RELIABILITY AND TRAINING

The Apollo command and service modules have approximately two million functional parts, miles of wiring, and thousands of joints. The operation and integrity of each part and structure must be assured.

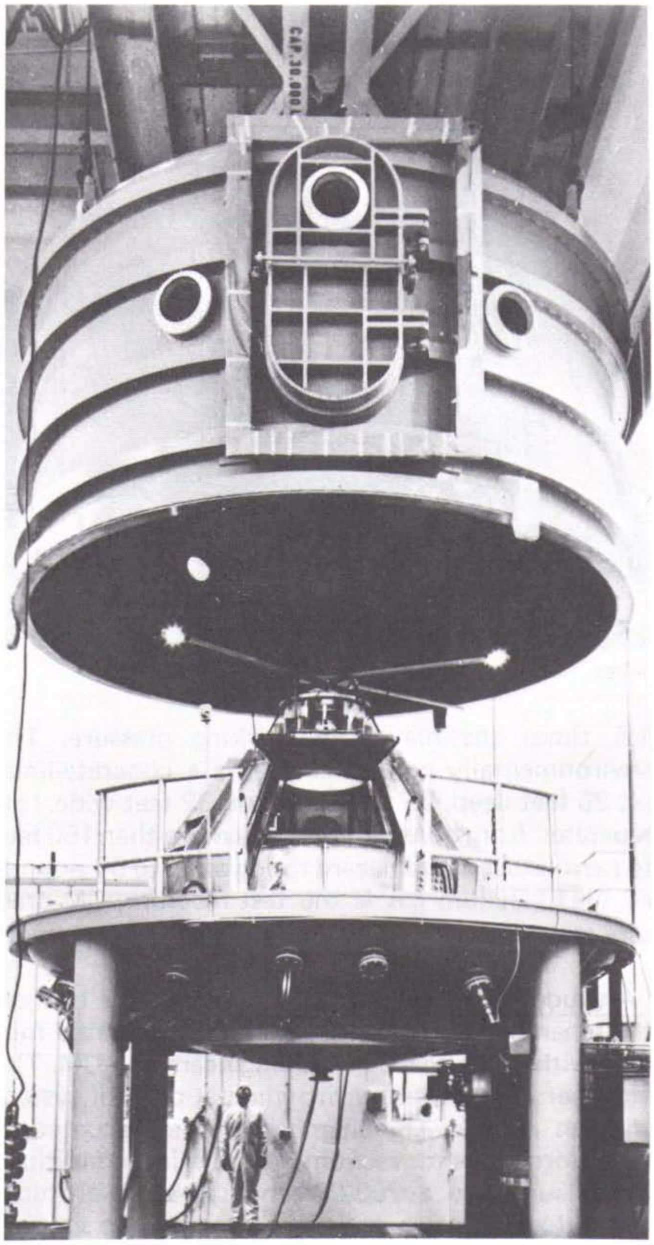
To do this, the Apollo spacecraft undergoes exhaustive testing, starting with the smallest component. Systems and subsystems are tested under various simulated mission conditions and in their interaction. All components are tested far beyond the required safety level.

There are 587,500 inspection points on the command and service modules. In addition, the vehicle is checked to make sure it conforms to each of approximately 8,000 drawings and 1,700 manufacturing and engineering specifications.

Integrity of hundreds of feet of weld and the thousands of joints must be verified. The adhesive bonded honeycomb structure of the modules is inspected ultrasonically and the brazed honeycomb heat shield structure is inspected radiographically. Deviation from the stringent requirements results in test to determine the cause, repair or replacement, and a new cycle of final tests.

But reliability is achieved primarily through preventive rather than curative measures. These include such things as conservative design (that is, design with a wide margin of safety) and stringent technical and administrative controls. Reliability assessment of critical components is performed at the end of development, at the end of qualification testing, and before flight.

Tests of Apollo CSM structure and systems have been performed at Downey, White Sands Missile Range, N.M., Manned Spacecraft Center in Houston, Tullahoma, Tenn., and Kennedy Space Center.



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Environmental (vacuum) chamber at Downey

In addition, more than 7500 hours of wind-tunnel testing has been conducted in government, university, and industrial facilities to gather data on aerodynamic performance during boost, spacecraft and booster loads, acoustic noise and aerodynamic heating, and lift-to-drag hypersonic velocities. Although the Apollo spacecraft operates in the atmosphere only for a few minutes, it underwent almost twice as much wind-tunnel testing as the X-15 and almost as much as the XB-70. The XB-70 had 11,500 hours of wind tunnel testing.

TESTING FACILITIES

Pressure Test Cell—This cell is used to test pressure and leakage of the service propulsion subsystem at

P-285 *Impact test facility*

1.5 times the maximum working pressure. The environmentally controlled cell is a concrete-lined pit 25 feet deep, 25 feet long, and 32 feet wide. It is separated from other buildings by more than 150 feet to permit test with a hazard rating of up to 50 pounds of TNT. Helium gas is the test medium. CM pressure tests also are conducted in the cell.

Altitude Chamber and Airlock—Called the bell jar, this chamber was used for a 14-day simulated mission with three space-suited engineers in a CM. The chamber contains an environmental control system with an airlock. The chamber can be evacuated to 10^{-4} torr (a hard vacuum), simulating conditions from launch to a 200,000-foot pressure altitude. The airlock contains instruments for the life support system. Ground support equipment was used to supply electrical power, potable water, and oxygen furnished in space flight by the fuel cell powerplants and cryogenic storage system.

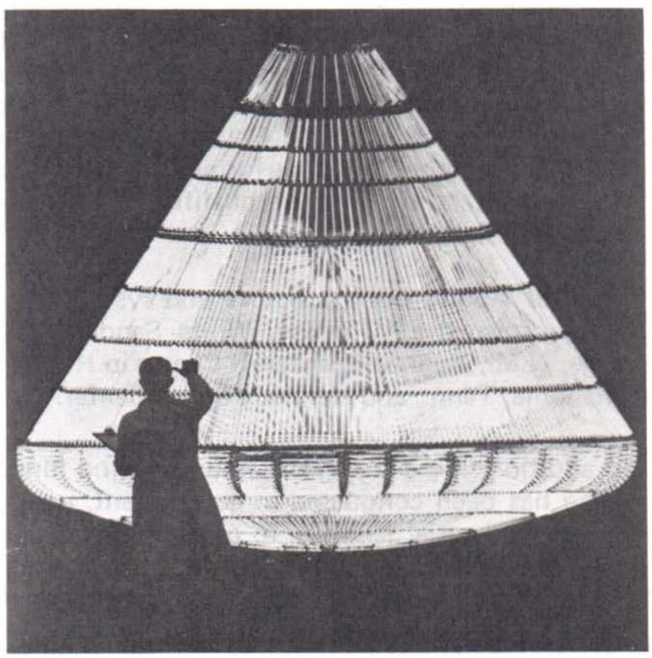
Impact Test Facility—This four-legged tower contains a pendulum that was used to swing a full-scale instrumented CM at controlled speeds and angles, dropping it into a water tank or on a special land impact area to simulate parachute landings. Drop tests provided information on how impact affects the spacecraft structure and crew system response. The impact information is relayed and recorded on oscillographs and magnetic tapes and is used to confirm and define spacecraft and equipment design. information is relayed and recorded on oscillographs and magnetic tapes and is used to confirm and define spacecraft and equipment design.

Tower height is 143 feet, height of the catwalk and pendulum pivot is 125 feet, length of pendulum arms is 91 feet, and maximum impact velocity is 40 feet per second vertical and 50 feet per second horizontal.

Space Simulation Facility—This provides a simulated space environment (high vacuum, solar radiation, and temperature extremes) to determine its effect on the spacecraft and its materials. The actual space vacuum (10^{-12} torr) can be achieved in the facility. Supporting test equipment includes temperature measurement, residual gas analysis, leakage measurement, spectrum analysis, and vacuum measurement systems.

Fuel Cell Test Facility—Fuel cells, power sources, power storage, and power distribution designs are tested in this facility. Bus switching techniques for single and parallel powerplant operations can be developed in the facility and transient susceptibility for spacecraft operation in a vacuum can be analyzed.

Structural Test Facility—This facility covers an area of 14,000 square feet and contains hydraulic



Oven-freezer tests CM structural strength by roasting one side at 600° while dousing other side with liquid nitrogen at 320° below zero

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equipment, including proportioning units, load cells, and hydraulic struts with loading capacities ranging up to 500,000 pounds, and four 24-foot-high test columns, each with the ability to react to 10,000,000 inch-pounds of moment.

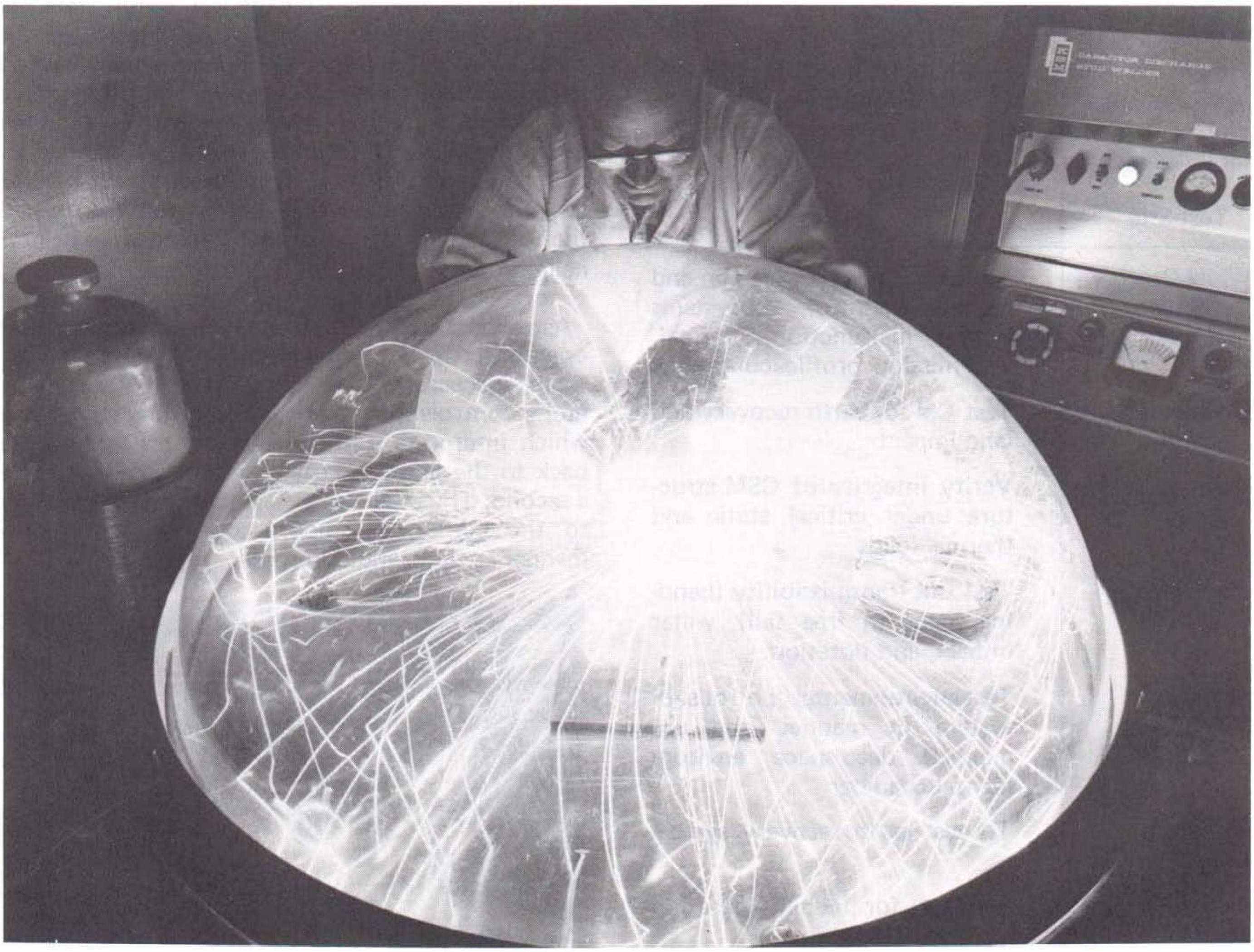
Plasmajet Test Facility—Approximately 1,000 plasmajet tests are conducted on ablative specimens, simulating radiative and convective heat fluxes. Heat fluxes from 5 to 800 British thermal units per square foot per second and gas stream enthalpies from 5,000 to 25,000 British thermal units per pound are produced. Panels of typical CM substructure covered with ablative material are cycled from room temperature through ascent heating temperatures, then down to space flight temperatures, and finally to temperatures simulating entry heating.

Radio Frequency Laboratory—All radio frequency characteristics of spacecraft, radio command, antenna, and telemetry systems are measured in this laboratory.

Climatics Laboratory—Spacecraft components are tested for resistance to elements in the ground and atmosphere environments in this facility. Laboratory equipment exposes equipment to sand, dust, rain, salt spray, and oxygen, individually and in combination.

Acoustics and Data Facilities—All types of dynamic tests (acoustic, vibration, shock, and acceleration) of Apollo components are conducted here. Test findings are recorded on dynamic data equipment (magnetic tape and oscillograph).

Electronic and Electrical Facilities—Electronic and electric circuits, components, and subsystems are



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Technician tests new welding technique for space metals at Downey laboratory tested and analyzed in these facilities and prototypes are developed and evaluated.

Clean Room—The final assembly and checkout area is in the world's largest known clean room. It contains 45,000 square feet of floor space and 2,500,000 cubic feet of air space. It is 410 feet long, 100 feet wide, and separated into two bays, one 63 feet high and the other 42 feet high. The air is filtered and changed three times an hour; temperature is kept at 73 degrees and humidity at 50 percent. Glassed areas on either side of the clean room are kept at higher levels of cleanliness and used for component assembly. Stringent rules govern the dress and operations of workers in the room. The command and service modules enter the clean room through huge airlocks and are tumbled and vacuum-cleaned to remove dust and debris. Subsystems are installed in the two modules and a number of tests performed, including the final series of checkout tests of the completed modules.

Many ground tests have been conducted during development with full-scale test modules. The major ground tests of combined command and service modules include:

Test Site	Purpose
White Sands Test Range, N.M.	Evaluate service propulsion and reaction control subsystems during malfunction, normal, and mission profile conditions
Downey and Houston	Test CM for earth recovery and land impact
Downey	Verify integrity of CSM structure under critical static and thermal loads
Downey and Gulf of Mexico	Test CM transmissibility (bending loads in free fall), water impact, and flotation
Houston	Test environmental control subsystem in manned and unmanned deep-space environmental chamber
El Centro, Calif.	To test earth recovery system
Houston	To test for launch vibration environment
Tullahoma, Tenn.	To test service propulsion engine altitude starting characteristics

TRAINING EQUIPMENT

The training program for management, staff, flight crew, and test and operations personnel parallels the design and manufacture of Apollo spacecraft.

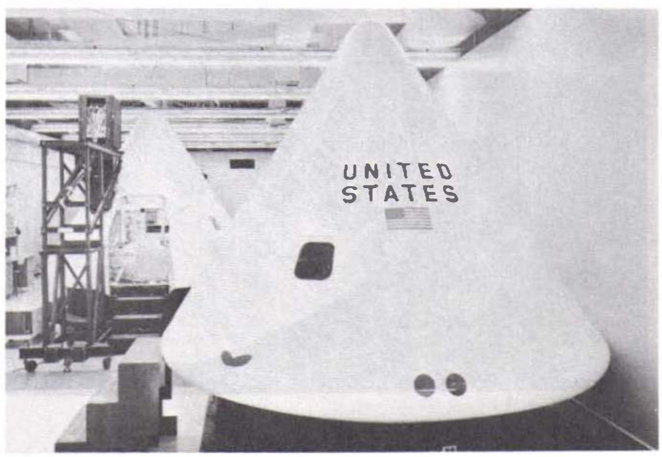
Special equipment for the training program includes spacecraft evaluators at Downey and mission simulators at the Manned Spacecraft Center in Houston and at Kennedy Space Center.

SPACECRAFT EVALUATORS

Apollo astronauts practice spacecraft procedures and operate the command module's displays and controls at the Space Division in Downey. The evaluators, simulated command modules with crew displays and controls and control system elements similar to the flight version, are connected to a computer complex which controls their operation.

Peripheral equipment includes an earth, stars, and sun as they would appear to the astronauts. The earth, a six-foot globe in which landmarks are scaled to an accuracy of within three miles of their actual position as seen from space, revolves in a manner to simulate its own revolution and the orbit of the command module. The revolution can be controlled to reproduce exactly that which would appear to the astronauts at different velocities and orbit heights.

Astronauts can "fly" the command module through operation of the same controls that are on the flight spacecraft. Data on operation of the evaluator's controls is sent to the computing equipment, which interprets it and relays the proper reaction back to the simulated spacecraft, all in a fraction of a second. Thus the displays in the evaluator respond to the command module controls in the same manner as they would in space.



Two spacecraft evaluators aid astronaut training

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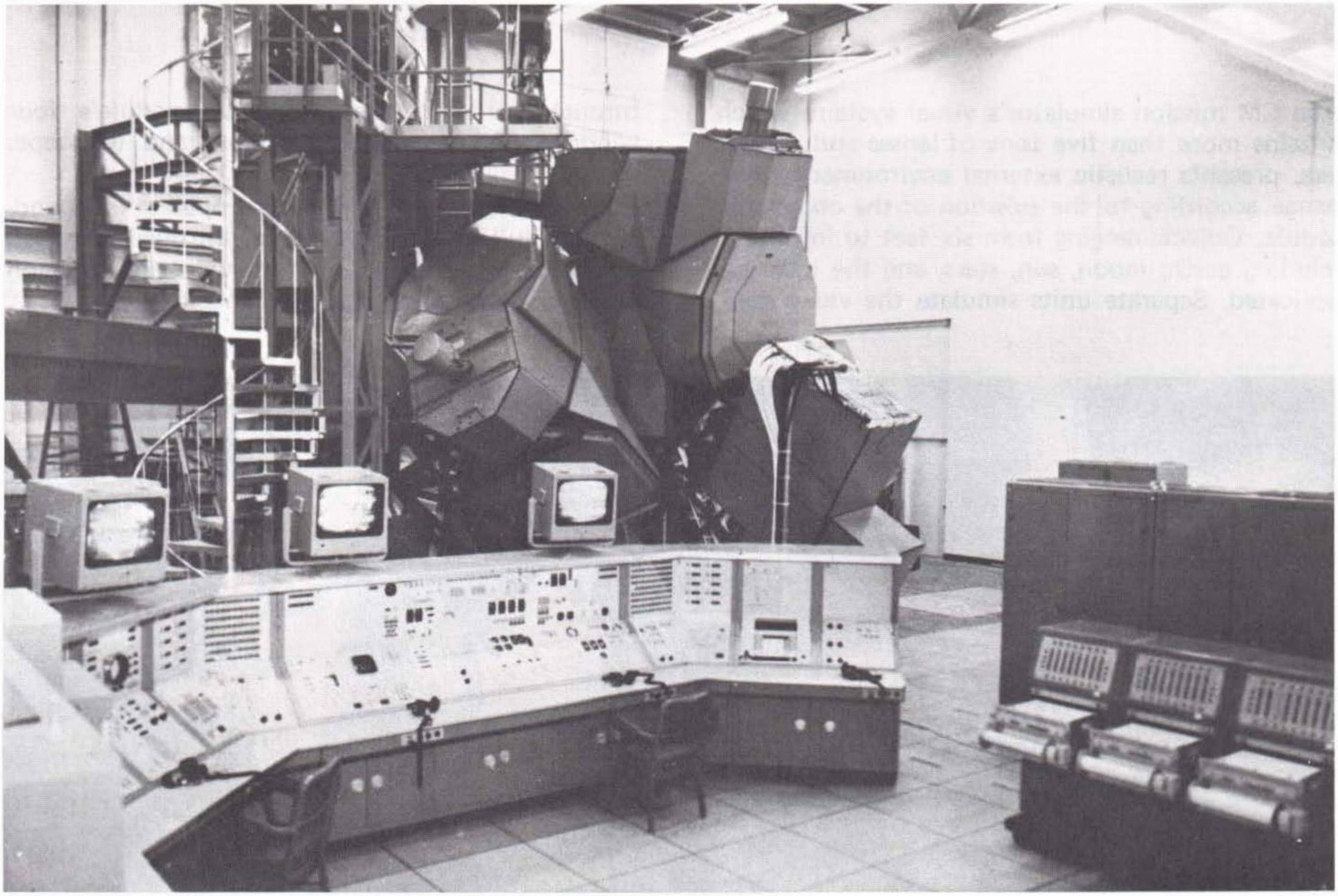

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Apollo mission simulator at Houston includes CM, peripheral equipment, control center

CM MISSION SIMULATORS

The command module mission simulators, built by the Link Group of General Precision Systems, Inc., Binghampton, N.Y., under contract to Space Division, are fixed-base trainers capable of simulating characteristics of spacecraft system performance and flight dynamics. In them the astronauts practice operation of spacecraft subsystems, spacecraft control and navigation, and crew procedures for space missions. Malfunctions and degraded performance of spacecraft subsystems also can be simulated.

The interior of the CM mission simulator is a replica of the actual command module, containing all panels, controls, switches, and equipment. The essential life support systems are designed to operate up to 14 days.

An entire lunar mission—except for lunar descent and ascent—can be simulated. Visual and acoustic effects are simulated; everything, in fact, except the sensations of weightlessness and the gravitational forces of launch and earth re-entry. (Training for the lunar descent and ascent is performed in the lunar module simulator.)

The CM mission simulator has four computers integrated into a single complex to provide real-time simulation of all spacecraft subsystems and equations of motion of both the CM and LM. Each of the computers can perform 500,000 mathematical operations per second. The complex has 208,000 memory core locations.

Each simulator is programmed to provide normal, emergency, and abort conditions. More than 1,000 training problems can be inserted into the simulated spacecraft subsystems, enabling the crew to prepare for nearly every situation. The computers also generate telemetry information in actual mission format for transmission to ground station equipment, thus training ground personnel.

The CM mission simulator's visual system, which contains more than five tons of lenses and curved glass, presents realistic external environments that change according to the position of the command module. Objects ranging from six feet to infinity—including earth, moon, sun, stars, and the LM—are duplicated. Separate units simulate the views seen through each of the command module's four windows and through the sextant and telescope.

The simulators are designed to operate independently as full mission trainers for astronauts, as well as to operate in connection with the Mission Control Center and the LM mission simulators.

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Astronauts (from left) Tom Stafford, John Young, and Eugene Cernan train in mission simulator