MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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APOLLO PROGRAM

On July 2, 1960, the House Committee on Science and Astronautics recommended "a manned lunar expedition within this decade." Just 27 days later, the National Aeronautics and Space Administration (NASA) announced at a NASA-Industry Conference in Washington, D. C., that Project Apollo would be the successor to Project Mercury and would place three men in sustained orbital flight or in circumlunar flight (the two-man Gemini Program later was determined to be the necessary intermediate step in manned space flight). Then on May 25, 1961, the late President John F. Kennedy, in a speech to Congress, made the lunar landing and the safe return of the astronauts before the end of the decade a national goal.

OBJECTIVES

The Apollo Spacecraft Program is managed by the Manned Spacecraft Center, Houston, Texas, under the direction of the Office of Manned Space Flight, NASA Headquarters, Washington, D. C.

The primary objectives of the Apollo Program are:

- To land two men on the moon
- Limited exploration in the landing area
- Return to earth of the astronauts and their lunar samples and photographs

THREE SPACE-SUITED ENGINEERS are shown in the couches at North American Aviation's Downey, Calif., plant during the launch phase of a simulated Apollo mission.

PROGRAM BACKGROUND

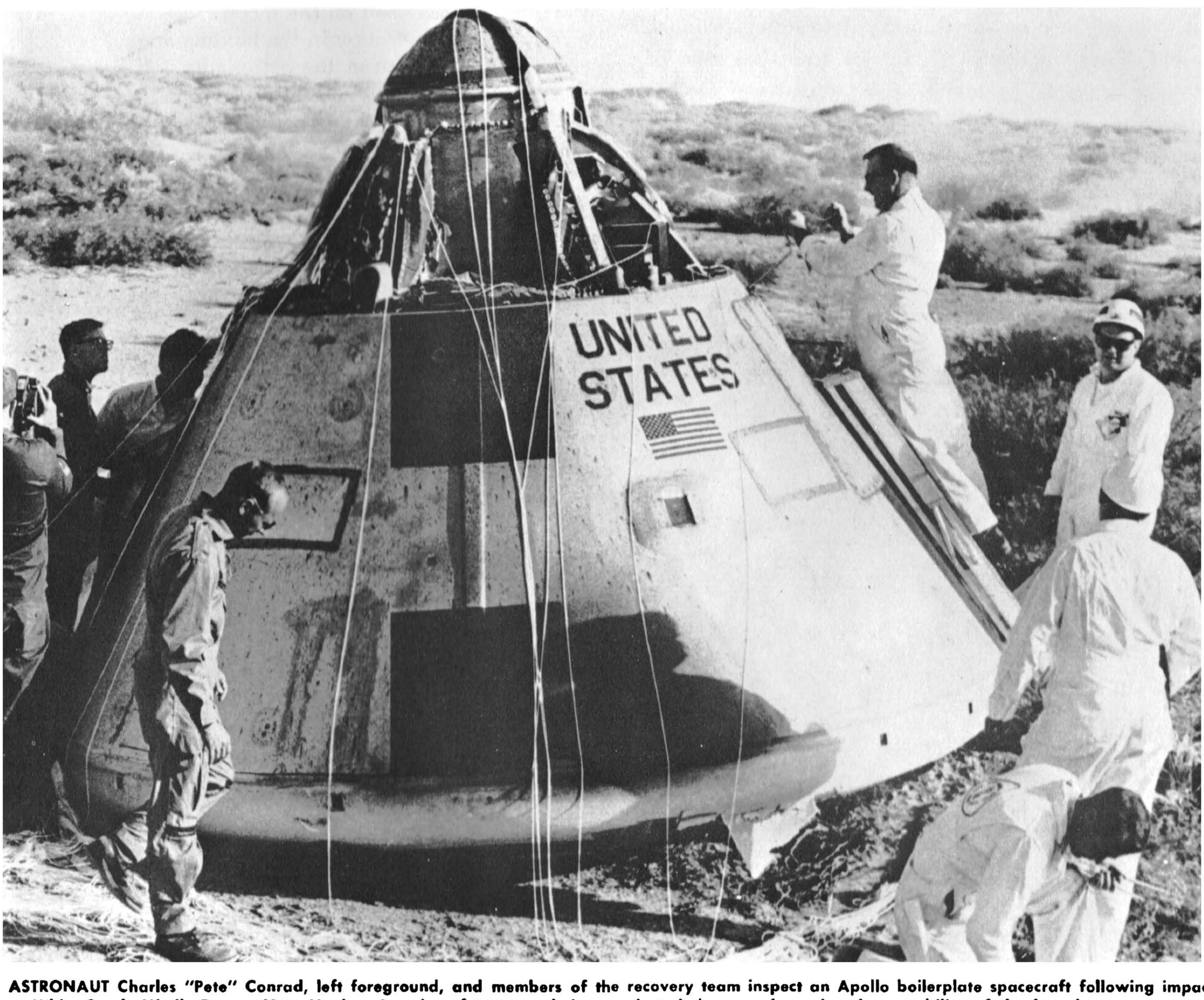
Among major problems which faced NASA engineers and scientists early in the program were choosing a family of launch vehicles for testing and operational missions, design of the spacecraft, and a method for achieving the objective.

The three proposed major methods of accomplishing the goal involved were: 1) a direct lunar landing mission, without rendezvous; 2) rendezvous of two parts of the mission payload in earth orbit with subsequent landing on the moon; and 3) a direct flight to lunar orbit and the use of a separate lunar landing spacecraft which would rendezvous with the return spacecraft in lunar orbit. Following the completion of these studies NASA announced, in July 1962, that the lunar orbit rendezvous method had been selected.

While these studies were in progress, concerted activities were underway in other problem areas. The original design concept for the spacecraft command and service modules was completed; and a decision was made to use the Little Joe II as the launch vehicle for high altitude and suborbital tests. Three configurations of the Saturn launch vehicle were chosen for various phases of testing the Apollo spacecraft in orbital flights and later for lunar missions. The Saturn development program is managed by NASA's Marshall Space Flight Center at Huntsville, Alabama.

NASA is conducting the series of Apollo-Little Joe II tests at the White Sands Missile Range, New Mexico. In addition, facilities have been erected there for static testing the propulsion engines of the Apollo service module and to fire the engines of the lunar excursion module (LEM) under simulated high altitude conditions.

White Sands Launch Complex 36 is also the site of pad abort tests. These tests are designed to demon-



ASTRONAUT Charles "Pete" Conrad, left foreground, and members of the recovery team inspect an Apollo boilerplate spacecraft following impact at White Sands Missile Range, New Mexico. A series of tests are being conducted there to determine the capability of the launch escape system, the parachute landing system, and the aerodynamic stability of the spacecraft under conditions of unusual stress.

strate both the capability of the launch escape system to propel a command module to safe distance from the launch vehicle and the aerodynamic stability of the Apollo configuration during pad abort conditions.

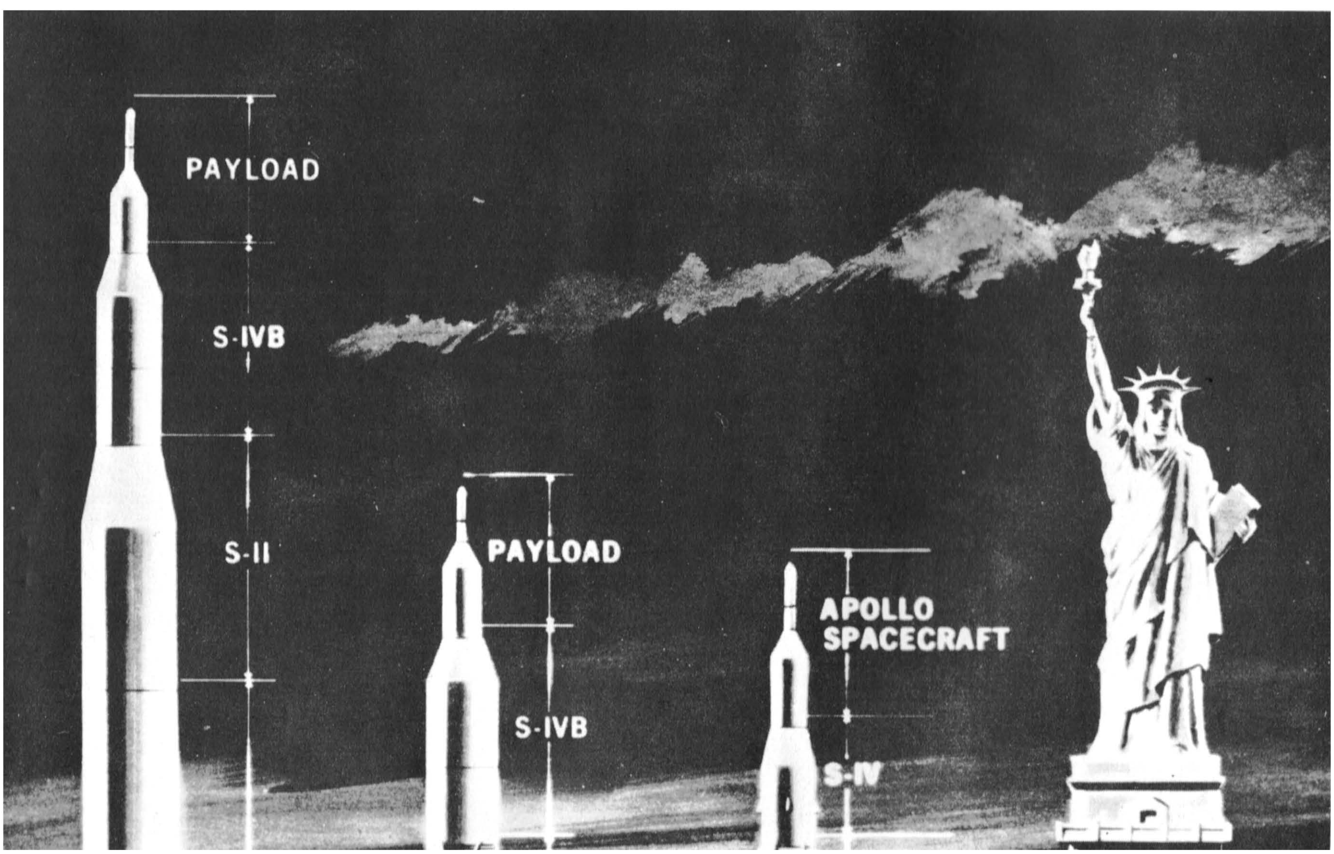
The Little Joe series, among other objectives, proved the structural integrity of the escape system and its ability to perform during an abort at high dynamic pressure in the transonic speed range. It also verified the spacecraft capability to perform using a boost protective cover over the command module and verified the abort capability under maximum dynamic pressure. In addition, it has tested the landing system.

LAUNCH VEHICLES

*The Little Joe II launch vehicle is a follow-on to the Little Joe used as a test vehicle during Project Mercury. It was conceived by Paul E. Purser, Special Assistant to the Director of Manned Spacecraft Center, and Maxime A. Faget, Assistant Director of Manned Spacecraft Center for Engineering and Development.

The Little Joe II is 29 feet high, 13 feet in diameter, and can carry payloads up to 80,000 pounds, thus easily accommodating the requirements for the sub-

A TEST OF THE APOLLO launch escape system was conducted at White Sands Missile Range, New Mexico, May 19, 1965. This is one of the series of tests being conducted at that location.



Pictured above is an artist's conception of the three Saturn-Apollo launch configurations as compared to the Statue of Liberty. The Saturn V configuration on the left will be about 362 feet high at liftoff; the Saturn IB will be about 223 feet high; and the Saturn I is about 190 feet high. The Statue of Liberty is 305 feet tall.

orbital testing phase of the Apollo Program. It incorporates provisions for use of a different number and kind of solid-propellant motors with a total thrust capability of up to more than 750,000 pounds, depending upon test requirements.

It has a guidance system which is easily adaptable to fit individual test requirements. Extensive instrumentation can be installed in the launch vehicle or in the boilerplate spacecraft used in the test. Prime contractor for the Little Joe II is General Dynamics/Convair.

*The Saturn 1 launch vehicle consists of two stages and an instrument unit. The S-1 stage is 81 feet tall, 22 feet in diameter, and uses eight engines to produce a total thrust of 1,500,000 pounds. The S-IV stage is 41 feet high, 18½ feet in diameter, and its six engines provide 90,000 pounds of thrust. The instrument unit is three feet high and 13 feet in diameter. (All launch vehicle and spacecraft dimensions, weights, and thrust used in this paper are approximate and subject to change as indicated necessary during the development phase of the program.)

By early 1965, there had been eight successful flights of the Saturn 1, several of these with unmanned Apollo boilerplate spacecraft aboard. When combined with the Apollo command and service modules and the launch escape system, the Saturn 1 configuration is 190 feet high, its loaded weight is 1,400,000 pounds, and it is capable of putting 22,500 pounds into near earth orbit.

*The Saturn IB launch vehicle also has two stages and an instrument unit. The S-1 stage is 81 feet high; it is 22 feet in diameter and its eight engines produce 1,600,000 pounds of thrust. The S-IVB stage is 59 feet high, 22 feet in diameter and its single engine can produce 200,000 pounds of thrust. The instrument unit is three feet high and 22 feet in diameter. When combined with the Apollo command, service, and lunar excursion modules and the launch escape system, the Saturn IB configuration will be 223 feet high, weigh 1,250,000 pounds loaded and be able to place a payload of 35,000 pounds in near earth orbit. The mission objectives for this configuration will be to launch unmanned and manned command, service, and lunar excursion modules in earth orbital flights.

*The Saturn V launch vehicle is designed to furnish the power to boost the Apollo command, service, and lunar excursion modules into both manned earth orbital and lunar flights. The launch vehicle has three stages and an instrument unit.

The S-IC stage will be 138 feet high, 33 feet in diameter, and five engines will generate a total of 7,500,000 pounds of thrust. The S-II stage will be 82 feet high, 33 feet in diameter, and its five engines will generate about 1,000,000 pounds of thrust. The S-IVB stage will be 59 feet tall, 22 feet in diameter, and its one engine will produce 200,000 pounds of thrust. The instrument unit will be three feet high and 22 feet in diameter.

When combined with the Apollo modules and the launch escape system, the total configuration will be 362 feet high, with a total weight, loaded, of 5,900,000 pounds. It is designed to place a payload of 280,000 pounds into near earth orbit and 95,000 pounds into the escape trajectory required for a lunar mission.

SPACECRAFT

The Apollo spacecraft is basically made up of three modules—command, service, and lunar excursion.

*The command module is the spacecraft's control center and provides combination living, working, and leisure time quarters for the three-man crew. It is conical in shape, 11 feet high and 13 feet in diameter, and will weigh 11,000 pounds.

Design and construction of the spacecraft presented many difficult problems. The structure must be strong enough to withstand the shock during the launch and landing phases as well as be resistant to the deep cold of space and the anticipated 5,000-degree temperature during reentry. The command module consists of two shells—an inner crew compartment and an outer compartment covered by a heat shield. Ablative materials are applied to the outer structure after its assembly and fit-check with the crew compartment. Sides of the outer shell are constructed primarily of stainless steel honeycomb, brazed between stainless steel sheets as thin as eight thousandths of an inch; and the inner shell is made of aluminum honeycomb bonded between sheets of aluminum alloy. Mechanical fasteners lock the outer and inner shells securely and rigidly together. Between the walls of the two shells is a layer of microquartz insulation varying from one tenth of an inch to an inch-and-a-half thick.

The inner crew compartment has two major parts. The aft section forms the lower wall and base of the module, and the forward (apex) section forms the upper tapered walls and the access hatch through which the astronauts will transfer to the lunar excursion module. Two-inch-thick honeycomb is used in the aft section which comprises the base heat shield.

The command module has openings for four windows through which the astronauts will be able to make navigational reckonings and observe flight progress and lunar orbit rendezvous operations.

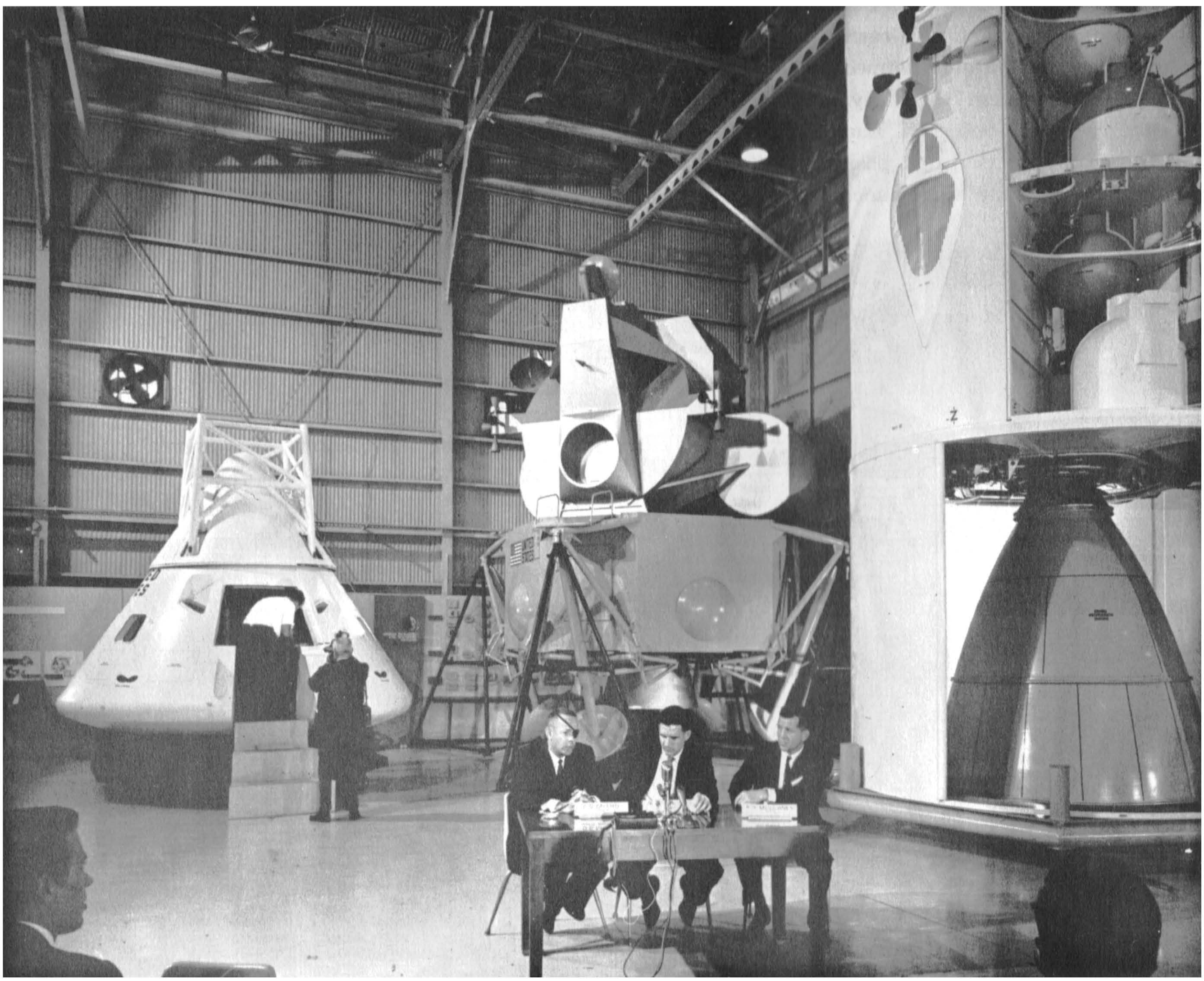
Upon completion of the inner crew compartment assembly, all windows and hatches are installed, and it is placed in a pressure chamber to check for leakage and structural stress under pressure. The outer shell is then installed.

*The service module is cylindrical, 14 feet high, and 13 feet in diameter. It houses the main propulsion engine which will be used for midcourse corrections on a lunar flight and for necessary propulsion on the return trip from the moon and for retrofire to place the spacecraft in a circular orbit about 90 statute miles above the lunar surface. This engine is capable of 22,000 pounds thrust.

Also housed in the service module are systems required to support the command module and crew. These systems include the electrical system, 16 reaction control engines, and part of the environmental control system not required during reentry. The major structural components are made of aluminum.

*The spacecraft LEM adapter, which is located between the service module and the Saturn launch vehicle is 29 feet high and 22 feet in diameter where it joins the S-IVB stage, tapering off to 13 feet where it joins the service module. The command and service modules and adapter are fabricated by North American Aviation's Space & Information Systems Division.

*The lunar excursion module, designed to land two astronauts on the moon and later return them to lunar orbit to rendezvous with the mother spacecraft, will be 19 feet high and 19 feet in diameter, and will weigh 30,000 pounds fully loaded, including 250 pounds of scientific equipment. The major structural material



MOCKUPS of, left to right, the command module, the lunar excursion module, and the service module were on display at Downey during a news conference. Participating in the conference were, left to right, D. D. Meyers of North American Aviation; Dr. Joseph F. Shea, Manager of Manned Spacecraft Center's Apollo Spacecraft Program Office; and R. S. Mullaney of Grumman Aircraft Engineering Corporation.

used is aluminum. The prime contractor is Grumman Aircraft Engineering Corporation.

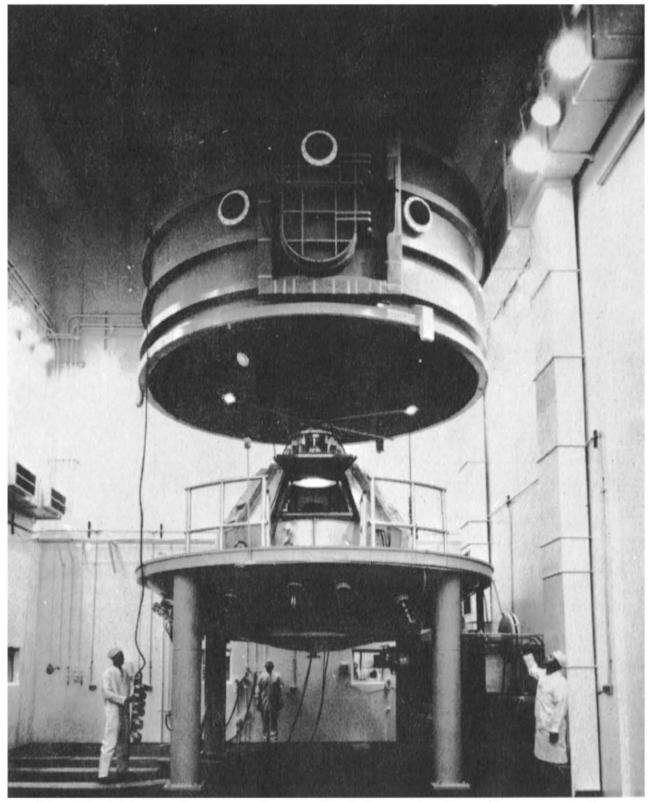
The LEM has two engines, one for lunar descent and the other for ascent from the moon. The cabin of the LEM will have about 240 cubic feet of pressurized space, including that needed for equipment. This module will have propulsion, environmental control, communications, and guidance and control systems similar to those in the command module, in addition to the portable equipment for exploring the surface of the moon.

HARDWARE TESTING

Every item of hardware in the Apollo spacecraft—beginning with nuts and bolts and continuing to the finished product—is subjected to rigorous inspections and tests. This phase of preparation for an eventual lunar landing flight is conducted to protect the astronauts on board and to insure success of the mission.

Tests are systematically carried out on each individual part, on the units formed by the parts, on the subsystem or system formed by the units, and finally on the complete spacecraft. Each subsystem and system is tested in its actual position in the spacecraft under various simulated launch, space, and reentry conditions, and finally in its interaction with other systems.

THE WATER IMPACT OF an Apollo boilerplate spacecraft at Downey provided a photographer with an opportunity for an unusual photo. The pendulum of the impact test facility there has been used extensively in tests and releases the spacecraft at controlled angles and speeds to simulate conditions the manned Apollo spacecraft will undergo on return to earth.



A SPACE JAR at Downey is readied by scientists for manned tests of the Apollo environmental control system which is designed to produce a habitable environment for astronauts. In accomplishing these tests, the 15-ton dome encloses the aluminum spacecraft and a space-like vacuum is created.

This activity includes x-ray and chemical tests; structural, static, and dynamic load tests; vibration tests, functional tests, and environmental tests.

Each component is tested far beyond the required safety level, and in many cases to the point of breakdown to determine performance margins. Since the systems are complex, failures must be anticipated and, in some instances, complete backup subsystems are provided, separate from the regular subsystems, to provide redundancy.

Although most testing is accomplished by measuring and probing, in some cases special techniques had to be devised to develop the effective equipment and systems. This has been especially necessary in the life support and environmental control systems. Crew couches can be used as an example. Astronauts are not uniform in size and weight and it presented a problem to design a couch that will support, restrain and protect an astronaut with maximum comfort regardless of his size or weight.

One of the special pieces of equipment developed to test environmental and life support systems is a

15-ton stainless steel vacuum chamber at North American Aviation's plant in Downey, California. Shaped like a laboratory bell jar, the chamber is 18 feet in diameter and 17 feet high. A simulated Apollo crew compartment has been installed in it and preliminary tests conducted in a vacuum environment.

ACCEPTANCE CHECKOUT EQUIPMENT

As a part of the testing program, preflight acceptance testing stations are being developed to provide a high-speed, reliable system to test the many spacecraft components. The stations, called ACE-S/C—which stands for Acceptance Checkout Equipment for Spacecraft—are located as follows:

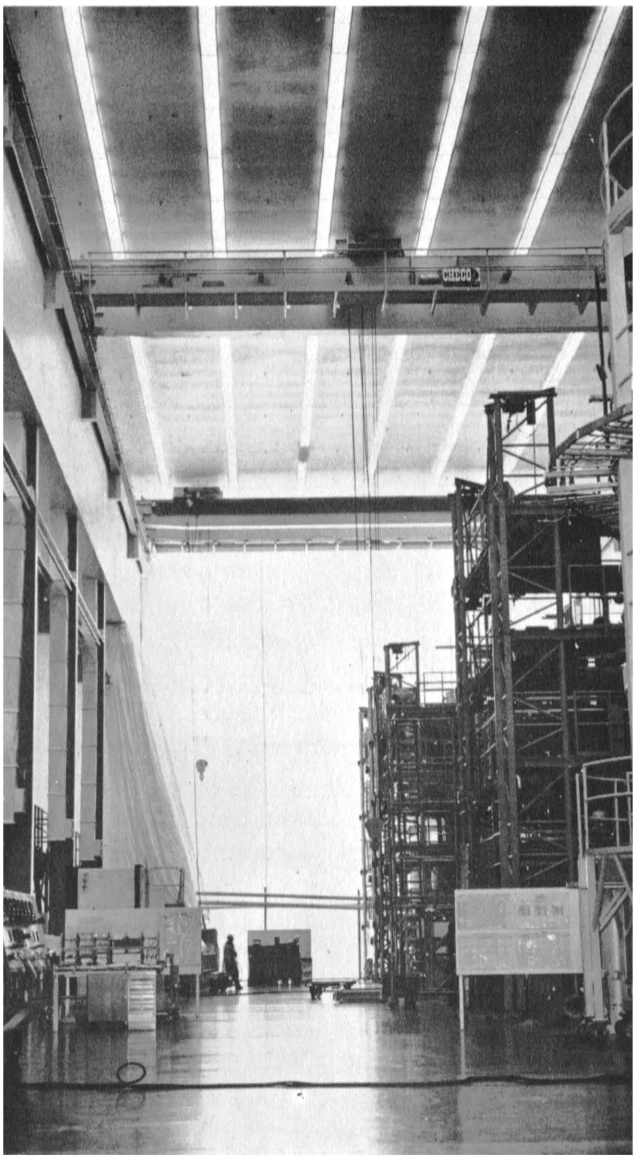
North American Aviation plant in Downey, California, for the command and service modules;

Grumman Aircraft Engineering Corporation at Bethpage, New York, for the lunar excursion module;

Manned Spacecraft Center, Houston, Texas, for testing spacecraft in simulated space and lunar environments; and

NASA facilities at Merritt Island, Florida, do the final compatability testing of Apollo spacecraft subsystems and integrated systems prior to launch.

These stations consist of a control room, a computer room, and a terminal facility room. The system permits a relatively small staff of engineers to monitor and control more than 25,000 samples of spacecraft test data per second.



IN ALL OF AMERICA'S space efforts to date, much stress has been devoted to all finalized testing and work on the complex components being completed under the most ideal conditions. To do this, the major contractors and NASA have developed working areas normally referred to as "white rooms" or "clean rooms." These rooms are maintained at a constant temperature, a constant humidity, and are dust free, and thus offer the least chance for any of the sensitive spacecraft components to become contaminated. The "white room" above at North American's Downey plant is the largest of its kind in this country.

MAJOR SUBSYSTEMS

As principal contractor for the command and service modules and the launch escape system, the Space and Information Systems Division of North American Aviation is utilizing the scientific, technological and manufacturing skills and capabilities of more than 1,550 subcontractors and vendors located in every section of the country. They produce many of the subsystems integrated in the spacecraft.

Some of the major subsystems are:

*Stabilization and Control System—an electrical-mechanical system that enables the flight crew to control and fly the spacecraft. It permits them to stabilize it and make navigational checks and midcourse flight corrections. Reaction control engines in the command module provide thrust for attitude control and stabilization during reentry. Similar engines in the service module provide like capability during the trip to and from the moon and during lunar orbit.

*Environmental Control System—this system provides a controlled atmosphere for three astronauts as well as control temperatures for other systems in the spacecraft. Its prime functions are to provide oxygen, remove carbon dioxide and odors from the spacecraft cabin, control heat generated by the crew and equipment, and maintain cabin and suit pressures during all operations, including emergencies. It will maintain cabin temperature — 75 degrees — and humidity — between 40 and 70 per cent — during normal operations, and provide thermally-controlled water for the crew.

*Communications and Data—this is one of the most complex systems aboard the spacecraft and provides contact between the spacecraft and earth. It includes spacecraft-to-earth television, telemetry, tracking, and ranging systems, two-way radio for voice communication between the spacecraft and earth, an intercom system, and a radio beacon system for recovery operations.

*Guidance and Navigation—this subsystem performs two basic functions during the Apollo mission. First, it controls thrust during powered phases of flight and controls lift during the reentry phase. Second, it determines position and velocity changes necessary to reach the target.

Guidance is based primarily on inertial measurements from an inertial platform. Using these measurement signals, the guidance and navigation subsystem generates steering and thrust commands to make desired changes in the trajectory.

Navigation information is obtained primarily from ground tracking inputs to the system but there is a backup capability on board.

*Displays and Controls—there are three distinct groups of equipment in the displays and controls subsystem.

One group includes: 1) the master caution and warning subsystem which notifies the crew of any system malfunction requiring immediate attention; and 2) the reentry monitor subsystem which furnishes the crew with information by which they may monitor flight performance during the reentry phase. The latter enables the crew to recognize malfunctions in the guidance and navigation or stabilization and control subsystems and to assume manual control during reentry.

Another group of equipment includes instrumentation on prime spacecraft systems which are operated or monitored by the astronauts, such as propulsion, electric power, and the environmental control subsystems.

The third group includes display and control devices which pertain to the guidance and navigation and the stabilization and control subsystems.

*On-Board Television—television cameras are included in the command and lunar excursion modules, as well as portable TV cameras to be used during lunar exploration.

*Central Timing System—an electronic timepiece designed to synchronize the spacecraft's telemetry, television, and on-board test equipment. It will also transmit the signals to the sequencer to jettison the launch escape system.

*Earth-Landing System—the system of parachutes to return the spacecraft to earth consists of two 14-foot-diameter, mortar-activated drogue chutes which will be deployed to stabilize the command module, three 7-foot pilot chutes which will pull out the main chutes, and three 83-foot-diameter main chutes.

*Electrical Fuel Cells—power to operate the spacecraft systems during flight is produced by fuel cells which convert hydrogen and oxygen into electricity. They are located in the service module, and, in addition to providing electrical power, they manufacture potable water for the crew and water for cooling spacecraft components. The command module carries three batteries to supply power after the service module has been jettisoned.

*Service Module Propulsion Engine—this engine generates approximately 22,000 pounds of thrust. It will be used for midcourse flight corrections while going to the moon and on the way back, for slowing the spacecraft sufficiently to place it in a circular lunar orbit, and for necessary propulsion of the spacecraft from the vicinity of the moon to start its return trip to earth. The engine can be re-started 50 times and can be used in emergency situations if required. Such situations could include boosting the spacecraft away from the launch vehicle to abort the flight after the launch escape system has jettisoned, and to recover the LEM if it fails to complete rendezvous with the spacecraft on its return to lunar orbit.

*Reaction Control Engines—these engines serve as an integral part of the spacecraft stabilization and control system. Both the service module and the LEM have four reaction control engines, each consisting of four symmetrically-arranged nozzles; and the command module has three engines with similarly-arranged nozzles. These engines may be used for small midcourse corrections and to assist in the docking maneuvers. The reaction control engines of the command module will be used primarily for attitude control and stabilization through the reentry phase until the parachutes are deployed.

*Launch Escape System—this system is designed to separate the command module from the launch vehicle in the event of an emergency while on the launch pad or during the early phase of powered flight. It will propel it to a safe altitude and distance from the launch vehicle. The launch escape system, about 29 feet in overall length, has as its primary components a launch escape motor, tower jettison motor, pitch control motor, tower, and separation devices and sequencers.

The pitch control motor, mounted forward of the launch escape motor, provides a sideways thrust which turns the escape vehicle (the command module and launch escape system) away from the path of the launch vehicle. The tower jettison motor is used to separate the launch escape system from the spacecraft. During a normal mission, the launch escape system is jettisoned about 35 seconds after the second stage engines are ignited.

TYPICAL APOLLO MISSION

A number of earth-orbital Apollo flights will be made before a lunar landing mission in order to qualify all the spacecraft systems, to provide rendezvous and docking experience, and to further train astronauts for the lunar flights.

In a typical lunar-landing mission it is difficult to ascertain where the mission really begins. All the work previously done has played an important part in readying the launch vehicle and the spacecraft, as well as the crew, for the historic flight. Basically, the mission will consist of pre-launch activities, the launch, earth orbit, injection into and the trans-lunar trajectory, lunar orbit, the LEM descent, lunar landing, lunar exploration, LEM ascent and rendezvous, injection into the trans-earth trajectory, and return, reentry, landing, and recovery phases.

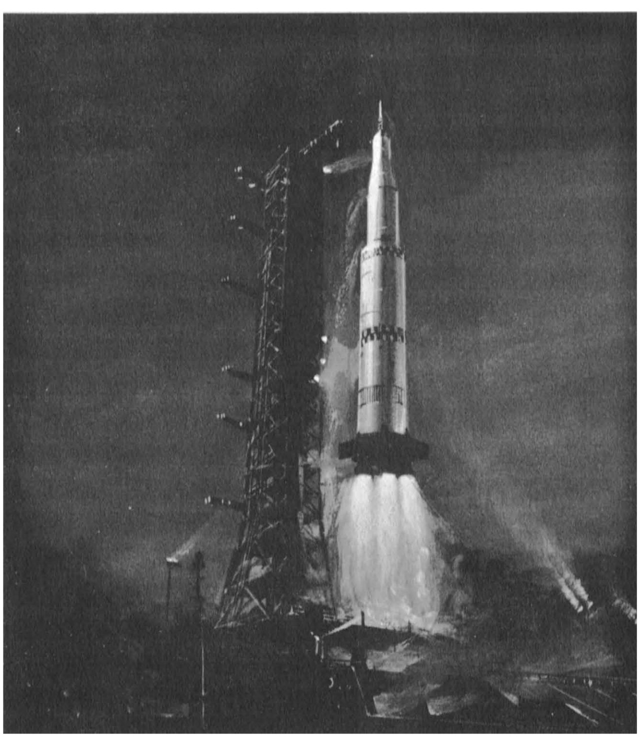
*After both the launch vehicle and spacecraft have undergone thorough checkouts at the manufacturers' plants they are taken to Kennedy Space Center facilities at Merritt Island. The Saturn V launch vehicle will be put together in a building-block manner with the S-IC stage being erected, the S-II stage placed on top, then the S-IVB stage and the instrument unit added.

When testing of the individual stages and the spacecraft at Cape Kennedy is completed, the component parts of the overall configuration will be moved into the high bay area of the Vehicle Assembly Building. This building, when completed will be the world's largest building in volume. The high bay area is 525 feet high, 518 feet wide, and 442 feet long.

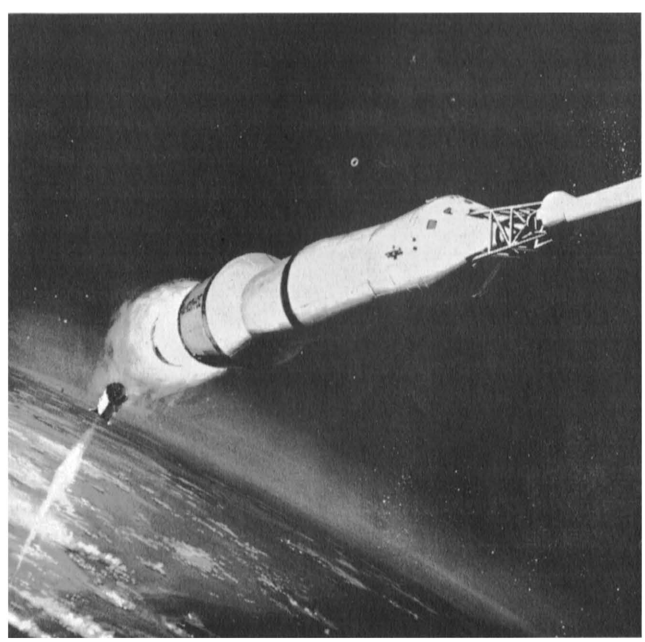
There the Saturn V stages will be mated on a 70-foot-high platform, the spacecraft components placed on top, and the entire configuration will undergo a final checkout.

Then the crawler-transporter will move under the platform, jack itself up under the enormous weight and ease out the 455-foot-high door of the building to start the three-mile journey to the launch pad. As it leaves the building the crawler will move down a five degree ramp to the crawlway with hydraulic jacking cylinders constantly adjusting the level of the platform to within one-tenth of a degree of horizontal.

The crawler, itself, is an almost unbelievable vehicle. When completed it will be 131 feet long, 114 feet wide and 20 feet high. It will have a truck at each corner with double treads and weigh about 3,000 tons. The crawler will be powered by two 2,750-horsepower diesel engines and will move to the pad at a speed of about



THE FOLLOWING SERIES of artist's conceptions portray major milestones of the planned lunar landing mission. Picture 1 shows the liftoff of the mighty Saturn-Apollo configuration from the Merritt Island, Fla., launch complex.



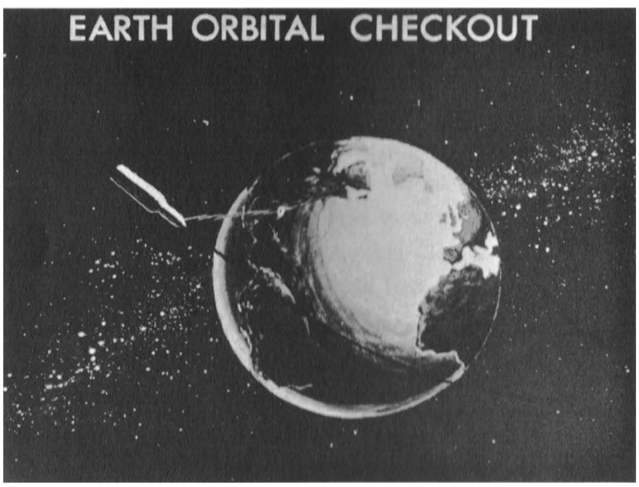
Picture 2 shows the separation of the S IC stage as the lunar bound vehicle is propelled toward its earth-orbital insertion point.

one mile per hour. Total weight of the crawler and the Saturn V configuration will be about 9,000 tons.

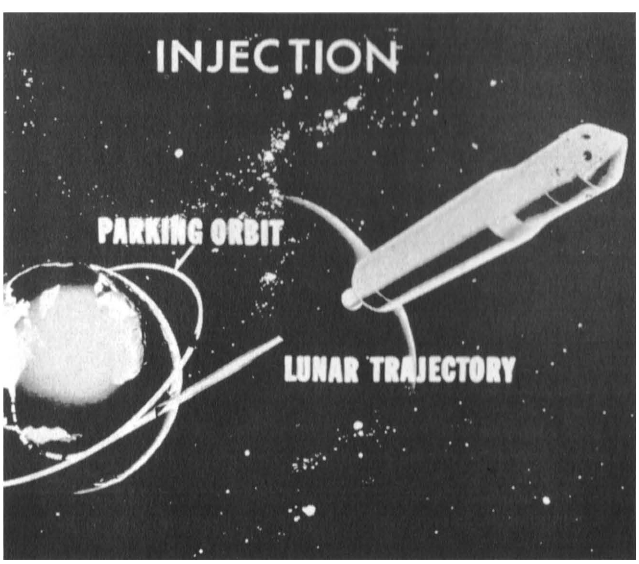
Towering over the Saturn-Apollo in the Assembly Building, and remaining alongside it until launch time will be a 450-foot-tall mobile umbilical tower.

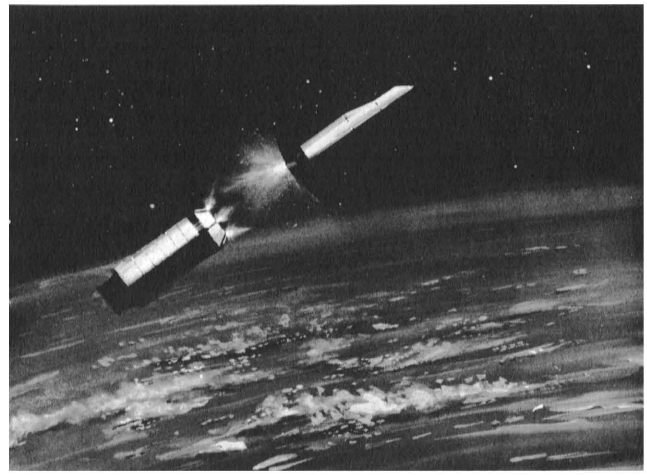
*At liftoff, the five stage one engines with a total of 7,500,000 pounds of thrust will propel the 6,000,000-pound vehicle spaceward. About three minutes later the first stage engines will burn out and then be jettisoned. The second stage engines will be ignited and the one million pounds of thrust will continue to propel the S-IVB stage and the payload toward an orbital insertion point. Shortly after the ignition of the second stage engines the escape tower will be jettisoned.

At burnout of the second stage engines, the one engine of the S-IVB will be ignited to provide sufficient impetus to place the payload into the desired earth parking orbit, then that engine will be shut off. The crew and the flight controllers on the ground will check all systems and determine the proper time and place to again fire the S-IVB engine to inject the spacecraft

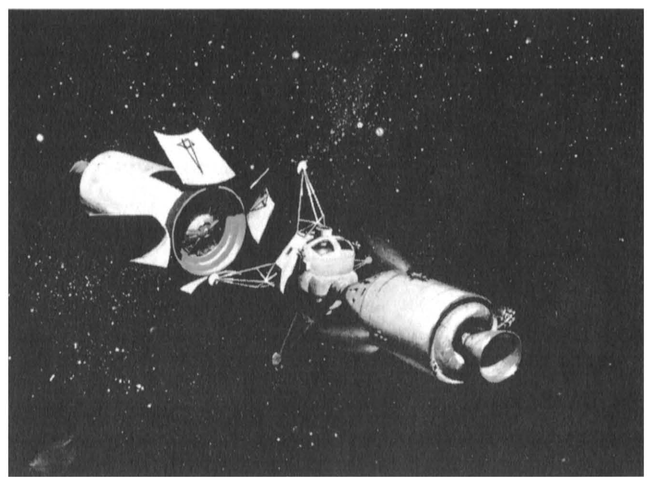


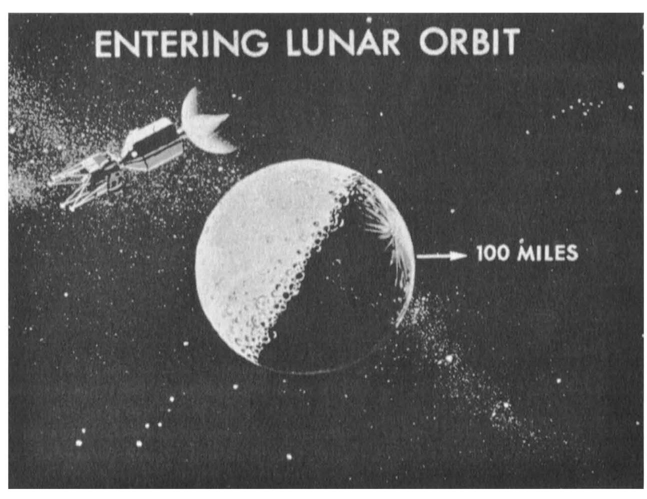
Pictures 3 and 4 show the spacecraft and S IVB stage in an earth orbit while all systems are checked out both by the flight crew and by ground personnel and the ultimate insertion into a lunar trajectory.





Picture 5, above, shows the separation of the Apollo command and service modules from the S IVB stage after insertion into the lunar trajectory has been achieved. Picture 6, below, portrays the nose-to-nose docking of the command and lunar excursion modules after the command module has completed a turnaround maneuver.





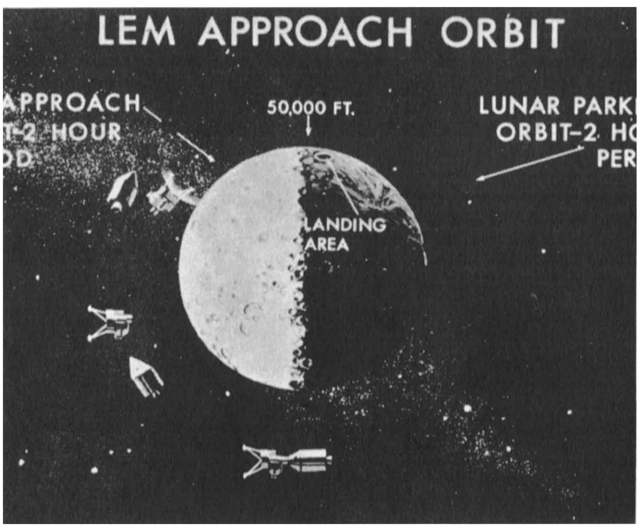
Picture 7 depicts the Apollo spacecraft with the engine of the service module firing to provide a necessary retrofire condition to place the configuration into a lunar orbit.

into the desired translunar trajectory. This will accelerate the spacecraft to the necessary escape velocity of about 25,000 miles per hour.

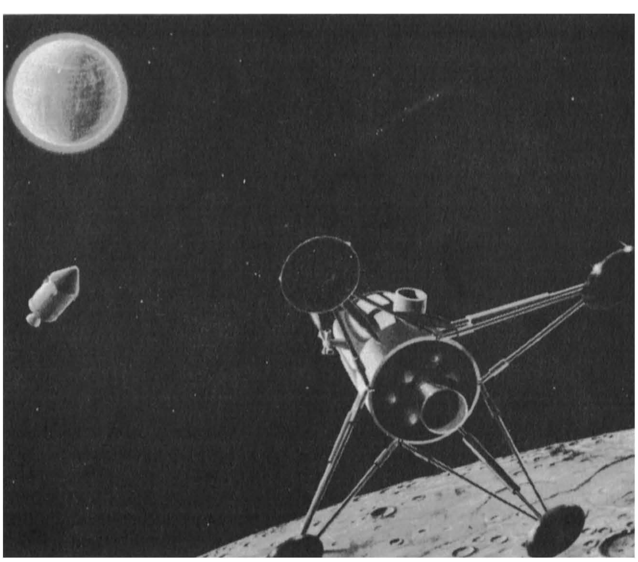
*After the trajectory has been established, the command and service modules will be separated from the adapter and following a free maneuver, by using the service module control thrusters, the command module will dock with the hatch of the LEM. The S-IVB stage will then be jettisoned and the three spacecraft modules will continue in a coasting maneuver toward the moon.

By use of information furnished by the ground and onboard guidance and navigation, up to three midcourse corrections may be made in order to assure a satisfactory lunar orbit.

The service module engine, with its 22,000 pounds thrust, will be ignited in a retrofire maneuver to place



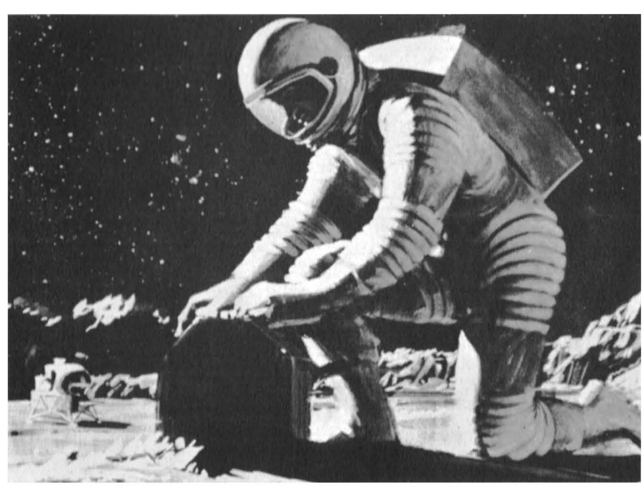
Picture 8, above, shows the scheduled activities prior to the descent of the lunar excursion module to the moon. Below, picture 9 shows the artist's conception of the descent of the LEM.



the spacecraft in a 90-statute-mile circular orbit around the moon.

*Two of the astronauts will enter the LEM through the hatch and check to determine that all systems in that part of the craft are in working condition. After one or two orbits around the moon, the descent phase will be started. It is expected that this maneuver will be initiated when the spacecraft is 180 degrees from the planned landing area. The LEM will be in a

Picture 10 shows a model of the LEM on a model of a small portion of the moon. The lunar area shown is based on the final camera picture transmitted by the Ranger VII spacecraft before it crashed into the lunar surface.



Picture 11 shows an astronaut performing scientific research on the lunar surface, with the LEM spacecraft visible in the background.

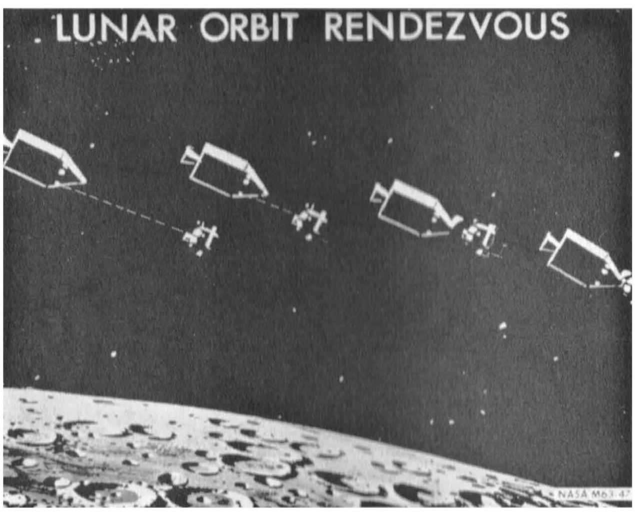
coasting mode and when it is about 10 miles above the lunar surface a burn of the descent engine will be made to bring the LEM down to a hover point several hundred feet above the surface. The pilot will then manually control the spacecraft to the final touchdown on the surface.

*After the touchdown, the crew members will check all the systems to make certain there has been no damage during the lunar landing. They will determine if there is any factor which might hinder the LEM in performing a successful ascent. The crew will then prepare for one of the astronauts to leave the LEM and perform the lunar exploration. These preparations will include surveying the surrounding lunar landscape, checking the LEM hatches, and performing a final check on the Portable Life Support Systems. All equipment in the LEM not required for the lunar stay will be turned off.

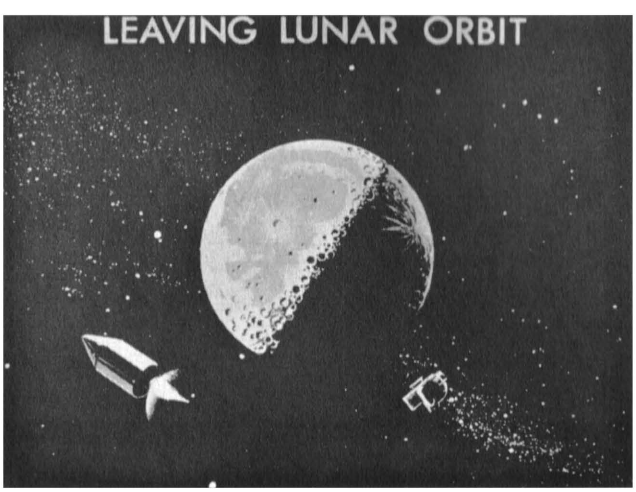
At this point, the cabin of the LEM will be depressurized briefly, and one of the astronauts will leave the spacecraft. The exterior of the vehicle will be checked by the exploring astronaut and a television system used to send pictures back to earth.

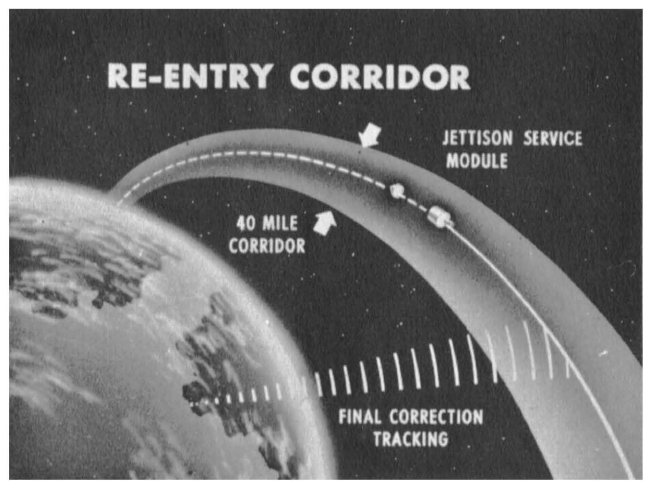
Photographic records will be made and samples from the lunar surface and subsurface collected. The astronaut outside the LEM will be in direct voice contact with the crew member who remains inside. The Portable Life Support System must be replenished after about three hours, and the life support stores onboard will permit six refills.

*Upon completion of the lunar surface operation, the astronauts will prepare the LEM for the launch and ascent phases of the mission. They will completely check out all subsystems. The navigation and guidance subsystem and the backup guidance section of the stabilization and control subsystem will be aligned. The LEM position in relation to the orbiting command and service modules will be determined. Since the

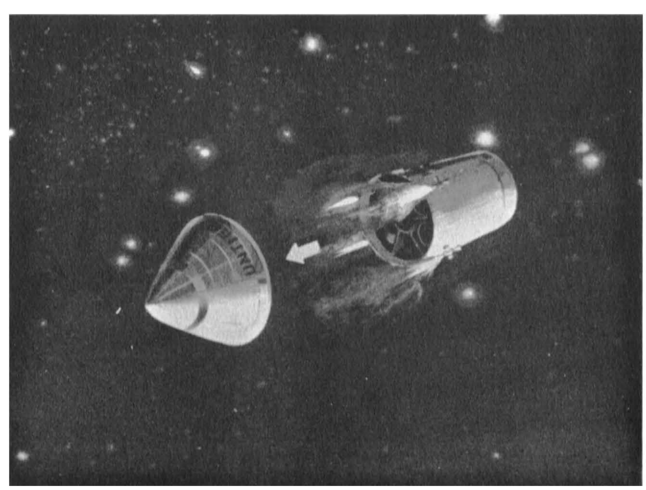


Pictures 12 and 13 portray the LEM closing with the mother craft in the lunar orbit rendezvous phase of the mission and the command and service modules entering a trans-earth trajectory for the return trip, leaving the LEM as an orbiting lunar satellite.





Picture 14, above, presents a graphic description of events which will occur shortly before the Apollo spacecraft re-enters the earth's atmosphere in the designated corridor for safe return. Picture 15 shows an artist's conception of the service module being jettisoned after the final trajectory corrections have been made.



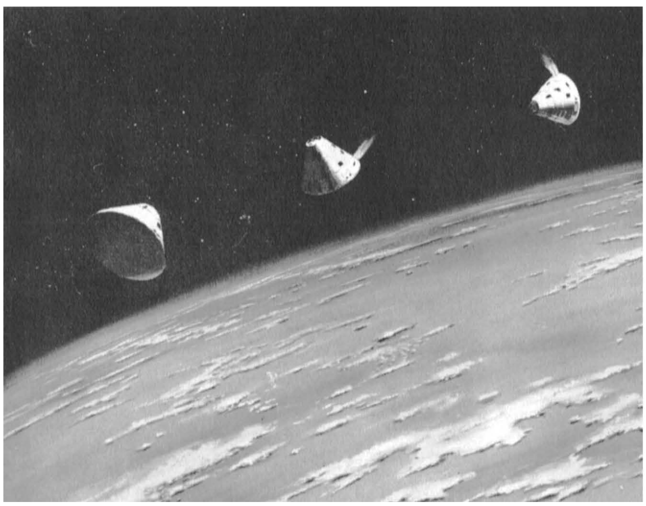
LEM descent stage will be left behind at launching, all connections between the two stages will be severed and the LEM will be ready for launch from the lunar surface for its rendezvous.

It is planned that the LEM will ascend to about 50,000 feet. It will stay in a parking orbit at that height until the proper time to again fire the ascent engine, on a trajectory to place it within rendezvous range of the command and service modules. The rendezvous phase will begin when the two spacecraft are about 20 miles apart. When the LEM closes to about 500 feet from the spacecraft, the pilot will manually bring the LEM into the correct docking attitude and adjust the rate of closure until the docking is complete.

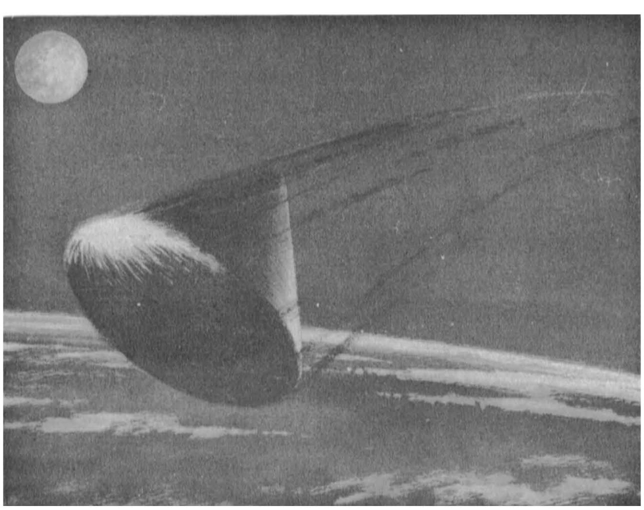
At this time, the pressure in the LEM and command module will be stabilized; the returning astronauts will turn off the LEM systems, transfer the scientific samples into the command module, and prepare for the return to earth.

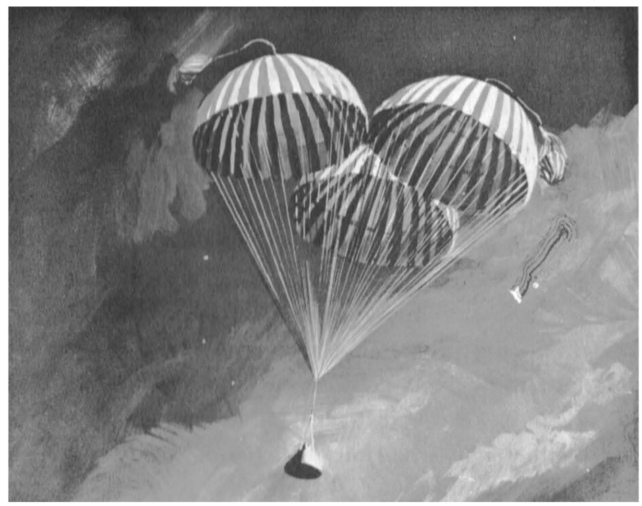
*The LEM will be jettisoned to remain in lunar orbit and the service module engine will be fired to give the spacecraft the necessary speed to take the spacecraft out of lunar orbit and into an earth trajectory. As on the outward journey, several midcourse corrections may be made again by firing the service module engine. The crew will monitor the spacecraft systems, make navigational "fixes," and carry out required scientific experiments and observations. Before reentering the earth's atmosphere the service module will be jettisoned.

The increased pull of earth's gravity will result in an increase in speed to about 25,000 miles per hour as the command module approaches the atmosphere. The crew will use the reaction control system to maneuver

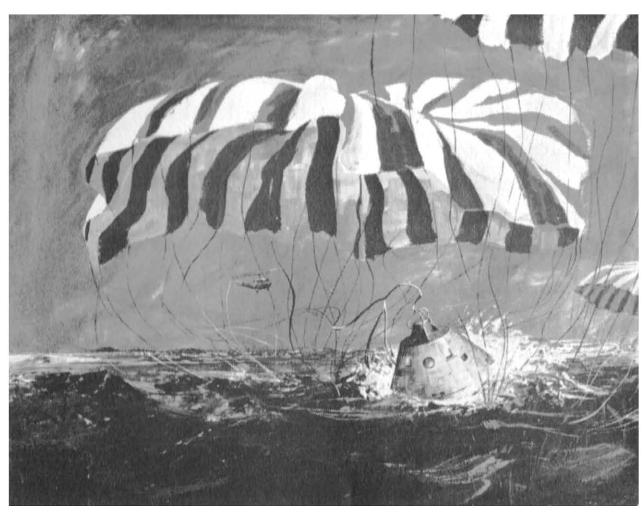


Picture 16, above, shows the maneuver following the service module jettison action which will orient the command module in a blunt end forward attitude for the re-entry and landing phases of the mission. Picture 17 presents an artist's conception of the manner in which the heat load will build up on the blunt end of the spacecraft during re-entry.





Picture 18 shows a sight which will be most welcome to the returning astronauts — three beautiful parachutes deployed and filled with air to lower them slowly to the water. Picture 19 shows the actual impact as the lunar mission reaches its final stages. All that remains after this time is recovery and the postflight debriefings and ceremonies.



the spacecraft into a blunt end forward attitude for the reentry period. This will take care of the heating situation as well as decrease the velocity to the required reentry speed. It is believed that the heat will approach 5,000 degrees on the blunt end during this phase of flight.

The forward compartment heat shield will be jettisoned at about 50,000 feet. Drogue chutes will be deployed at about 25,000 feet, and the three main chutes will be deployed at about 15,000 feet. This will permit the spacecraft and its occupants to land at a speed of 24 feet per second. At this point, the recovery forces will go into action and locate and retrieve the astronauts and the spacecraft.

FLIGHT OPERATIONS CONSIDERATIONS

During the period the launch vehicle and spacecraft were undergoing their design, fabrication, and testing periods, flight operations personnel have been busily engaged in developing plans for controlling both the earth-orbital and lunar-landing missions. They have developed criteria for mission operations for all phases of both the earth-orbital and lunar missions.

This has involved many problems, and a number of detailed mission and trajectory analyses have been completed in order to arrive at an operational mission that is within the capabilities of the spacecraft systems. To add to the problems, the overall operational plan not only must be able to meet the specific mission objectives but also must be flexible enough to handle any contingency situations which might occur during the mission.

A close check has been maintained during the design and testing phases of the spacecraft as far as defining the limitations of the spacecraft systems. When such limitations have been recognized the operational plan has been reevaluated and modified as necessary.

The most important aspect of flight operations planning—to insure that the mission will be under control at all times—has been the establishment of mission rules. Mission rules are, in effect, a restatement of the systems and operational constraints and generally define the mission profile and trajectory limits as well as network and communications requirements.

In order to provide effective flight monitoring and support capability at the Mission Control Center, comprehensive computer programs must be devised. They must have enough flexibility so that deviations from the normal mission progress can be evaluated rapidly through manual interrogation of the computer. Extensive preparations of standard flight procedures are being made so that if contact with the ground network fails, independent action on the part of the crew will insure their safe return.

The Apollo flights will be controlled, after launch, from the Mission Control Center at MSC, Houston, Texas. A centralized group of flight control personnel will maintain contact with the Apollo spacecraft through a network of remote sites. These sites will consist of fixed sites, ships, and aircraft located to provide timely support of the mission. The fixed sites consist of both deep space communications sites and near space communications sites. Present plans call for the near space sites and the ships to utilize 30-foot dishes, while the three deep space sites—Goldstone, California; Madrid, Spain; and Canberra, Australia - will have 85-foot dishes. It is expected that five tracking ships will be used during the lunar missions. During and immediately following the S-IVB injection thrust, eight or more aircraft will be used to record voice and telemetry. These aircraft will also provide an automatic voice relay to the flight control team.

The near space sites will serve as the information link to the Apollo spacecraft from liftoff to separation from the S-IVB stage. This will occur about one hour after the spacecraft has been injected into its translunar trajectory. During this time period, the critical maneuvers of the command and service modules' separation, transposition, and docking with the LEM also will have been completed. The deep space sites will come into effect by that time, or before, and will serve as the communications link from that point on through the remainder of the mission until the spacecraft reaches about the same distance on the return trip. At this time, the near space stations will again become the primary link.

The four basic systems in the Mission Control Center are the Display/Control System, the Real Time Computer Complex, the Communications System, and the Simulation, Checkout and Training System. The primary functions of these systems are as follows:

*The Display/Control System will be used to present flight controllers in MCC pertinent information on Apollo flight dynamics, spacecraft status, and crew status. Although standard display devices such as plotboards and chart recorders are used in some areas, the heart of the system is closed loop television. The TV display derives its inputs from a computer, a reference slide file, and cameras. The TV presentation is utilized in both the individual consoles and in summary displays used to present information on vital systems to the flight controllers.

*The Real Time Computer Complex (RTCC) will be used to perform the lunar trajectory computations during the flight. The computed results will be compared with the nominal trajectory. Necessary velocity changes will be recommended, based on real-time trajectory analysis, which will take into consideration the operational constraints appropriate to the current stage of the mission. The computer will also generate messages to the spacecraft for periodic up-dating of the guidance and navigation system. This computer complex also will serve the Display/Control System by performing telemetry data processing, TV image generation, display slide filing, and mission data storage and summarization. The RTCC is located on the first floor of the three-story Mission Control Center. It consists of four IBM 7094 computers which can be used in any combination. Supporting a lunar mission will require full use of at least one computer. A second computer, required as a dynamic standby, loaded with the identical program, will operate in parallel with the computer supporting the mission.

*The Simulation, Checkout, and Training System provides a facility for several flight controller activities. It is used to develop operational procedures, to establish confidence in the readiness of the operational facilities, and to train flight controller personnel. The total training simulation program includes familiarization with the spacecraft and ground systems through personal study, formal lectures, and training time in a procedures trainer. Also, team training in operating

AN OVERALL VIEW OF the Mission Operations Control Room in the Mission Control Center, Houston, Texas, during the Gemini 4 mission. This and another identical control room in the building will be used to control the Apollo flights.

procedures both within a remote site and with the entire network is conducted.

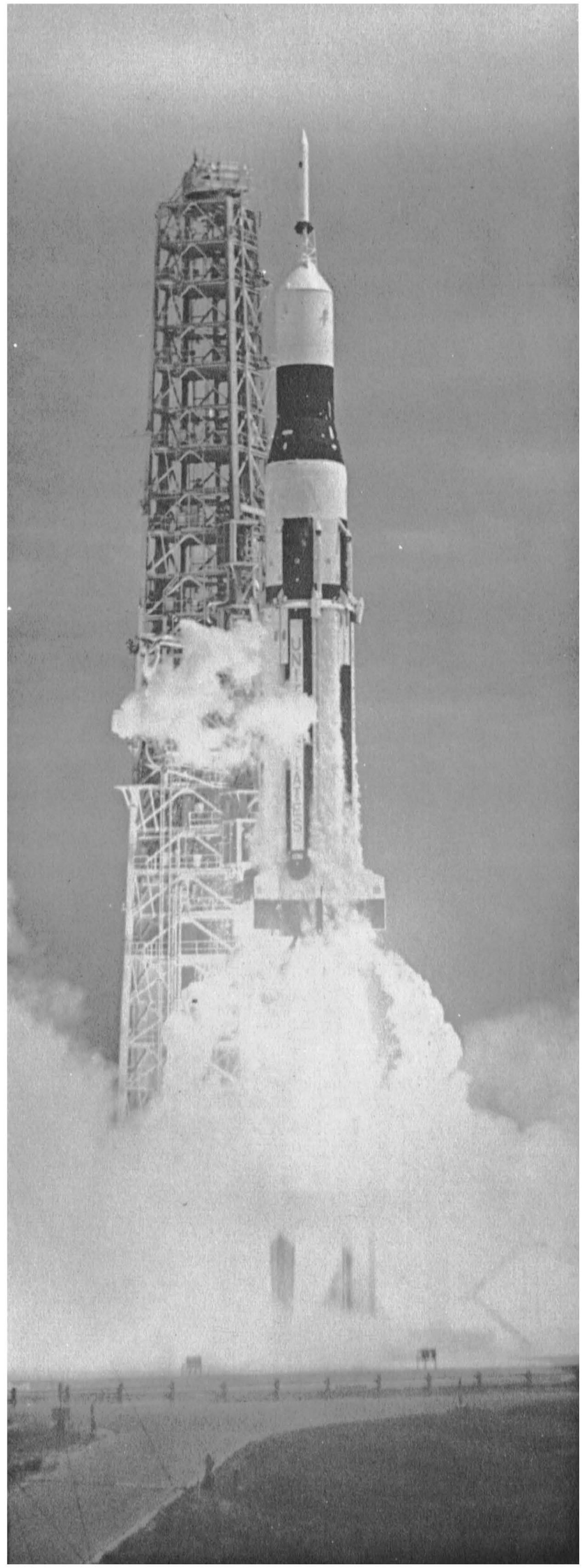
*The Communication System in MCC consists of various data systems such as telemetry, up-data, and voice, and a communications processor through which most of these data flow. The processor consists of two Univac 490 computers. Primary functions of this system are to perform line switching and data routing, to detect data transmission errors, and to make a record of the information it processes. One of the computers will serve as a dynamic standby during the mission.

Due to the nature of the Apollo missions, additional problems have been presented to those in the recovery phase of the operation, and it has been necessary to develop improved location and recovery techniques.

There are two planned primary landing locations currently considered for the Apollo missions. One area is in the northern hemisphere and the other in the southern hemisphere at the corresponding latitude. In general, the reentry ranges will be restrained to within 1,200 to 2,500 nautical miles in order to be within undershoot control and maximum heat parameters. Additionally, the ground track inclination to be used will be such as to constrain the landings to the warmer latitudes.

Recovery forces must be prepared to locate the spacecraft anywhere within the prescribed landing area. In order to do this, two methods of location will be utilized. First, is to take advantage of the existing tracking network which includes both land and ship stations. The second method will be to utilize airborne tracking systems. A number of long-range aircraft, with special electronic equipment onboard, will be positioned in the planned landing areas. This equipment is capable of receiving both telemetry and voice transmissions from the spacecraft and can determine the angle but not the range. Therefore two or more of these aircraft will be needed to record the transmissions in order to obtain a "fix" on the spacecraft and thereby locate the point of landing.

The search aircraft, in addition to location capabilities, also can assist the crew after location. Pararescue personnel capable of rendering medical aid, if necessary, can be deployed, and flotation equipment will be dropped and attached to the spacecraft. If it becomes necessary for the aircraft to leave the area before the arrival of the retrieval ship, it will drop additional electronic mark buoys before departing, to assure relocation of the spacecraft by other search aircraft which will "stand by" until the arrival of the retrieval ship.



THE LIFTOFF of the Saturn Apollo 7 from the pad at Cape Kennedy, Florida, shows the power of the huge rocket. Apollo boilerplate command and service modules formed the payload.