM takes about 30 minutes to intercept the CSM, during which course corrections are made with the reaction control engines. The firings are controlled by the LM computer on the basis of data supplied by the ground. The LM closes on the CSM through a series of short reaction control engine firings. The commander takes over control of the LM and maneuvers it with short bursts of the reaction control engines to a docking with the CSM.

## LUNAR ORBIT COAST

After docking, the spacecraft coasts in lunar orbit while the crew transfers equipment and samples into the CSM, returns to the CSM, jettisons the LM ascent stage, and prepares for transearth injection.

The LM crew opens the LM hatch after the CSM and LM pressures have been equalized and the CM pilot removes the CM tunnel hatch. The drogue and probe are removed and stowed in the LM. Lunar samples, film, and equipment to be returned to earth are transferred from the LM to the CM; equipment in the CM that is no longer needed is put into the LM and the LM hatch is closed, the CM hatch is replaced, and the seal checked.

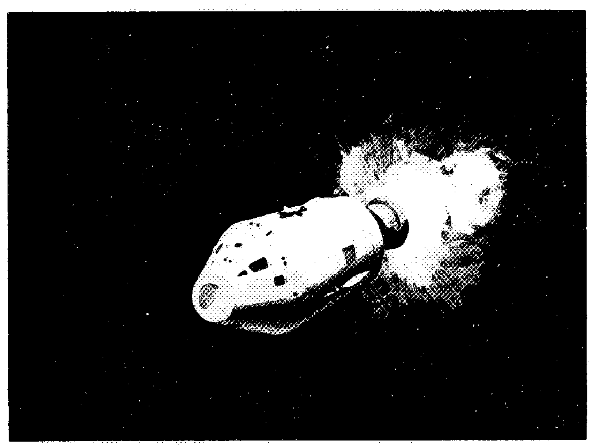


P-33 *Astronauts return to CM, prepare to jettison LM*

The LM is jettisoned by firing small charges around the CM docking ring. The entire docking mechanism separates from the CM and remains with the LM ascent stage. The SM reaction control engines are fired in a short burst to assure separation and to put the CSM into the lead in the orbit.

## TRANSEARTH INJECTION

The service propulsion engine injects the CSM into a trajectory for return to earth. The engine fires for about 2-1/2 minutes to increase the spacecraft's velocity relative to the moon from about 3600 to nearly 5500 miles per hour. This maneuver takes place behind the moon, out of communications with earth. Communication is regained about 20 minutes after the engine has cut off.

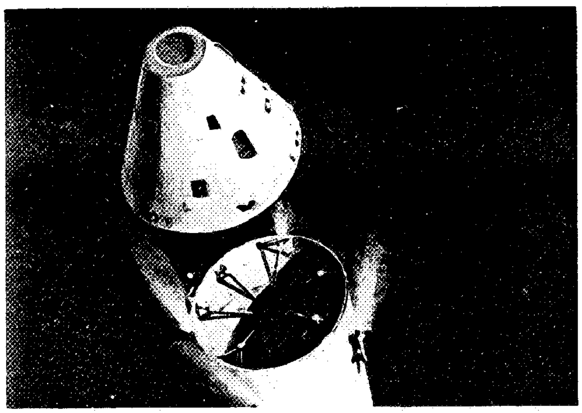


P-34 *After jettisoning LM, the CSM heads for earth*

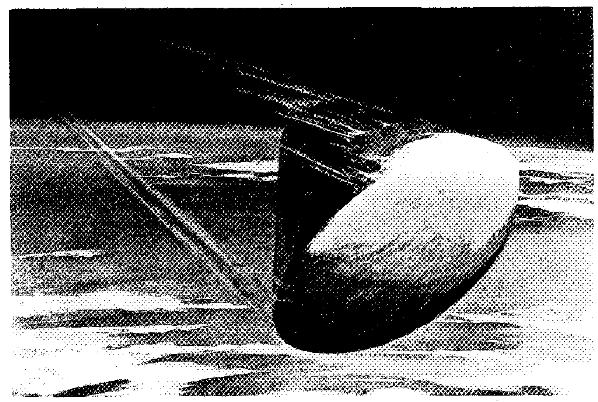
## TRANSEARTH COAST

The trip from lunar orbit back to the earth's atmosphere could be the longest phase of the mission, lasting anywhere from 80 to 110 hours. The spacecraft's velocity on the coast back gradually decreases because of the moon's gravitational pull and then increases again when the spacecraft comes into the earth's sphere of influence. When the spacecraft enters the atmosphere, its velocity has increased to about 25,000 miles per hour.

Crew duties during the homeward coast are similar to those of the outbound journey. The spacecraft is again in a slow roll for thermal control. Crewmen make any necessary course corrections, maneuver



P-35
*Shortly before entry, the CM separates from SM*



P-37
*Aft heat shield chars to absorb 5,000-degree heat*

the spacecraft for inertial measurement unit alignments and regularly check subsystems.

About three and a half hours before entry, the CSM is rotated and held in an attitude that puts the forward heat shield of the CM in shadow. This cooling of the shield lasts for about an hour and a half, after which the attitude must be changed for the final course correction.

Shortly before entry into the earth's atmosphere, the service module is jettisoned. The CM and SM are separated by small explosive devices in the SM. The SM reaction control engines fire simultaneously to increase separation and assure that the two modules will not collide.

## ENTRY

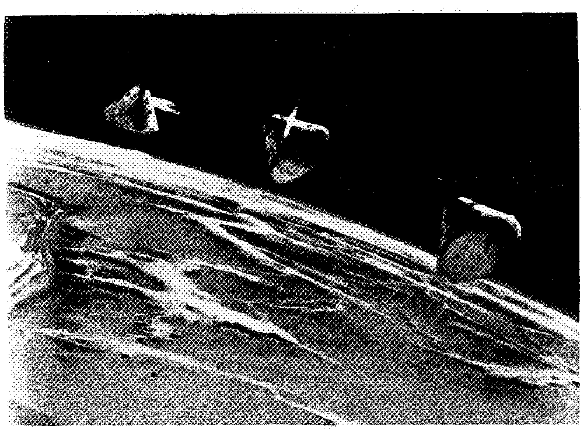
The desired entry conditions include the arrival of the CSM at a particular point above earth at a particular time and with a proper flight path angle, neither too steep nor too shallow.

Entry is considered to begin at an altitude of about 400,000 feet, when the CM begins to meet the resistance of the atmosphere. At this point the CM is traveling about 24,500 miles an hour, and the heat generated on its plunge through the atmosphere may reach 5000 degrees Fahrenheit on the blunt aft heat shield.

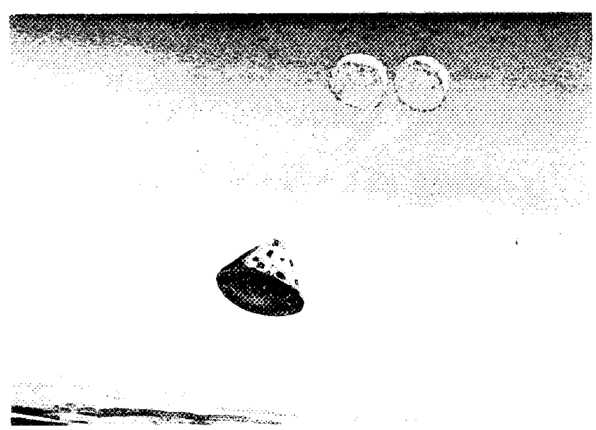
But despite the heat generated on the outside of the CM, its cabin will remain at 80 degrees. The maximum gravitational forces felt by the astronauts will be a little over 5 G's.

## LANDING

The landing is controlled automatically by the earth landing subsystem, although the crew has



P-36
*CM is oriented blunt end forward for entry*

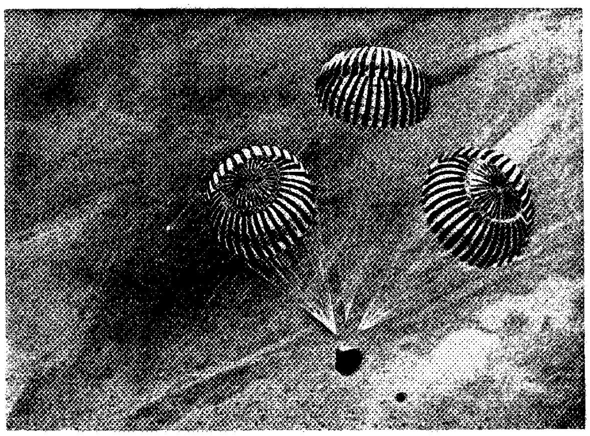


P-38
*Drogue chutes open to provide initial slowing*

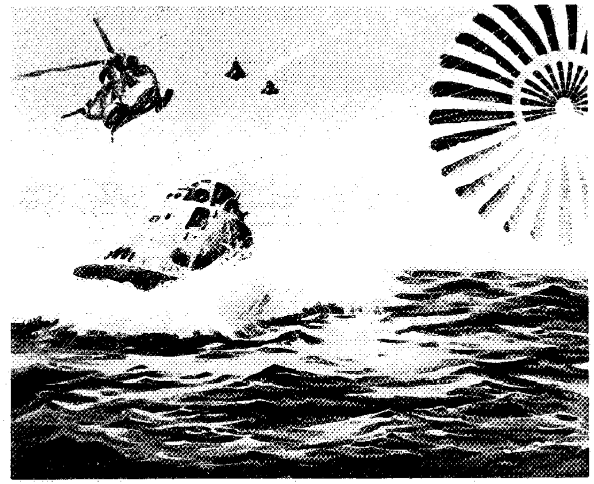
backup controls. At about 24,000 feet, a barometric switch closes to start the subsystem in operation.

The forward heat shield is jettisoned to permit deployment of parachutes, and the drogue parachutes are immediately released. They are deployed reefed (half closed) and open after a few seconds. The drogues orient the CM for main parachute deployment and reduce the CM's speed from an estimated 325 to 125 miles an hour.

At an altitude of about 10,700 feet the drogues are disconnected and the pilot parachutes are deployed. They pull out the main parachutes. The main parachutes are double reefed, which means they open in two stages. They further slow the CM, and final descent and splashdown is made at about 22 miles an hour.



P-39
*CM drifts gently to splashdown on main chutes*



P-40
*Recovery helicopters move in as CM floats in water*

As soon as the main parachutes are disreefed, the crewmen start burning the remaining reaction control propellant, activate the VHF recovery beacon, adjust their couches for landing, and purge the propellant lines. Final descent on the main parachutes takes about 5 minutes.

In addition to the recovery beacon deployed by the crew, two VHF antennas are deployed automatically shortly after the main parachutes are deployed. These provide voice communication with the recovery forces. The recovery beacon transmits a continuous signal.

The main parachutes are released by the crew at splashdown and postlanding ventilation is turned on.

# THE MOON

The landing of Apollo astronauts, and their return to earth with lunar soil samples, will help solve some of the mysteries of the moon. What is known about the moon, from centuries of astronomical observation and from the recent space mission, is this:

Terrain—Mountainous and crater-pitted, the former rising thousands of feet and the latter ranging from a few inches to 180 miles in diameter. The craters are thought to be formed by the impact of meteorites. The surface is covered with a layer of fine-grained material resembling silt or sand, as well as small rocks.

Environment—No air, no wind, and no moisture. The temperature ranges from 250 degrees in the two-week lunar day to 280 degrees below zero in the two-week lunar night. Gravity is one-sixth that of earth. Micrometeoroids pelt the moon (there is no atmosphere to burn them up). Radiation might present a problem during periods of unusual solar activity.

Dark Side—The dark or hidden side of the moon no longer is a mystery. It was first photographed by a Russian craft and since then has been photographed many times, particularly by NASA's Lunar Orbiter spacecraft.

Origin—There is still no agreement among scientists on the origin of the moon. The three theories: (1) the moon once was part of earth and split off into its own orbit, (2) it evolved as a separate body at the same time as earth, and (3) it formed elsewhere in space and wandered until it was captured by earth's gravitational field.

**Physical Facts**

| | |
|---|---|
| Diameter | 2,160 miles (about 1/4 that of earth) |
| Circumference | 6,790 miles (about 1/4 that of earth) |
| Distance from earth | 238,857 miles (mean; 221,463 minimum to 252,710 maximum) |
| Surface temperature | 250 (sun at zenith) -280 (night) |
| Surface gravity | 1/6 that of earth |
| Mass | 1/100th that of earth |
| Volume | 1/50th that of earth |
| Lunar day and night | 14 earth days each |
| Mean velocity in orbit | 2,287 miles per hour |
| Escape velocity | 1.48 miles per second |
| Month (period of rotation around earth) | 27 days, 7 hours, 43 minutes |

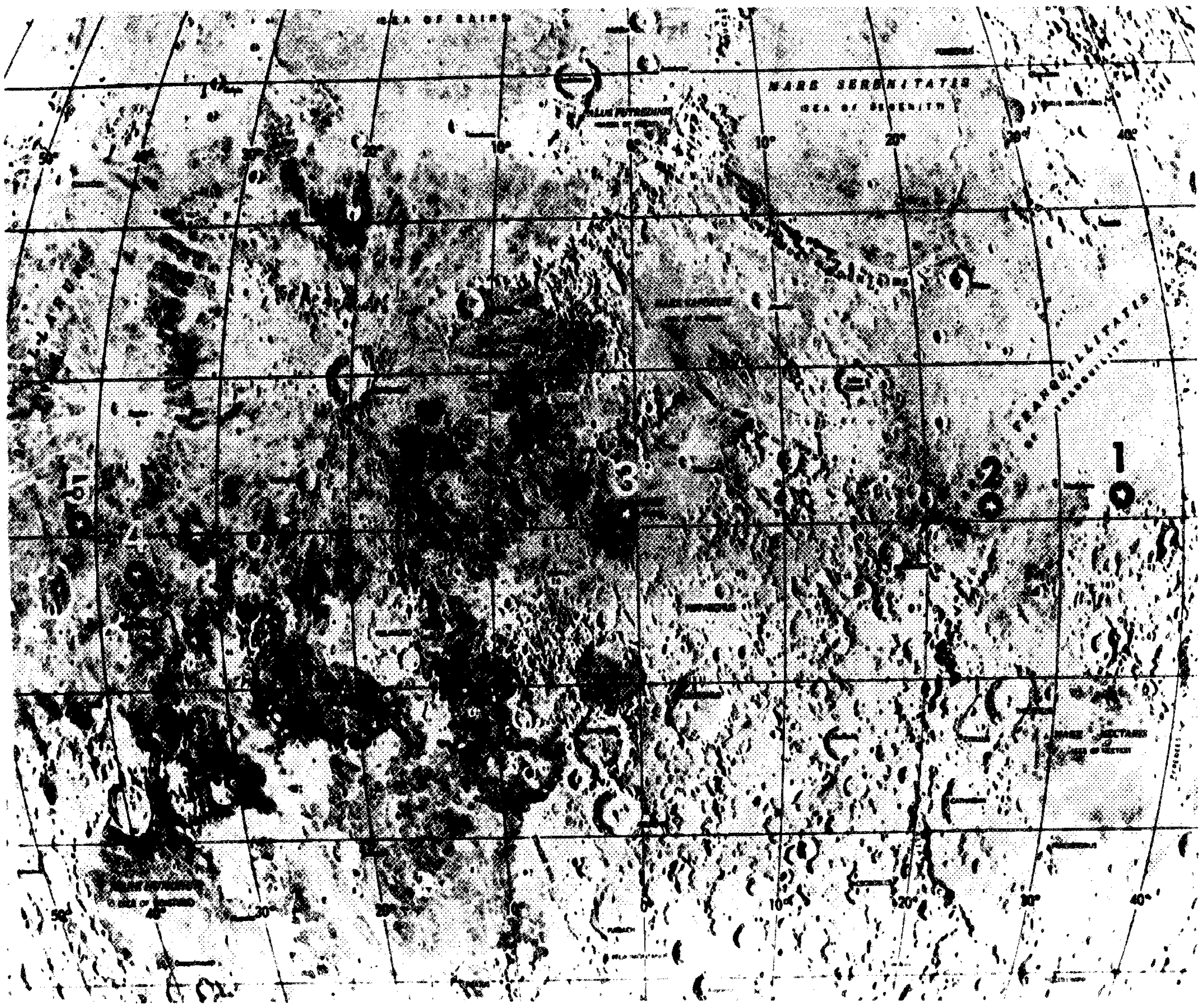
Possible landing sites for Apollo's lunar module have been under study by NASA's Apollo Site Selection Board for about two years. Thirty sites originally were considered, and these were later narrowed down to eight.

Selection of the final five sites was based on high-resolution photographs returned by Lunar Orbiter, plus close-up photos and surface data provided by Surveyor.

All of the original sites were on the visible side of the moon within 45 degrees east and west of the center of the moon and 5 degrees north and south of its equator.

The final five choices were based on these factors:

- Smoothness (relatively few craters and boulders)
- Approach (no large hills, high cliffs, or deep craters that could cause incorrect altitude signals to the landing radar)
- Propellant (selected sites allow the least expenditure of propellant)




P-41

*The five Apollo moon landing sites*

- Recycling (selected sites allow for necessary recycling time if the Apollo/Saturn countdown is delayed)
- Free return (sites are within reach of the spacecraft in a free-return trajectory)
- Slope (there is little slope—less than 2 degrees—in the landing area and approach path)

Three of the five sites will be chosen for a specific lunar landing mission so that a three-day period each month will be available for the launch.

The Apollo lunar landing sites:

| No. | Coordinates | Location |
|---|---|---|
| 1 | 34° E, 2 40'N | Sea of Tranquility |
| 2 | 23°37'E, 0°45'N | Sea of Tranquility |
| 3 | 1°20'W, 0°25'N | Central Bay |
| 4 | 36°25'W, 3°30'S | Ocean of Storms |
| 5 | 41°40'W, 1° 40'N | Ocean of Storms |

# MANNED SPACE PROGRAM

The United States manned space program has been conducted in three major phases—Mercury, Gemini, and Apollo. Each manned flight has led to increased knowledge of the systems and techniques needed to operate successfully in space, and each phase represents a significant advancement over the previous one.

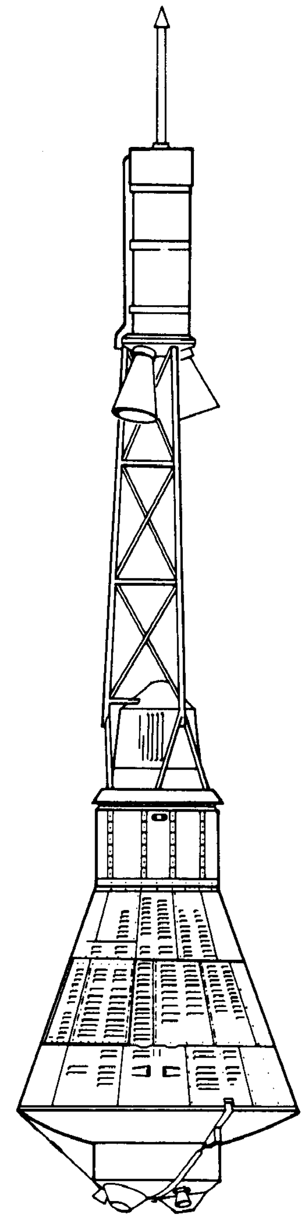
The first man in space was the Russian Yuri Gagarin, who made one orbit of the earth in his Vostok 1 spacecraft on April 12, 1961. The first American spaceman was Alan B. Shepard, Jr., who rode his Mercury spacecraft into space atop a Redstone booster on May 5, 1961. The first American to orbit the earth was John H. Glenn, Jr., who made three orbits in a Mercury spacecraft on Feb.20,1962.

To date (August 1, 1968), 19 Americans have been in space, and seven of these have made two space flights. There were six manned flights during the Mercury program and 10 manned flights in the Gemini program.

Eleven Russians have been in space in their nine-launch program. The Russian manned program also has involved three spacecraft, with six flights aboard the one-man Vostok, two flights with the Voskhod (one a three-man and the other a two-man craft), and a single flight with the Soyuz spacecraft.

There have been no fatalities in space, but accidents have marred the advanced programs of both the United States and Russia. Three American astronauts—Virgil I. Grissom, Edward H. White, II, and Roger B. Chaffee—died in a fire aboard an Apollo spacecraft on the pad at Kennedy Space Center. Grissom, a veteran of two space flights, was pilot of the second Mercury spacecraft and commander of the first Gemini to go into space. White was aboard the second manned Gemini spacecraft in orbit, and made the historic 21-minute "walk in space." The accident occurred on Jan. 27, 1967, as the three men were rehearsing countdown procedures for what was to have been the first Apollo manned launch.

The Russian tragedy occurred during a space mission, but not in space. Cosmonaut Vladimir Komarov died in the Soyuz 1 spacecraft on April 24, 1967, when it crashed during landing. The Soyuz flight, which lasted about 25 hours, had been characterized as successful by the USSR. It had entered the atmosphere and was at an altitude of about 4.3 miles when its parachutes became fouled and it plunged to earth. Komarov was the first Russian to go into space twice: he was one of the three cosmonauts aboard the Voskhod 1.



P-42 *Mercury spacecraft*

## MERCURY

Project Mercury was America's first step into space. The one-man Mercury capsules were designed to

## MERCURY FLIGHTS

| Date | Vehicle | Astronaut | Revolutions | Hours | |
|---|---|---|---|---|---|
| May 5, 1961 | Mercury-Redstone 3 | Alan B. Shepard, Jr. | * | 00:15:22 | First American in space; Freedom 7 |
| July 21, 1961 | Mercury-Redstone 4 | Virgil I. Grissom | * | 00:15:37 | Capsule sank; Liberty Bell 7 |
| Feb. 20, 1962 | Mercury-Atlas 6 | John H. Glenn, Jr. | 3 | 04:55:23 | First American in orbit; Friendship 7 |
| May 24, 1962 | Mercury-Atlas 7 | M. Scott Carpenter | 3 | 04:56:05 | Landed 250 miles from target; Aurora 7 |
| Oct. 3, 1962 | Mercury-Atlas 8 | Walter M. Schirra, Jr. | 6 | 09:13:11 | Landed 5 miles from target; Sigma 7 |
| May 15-16, 1963 | Mercury-Atlas 9 | L. Gordon Cooper, Jr. | 22 | 34:19:49 | First long flight; Faith 7 |

*Sub-orbital

answer the basic questions about man in space; how he was affected by weightlessness, how he withstood the gravitational forces of boost and entry, how well he could perform. A milestone in applied science and engineering, the Mercury flights proved that man not only could survive, he could greatly increase the knowledge of space.

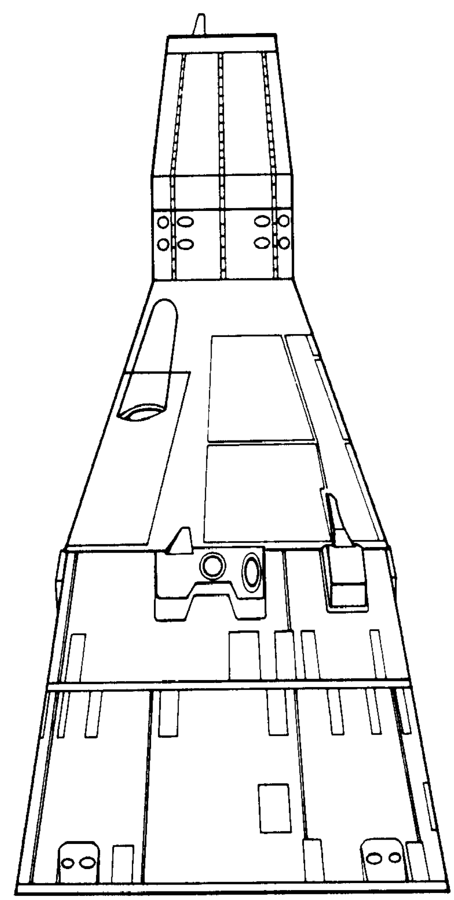
## GEMINI

Gemini was the next step in NASA's program. The goal of these two-man flights was to find out how man could maneuver himself and his craft, and to increase our knowledge about such things as celestial mechanics and space navigation. Gemini has a record of 10 successful manned flights and set many records, including the longest duration (almost 14 days), the first rendezvous by two maneuverable spacecraft, and the first docking.

## RUSSIAN MANNED PROGRAM

The Soviet Union opened the space age when it put the first man, Yuri Gagarin, into space in April of 1961. They followed four months later with the 25-hour flight of Gherman Titov.

The Russians waited a year after the Gagarin flight before their next, but that was the first group flight;



P-43 *Gemini spacecraft*

## GEMINI FLIGHTS

| Date | Vehicle | Astronauts | Revolutions | Hours | |
|---|---|---|---|---|---|
| Mar. 23, 1965 | Gemini III | Virgil Grissom<br>John Young | 3 | 4.9 | First manned orbital maneuvers |
| June 3-7, 1965 | Gemini IV | James McDivitt<br>Edward White | 62 | 97.9 | 21-minute "space walk" by White |
| Aug. 21-29, 1965 | Gemini V | Gordon Cooper<br>Charles Conrad | 120 | 190.9 | First extended manned flight |
| Dec. 4-18, 1965 | Gemini VII | Frank Borman<br>James Lovell | 206 | 330.6 | Longest space flight; served as Gemini VI-A target vehicle |
| Dec. 15-16, 1965 | Gemini VI-A | Walter Schirra<br>Tom Stafford | 16 | 25.9 | Rendezvous within 1 foot of Gemini VII |
| Mar. 16-17, 1966 | Gemini VIII | Neil Armstrong<br>David Scott | 6.5 | 10.7 | First docking, to Agena target; short circuit cut flight short |
| June 3-6, 1966 | Gemini IX-A | Tom Stafford<br>Eugene Cernan | 45 | 72.3 | Rendezvous, extra-vehicular activity, precision landing |
| July 18-21, 1966 | Gemini X | John Young<br>Michael Collins | 43 | 70.8 | Rendezvous with 2 targets; retrieved package from Agena in space walk |
| Sept. 12-15, 1966 | Gemini XI | Charles Conrad<br>Richard Gordon | 44 | 71.3 | Rendezvous and docking, 161-minute extravehicular activity |
| Nov. 11-15, 1966 | Gemini XII | James Lovell<br>Edwin E. Aldrin | 59 | 94.6 | 3 successful extra-vehicular trips, rendezvous and docking, rendezvous with solar eclipse |

two spacecraft on successive days. A 10-month lull followed before the second group flight, this time including a woman, Valentina Tereshkova, as one of the cosmonauts.

These six flights were with the Soviet Union's first manned spacecraft, the Vostok. Their second-generation spacecraft, the Voskhod, made only two flights about six months apart. The first Voskhod mission, 16 months after the last Vostok flight, carried a crew of three and was the first spacecraft with more than one passenger. The second Voskhod flight carried only two men but featured the first man to leave his spacecraft and "walk" in space.

The Soviet Union's third-generation spacecraft, Soyuz, made its only flight in April of 1967, when Komarov was killed.

RUSSIAN MANNED FLIGHTS

| Date | Spacecraft | Cosmonaut | Revolu-tions | Hours | |
|---|---|---|---|---|---|
| Apr. 12, 1961 | Vostok 1 | Yuri Gagarin | 1 | 1.8 | First manned flight |
| Aug. 6, 1961 | Vostok 2 | Gherman Titov | 17 | 25.3 | More than 24 hours in space |
| Aug. 11, 1962 | Vostok 3 | Andrian Nikolayev | 64 | 94.4 | First group flight |
| Aug. 12, 1962 | Vostok 4 | Pavel Popovich | 48 | 71.0 | Came within 3.1 miles of Vostok 3 on first orbit |
| June 14, 1963 | Vostok 5 | Valery Bykovsky | 81 | 119.1 | Second group flight |
| June 16, 1963 | Vostok 6 | Valentina Tereshkova | 48 | 70.8 | Passed within 3 miles of Vostok 5; only woman in space |
| Oct. 12, 1964 | Voskhod 1 | Vladimir Komarov<br>K. Feoktistov<br>B. Yegorov | 16 | 24.3 | First 3-man craft |
| Mar. 18, 1965 | Voskhod 2 | A. Leonov<br>P. Belyayev | 17 | 26.0 | Leonov was first man outside spacecraft in 10-minute "walk" |
| Apr. 23, 1967 | Soyuz 1 | Vladimir Komarov | 17 | 25.2 | Heaviest manned craft; crashed killing Komarov |

## SPACECRAFT DIFFERENCES

Many differences in the three manned U.S. spacecraft are readily apparent, such as size and weight. The major differences are in the complexity and refinement of subsystems. Apollo's requirement for hardware "maturity" is significantly higher than for earlier spacecraft programs. Each subsystem has become progressively more complex, with many more demands made upon it and a correspondingly greater capability. Only Apollo has its own guidance and navigation system.

Electrical power is a good example of increased system complexity. Electrical power for Mercury was supplied by six batteries; for Gemini, it was supplied by seven batteries and two fuel cell powerplants; for Apollo, it is supplied by five batteries and three fuel cell powerplants. The three systems do not sound too different physically. In operation, however, the differences are considerable.

The greatest demand on the Mercury system was to supply power to sustain the 4,265-pound spacecraft and its single astronaut for a day and a half (the 34-hour flight of Gordon Cooper). In Gemini, the electrical power system had to provide sufficient power to operate a typical 7,000-pound craft containing two astronauts for as long as two weeks (the 14-day flight of Frank Borman and James Lovell). In Apollo, the system is designed to support a 100,000-pound spacecraft carrying three men for up to two weeks.

## BASIC SPACECRAFT DIFFERENCES

| | Mercury | Gemini | Apollo |
|---|---|---|---|
| Height | 26 ft | 19 ft | 82 ft |
| Diameter | 6.2 ft | 10 ft | 12 ft 10 in. |
| Launch weight | 4265 lb at launch<br>2987 lb in orbit<br>2422 lb at recovery | 8360 lb | 109, 500 lb at launch<br>100,600 lb injected |
| Crew | 1 | 2 | 3 |
| Major components | Manned capsule (6 ft 10 in.)<br><br>Adapter (4 ft 3 in.)<br><br>Launch escape tower (16 ft 11 in.) | Entry (manned) module (11 ft 4 in.)<br><br>Adapter module (7 ft 6 in.) | Command module (10 ft 7 in.) (top of apex cover)<br>Service module (24 ft 2 in.) (top of fairing)<br>Lunar module (22 ft 11 in.) (legs folded)<br>Launch escape system (33 ft)<br><br>Adapter (28 ft) |
| Subsystems | | | |
| Abort | Launch escape rocket and tower to carry manned capsule to safety | Ejection seat for each astronaut up to about 70,000 ft; malfunction detection system | Launch escape rocket and tower (similar to Mercury but about twice the size); emergency detection system |
| Communications | UHF and HF for voice; UHF for telemetry; C-band and S-band tracking radar | UHF primary for voice with HF backup; C-band tracking beacon; rendezvous radar; 300 flight measurements telemetered to ground | VHF-AM primary for near earth; S-band primary for deep space; rendezvous radar; 700 flight measurements telemetered to ground |
| Docking | None | Index bar (to fit in notch on target vehicle) and latches | Probe and docking ring on CM, drogue on LM |
| Earth Landing | 4 chutes: main, drogue, reserve, pilot | 3 chutes: main, drogue, pilot, and ejection seats | 8 chutes: 3 main, 2 drogue, 3 pilot |

| | Mercury | Gemini | Apollo |
|---|---|---|---|
| Electrical Power | 6 batteries: 3 main auxiliary, 2 stand-by, and 1 isolated | 2 small fuel cells; 2 cryogenic tanks, 4 entry batteries, 3 pyro batteries | 3 large fuel cells; 4 cryogenic tanks; 3 entry batteries; 2 pyro batteries |
| Environmental Control | Suit cooling and oxygen loop, cabin cooling loop (water coolant); cabin pressurized to 5 psi; no space radiators | Suit cooling and oxygen loops; redundant cabin cooling loops (silicon ester coolant); cabin pressurized to 5 psi; space radiators, coldplates for operating equipment; shirtsleeve environment | Four major loops: oxygen, suit circuit, water, and coolant (water-glycol); space radiators and coldplates; cabin pressurized to 5 psi; shirtsleeve operations |
| Guidance and Control | Attitude control equipment (2 attitude gyros, 3 rate gyros, logic and programming circuits); automatic system using 12 small $H_2O_2$ thrusters and manual system using 6 small $H_2O_2$ thrusters; horizon sensors, periscope | Small computer (4,000-word memory), horizon sensor, no redundancy; 16 orbital attitude maneuvering system thrusters of 25 to 100 lb (No redundancy); 16 entry control thrusters (redundant systems of 8 25-lb engines); inertial platform, rendezvous radar | Large computer (39,000-word memory), telescope and sextant; semi-automatic operation; optical, inertial, and computer systems; attitude control through stabilization and control systems; 16 SM reaction control engines (100-lb) redundant systems, 12 CM reaction control engines in redundant systems; separate guidance and control systems in LM |
| Propulsion | 3 posigrade rockets for separation from booster, 3 retrograde rockets for entry from orbit | 4 retrograde rockets for entry (2,500 lb each) | Restartable service propulsion engine (20,000 lb); liquid propellant rodset propulsion with unlimited restart and thrust vector control (automatic and manual) |

# APOLLO FLIGHT TESTS

The Apollo flight test program up to September, 1968, included space tests of four command and service modules, one lunar module, and space and atmospheric tests of 10 boilerplate (test) command and service modules. These tests were conducted under the "all-up" philosophy of testing as many things simultaneously as possible and thus minimizing the number of launches, as well as cost and time.

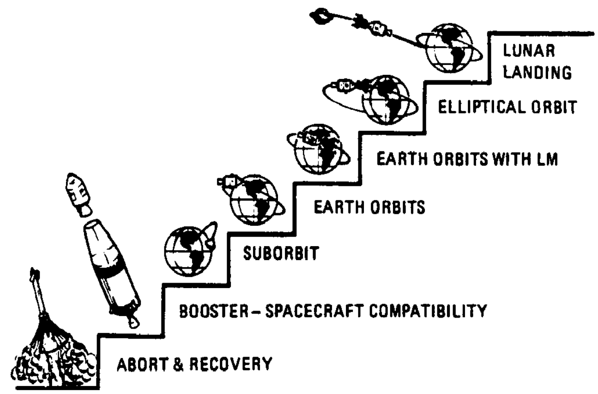
The program is aimed at designing the spacecraft so that all launches contribute to its development. The command and service modules are being developed separately from the lunar module; this permits both modules to be tested on the smaller Saturn IB launch vehicle. The test program depends on the Saturn V only for missions that require its large payload.

Another test program goal has been maximum development on the ground; space flights have been undertaken only with spacecraft with almost all systems aboard and operating.

An example of this philosophy of combining many tests on one flight was the Apollo 6 mission on April 4, 1968. This mission included the second flight of a Saturn V launch vehicle as well as a number of important spacecraft tests.

Although launch vehicle problems caused selection of an alternate mission and prevented achievement of some major objectives, NASA termed the spacecraft's accomplishments impressive. These included the longest single burn in space of the service propulsion engine (7 minutes, 25 seconds), proper control of the engine during this burn by the guidance and navigation subsystem, proper maintenance of spacecraft attitude by the reaction control subsystem during the long cold soak period, and another successful test of the spacecraft's heat shield. This also was the first space test of the new unified crew hatch and seals and they withstood the mission in good condition.

The first flight of the Saturn V was on Nov. 9, 1967, in the Apollo 4 mission, which also was a major test of the CM's heat shield, service propulsion subsystem, guidance and navigation equipment, and environmental control subsystem. The major objectives of Apollo 4, all fulfilled, were: the first launch of the Saturn V first stage, the first




P-44 *Apollo development sequence*

flight of the hydrogen-powered second stage, restart of the third stage in earth orbit, restart of the service propulsion engine in space and its record firing for nearly 5 minutes, a hot and cold soak of the spacecraft far out in space, and entry under the severest conditions yet encountered by a spacecraft (a velocity of 24,913 miles per hour and a heat shield temperature of about 5,000 degrees F).

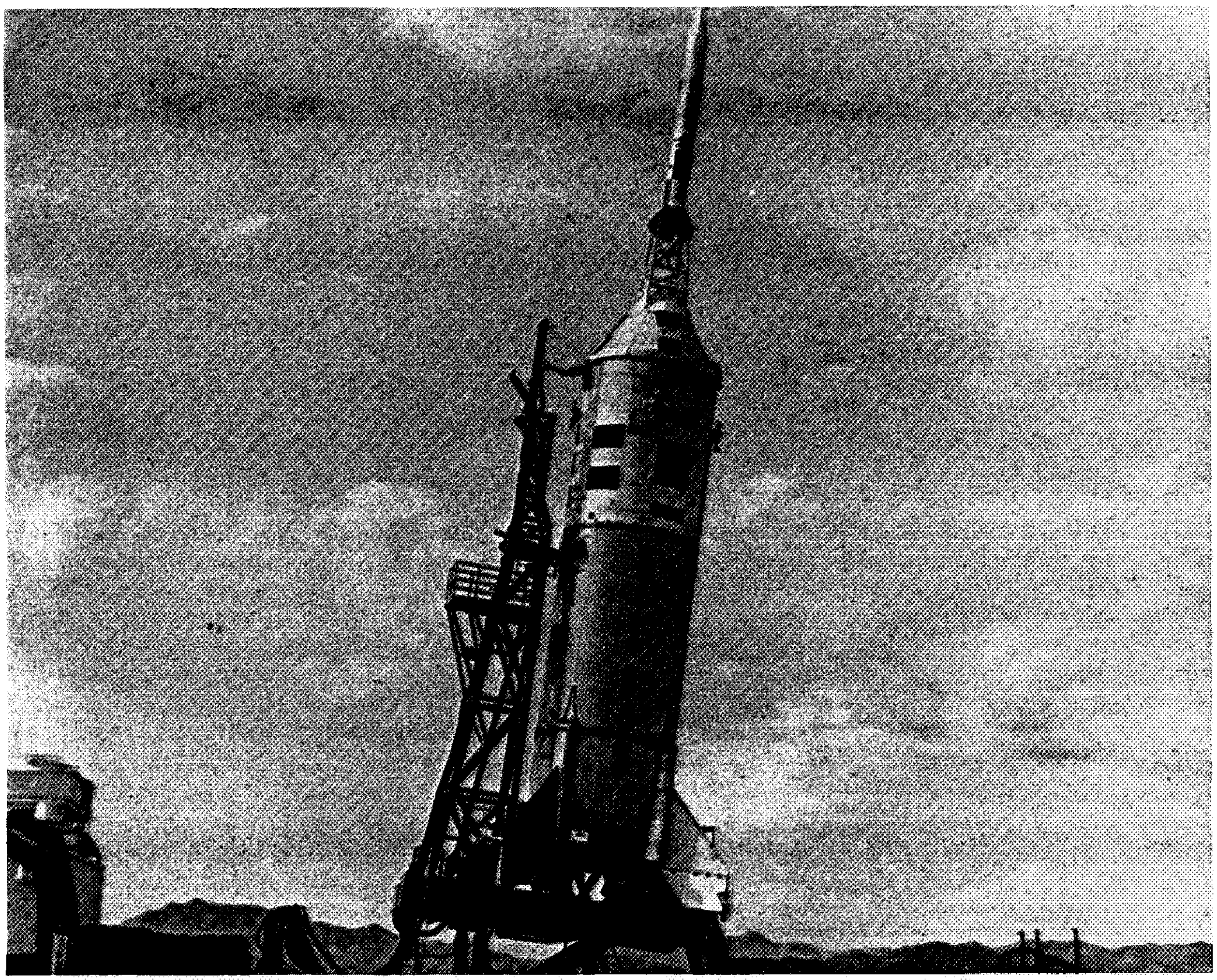
The Apollo 4 results were impressive. There was no structural damage to the command module and no areas of burn-through on the heat shield. The environmental control subsystem kept the cabin temperature between 60 and 70 degrees even through the fiery entry. Cabin pressure remained between 5.6 and 5.8 psia during the entire mission, indicating negligible leakage rate. Fuel cells and subsystems using cryogenics operated satisfactorily, as did all other operating subsystems.

The first space test of the lunar module came Jan. 22, 1968, on the Apollo 5 mission. The LM was launched by a Saturn IB, with the apex of the vehicle covered by an aerodynamic shroud. The shroud was jettisoned and then the spacecraft-LM adapter panels deployed as on a lunar mission. The lunar module's descent engine was burned three times and performed as expected. At the end of the third burn, a "fire-in-the-hole" abort—in which the LM's ascent and descent stages separate, the ascent engine begins to burn and simultaneously the descent engine stops firing—was performed successfully. A second ascent engine burn was performed later in the mission. Data telemetered to the ground indicated that all other subsystems of the module operated satisfactorily.

The Apollo 4, 5, and 6 missions were part of the earth-orbital phase of the flight test program. (There were no Apollo 1, 2, or 3 missions.) The program is divided into two blocks with interrelated phases: launch abort, sub-orbital, and earth-orbital (Block I) and earth-orbital and lunar (Block II).

For economy, boilerplate spacecraft are used in the program where an actual spacecraft is not required. Boilerplates are research and development vehicles that simulate production modules in size, shape, structure, mass, and center of gravity. Each boilerplate has instruments to record data for engineering evaluation.

The sub-orbital flights tested the heat shield and the operation of subsystems. The earth-orbital portion of the flight test program tests further the operational abilities of subsystems, the Saturn I, the Saturn IB, and Saturn V operation and compatibility, and operations during earth orbit, and also develops qualified teams for checkout, launch, flight operations, mission support, recovery, and flight analysis.



P-45

*Command and service modules mounted on Little Joe II booster at White Sands, N.M., for test of launch escape subsystem*

## APOLLO FLIGHT TESTS

| DATE | SITE | | SPACECRAFT | RESULT |
|---|---|---|---|---|
| Apr. 4, 1968 | Kennedy Space Center | Apollo 6: Second flight of Saturn V; launch vehicle engine problems caused spacecraft to go into alternate mission; service propulsion engine burned for record length, other subsystems performed well | SC020 | Partial success |
| Jan. 22, 1968 | Kennedy Space Center | Apollo 5: First space flight of lunar module; tested ascent and descent engines and ability to abort lunar landing and return to orbit; Saturn IB was launch vehicle | LM-1 | Successful |
| Nov. 9, 1967 | Kennedy Space Center | Apollo 4: First Saturn V launch; spacecraft entered atmosphere at almost 25,000 mph; heat shield temperatures reached about 5000°F; first test at lunar return speed | SC017 | Successful |
| Aug. 25, 1966 | Kennedy Space Center | Second flight of unmanned Apollo spacecraft to test command module's ability to withstand entry temperatures under high heat load; Saturn IB was launch vehicle | SC011 | Successful |
| Feb. 26, 1966 | Kennedy Space Center | First flight of unmanned Apollo spacecraft to test command module's ability to withstand entry temperatures; determine CM's adequacy for manned entry from low orbit test CM and SM reaction control engines and test service propulsion engine firing and restart; this was also first flight of the Saturn IB | SC009 | Successful (Service module engine produced slightly less thrust than expected, resulting in slightly lower reentry speed and temperatures.) |

| DATE | SITE | | SPACECRAFT | RESULT |
|---|---|---|---|---|
| Jan. 20, 1966 | White Sands | Final abort test utilizing actual spacecraft to test escape in high tumbling region; this completed the abort test phase, qualifying the astronaut escape system for manned flights; Little Joe II was booster | SC002 | Successful |
| July 30, 1965 | Kennedy Space Center | Third Pegasus meteoroid detection satellite; launched by Saturn I; Apollo spacecraft shell and spacecraft-LM adapter housed and protected the Pegasus payload until reaching orbit where SLA panels opened, permitting the satellite to deploy | BP 9A | Successful |
| June 29, 1965 | White Sands | Pad abort: Second test of the launch escape system's ability to work in emergency before launch and while still on the pad; canards, boost protective cover, jettisonable apex cover, and dual reefed drogue chutes were tested | BP 23A | Successful |
| May 25, 1965 | Kennedy Space Center | Second Pegasus meteoroid detection satellite; Saturn I was launch vehicle | BP 26 | Successful |
| May 19, 1965 | White Sands | Planned high-altitude launch escape system test to determine performance of launch escape vehicle canard subsystem, and to demonstrate orientation of launch escape vehicle (Little Joe II) | BP 22 | Partially successful (boost vehicle guidance malfunctioned causing premature low-altitude abort; Apollo systems functioned perfectly, pulling command module away from debris and lowering it safely to earth) |
| Feb. 16, 1965 | Kennedy Space Center | First Pegasus micrometeoroid detection satellite; Saturn I was launch vehicle | BP 16 | Successful |