

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE, NAVIGATION
AND CONTROL

MIT INSTRUMENTATION
LABORATORY

CAMBRIDGE 39, MASSACHUSETTS

PROGRAM FOR MIT COMMUNITY CONVOCATION - 13 FEBRUARY 1969

Howard Johnson, President

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BACKGROUND
on the
GUIDANCE AND NAVIGATION SYSTEM
for the
PROJECT APOLLO SPACECRAFT

SYNOPSIS

For Project APOLLO, the U. S. effort to send men to the moon and back, the Instrumentation Laboratory, Massachusetts Institute of Technology, under contract to the Manned Spacecraft Center, National Aeronautics and Space Administration, Houston, Texas, has several roles. These include:

- (1) Conception, design and development of the guidance, navigation and control systems used both in the APOLLO command modules and the APOLLO lunar modules.
- (2) Support to NASA in monitoring systems from production through testing through spacecraft installation through launch from Cape Kennedy to ensure achievement of mission flight objectives.
- (3) Development of the programs for the on-board guidance and navigation system computer for each APOLLO mission.
- (4) Generation of test procedures for G&N at the Kennedy Space Center, Cape Kennedy, Fla., during checkout and prelaunch countdown including the generation of data for computer initialization prior to launch.
- (5) Support for mission controllers at Cape Kennedy and at Houston, Texas, during missions to assist in solving problems if they arise. Support is provided by engineers at the two locations and by engineers at the Laboratory in contact with the control centers via restricted telephone lines.

- (6) Analysis of post flight data to determine system and spacecraft performance following a mission.
- (7) Training of APOLLO crews in the general principles of space guidance and navigation, in the use of the APOLLO G&N systems in general, and, by using simulation devices, in carrying out specific mission segments as programmed in the flight computers.

The Laboratory's contributions to APOLLO are primarily conceptual, intellectual, educational. All production is carried out by private industry working under direct contracts from the National Aeronautics and Space Administration. MIT receives no fee for the APOLLO work or for any of the numerous other programs carried out by Instrumentation Laboratory on behalf of the federal government.

THE SYSTEM CONCEPT

The guidance and navigation system three APOLLO astronauts use to steer their way to the moon and back is self-sufficient, flexible and makes maximum use of the capabilities of both man and machine.

The system is self-sufficient in that it can be programmed to perform, on board and in flight, all guidance and navigation functions for an entire mission, including aborts, with no aid from the ground. There is present, however, a redundant operational capability from the ground via tracking networks and radio links.

The system is flexible in that it can be used in alternative ways and modes to accomplish the complex task of guiding and navigating men to the moon and back. For example, in-flight modifications in flight plans and trajectories are easily accommodated if necessary.

By coupling what men do best (pattern recognition in sighting stars and landmarks, decision making, etc.) with what machines do best (tedious and repetitive computation, high-speed switching, etc.) the engineers and scientists responsible for design were able to evolve a system that offers the crew many operational options and aids in carrying out their mission efficiently.

36,000 words. Erasable memory, with a capacity of 2,048 words, consists of ferrite core planes. The processor portion is formed from integrated circuits. Total computer weight is 65 pounds.

Astronaut and computer communicate in a number language via the DSKY (pronounced disk and standing for "display and keyboard"),--a 21-digit character display and 19-button keyboard. Two-digit numbers represent programs, verbs and nouns. Five-digit numbers stand for data such as position, velocity, etc. The astronaut punches data and commands into the system. These are displayed to him for verification in counter-type read out windows. The computer communicates with the astronaut by displaying readout numbers in the same windows. (When the computer requests the astronaut to take some action, the numbers flash in a periodic way to attract attention.)

Two other sub-units complete the system. The Power Servo Assembly (PSA) converts power from the spacecraft main power supply into various required currents and frequencies and amplifies servo-mechanism signals. The coupling and display unit (CDU) provides the signal interface between the computer and the angles associated with the IMU and optics. The CDU is electronic; the astronaut commands the IMU and optics through the computer.

The command module G&N system and the lunar module G&N system are almost identical, except that in the lunar module system the telescope is somewhat different than the one in the command module and there is no sextant.

The industrial team which produces the systems is headed by AC Electronics Division of General Motors Corporation, Milwaukee, Wis. As prime contractor to NASA, AC Electronics is responsible for manufacturing, assembly, testing, and subsystem integration.

Subcontractors to AC Electronics for major subsystems are Space and Information Systems Division, Raytheon Co., Sudbury, Mass., for the digital computer, and associated display keyboards and Kollsman Instrument Corporation, Syosset, N.Y., a subsidiary of Standard Kollsman Industries, Inc. for the optical subsystem. Sperry Gyroscope Co., Great Neck, N.Y.,

supplies the accelerometers under a direct contract from NASA. This same industrial team provided industrial support for the MIT design and development effort.

THE SYSTEM SOFTWARE

A major part of the APOLLO effort at Instrumentation Laboratory is the development of the flight guidance computer programs for each APOLLO mission. The fixed core rope memory units in the computers consist of tiny nickel-iron cores woven together by copper wires rope-fashion and encapsulated in plastic by the computer manufacturer, the Raytheon Co. The programs for each mission determine the core rope wiring sequence and, hence, programs for individual missions must be written and verified error-free before the memory units for the missions can be fabricated.

Developing and verifying the program for a particular mission requires, typically, about a year. NASA's Manned Spacecraft Center at Houston transmits to Instrumentation Laboratory a description of the functions that will be required of the G&N system. Working with MSC engineers, the Laboratory first develops a Guidance System Operations Plan (GSOP), a specification document sometimes three or four inches thick, which sets forth how the G&N system will perform its functions in careful detail and under all possible conditions.

The GSOP then is used to develop the mission program -- the sequence of coded instruction plus the library of needed basic information such as star charts and mathematical constants. Primary tools used in generating the program are powerful scientific general purpose computers. Updates and revisions in the program are made continuously to reflect alterations in the mission profile.

Verification of the programs to ensure that they will perform the missions as prescribed is an equally important task. This verification is carried out using general purpose computers. These include two Honeywell 1800s, two IBM 360/75s, and two SDS 9300s.

More recent programs, particularly those that are used in manned flight, are further verified using analog-digital hybrid computer techniques, command module and lunar module simulators, and actual flight computers. The Laboratory operates two analog-digital hybrids supplied by Beckman Instruments, Inc., Richmond, Calif.; one linked to a lunar module simulator, the other to a command module simulator. The hybrids simulate all APOLLO systems and all the dynamics of a particular mission. The mission program itself is operated on a "core rope simulator" developed at Instrumentation Laboratory. An actual flight computer is used for all other computer functions.

The same system of verifying the mission flight programs also is used to train the APOLLO crews in operating the G&N system during the missions to which they are assigned.

When a flight program is completed and verified, the general purpose computers are used to produce magnetic tapes which are forwarded to Raytheon for use in operating the machines that weave the core rope memories. A typical mission requires weaving tape and checker tape, the latter to ensure that the weaving corresponds precisely to the programmed instructions.

MIT engineers responsible for the programming effort began the practice of giving each mission flight program an identifying name. The practice was informal to begin with, but has since been adopted as official nomenclature associated with Project APOLLO.

The program that controlled an unmanned command module in the suborbital APOLLO flight test was called CORONA. Other programs are:

SOLARIUM	unmanned earth orbital command module flight program.
SUNBURST	unmanned earth orbital lunar module flight program.
SUNDISK	manned earth orbital command module flight program.
SUNDANCE	manned earth orbital lunar module flight program.
COLOSSUS	the flight program for the command module for manned flight to the moon.
LUMINARY	the flight program for the lunar module for manned flight to the moon.

LABORATORY APOLLO GROUP

The director and founder of the Instrumentation Laboratory is Dr. Charles Stark Draper, Institute Professor Emeritus and Professor Emeritus of Aeronautics and Astronautics. Dr. Draper is a former Head of the Department of Aeronautics and Astronautics and has been associated with MIT since he entered the Institute as a student in the early 1920s. He holds three MIT degrees -- S.B. 1926, S.M. 1928 and Sc.D. 1938.

Principal engineers in the Laboratory APOLLO group -- many of whom also hold degrees from MIT -- include Ralph R. Ragan (S.M. '52), Deputy Director for all NASA programs, and David G. Hoag (S.B. '46, S.M. '50) a Laboratory Associate Director who heads the APOLLO program specifically. Mr. Ragan earlier directed the Laboratory's design and development of the POLARIS missile guidance system for the U.S. Navy. Mr. Hoag was Technical Director of the POLARIS program.

Dr. Richard H. Battin (S.B. '45, Ph.D. '51), an Associate Director of the Laboratory, is APOLLO Technical Director for Mission Development and is an authority on astronautical guidance theory. John E. Miller (S.M. '59), another Associate Director, is the APOLLO Technical Director for mechanization of the G&N system. Eldon C. Hall (S.B. '53) leads the team which designed the flight computer and Lewis E. Larson, Jr. (S.M. '47), is Management Director in charge of the scheduling and financial aspects of the APOLLO Program.

Working under Mr. Miller in mechanization design are: Ain Laats, in charge of systems test; Jerry Gilmore (S.M. '67), in charge of the inertial subsystem; John Lawson, in charge of navigation sensors; Robert Crisp, in charge of electronics; and James Flanders (S.B. '53, S.M. '57), in charge of advanced programs.

Working with Dr. Battin in Mission Development is Norman E. Sears (S.M. '52). Flight computer programming is performed in Mission Development with: E.M. Copps, (S.B. '56, S.M. '59), in charge of support program development; W. Marscher, (S.M. '60), in charge of space guidance analysis;

D. Lickly, (S. M. '55), in charge of Guidance Programs; and J. L. Nevins, Jr. (S. M. '56), in charge of display and human factors. Dr. F. H. Martin, (S. M. '59, Sc. D. '65) is project manager for the COLOSSUS program; G. W. Cherry is project manager for the LUMINARY program.

THE MIT INSTRUMENTATION LABORATORY

The MIT Instrumentation Laboratory is no stranger to automatic guidance, navigation and control systems. In fact, work on manned spacecraft guidance and navigation was initiated at the Laboratory in early 1961 even before the Project APOLLO lunar effort was adopted as a major national goal. When President Kennedy announced this goal May 25, 1961, the Laboratory already had established the basic guidance and navigation concepts required and -- in response to federal request -- initiated a design and development program quickly.

Professor Draper pioneered the development of -- and, indeed, coined the name for -- inertial guidance and navigation systems for airplanes, ships, submarines, missiles, satellites and spacecraft in this country. Because of his work, Dr. Draper is often called the father of inertial guidance in the U. S.

MIT receives no fees or profits for the work the Laboratory does. Sponsoring agencies simply reimburse the Institute for the costs incurred in operating the Laboratory. As a national resource of talent and skill built up over the years at the request of sponsoring federal agencies, MIT makes the Laboratory available to help to the extent that it can in the achievement of national goals. The benefits that accrue to MIT are the educational contributions the Laboratory makes to the undergraduate and graduate educational programs offered by the Institute.

The Laboratory is an environment where graduate students, working under supervision of skilled faculty, engineers and scientists, may carry out thesis research leading to advanced degrees. In addition, Laboratory research generates new technology and knowledge for courses that are quickly incorporated into the regular Institute curriculum.

An illustration of the Laboratory's link to education is Dr. Draper himself. He was for many years both Head of the Department of Aeronautics and Astronautics as well as Director of the Laboratory. Scores of his students from the Department have performed their thesis research under his supervision at the Laboratory and have gone on to occupy positions of major responsibility in national defense and space programs.

Eight NASA astronauts hold MIT degrees. Of these, six earned degrees in Aeronautics and Astronautics through thesis research conducted at, or in connection with, the Laboratory. The six include: Lt. Col. David R. Scott (S.M. '62, Eng. '62), Lt. Col. Edwin E. Aldrin (Sc.D. '63), Russell L. Schweickart (S.B. '56, S.M. '63), Lt. Cmdr. Edgar D. Mitchell (Sc.D. '64), Capt. Charles M. Duke (S.M. '64), and Dr. Philip K. Chapman (S.M. '64, Sc.D. '67). Schweickart also was a member of the Measurement Systems Laboratory staff before becoming an astronaut. (Dr. Chapman was among 11 scientist-astronauts selected in 1967. Two other MIT men -- Dr. William B. Lenoir (S.B. '62, S.M. '62, Ph.D. '65) of the MIT Research Laboratory of Electronics and Anthony W. England (S.B. '65, S.M. '65) of the Department of Geology and Geophysics -- also are among the scientist-astronauts.)

The number of advanced degrees based on student research performed under the Laboratory's full spectrum of projects averages about 60 a year. During the three-year period 1964-67, MIT awarded 175 degrees which were based on thesis research at the Laboratory. These include 22 doctoral degrees, four engineer degrees, 131 master of science degrees and 18 bachelor of science degrees. During the period the Laboratory has been designing the APOLLO G&N system, 60 students have completed theses based on APOLLO-related research and leading to doctor of science, engineer, master of science and bachelor of science degrees. Students come not only from the Department of Aeronautics and Astronautics, but also from such other departments as Electrical Engineering, Mechanical Engineering, Physics and Mathematics. All three military academies annually send outstanding graduates to MIT for graduate study at the Instrumentation Laboratory.

New courses constantly evolve out of Laboratory research. The Department of Aeronautics and Astronautics has been teaching classes in guidance and control developed out of Laboratory research for more than 25 years. One of the early faculty members who began teaching courses based on Laboratory research was Dr. Robert C. Seamans, Jr. (M.S. '42, Sc.D. '51), formerly Deputy Administrator of NASA and now Secretary of the Air Force, who earned his own doctoral degree via thesis work at the Laboratory.

Professor Walter Wrigley (S.B. '34, Sc.D. '41), Laboratory educational director, began offering the first regular course in inertial guidance in the mid-1950s. Dr. Richard Battin, who heads the Laboratory group working out computer programs for APOLLO missions, also teaches a course in astronautical guidance. In all, more than 20 different courses, now a regular part of the MIT curriculum, have grown out of the research projects carried out at the Laboratory.

Dr. Draper started the Laboratory just prior to World War II to develop lead-computing gyroscopic gunsights for Navy anti-aircraft guns. His Mark 14 gunsight was the first of its kind to reach the fleet and played an important role in naval engagements of World War II.

Toward the end of World War II, Dr. Draper and his associates developed gyro-stabilized gun-bomb-rocket sights for Air Force fighter planes and one of these saw extensive service in the Korean War aboard F-86 fighters.

Following World War II, Dr. Draper began applying knowledge of gyroscopic stabilization and feedback control to the original work done in this country on inertial navigation and guidance. Interest in this work actually originated with Dr. Wrigley's own doctoral thesis research supervised by Dr. Draper in the late 1930's.

Dr. Draper made his first inertial system transcontinental test in an airplane flight from Massachusetts to Los Angeles in 1953, demonstrating feasibility of such systems. Since then from the Laboratory have come designs and design concepts for many now-operational systems.

In APOLLO, as in all of its programs, the Laboratory works closely with government-selected participating contractors in developing system designs, fabricating prototypes, carrying out engineering design tests and supporting operational use. System production and manufacturing, of course, is performed by industry. Of federal funds expended for design, development, test and procurement of these systems, the bulk goes to the participating industrial contractors for manufacture and fabrication, and only a small portion to support MIT's design, test and operational support efforts.

- end -



Dr. C. S. Draper

NASA FACTS

AN EDUCATIONAL PUBLICATION OF THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NF-23/VOL. IV, NO. 7 *



Manned Space Flight : Apollo

Apollo is the third step in NASA's manned space flight program. Its goals:

- * To land American explorers on the moon and bring them safely back to earth.

- * To establish the technology required to meet other National interests in space.

- * To achieve for the United States pre-eminence in space.

Apollo was preceded by Project Mercury which pioneered the technology and man's capabilities for manned space flight and by Gemini which significantly extended the technology and experience gained through Mercury. Both Mercury and Gemini were programs in which astronauts test piloted spacecraft which were largely experimental. Apollo, on the other hand, calls for an operational spacecraft capable of carrying astronauts safely to and from another body in the solar system.

LUNAR ORBIT RENDEZVOUS

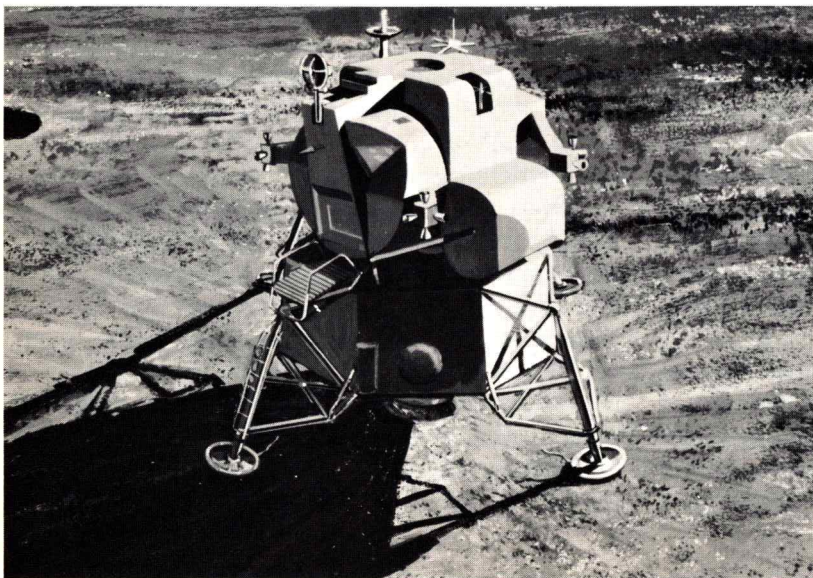
Three methods were considered to accomplish the manned lunar landing mission. They were: 1) direct flight of a full-size spaceship from the earth

to the moon and back, 2) launching two separate sections of a spaceship from earth into orbit, joining them together, and sending them as a single spacecraft to land on and take off from the moon; and 3) launching the whole spacecraft from earth to lunar orbit and landing a section of the craft on the moon while the other part waits in orbit for the landing craft to return.

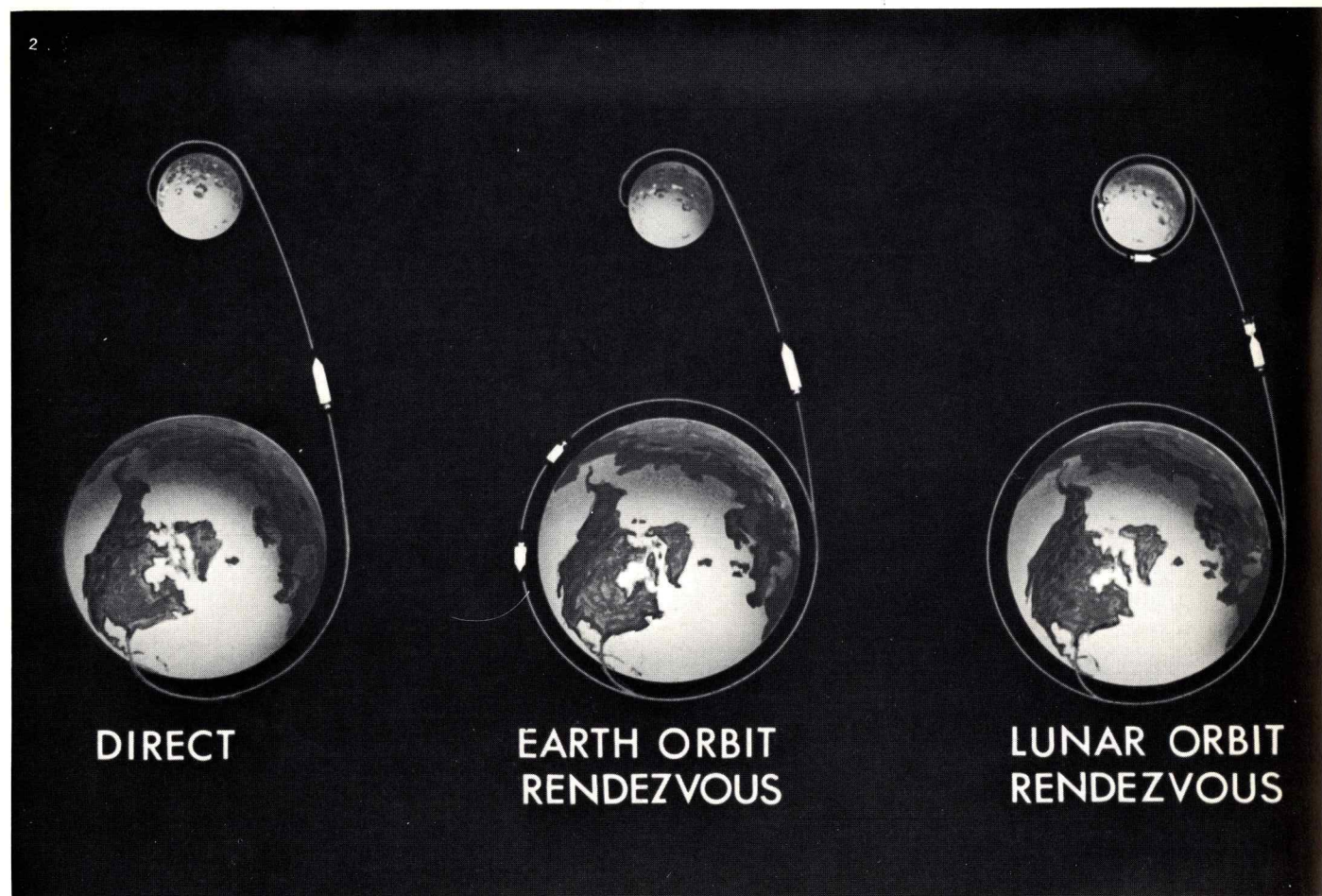
The third method, called lunar orbit rendezvous, was chosen after careful study. This method reduced significantly the rocket power required for landing on and taking off from the moon. Moreover, a craft using the earth-orbital rendezvous method (2) would weigh more than twice as much as the one using the lunar-orbit rendezvous method, mainly because of additional fuel.

APOLLO SPACECRAFT

The Apollo spacecraft assembly is 82 feet tall and weighs about 45 tons. It is composed of three modules (separable units or "blocks"), plus an adapter and a launch escape system (LES).



Lunar Module of Apollo spacecraft, piloted by two astronauts, moments after touchdown on the moon.



COMMAND MODULE

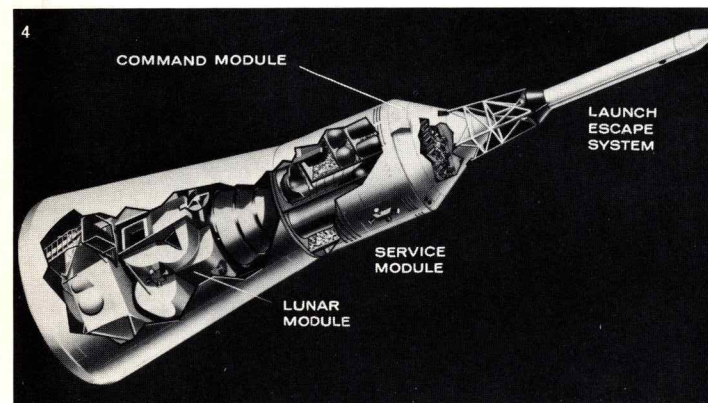
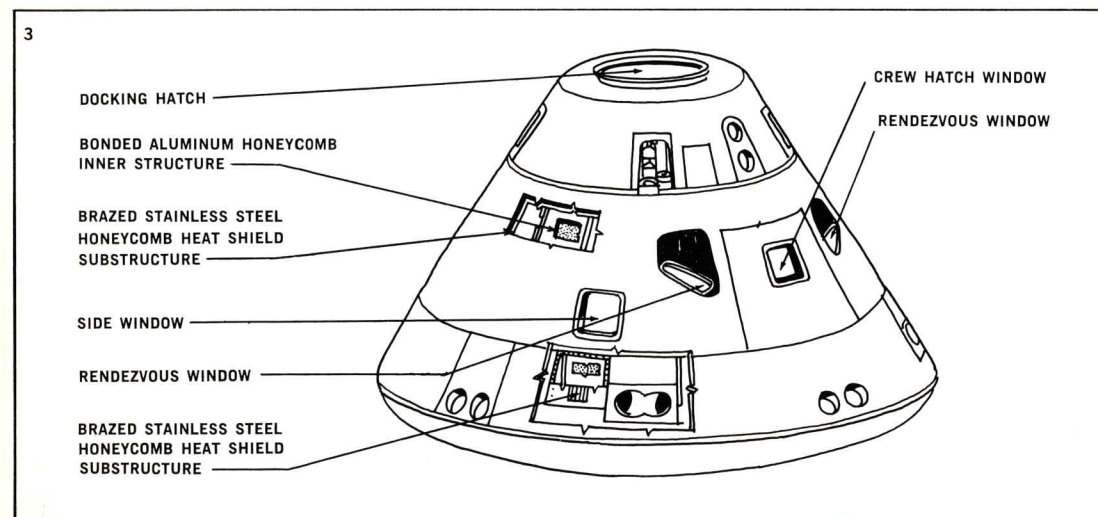
The Command Module (CM) is the only module which will return to earth from the lunar mission. It contains the crew's living compartment and all the controls for the various in-flight maneuvers. Similar in shape to a cone, this module has a bottom width of 13.8 feet and stands about 12 feet high. It consists of two shells: a pressurized inner crew compartment and an outer heat shield. Launch weight is about 12,000 pounds. More elaborately equipped for human comfort than either the Mercury or Gemini spacecraft, the Apollo CM contains a pilot cockpit for three astronauts. It has two side windows, a crew hatch window, and two rendezvous windows which face toward the nose of the CM.

The Apollo Environment Control System (ECS) is similar to that of the Gemini spacecraft. It supplies pure oxygen in the cabin at 5 psi (pounds per square inch), a temperature of approximately 75° with a humidity index between 40% and 70%.

LAUNCH ESCAPE SYSTEM

On top of the Command Module at launch is the Launch Escape System (LES) tower, with rocket motors similar to those used on the Mercury escape system. The LES is 33 feet tall and weighs about 8,200 pounds. With this tower and motors, the launch pad Apollo spacecraft (without its booster) has a total height of 82 feet. It is almost as tall as the combined Mercury-Atlas vehicle that placed John Glenn in orbit on America's first manned orbital flight in 1962.

The LES is designed to separate the command module from the rest of the launch vehicle should an emergency occur on the launch pad or shortly after lift-off. The system rockets the command module a safe distance away from the launch vehicle and to an altitude high enough for parachutes in the module to function for descent to earth. The LES is jettisoned about 35 seconds after ignition of the launch vehicle's second stage.



- 2 Techniques considered for the lunar landing mission.
3 Apollo Command Module.
4 Apollo spacecraft.

SERVICE MODULE

Beneath the Command Module at launch is the Service Module, a cylindrical unit 12.8 feet in diameter and 22 feet tall, weighing 55,000 pounds. It contains the spacecraft's electrical power supply equipment and its primary propulsion system, which produces 22,000 pounds of thrust. This stop-and-restart engine will be used for several important maneuvers while the spacecraft is moon-bound. It will also be used to slow the spacecraft to go into lunar orbit, to make midcourse corrections while earth-bound.

Having fulfilled all these functions during the round trip, the Service Module will be jettisoned prior to the Command Module's reentry into the earth's atmosphere.

ADAPTER

Under the Service Module, at launch, is the adapter section which connects the Apollo spacecraft to the third stage of the Saturn V launch

vehicle and serves as the housing for the Lunar Module (LM), the lunar landing vehicle.

The adapter section is a fairing 28 feet tall. It is 12.8 feet in diameter at the top to match the width of the Apollo spacecraft. At the bottom it flares out to a diameter of 22 feet in order to match the width of the Saturn V booster's third stage (S-IVB). Weight of the adapter section is about 4,000 pounds.

LUNAR MODULE

The Lunar Module (LM), which weighs approximately 35,000 pounds, is the flight unit that will detach from the orbiting Command and Service Modules and descend to the moon's surface with two of the three astronauts aboard. Called the "bug" because of its appearance, it has two windows that will serve as "eyes" for the landing maneuvers, a tubular "mouth" for entry and exit, and four spidery "legs" for steady support after lunar touchdown.

The LM has its own complete guidance, propulsion, computer, control, communications, and environmental control systems, all with at least one and sometimes two backup systems. These precautions are necessary because landing on the moon will be the lunar mission's most critical phase.

The LM's descent propulsion system has a throttle control—its rocket engine's thrust power can be varied from low to high (1,050 pounds to 10,500 pounds) in order to control the lunar touchdown flight with great precision. The pilots will use this engine to provide braking thrust for the moon landing.

The final descent can be slowed to 3 mph at an altitude of 15 feet, but if the LM should drop at twice this speed, its four jointed steel-truss legs can absorb the landing shock without harm to the craft or crew. The legs are also designed to land on slopes up to 12 degrees in slant, or to retain balance if one or two legs sink into a layer of dust as much as 12 inches deep.

The LM is a two-stage vehicle. The bottom stage contains the rocket engine and legs for lunar landing. For the return trip, this stage also serves as the "launch platform" for the upper stage, which includes the cabin for the astronauts and the ascent engine. The ascent engine propels the upper stage from the lunar surface for rendezvous and docking with the CSM (combined Command and Service Modules) which had remained in lunar orbit.

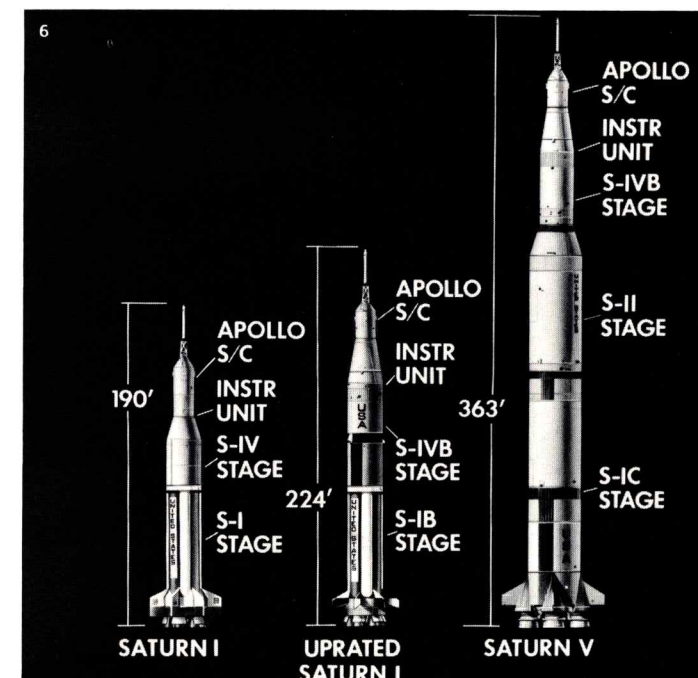
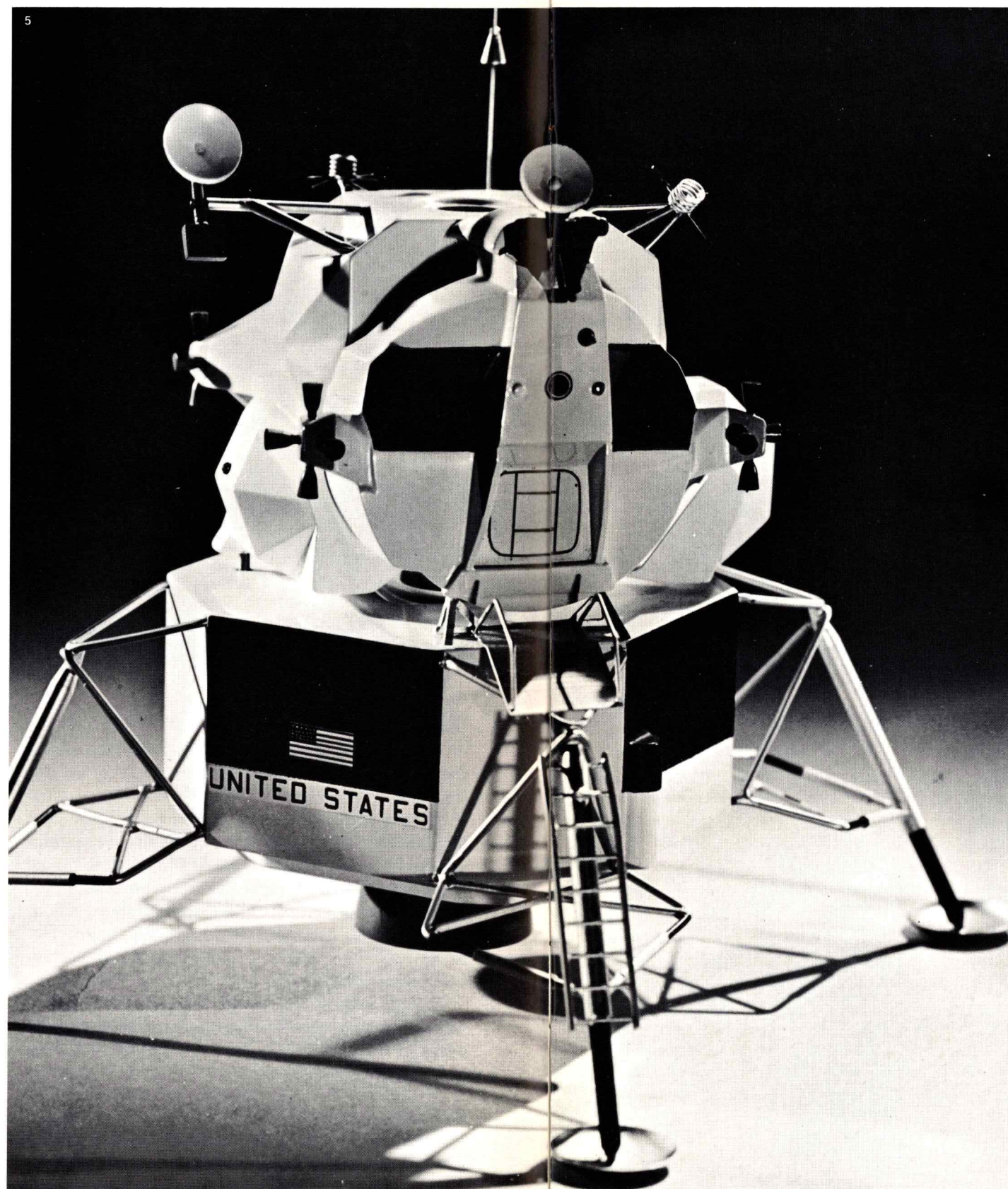
GUIDANCE AND NAVIGATION

The Apollo space navigation system includes two relatively conventional units—inertial guidance platform and flight pattern computer. A third unit is an optical space sextant with which the astronauts will take sightings of the earth, moon, and reference stars to check out their position before each maneuver.

ASTRONAUT WARDROBE

The Apollo crewmen will have a changeable wardrobe for wear at different times. On the trip, two of the men (in rotation with the third) may relax in their "constant wear garment," a two-piece, close-fitting garment which covers all the body except the head and hands.

The third man will be in the Apollo space suit, with "accordion" joints (bellows principle) for flexible ease in walking, bending, or moving his limbs, and a helmet that has a pivoted visor for

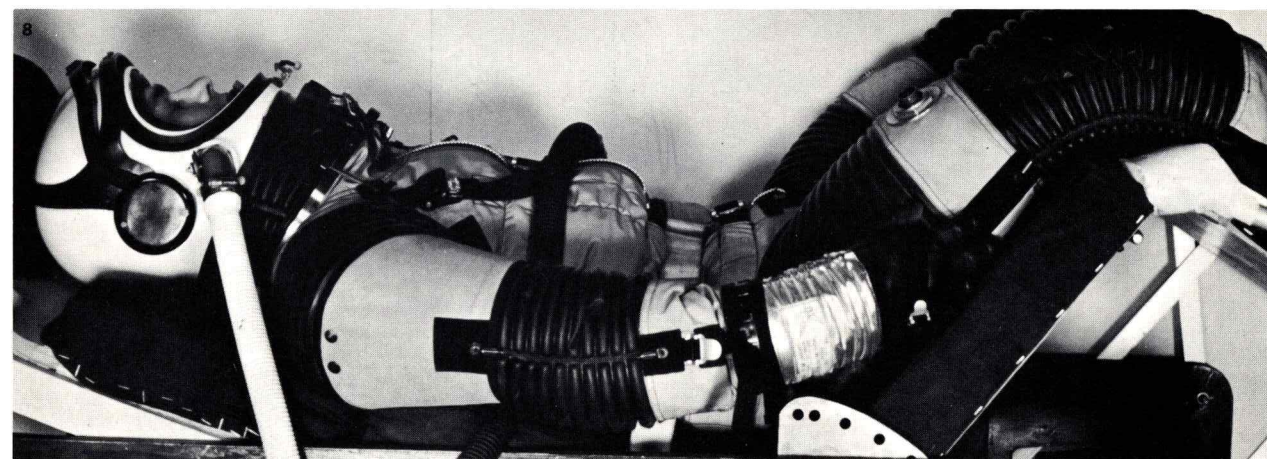


5 Model of Apollo Lunar Module.

6 The Apollo launch vehicles. (see text page 7)



7 Wearing an Apollo pressure suit and buoyed by apparatus that cancels out five-sixths of his weight, an engineer carries out an experiment in a simulated lunar crater.



8 Test of Apollo pressure suit.

quick closing and sealing.

The same type of space suit will be worn by the two LM astronauts who explore the moon. Underneath the pressure suit will be a special undergarment interwoven with a fine network of water-circulating tubes to carry away body heat. Covering the entire space suit will be a "thermal garment," or a white coverall with hood, to protect the astronaut from blistering sunshine on the airless moon. Finally, a "meteoroid cape" on his back will protect him from micrometeoroid dust which may rain down on the moon at high speed. Meteoroids that would penetrate the cape are calculated to be rare.

An important unit of the Apollo space suit system is the strap-on backpack for lunar exploration which includes a 4-hour oxygen supply, two-way radio, heat-dumping radiator, and dosimeter (radiation gauge). Partial radiation protection is built into the space suit fabric.

LAUNCH VEHICLES

The Apollo launch vehicles are the Saturn I, Uprated Saturn I, and the Saturn V.

(1) The Saturn I developed 1.5 million pounds of thrust in its first stage (S-1) through the clustering of eight H-1 rocket engines burning RP-1 (refined kerosene) and LOX (liquid oxygen). Its

second stage (S-IV) had six RL-10-A3 engines burning liquid hydrogen and LOX, producing 90,000 pounds total thrust. With a diameter of 21.5 feet and standing 125 feet tall (without spacecraft), this two-stage vehicle delivered a payload of 22,000 pounds into low earth orbit.

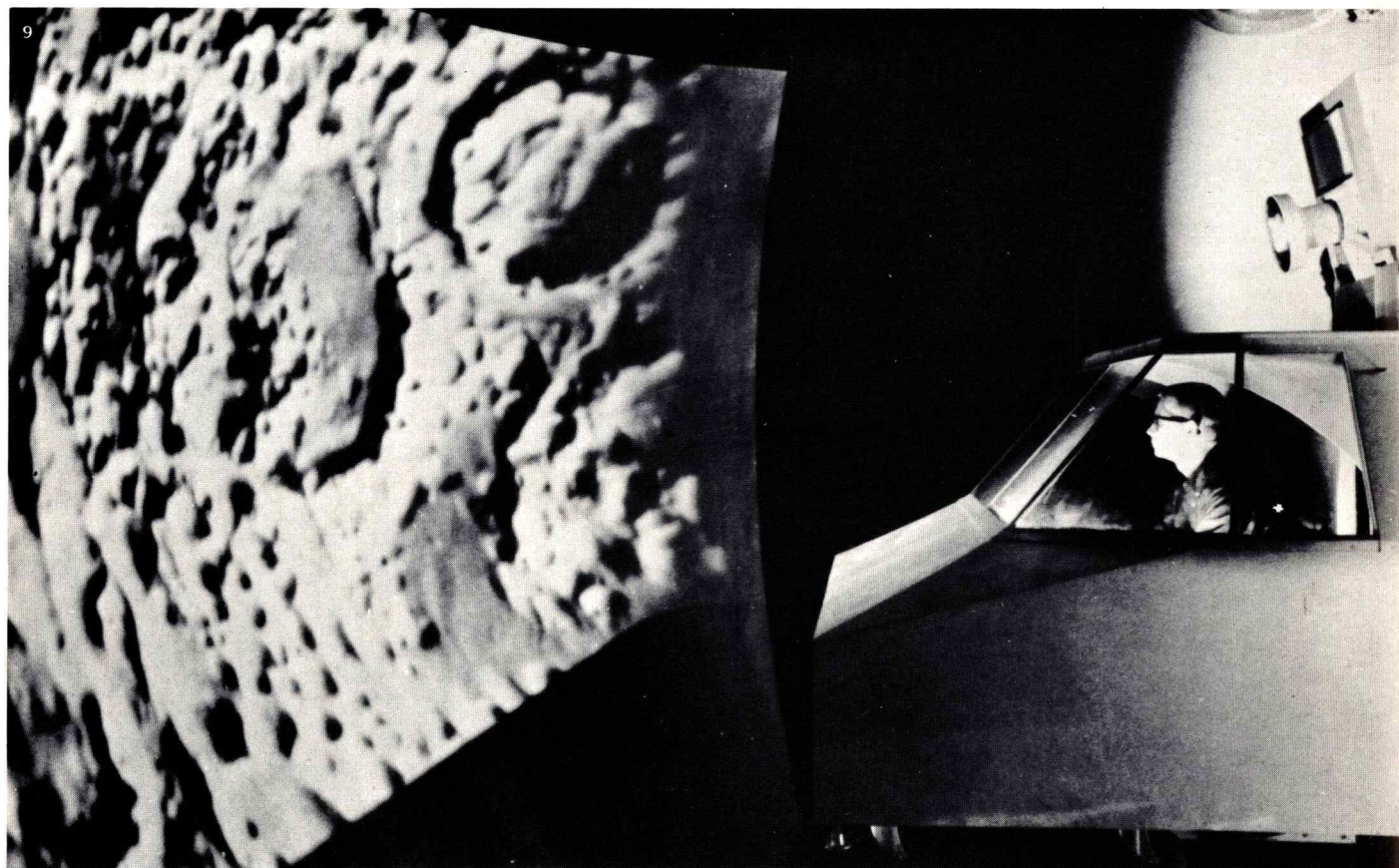
The Saturn I has placed the Command and Service Modules of the Apollo spacecraft into orbit in unmanned test flights and has been used to launch the Pegasus micrometeoroid technology satellites. The Saturn I program was completed in 1965 with ten successes in as many launches.

(2) The Uprated Saturn I has an improved version of the Saturn I first stage and a new and more powerful second stage—the S-IVB. The Uprated Saturn I is designed to launch the first manned Apollo flights into earth orbit.

The second stage (S-IVB) has one J-2 engine which burns liquid hydrogen and LOX and produces 200,000 pounds thrust. Low earth-orbit payload for the Uprated Saturn I is 40,000 pounds.

(3) The Saturn V is a vehicle of gigantic size and power. The first stage (S-IC) has a diameter of 33 feet and is powered by a cluster of five F-1 engines, each developing 1.5 million pounds of thrust, for a total of 7.5 million pounds.

The Saturn V second stage (S-II) has a cluster



9 Space flight simulator, with image of the moon on left, shows what man can and cannot do in controlling spacecraft during actual missions.

10 An Apollo-Saturn V test vehicle.



of five J-2 engines that furnish a total of 1 million pounds of thrust. The Saturn V's third stage (S-IVB) is identical with the Uprated Saturn I's second stage and produces 200,000 pounds of thrust.

This immense three-stage booster is 281 feet tall. The entire Apollo-Saturn V assembly will stand 365 feet high at the launch pad and will weigh 6 million pounds fueled before a moon flight. It will furnish the power to boost the Apollo Command, Service, and Lunar Modules into both manned earth orbital and lunar flights.

The mighty Saturn V launch vehicle will be able to launch 140 tons into a low earth orbit at a speed of 5 miles per second (mps), and accelerate 47.5 tons of payload to an escape velocity of 7 mps. This means that both the Apollo spacecraft and the Saturn V third stage will go into parking orbit, after which the S-IVB will re-ignite and add speed of 2

mps to send the spacecraft on its way to the moon.

UNMANNED MOON EXPLORATION

Three manned spacecraft programs are contributing to planning for manned landings by providing close-range pictures and other information about the moon. The first of these was Ranger, completed in 1965, which telecast close-ups of selected lunar areas before crashing as intended on the moon.

Another spacecraft is Lunar Orbiter which takes sharp close-range photographs of extensive areas from relatively low orbits around the moon. The photographs are being used primarily to select sites for manned landings. In a closely coordinated effort, Surveyor spacecraft are soft-landed on the moon to transmit pictures and other information about the lunar surface in their vicinity. These are coordinated with the broader overhead views provided by Lunar Orbiters.

TRAINING

Astronaut training for the Apollo program includes the "basic space training" of the Mercury and Gemini programs along with the new Apollo specialties which are added from time to time, among them:

- * "Moon Trips" in trainers that provide a realistic simulation of travel through space, descent to the moon, and return to earth.

- * "Lunar Obstacle Course," a 328-foot-wide simulation of the moon's rugged surface, complete with craters up to 50 feet wide and 15 feet deep, large boulders, a dust layer, and fissures over which to jump. A suspension harness reduces an astronaut's weight to the moon's value (1/6th earth weight).

- * "Space Suit Workouts," during which astronauts wear experimental Apollo pressure garments to practice walking, bending, opening of visor, and other operations.

MOON FLIGHT TRACKING SYSTEM

A network of tracking stations around the world was established for Project Mercury, augmented for Gemini, and redesigned and rebuilt for Apollo.

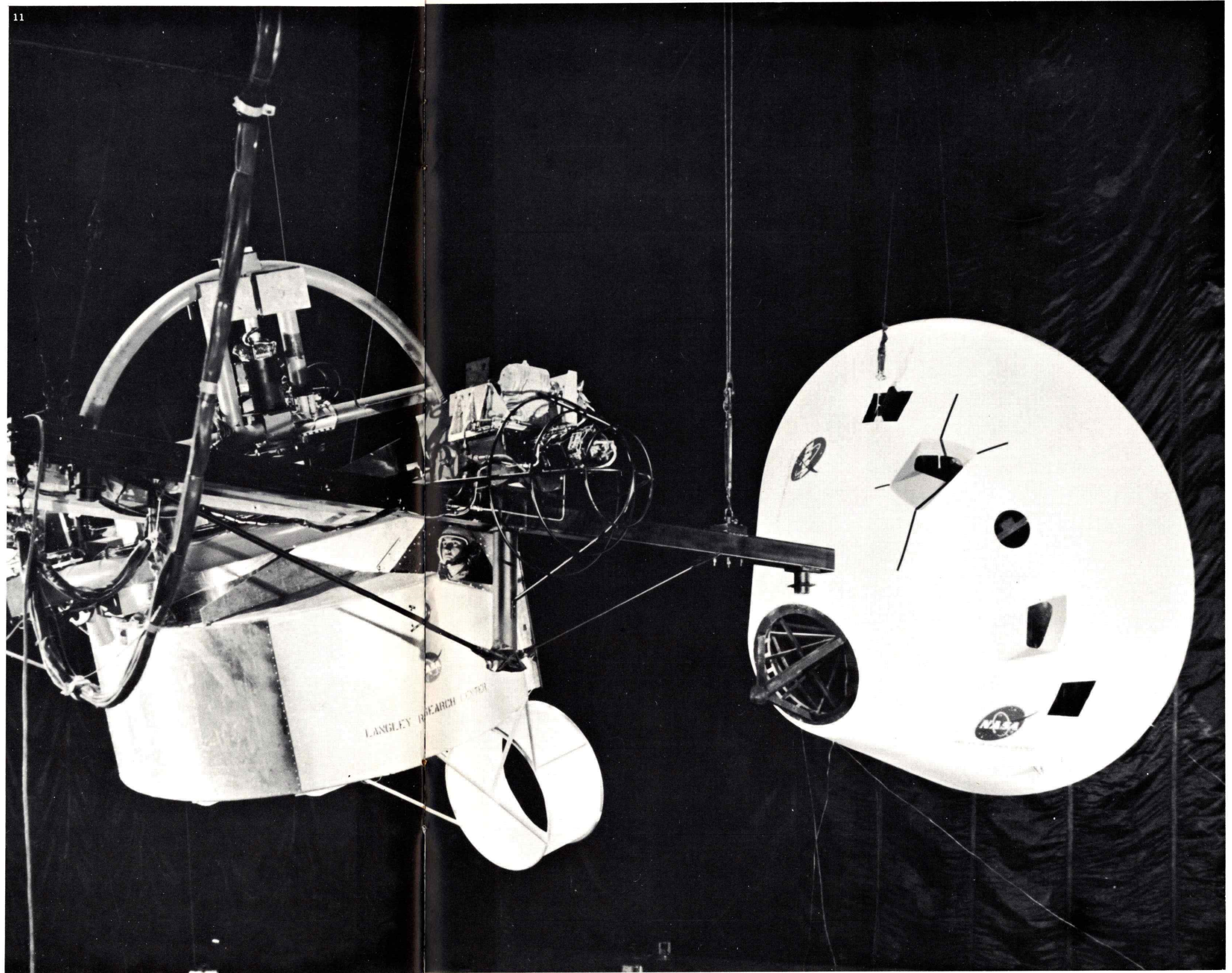
One group of network stations will follow the Apollo spacecraft at launch, during earth orbit, and again at the end of the flight after the moon trip is finished.

As the spacecraft leaves earth orbit and starts toward the moon, it passes from range of these stations. Tracking then switches to a second group of stations whose powerful transmitters and sensitive receivers are dependable for communications at great distance.

These stations have huge 85-foot diameter dish-shaped antennas and are similar in appearance to those which communicate with spacecraft, such as Mariner, millions of miles away in the vicinity of Mars or Venus or orbiting the sun.

Located at Goldstone, California; Madrid, Spain; and Canberra, Australia, they stand approximately one-third of the earth's circumference (120°) apart. As the rotating earth cut off one station's direct line of contact with the spacecraft on its way to the moon or back, the next station rises above the horizon and takes over.

When the returning Apollo, speeding toward earth at 25,000 mph, enters the range of the earth-orbital tracking chain, these stations go into operation again and monitor the vital reentry and recovery.



11 Rendezvous docking simulator enables astronauts to practice the last 200 feet of lunar orbit rendezvous and docking.

FLIGHT TO THE MOON

The first U.S. manned flight to the moon will take place sometime before the end of this decade. The mission will begin with launch of the 365-foot Apollo-Saturn V vehicle. The first and second stages will be jettisoned after burning all their propellants, but the third stage will burn only enough to place itself and the three-module Apollo spacecraft in "parking" orbit about 100 miles high.

Later, when the lunar "launch window" (best period of time for takeoff) is open, the third stage will refire and add enough speed for the Apollo spacecraft to escape from earth orbit.

On the way to the moon, the crew will reorient the combined Command and Service Modules (CSM) and dock (link-up) the nose of the Command Module with the nose of the Lunar Module (LM). The CSM then extracts the LM from the adapter section and the third stage of the launch vehicle.

Mid-course maneuvers may be made if the lunar trajectory, or flight path, requires adjustment. The maneuvers are accomplished by firing the Service Module's 22,000-pound-thrust rocket engine.

By about 54 hours after launch, earth's gravity will have slowed the spacecraft gradually from about 25,000 mph to about 2,500 mph. When it enters the area where the moon's gravitational field is dominant, the spacecraft will be accelerated toward the moon.

About 64 hours after launch, the spacecraft will near the moon at a speed of about 5,200 mph and the astronauts will apply the retro power of the Service Module propulsion system for about 6 minutes to slow the spacecraft down to about 3,600 mph. This will cause the craft to swing into a lunar orbit about 80 miles high. For the lunar landing, two men will transfer into the LM.

After about 68 hours of mission time, the LM will separate from the CSM with a difference in

velocity of about 3 mph and will move away about 735 feet. The descent engine will then put the LM into a transfer orbit at a velocity of 3,500 mph. The LM will coast until an altitude of about 49,500 feet is reached; then powered descent will begin. Powered descent will take the LM to the hover altitude of 200 feet, where either a manual or automatic hover-to- touchdown procedure will be initiated. In either method, the engine will be cut off at LM altitude of about 15 feet, giving the LM a lunar impact speed of about 3 mph.

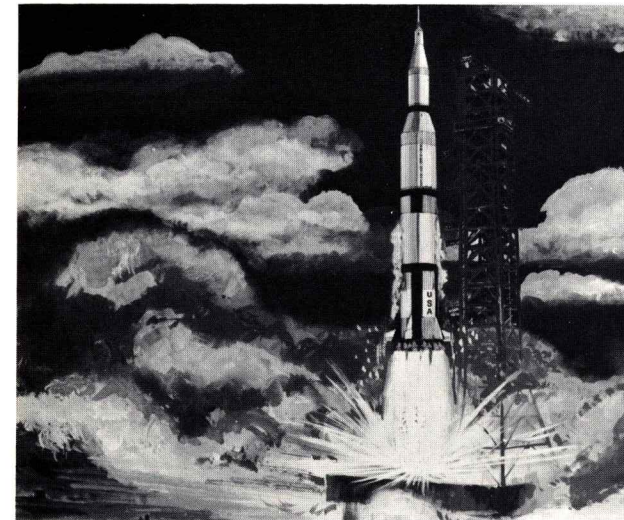
ASTRONAUT EXPERIMENTS ON THE MOON

Plans call for the astronauts to stay on the moon about 18 hours. Of this time, they will work on experiments for two separate 3-hour periods, in between which they will have about 6 hours of sleep. The remaining time will be spent on such matters as equipment checks, meals, making ready for experiments, post-landing inspection, and preparation for take-off.

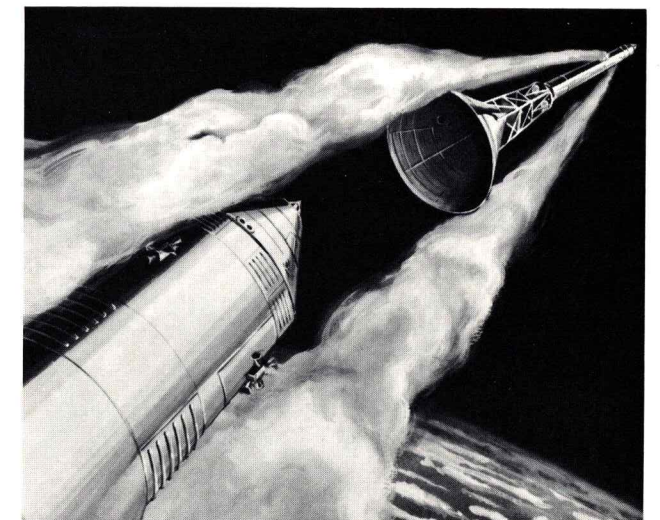
The most important parts of the astronauts' duties are their radioed descriptions, photographs, and direct telecasts of the moon and the 60 pounds of assorted rock samples they are to bring home in vacuum-sealed containers. In addition, the astronauts are to set up a group of Lunar Surface Experiments which will continue to radio their information to earth for as long as a year. The experiments are designed to report on such scientific phenomena as temperature changes, radiation levels, moonquakes, and micrometeoroids (tiny particles of matter in space).

RETURN FLIGHT TO THE EARTH

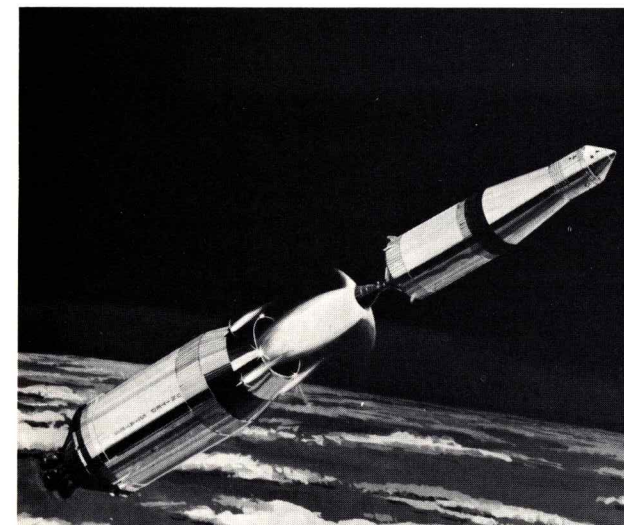
When the time arrives for leaving the moon's surface and joining the orbiting CSM, the lower stage of the LM will be used as a launching pad and left behind on the moon.



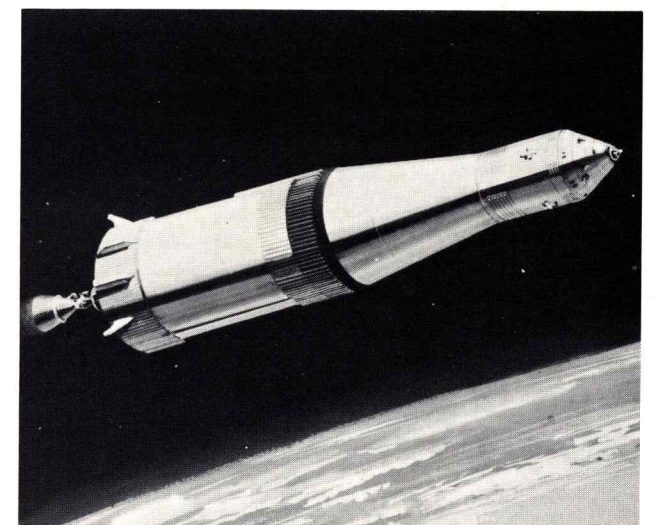
1 Lift Off.



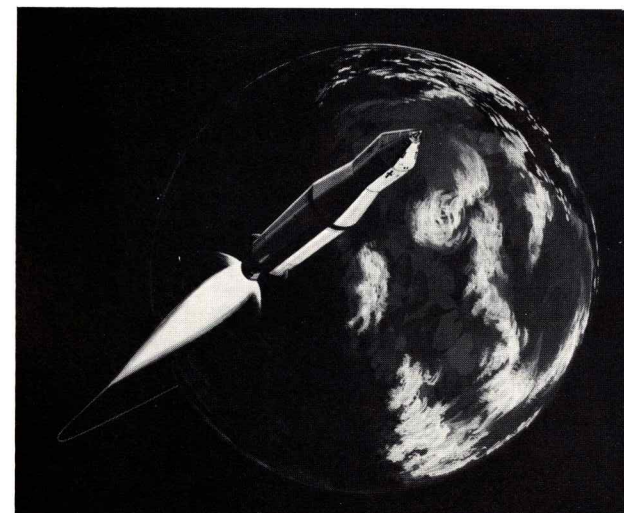
2 Jettison Launch Escape System



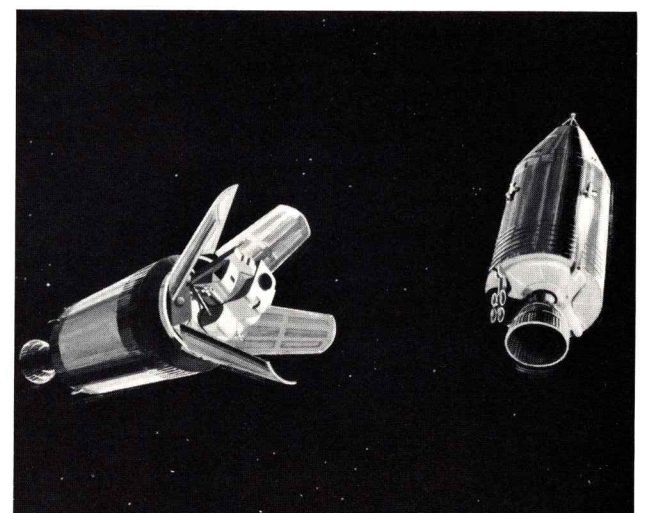
3 S-II Stage Separation, S-IVB Stage Thrusting.



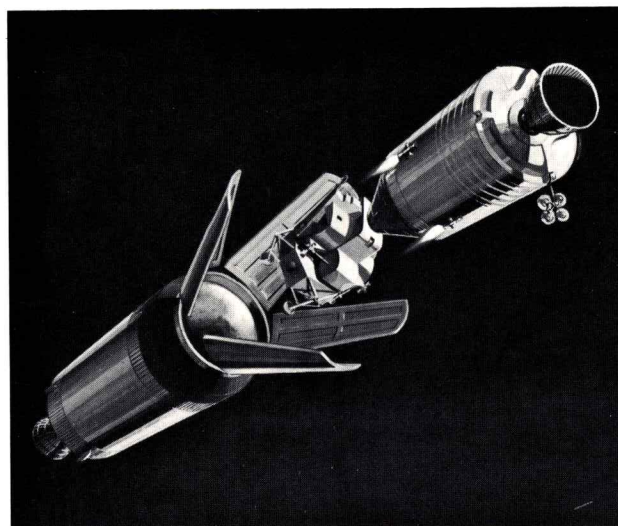
4 Earth Orbit Insertion of the S-IVB Stage and Spacecraft



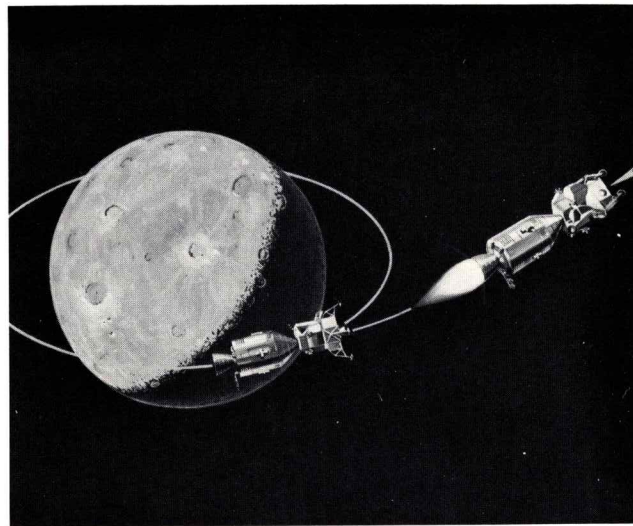
5 Translunar Injection.



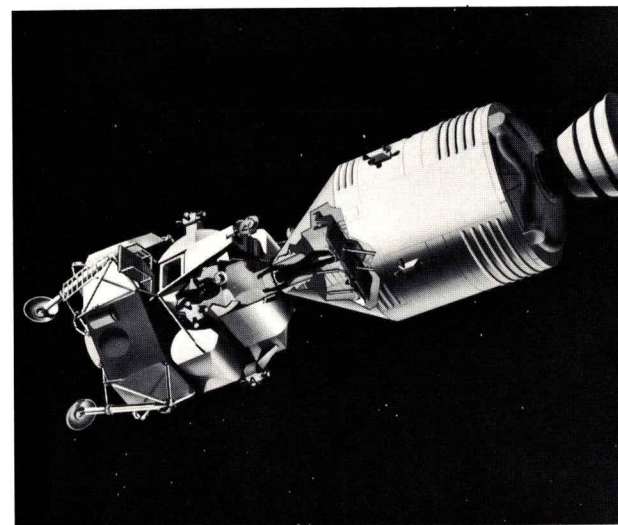
6 Turnaround of CSM.



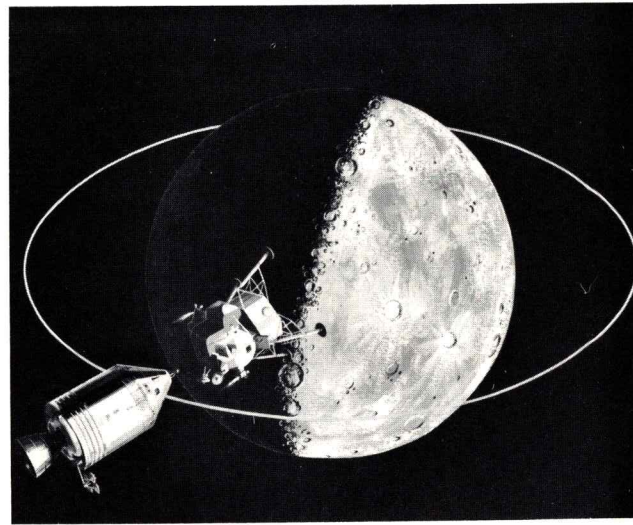
7 Docking and Separation of Spacecraft From S-IVB



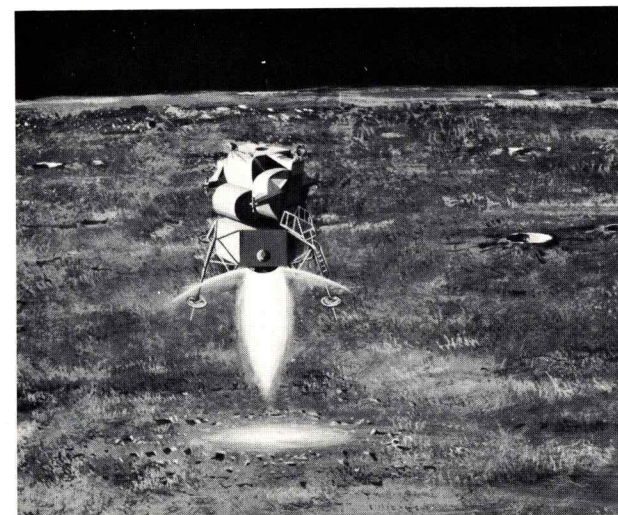
8 Lunar Orbit Insertion



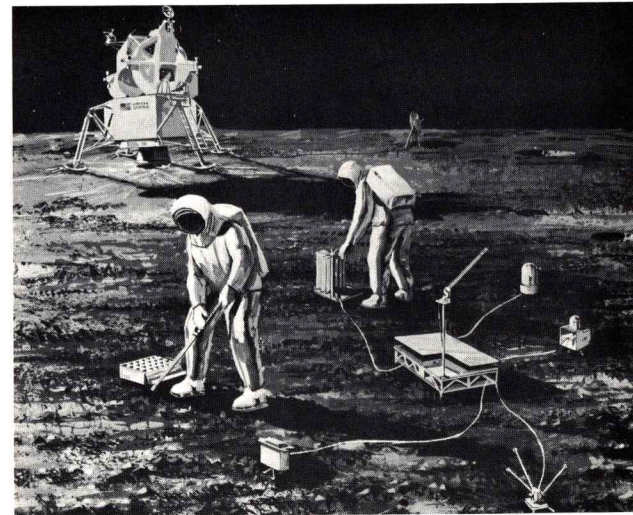
9 Transfer to LM



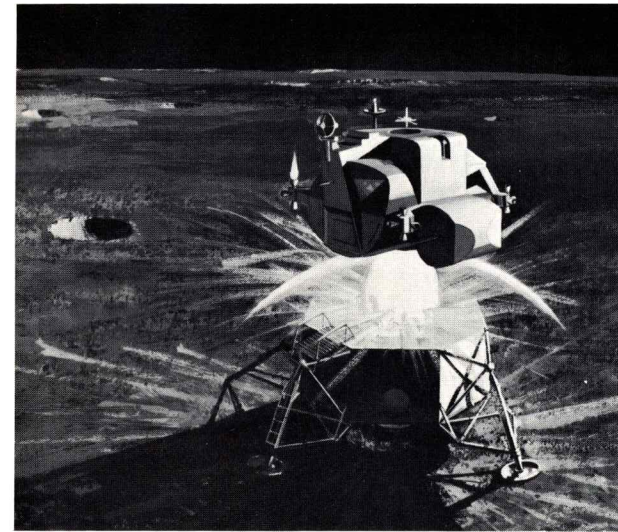
10 LM Separation



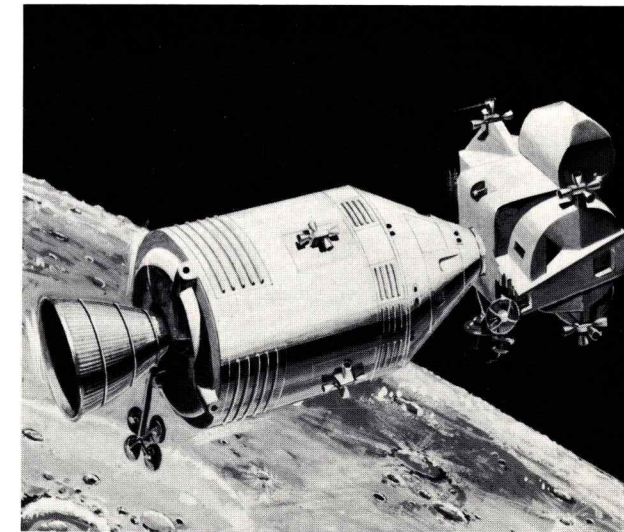
11 Final Descent



12 Exploration of Lunar Surface



13 Ascent Stage Liftoff



14 LM Ascent—CSM Docked



15 LM Jettison

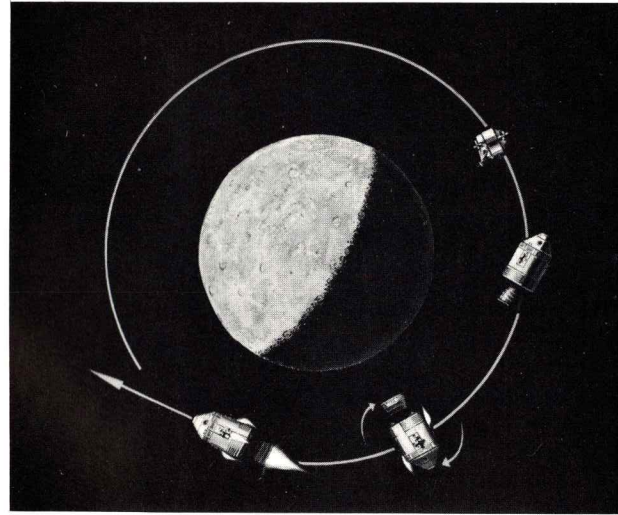
With launch timed for rendezvous with the orbiting CSM, the LM ascent stage will ascend to an altitude of 80 miles and dock with the CSM. After the two astronauts have transferred to the CSM, the LM will be jettisoned and left in moon orbit. The Service Module's rocket engine will be ignited to build up lunar escape velocity of 5,460 mph. About 29,000 miles outward, the spacecraft will reach the point where the earth's gravitational influence becomes dominant. Then, subject to the earth's pull, the CSM will return at ever-increasing speed until it reaches the same velocity at which the spacecraft left earth—about 25,000 mph.

After using its propulsion for final course corrections, the Service Module will be jettisoned, leaving the Command Module to plunge into the earth's atmosphere.

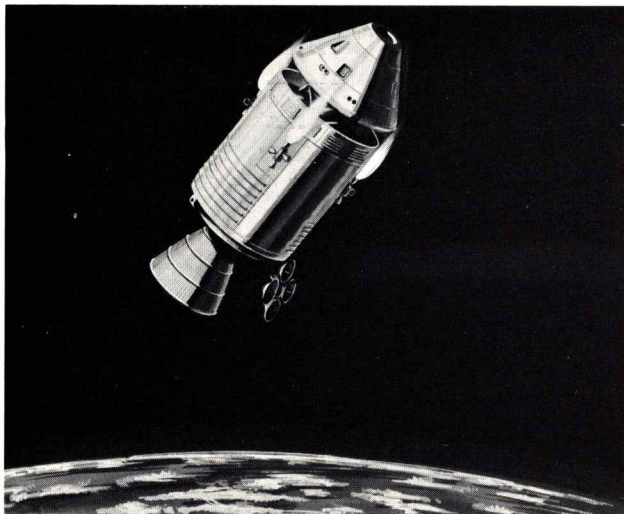
At the velocity of 25,000 mph, reentry will be trickier for the Apollo spacecraft than it was for the Gemini or Mercury spacecraft. The Command Module must enter the top of the earth's atmosphere and transfer into an earthbound ballistic path. The safe "reentry corridor" will be only 40 miles wide, while the angle of attack (slant toward earth horizontal) must be kept between $5\frac{1}{2}^\circ$ to $7\frac{1}{2}^\circ$.

Apollo's reentry temperature will be about 5,000°F. As in Mercury and Gemini, the heat shield will protect the crew as air resistance rapidly cuts velocity to a safe point for parachute deployment and landing.

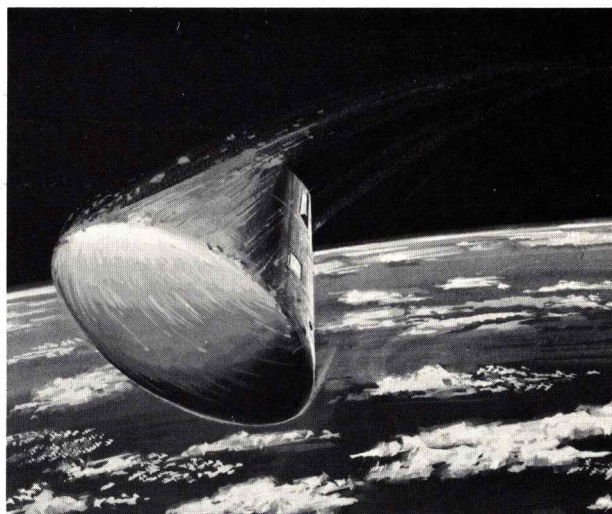
From earth launch to earth touchdown, the total moon trip time will be approximately 198 hours, or about 8 days.



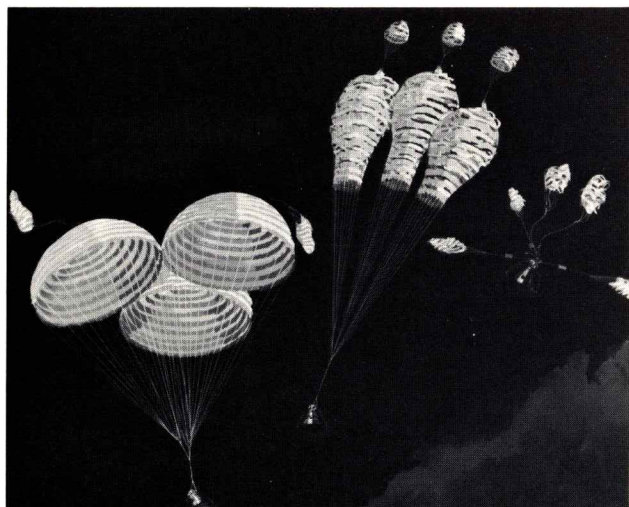
16 Transearth Injection



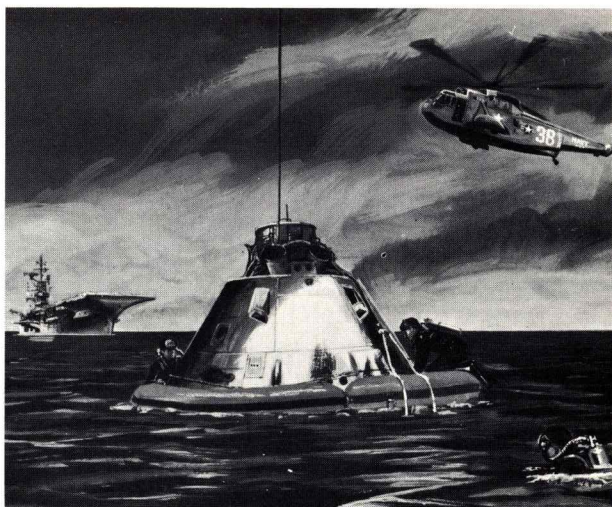
17 CM.SM Separation



18 Entry into Earth Atmosphere



19 Main Parachute Deployment



20 Spacecraft Recovery

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For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 — Price 15 cents

*U. S. GOVERNMENT PRINTING OFFICE : 1967 O - 275-553

NASA FACTS

AN EDUCATIONAL PUBLICATION OF THE
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* NF-8/12-67



Space Launch Vehicles

Whatever space mission is undertaken, manned or unmanned, the spacecraft carrying the payload must first be put into space. This is the job of the launch vehicle.

A launch vehicle is the rocket that propels a spacecraft and its payload into space on one of four general categories of flight missions:

- A *sounding mission* is one that investigates the upper atmosphere outward from earth to 4,000 miles into space.
- A *space probe* is a mission extending beyond 4,000 miles.
- An *orbital mission* is a flight reaching a velocity of at least five miles per second (17,500 miles per hour) and upward to seven miles per second (24,600 miles per hour). Spacecraft speeds between these two velocities will remain within the earth's gravitational influence and orbit (fall around) the earth.
- A *deep-space probe* is a trajectorial flight to another celestial body—our moon or another planet. It must attain a speed above seven miles per second to escape earth's gravitational influence and enter a solar orbit to its target.



The basic principle, applicable to the rocket engine and explaining the work of the launch vehicle, was recognized by Sir Isaac Newton nearly 250 years ago when he defined and wrote the laws of motion. His third states: "For every action there is an equal and opposite reaction." As fuel burns in a rocket engine chamber, the gases created in the burning expand and escape through its chamber nozzle at high velocity, creating reaction or thrust in the opposite direction.

While there are a number of advanced types of rocket engines in development such as nuclear and electric propulsion, rocket engines now in use all burn a chemical fuel, either liquid or solid.

There are certain advantages in both types of fuel. Solid fuel engines are quite simple and the fuel may be stored for long periods of time in the rocket. Liquid engines are very complex and generally their fuel must be loaded just before firing. The primary advantage of liquid fuels, however, is that they are more controllable than solids. Liquid fuel engines are easily stopped and started, whereas solid fuel engines present more difficulty in this regard.

In a liquid rocket, the fuel and oxidizer are carried in separate tanks and burned in the combustion chamber. Kerosene is used in rocket boosters such as Atlas, Delta and Saturn. The Titan II vehicle uses aerzine, a 50-50 mixture of unsymmetrical dimethyl hydrazine (UDMH) and hydrazine. Common oxidizers are liquid oxygen, inhibited red fuming nitric acid (IRFNA- and nitrogen tetroxide. In recent years the development of high-energy propellant technology has led to the operational use of liquid hydrogen as in the case of the Centaur engine and upper stages of Saturn. Development of other chemical combinations, for even higher energy, is under way.

Solid rocket motors are used primarily for sounding and military rockets and other experimental test purposes. However, solid rocket motor technology is advancing rapidly and some engines now can produce as much as three million pounds thrust. Advanced methods for starting and stopping them are also in development.

In a solid rocket, the propellant is cast into a solid mass of mixed fuel and oxidizer and is bonded to or supported inside the motor case. The propellant cast, called a grain, usually has a hole running down its center. Burning takes place

along the exposed surface of the grain and progresses radially toward the case. Fuels used in solid propellants are asphalts, waxes, oils, plastics, metals, rubber, and resins. Their oxidizers are often common nitrates and perchlorates.

Most rockets are now built in stages so that, as the propellants are consumed, the empty stages can be separated and dropped away. The remainder of the launch vehicle, after stage separation, is much lighter and can continue on its course using smaller engines and less fuel.

The earth's gravity exerts the greatest pull at ground level and, of course, the launch vehicle and its payload at launch time has no momentum. Also, the total weight is greatest at launch because the vehicle propellant tanks are loaded.

To overcome the greatest gravitational forces. The first stage has the greatest amount of total thrust. The thrust then is usually less in the second, third and fourth stages, or however many stages the rocket contains. As the pull of gravity diminishes with distance from the earth and as velocity increases, the other stages are fired and then separated to lighten the load, until only the speeding payload remains.

Aside from the basic problem of getting enough thrust for a long enough time to counteract gravity for a particular weight, the rocket engineer must also control the rocket's flight and give it only enough velocity for the chosen flight path. The nearer the satellite's planned orbit is to the earth, the stronger the gravitational pull, and therefore the greater the velocity needed to keep the satellite in orbit. At 200 miles from the earth, a satellite needs a velocity of about 17,500 m.p.h. to stay in orbit. At 250,000 miles from the earth—approximately the distance of the moon—it needs 2,000 m.p.h. When a payload reaches a velocity of 24,600 m.p.h. after launch, it completely overcomes the earth's gravitational pull, escapes earth-orbit and goes into a solar orbit.

A satellite's path around the earth generally is elliptical rather than circular. With exceedingly precise guidance and velocity control, a spacecraft can be put into circular orbit, but the slightest deviation in velocity will produce an ellipse.¹ Earth satellites often are put into elliptical orbits deliberately, so as to produce a variety of altitudes and data.²

If an escaping spacecraft is given a greater velocity than the earth's orbital velocity around the sun, it may achieve an orbit with a greater

mean distance from the sun. With the correct velocity and guidance, it can be made to reach an "outer" planet (i.e., farther from the sun than the earth) such as Mars. But if the spacecraft is launched against the earth's rotation around the sun, it falls toward the sun and achieves a smaller orbit. With proper guidance, it could reach Venus or Mercury.

The flight path chosen for a payload and the payload weight determine what capabilities are required of the particular launch vehicle. Obviously, it would not make sense to use a moving van to deliver a few parcels. Similarly, it would be impractical to use a Saturn vehicle to orbit a small, light-weight group of scientific instruments. That is why this country has developed a family of reliable launch vehicles of various sizes, shapes, and capabilities. First, this policy is economical. Second, the more experience we have with a few particular kinds of vehicles, the more reliable they become. The aim is to use the smallest number of vehicles consistent with the full scope of space missions now foreseen.

Each member of the launch vehicle family has been assigned appropriate missions. These range from scientific research and exploration to, and including, manned space flight projects.

At present, NASA launch vehicles include Scout, Delta, Thor-Agena, Atlas-Agena, Atlas-Centaur, Uprated Saturn I, and Saturn V. The famous Mercury-Atlas launch vehicle of Project Mercury and the Gemini Launch vehicle (Titan II) in Project Gemini have completed their missions.

¹ Orbits for the Projects Mercury and Gemini flights generally were elliptical. For example, Faith 7, with Mercury Astronaut Gordon Cooper, had an orbit with a perigee (nearest to earth) of 100 miles, and apogee (farthest from earth) of 166 miles. The Gemini spacecraft, after docking with the Agena stage, used the Agena propulsion systems to change its orbit significantly. In Gemini XI the Agena rocket was fired to raise the apogee from an initial 177 miles to 850 miles, a new altitude record. The Apollo spacecraft has its own propulsion system, which gives it the ability to make orbital changes.

² Explorer XVIII, launched November 27, 1963, achieved an orbit with a perigee of 120 miles and an apogee of 23,000 miles.

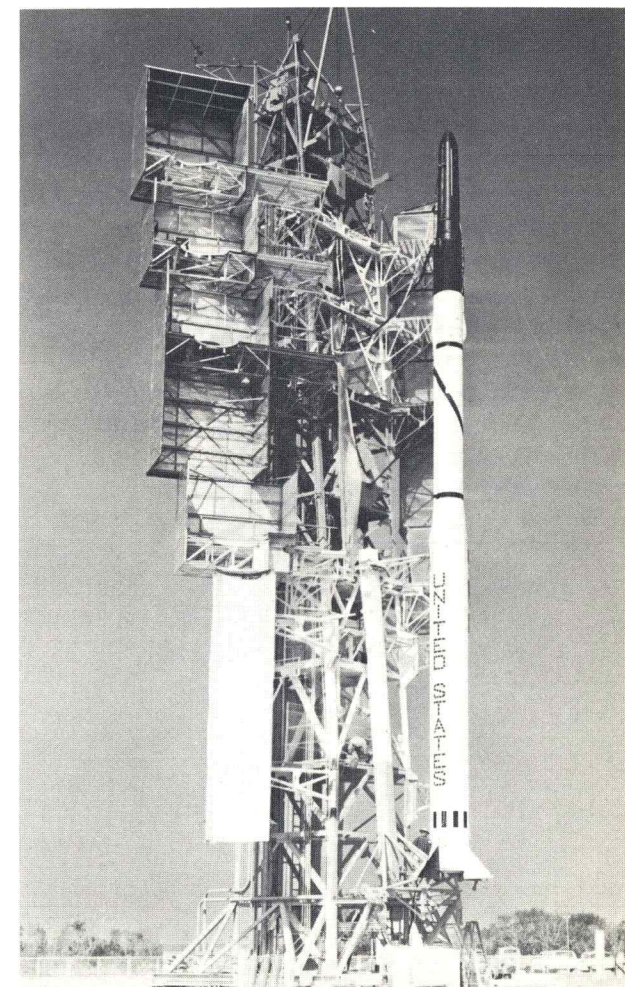
SCOUT

Scout, the smallest of the basic launch vehicles, is a reliable and relatively inexpensive launch vehicle for payloads weighing up to 240 pounds. It is used for unmanned small satellite missions, high-altitude probes, and re-entry experiments.

Scout has four stages, is 68 feet high (less the spacecraft), and has a maximum diameter of 4 feet at its widest cross section.

Guidance is provided by a strapped-down gyro system, and the vehicle is controlled by a combination of aerodynamic surfaces, jet vanes, and hydrogen peroxide jets.

The only U.S. launch vehicle with solid propellants exclusively, the Scout has a first-stage thrust of 88,000 pounds. It can put a 400-pound payload into the lower levels of space, put 240 pounds into a 300-nautical mile orbit, or can carry a 100-pound scientific probe about 7,000 miles away from the earth.



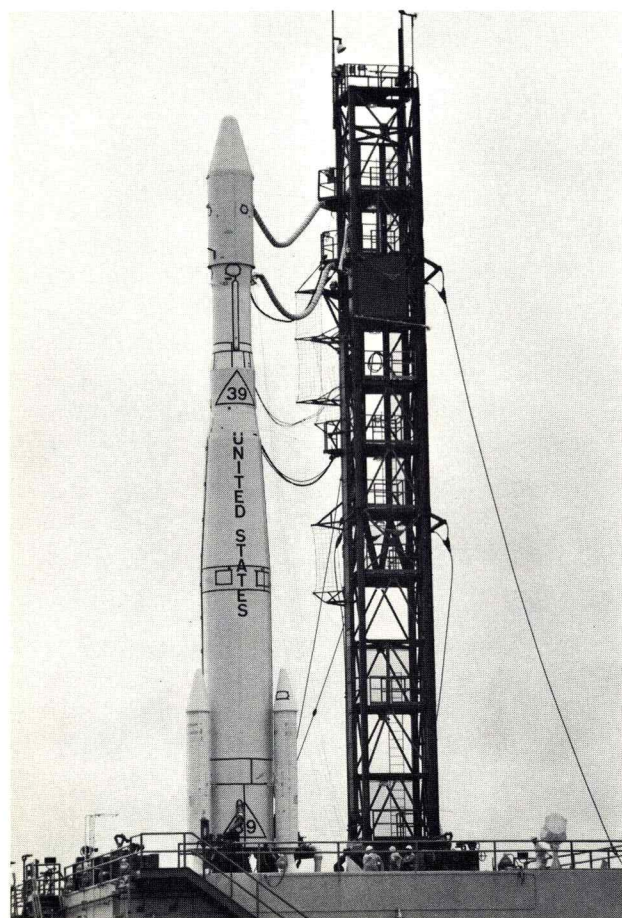
DELTA

Delta has two liquid-fueled stages topped by a solid-fuel stage. Ninety feet high and 8 feet in diameter at the base (excluding fins), it can boost 550 pounds into a 500-nautical-mile earth orbit. Its gross weight is 114,200 pounds, and the total thrust of the first stage is 170,000 pounds.

Delta is a workhorse NASA vehicle for a wide range of small-payload satellite missions and space probes. It launched the first Orbiting Solar Observatory, some of the Tiros weather satellites, and has been used in the communications-satellite Echo I, Telstar, Relay, and Syncom programs.

First launched by NASA in May 1960, Delta has a long list of successful firings to its credit.

Its first stage is a modified Thor, its second a modified and improved stage from the Vanguard and Thor-Able programs, and its third stage is the spin-stabilized, solid-propellant Altair. The Altair is also derived from the earlier Vanguard and Thor-Able vehicles. Delta thus utilizes proven engines, modified to gain high reliability and perform a variety of missions.



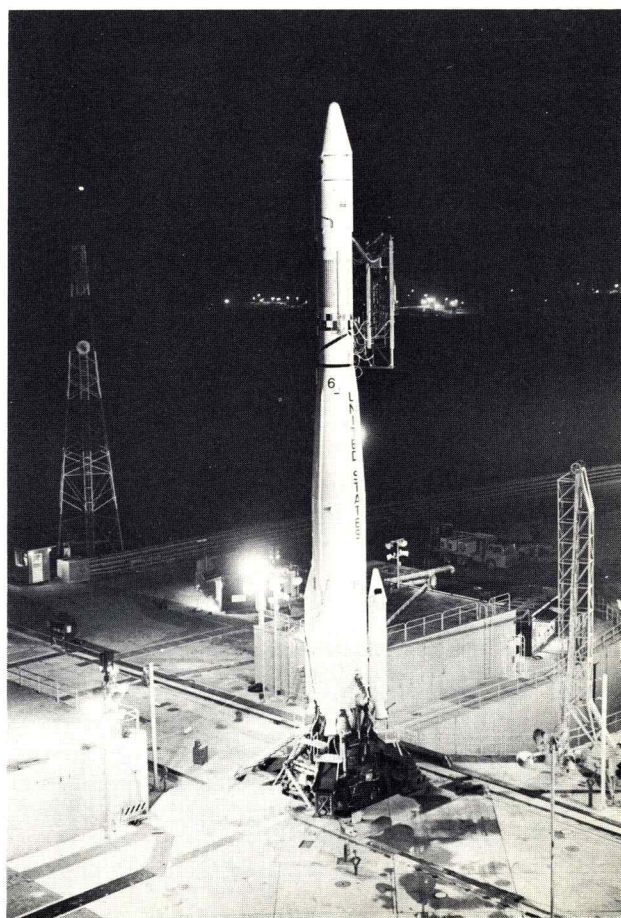
THOR-AGENA

Thor-Agena is a two-stage vehicle that can send 1,150 pounds into an earth orbit of 100 nautical miles, or 600 pounds into a 1,200-mile orbit.

Both stages burn liquid propellants, and the total thrust of both stages is 186,000 pounds. The vehicle is 76 feet high (without spacecraft) and 8 feet wide (without the fins). NASA launched its first Thor-Agena in September 1962.

The second stage is the restartable Agena, which permits great precision in selecting an orbit. Agena was developed by the Air Force as a second stage for use in its own programs. Early in 1960 NASA decided to use it in combination with Thor and Atlas rather than develop a similar vehicle. The NASA version of Agena, developing 16,000 pounds thrust, is modified so that various types of payloads can be bolted to the front end.

Thor-Agena is used by NASA for meteorological, communications, and scientific satellites, including the Orbiting Geophysical Observatory, Nimbus, Sert II, and Pageos programs.



ATLAS-AGENA

The Atlas-Agena is a two-stage all-liquid-propellant vehicle capable of putting 5,950 pounds in a 100-nautical mile earth orbit and of sending instrumented payloads of 950 pounds to the moon and 600 pounds to Mars or Venus. It is 88.3 feet high (less the spacecraft) and 10 feet in diameter. Total thrust is 404,000 pounds.

The Atlas booster, developed from the Air Force Atlas intercontinental ballistic missile, won fame in the Mercury manned space flight program. The first NASA Atlas-Agena launch was in August, 1961 (Ranger I).

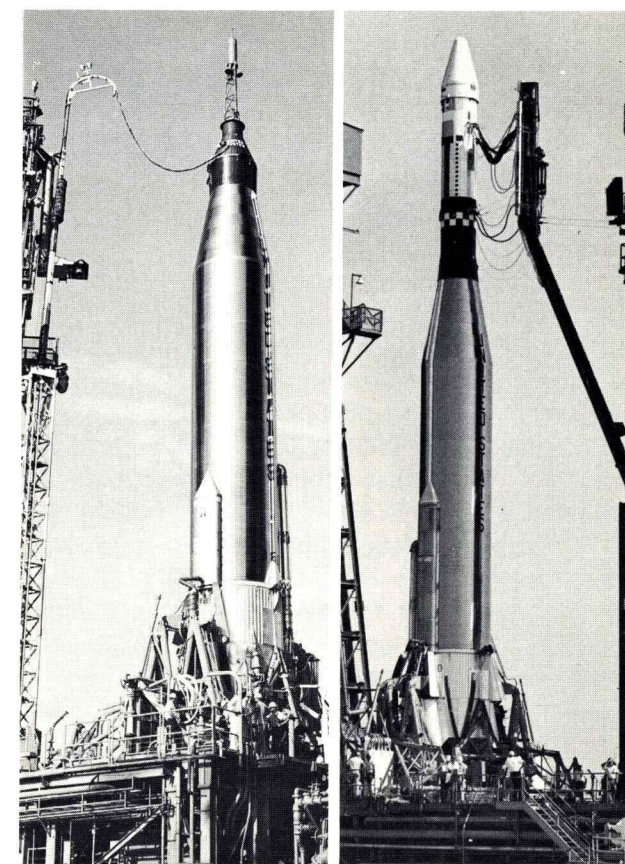
NASA uses the Atlas-Agena to launch a variety of scientific payloads. It can orbit large earth satellites and place into escape trajectories, lunar probes and interplanetary and planetary exploration spacecraft. When used as the launching vehicle for a satellite, the entire Agena stage, after separation of the spacecraft, also becomes a satellite.

This vehicle consists of an Atlas first stage and an Agena second stage. With its standard three-engine propulsion system plus two small vernier³ rockets, the Atlas weighs about 260,000 pounds. The second, or Agena, stage has a 16,000-pound-thrust engine that can be stopped and started in space.

Components of the Atlas-Agena guidance system are the inertial guidance system, timing devices, a velocity meter, and an infrared horizon sensor. During powered flight, pitch and yaw control is maintained by gimbaling the rocket motor. During coast periods, high-pressure jets are used.

In a typical lunar application (for example, the Ranger VII launched in July 1964) the Atlas' five engines burn for about 2½ minutes before the outer engines cut off and drop away. The smaller center engine and vernier engines continue firing for another 2 minutes, taking the vehicle to an altitude of 80 miles. The two small 1,000-pound-thrust vernier engines continue firing after center engine cutoff long enough to trim velocity. An on-board computer commands the Atlas airborne guidance system to start the timer on the Agena stage.

After the verniers cut off, the Atlas-Agena coasts for a few seconds. Then the spring-loaded aerodynamic shroud protecting the payload is discarded. Explosive charges separate the Agena from the Atlas first stage. The Agena goes through a pitch maneuver to bring it into horizontal align-



ment with the earth's surface. Then the timer signals the propulsion system and ignition occurs.

During the 2½ minutes of powered flight, the Agena is controlled by the hydraulic control system. When the engines cut off, the payload is in a circular parking orbit approximately 100 miles above the earth. After a 14-minute coast period, the Agena engine re-ignites and powers the payload for another 1½ minutes, placing it in the lunar trajectory. Some 2½ minutes after engine cutoff the Agena and the payload separates, and the spacecraft continues alone.

The vehicle with which the Gemini spacecraft rendezvoused in space was the Agena, a 1,700-pound Air Force upper stage modified to fit the requirements of Project Gemini. The changes included addition of a secondary propulsion system, modifications to the primary propulsion system to provide restart capability, electronics modifications for command and docking, a systems status panel which told the astronauts the status of the Agena systems, and an adapter for docking operations.

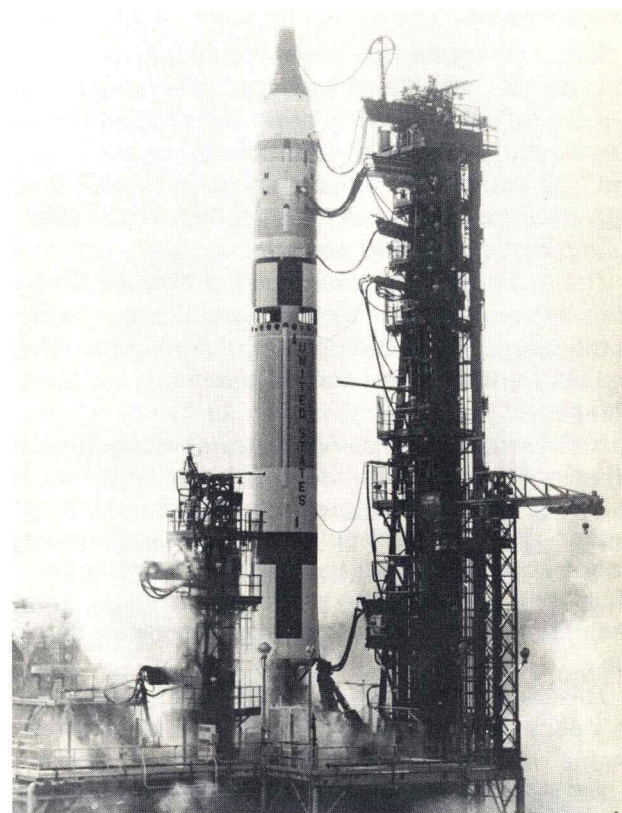
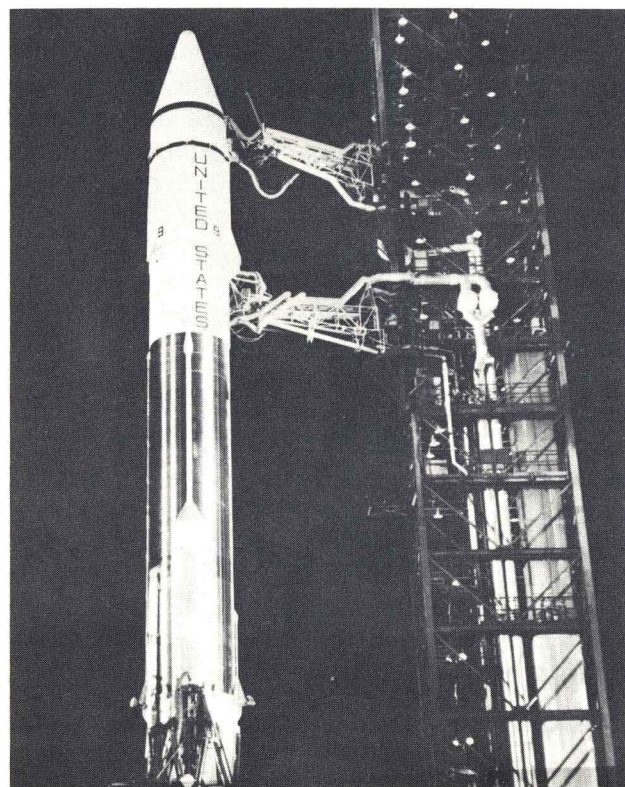
³ Verniers are small rocket engines used primarily to obtain a fine adjustment in the velocity and trajectory of a space vehicle or missile.

ATLAS-CENTAUR

Atlas-Centaur, with an Atlas first stage and a Centaur second stage, is the most advanced of the Atlas-based series of launch vehicles. This 100-foot-long, 300,000-pound vehicle is capable of sending approximately 8,500 pounds into low earth orbit, 2,150 pounds to the moon, and 1,300 pounds to Venus and Mars.

The two-stage liquid-fueled vehicle develops a total thrust of more than 400,000 pounds. (Atlas develops 388,000 pounds thrust and the Centaur develops 30,000 pounds thrust). The Atlas-Centaur combination is a high-performance, general-purpose launch vehicle for use by NASA and the Department of Defense. The Centaur program has pioneered research to develop a rocket vehicle that can utilize high-energy liquid hydrogen as fuel. It has provided much of the basic high energy knowledge required for the design of the upper stages of Saturn vehicles and propulsion systems which will use the same fuel.

Atlas-Centaur can fly unmanned lunar and planetary spacecraft beyond the capabilities of the Atlas-Agena launch vehicles. It launched the highly successful Surveyor spacecraft that soft-landed on the lunar surface and relayed photographs back to earth.



GEMINI-TITAN

The powerful Titan II was selected as the launch vehicle to boost the Gemini two-man spacecraft into orbit. It was first used successfully in the unmanned flight of Gemini on April 8, 1964.

It was chosen for the Gemini mission because of its payload capability and importantly because its propellants are non explosive—a feature permitting use of an ejection-seat escape system instead of the rocket escape tower of Mercury. All engines operate on a mixture in which the fuel is a blend of unsymmetrical dimethylhydrazine (referred to as UDMH) and hydrazine, and the oxidizer is nitrogen tetroxide. The mixture is hypergolic, meaning that when the fuel and oxidizer are brought together the combination ignites spontaneously, without need for an ignition system.

The propellants can also be stored for some time in Titan's fuel tanks. As a result, the launch vehicle can be readied for use on comparatively short notice and need not be drained of fuel if a launch is postponed.

Titan II has a 430,000-pound-thrust first stage and a 100,000-pound-thrust second stage. It is 90 feet high (less payload) and 10 feet in diameter at the base.

UPDATED SATURN I

The original Saturn launch vehicle project was conceived in 1948 to provide early capability for large payloads. The decision to arrange the engines and tanks in clusters allowed the use of equipment already developed for earlier rockets as well as the machine tools that produced them. Thus, the first stage of the two-stage Saturn I was a cluster of eight H-1 engines, each capable of generating 188,000 pounds of thrust. The second stage of the early version had six liquid-oxygen, liquid-hydrogen RL-10 engines, each generating 15,000 pounds of thrust.

Saturn I is part of a family of heavyweight lifting launch vehicles, used first in the Apollo program. The first ten vehicles, called Saturn I, were launched for research and development purposes, and also placed into earth orbit engineering test models of the command and service modules of the Apollo spacecraft. The last three Saturn I's placed meteoroid technology satellites into earth orbit to examine the size and distribution of particles in space near the earth.

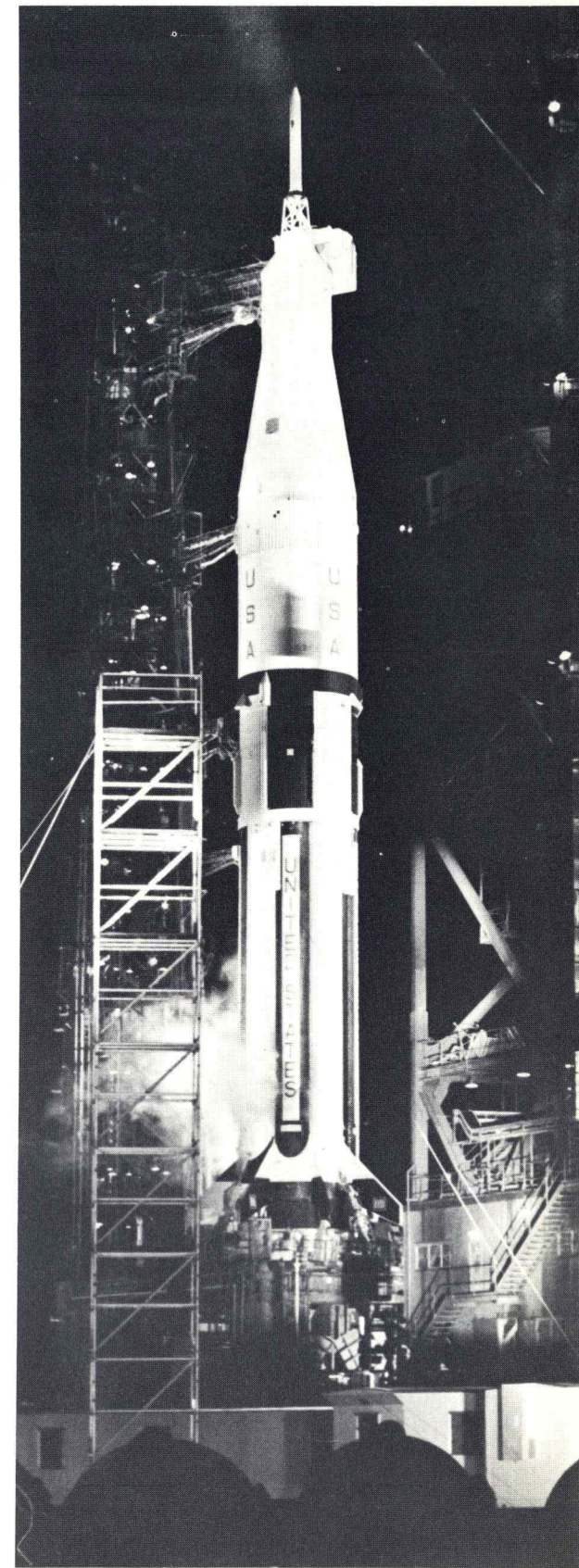
The first Saturn I was launched successively in October, 1961, with only the first stage live. When a live second stage was used for the first time, in January, 1964, the fifth Saturn I placed 37,900 pounds into earth orbit.

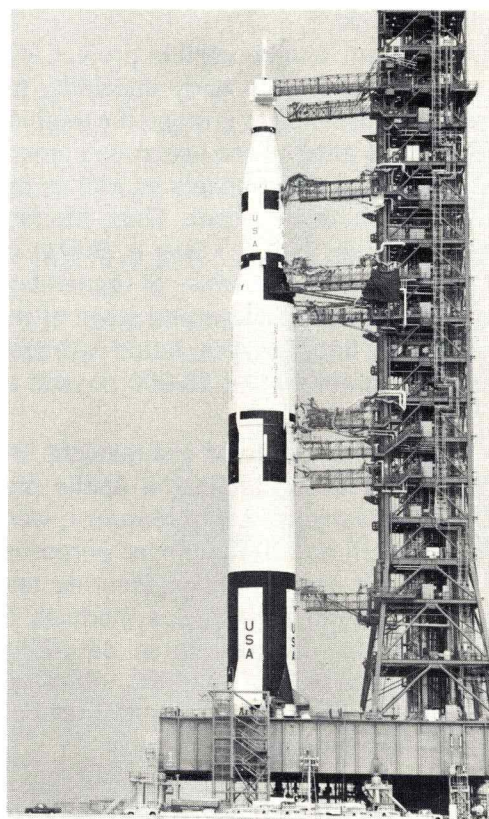
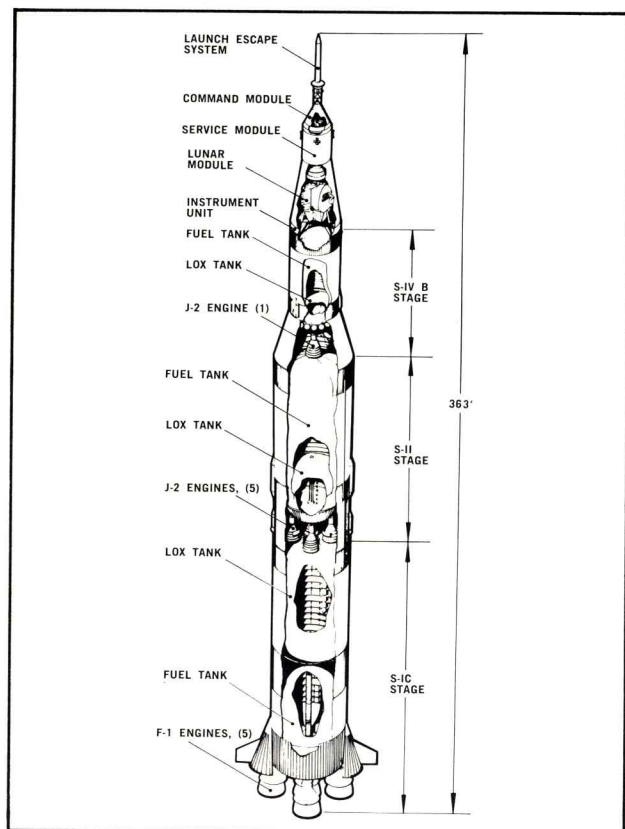
Beginning with the eleventh flight, a new, more powerful second stage was used on the Saturn I. This new second stage has a single 200,000-pound thrust liquid hydrogen-liquid oxygen J-2 engine, replacing the six-engine stage used in the early vehicles. The first stage of the Up-rated Saturn I has the same eight liquid oxygen-kerosene engines used previously, but with total thrust uprated to 1.6 million pounds.

Saturn I's first-stage thrust of 1.6 million pounds may be compared with the 360,000 pounds of thrust of the Atlas vehicles that launched the Mercury astronauts into earth orbital flights.

The Up-rated Saturn I mated to the Apollo spacecraft and its launch escape system stands 225 feet high. It can orbit 40,000 pounds and will be used to launch manned and unmanned modules of the Apollo spacecraft into earth orbit.

On its first flight, in January, 1966, the Up-rated Saturn I was used to test the Apollo command/service modules in a suborbital mission. After three test flights, the improved launch vehicle was declared ready for manned Apollo missions.





SATURN V

The three-stage Saturn V stands 363 feet high with its Apollo spacecraft in place, and has a liftoff weight of more than 6.1 million pounds. The first stage is powered by five F-1 engines which burn kerosene and liquid oxygen. The five engines consume 15 tons of propellant a second and produce 7.5 million pounds of thrust.

On a trip to the moon, the first stage engines burn for about 2½ minutes, boosting the Apollo astronauts to an altitude of 36 miles and a velocity of about 6,000 miles per hour. The first stage then drops away, and the second stage ignites.

The second stage is powered by five J-2 engines, each producing 200,000 pounds thrust. These hydrogen-oxygen engines, burning for 6½ minutes, push the spacecraft to an altitude of about 100 miles and near-orbital velocity. Its mission completed, the second stage is separated and falls back to earth.

The third stage of the Saturn V, the same as the second stage of the uprated Saturn I, has a single J-2 engine which develops 200,000 pounds thrust. This stage ignites to give Apollo spacecraft the final shove that places it into earth orbit, at an altitude of about 115 miles. Then the engine shuts down, while the spacecraft is checked out, and the proper moment is awaited for continuing the trip to the moon. At the precise moment, the third stage engine is reignited. It burns for about 6½ minutes, accelerating the spacecraft from its earth orbital speed of 17,400 miles an hour to about 24,600 miles an hour, the velocity needed to overcome earth's gravity.

The Saturn V can place a payload of 285,000 pounds into earth orbit or send almost 98,000 pounds to the moon. This heavy payload capability will be used in both manned and unmanned missions for the continuing exploration of space.

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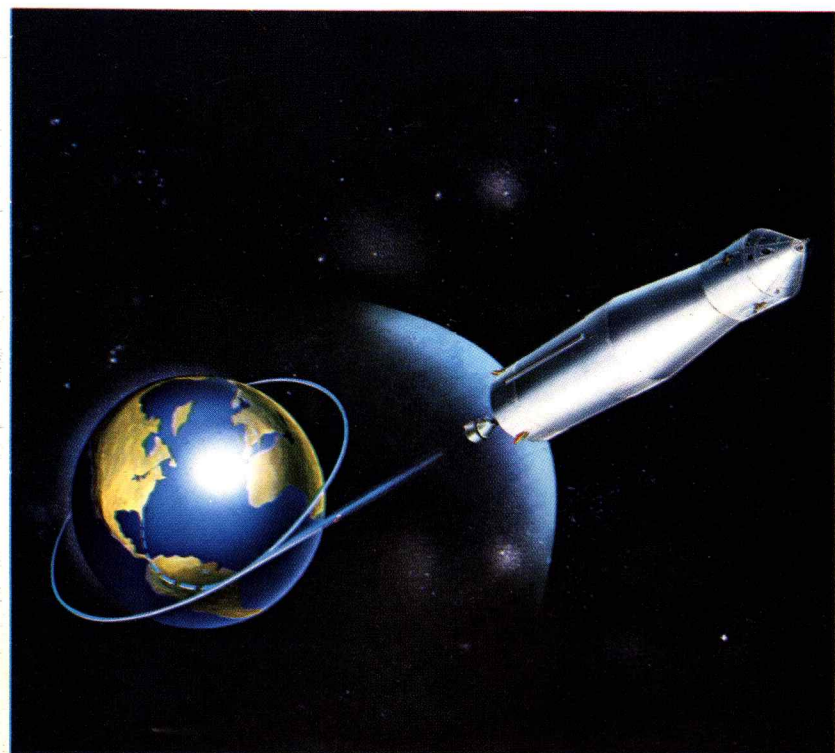
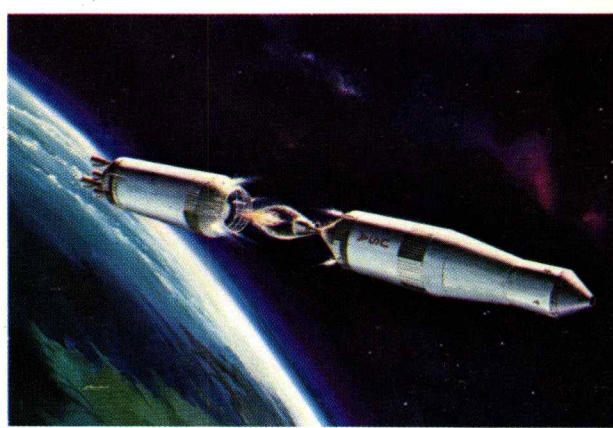
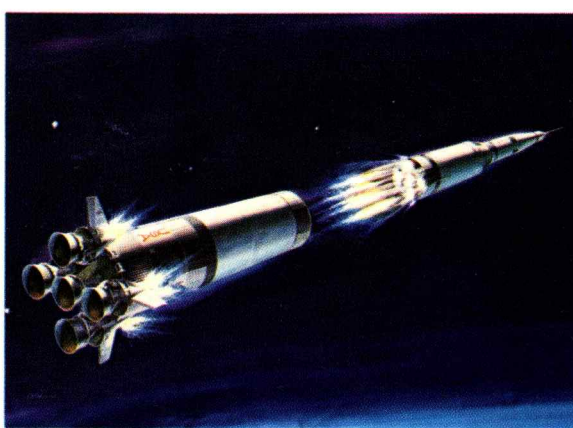
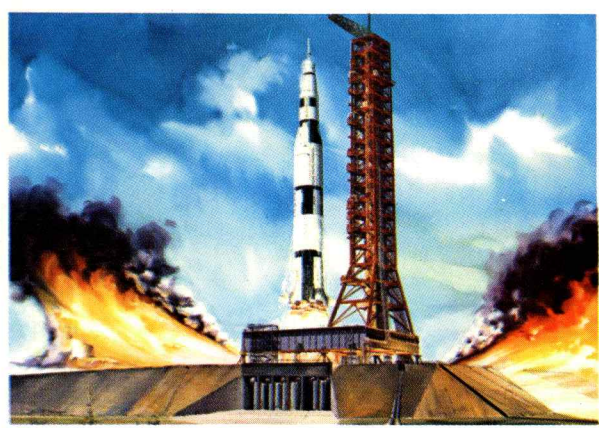
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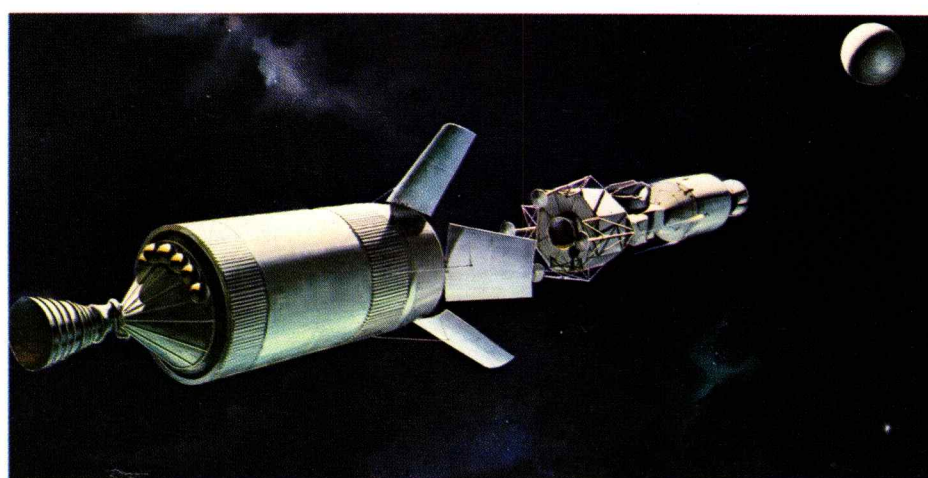
SATURN V

MANNED FLIGHT TO THE MOON

The Saturn V provides capability, in the United States space program, to put into earth orbit 280,000 pounds of payload or to send 95,000 pounds to the moon. Largest in the U.S. family of launch vehicles, the Saturn V has the mission of launching the Apollo spacecraft which will carry men to the moon before the end of this decade, and is available for other missions requiring comparable lifting ability.



In the three pictures above, lift-off, second stage ignition and third stage ignition are illustrated. The third stage takes itself and the spacecraft into earth orbit. At left is a description of the earth parking orbit and subsequent re-ignition of the third stage engine to send the vehicle out of earth orbit and into a lunar escape trajectory. Below, the spacecraft pulls away from the third stage and continues its lunar journey.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

SATURN V - Mightiest Space Vehicle

AMERICA'S MOON ROCKET

The first stage of the Saturn V launch vehicle starts the Apollo spacecraft, with three astronauts aboard, on the journey to the moon. The second and third stages place the spacecraft in earth orbit and on the trajectory to the moon.

The Apollo Program is directed by NASA's office of Manned Space Flight. The Marshall Center is providing the Saturn launch vehicles. The Manned Spacecraft Center at Houston is providing the three separate modules of the spacecraft, selecting and training the astronauts, and will operate the Mission Control Center. The Kennedy Space Center in Florida will launch the astronauts on their epic flight.

When fully operational, the Saturn V will be able to launch into orbit more than a quarter of a million pounds. The total orbiting tonnage in the lunar mission will be about 280,000 pounds. This includes the weight of the third stage and instrument unit section. The fully fueled and loaded Apollo Spacecraft, in its lunar mission configuration, will weigh about 95,000 pounds.

The Saturn V, with its Apollo payload, is 365 feet tall. Physical and performance characteristics of the stages, in a mission such as the lunar trip, are as follows:

FIRST STAGE

The first stage burns over 15 tons of propellants per second during its two and one-half minutes of operation to take the vehicle to a height of about 36 miles and to a speed of about 6,000 miles-per-hour. The stage is 138 feet long and 33 feet in diameter.

Fire cannot burn without oxygen. Since rocket engines operate in space where there is no oxygen, a supply must be carried along. All Saturn mainstage engines use liquid oxygen for this purpose. Liquid oxygen, or LOX, is a super-cold liquid that boils at 297 degrees below zero Fahrenheit. To achieve the desired rocket engine reaction, the LOX is mixed with a flammable fuel, a spark is provided, and the engines roar to life with power comparable to thousands of ordinary gasoline engines.

In the cut-away illustration of the Saturn V, shown here, the LOX tanks of the stages are colored green. In the first stage, the fuel used is RP-1, a form of kerosene. The RP-1 tank is shown in red. LOX lines carry the super-cold liquid down through the RP-1 tank to the engine combustion chambers, where it is mixed with RP-1 and the rocket begins its journey into space.

In the second and third stages, liquid hydrogen is used as fuel and is piped to the engine combustion chambers to be mixed with LOX and ignited. Liquid hydrogen tanks are shown in blue.

The total overall length of the vehicle, from engines to top of escape tower is 365 feet. The 7.5 million pounds thrust in the first stage is comparable to 160,000,000 horsepower.

SECOND STAGE

The second stage burns over one ton of propellants per second during about six and one-half minutes of operation to take the vehicle to an altitude of about 108 miles and a speed of near orbital velocity, which in this case is about 17,400 miles-per-hour. It is 33 feet in diameter and 81½ feet long.

THIRD STAGE

The third stage has two important operations during the Project Apollo lunar mission. After the second stage drops away, the third ignites and burns for about two minutes to place itself and the spacecraft into the desired earth orbit. At the proper time during this earth parking orbit, the third stage is re-ignited to speed the Apollo spacecraft to escape velocity of 24,900 miles per hour. In this second sequence, the stage burns for about six minutes. The stage is 58 feet long and 21.7 feet in diameter.

INSTRUMENT UNIT

The instrument unit, located atop the third stage, between the stage and the payload, contains guidance and control equipment for the launch vehicle. It is 3 feet long and 21.7 feet in diameter.

APOLLO SPACECRAFT

Command Module: 13 feet in diameter; weight, 11,000 pounds.

Service Module: 13 feet in diameter, 22 feet in height; weight, 52,000 pounds; 22,000-pound thrust engine.

Lunar Module: Two stages; total weight, 32,000 pounds. Descent engine's thrust can be varied from 1,050 to 10,500 pounds.

FIRST STAGE

Power: Five F-1 engines with combined thrust of 7.5 million pounds

Propellants: RP-1 kerosene, 214,200 gallons

Liquid oxygen 346,400 gallons

Fueled weight of stage: 5,028,000 pounds

SECOND STAGE

Power: Five J-2 engines with a combined thrust of 1,000,000 pounds

Propellants: Liquid hydrogen, 267,700 gallons

Liquid oxygen, 87,400 gallons

Fueled weight of stage: 1,064,000 pounds

THIRD STAGE

Power: One J-2 engine, 200,000 pounds thrust

Propellants: Liquid hydrogen, 66,900 gallons

Liquid oxygen, 20,400 gallons

Fueled weight of stage: 265,000 pounds

INSTRUMENT UNIT

Weight: About 4,100 pounds

APOLLO SPACECRAFT

SATURN V

U.S. GOVERNMENT PRINTING OFFICE : 1967 O-249-077

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SATURN V

Albert Long