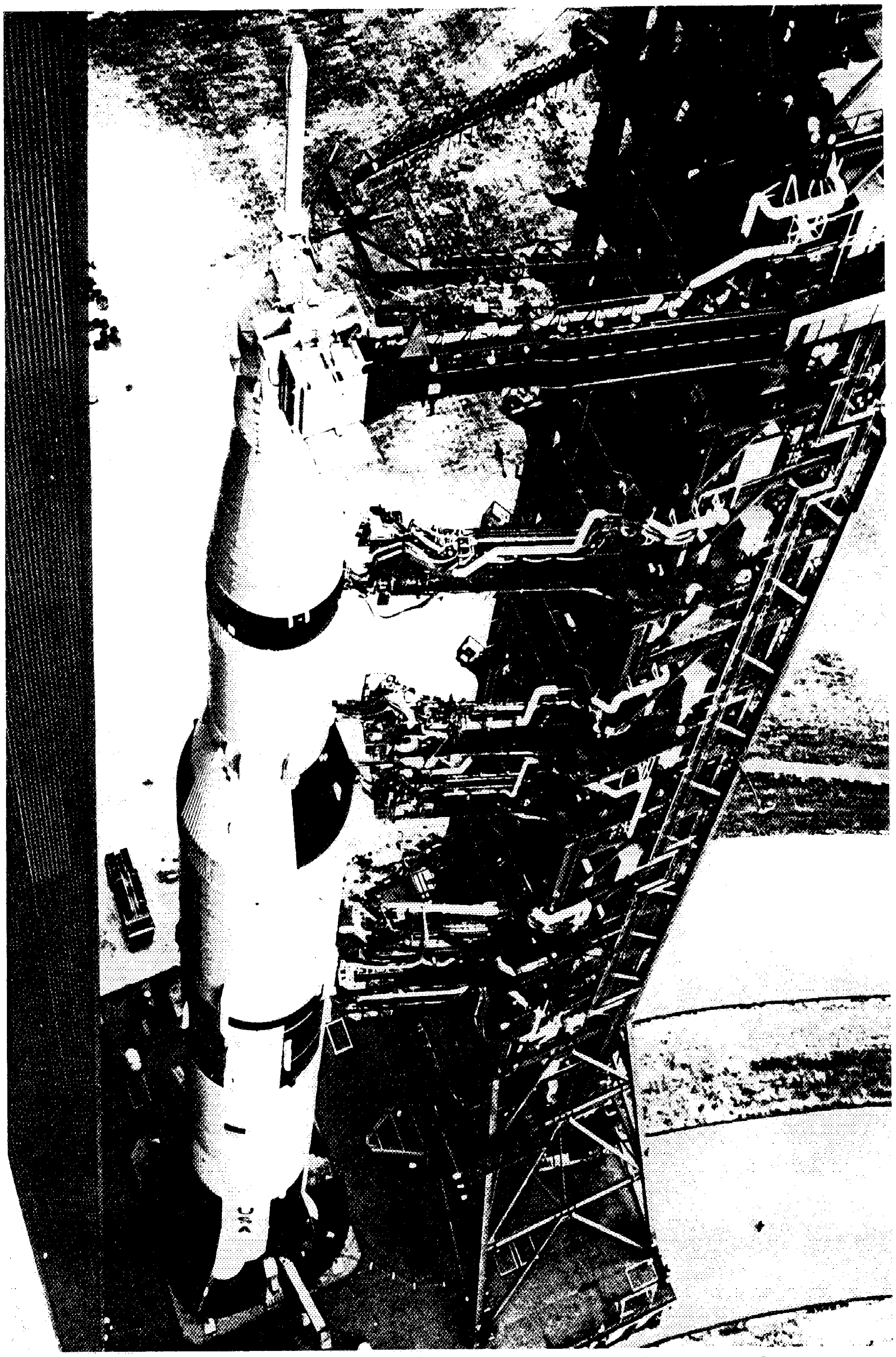


P-280 *Final tests of spacecraft and launch vehicle are performed on pad at Kennedy Space Center*

SAFETY

Apollo safety requirements in space and on the ground required new hardware and procedures in Block II (lunar mission type) spacecraft. Major changes affect the command module's test and pre-launch atmosphere, the hatch, the use of non-metallic materials, cabin emergency oxygen and fire-fighting provisions, wiring protection, and monitoring of crew and command module interior during hazardous ground tests.

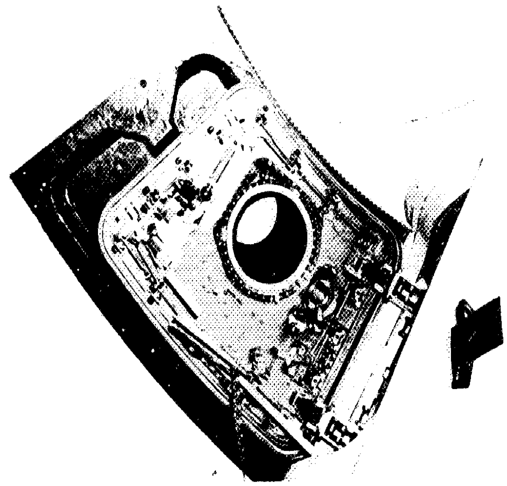
GROUND ATMOSPHERE

The atmosphere in the cabin of the command module for tests on the launch pad and at launch will be 60-percent oxygen and 40-percent nitrogen (60/40) rather than pure (100-percent) oxygen. The new mixed-gas atmosphere is supplied by ground equipment. Astronauts breathe pure oxygen in their space suits from Apollo's on-board systems. After launch, the cabin atmosphere is vented at a controlled rate, then replenished with pure oxygen so that in 4 to 6 hours it is approximately 95-percent oxygen. The safety of the modified spacecraft was judged acceptable in the 60/40 mixed-gas atmosphere of 16 psi, and in a pure oxygen atmosphere at the space pressure of about 6 psi after extensive tests at NASA's Manned Spacecraft Center.

SIDE HATCH

A one-piece door replaces the two-cover hatch system on the command module. The side hatch is made of aluminum with fiberglass and ablative material. The door deployment mechanism has a gas-operated counter-balancing device that offsets gravity and permits easy opening on the ground. The hatch can be unlatched and opened by the flight crew in less than seven seconds and by the ground crew in about 10 seconds.

On the ground and during the early part of boost, the command module is shielded from boost heating by the boost protective cover. This cover, which is attached to and jettisoned with the launch escape tower, also has a hatch. As the unified hatch is opened from the inside, it activates a release mechanism between it and the boost protective cover hatch. The mechanism releases the single latch of the cover hatch and the two hatches swing open together.



New hatch with boost protective cover hatch opening

P-281

MATERIAL

All materials in the spacecraft command module have been re-evaluated. Non-metallic materials were subjected to a rigid series of flammability tests and were replaced as required.

Among the more important changes are the use of stainless steel tubing instead of aluminum for the astronauts' high-pressure oxygen system. Aluminum solder joints of lines carrying water-glycol liquid for cooling or heating have been reinforced with protective armor where necessary. Protective plates cover coolant lines and also protect wiring against wear or accidental damage. Stowage boxes are made of aluminum.

Flammable materials are stowed in fireproof containers (metal or polyimide fiberglass storage boxes and Beta Cloth stowage bags).

Nylon Velcro material, used to grip or hold objects in the weightlessness of space, has been replaced with a new Teflon and polyester Beta fiberglass product, and wherever practical, mechanical fasteners are used to "button down" or hold equipment. A new flame-resistant material called Ladicote has been introduced and is applied by brush to potted connections.

Significant material changes include:

Old	New
Nylon Velcro	Teflon Beta fiberglass (for the pile); polyester Beta fiberglass (for the hook)
Polyurethane line insulation	Molded glass fibers
Nylon Raschell knit debris trap	Aluminum coverings
Silicone rubber wire bundle antichafe wrap	Teflon sheet
Nomex (nylon) wire bundle spot ties	Teflon-coated Beta fiberglass
Mylar window shades	Aluminum sheeting (not roll-up type)
Silicone heat-shrink wire insulation	Teflon heat-shrink wire insulation
Trilock couch padding	A new fabric couch pad made of Teflon-coated fiberglass
Most plastic knobs and switch levers	Aluminum
Polyolefin coaxial cable	Wrapped with aluminum foil tape; later spacecraft to have Teflon cable
Plastic switches in main display panel	Metal
Silicone oxygen umbilical hose	Covered with Fluorel
Crewman's communications umbilical (silicone rubber)	Molded Fluorel
Epoxy laminate food boxes	Polyimide laminate
Silicone laminate panel scuff covers	Polyimide laminate covers
Electroluminescent panels	Covered with copper overcoat
Silicone rubber spacers	Covered with Beta fabric
Nylon zipper on space-suit bags	Metal
Circuit breakers of diallylphthalate (DAP) and Melamine, both resins	Covered with Ladicote
Epoxy laminated structures	Polyimide structures
Postlanding vent duct (silicone laminate)	Metal and Fluorel impregnated glass fabric

Old	New
Felt filters in lithium-hydroxide canisters	Teflon felt
Uralane foam (cushion material for mirrors, etc.)	Fluorel foam
Fiberglass tape	Aluminized tape
Nylon webbing (such as hook on CO_2 absorber)	Beta webbing
Dacron cloth in the environmental control system	Armalon cloth
Aluminum high-pressure oxygen lines of environmental control system	Stainless steel

CABIN PROVISIONS

An emergency oxygen system with three masks and an independent oxygen supply would protect the crew from toxic fumes. Special fire-fighting provisions include a portable fire extinguisher, protection panels to isolate a fire, and special ports where the extinguisher's nozzle is inserted to douse a flame behind a panel.

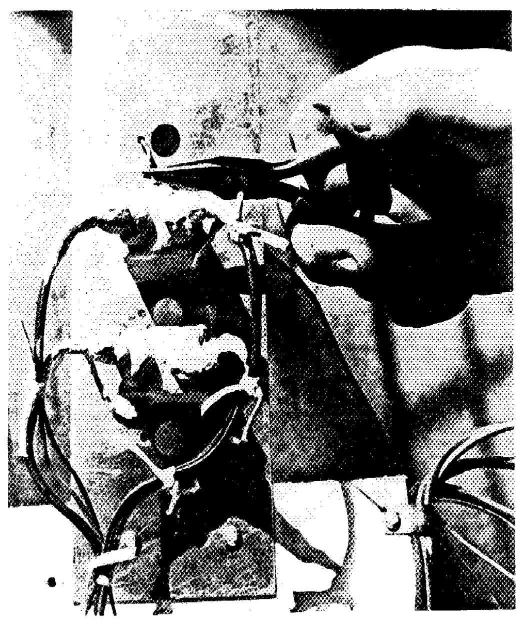
WIRING PROVISIONS

A number of changes makes the estimated 15 miles of wiring safer in Block II spacecraft. Some circuit breakers were added and others reduced in capacity to improve wiring protection. Teflon wrapping separates power wires from others in a bundle. Aluminum enclosures protect wire runs in the crew compartment.

Ladicote, a special fire-resistant material which is applied by a brush, coats terminals, metallic electronic components, and circuit breakers. Ladicote was developed by chemists at North American Rockwell's Los Angeles Division.

MONITORING

Hazardous ground tests are more closely controlled by monitoring of biomedical data from the three crew members and observation through closed-circuit television of the command module interior.



Wire terminals coated with Ladicote fire retardant

P-282

EARTH LANDING SUBSYSTEM

The earth landing parachute system has been modified to handle the increased weight of the command module. Its two drogue parachutes were expanded from 13.7 to 16.5 feet. A dual-reefing feature was added to permit the three main chutes to open more slowly.

P-283

Astronaut Wally Schirra leaves CM after Downey test of Block II spacecraft

238

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.

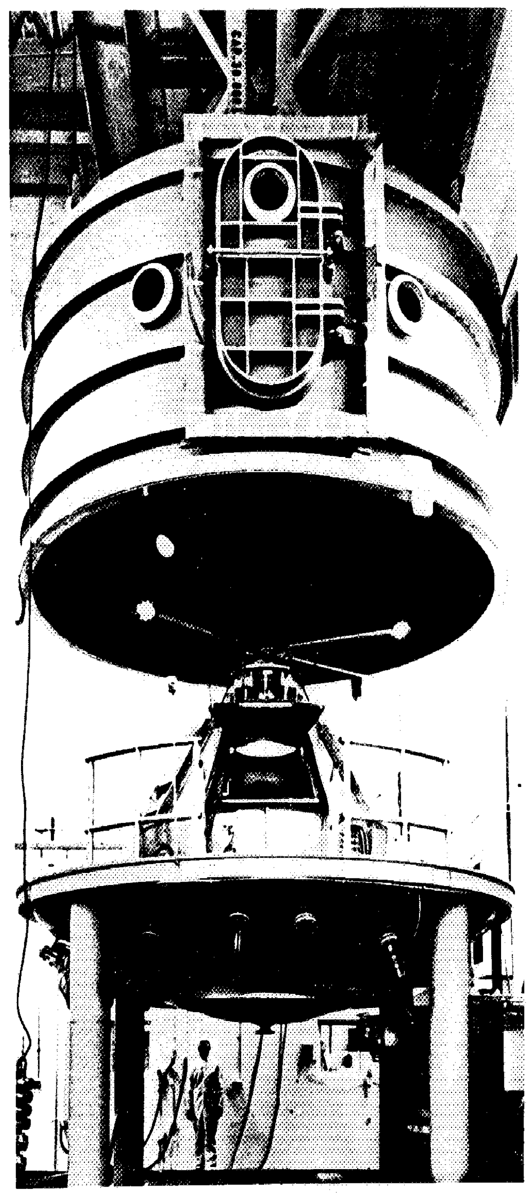
There are 587,500 inspection points on the command and service modules. In addition, the vehicle is checked to make sure it conforms to each of approximately 8,000 drawings and 1,700 manufacturing and engineering specifications.

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.

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



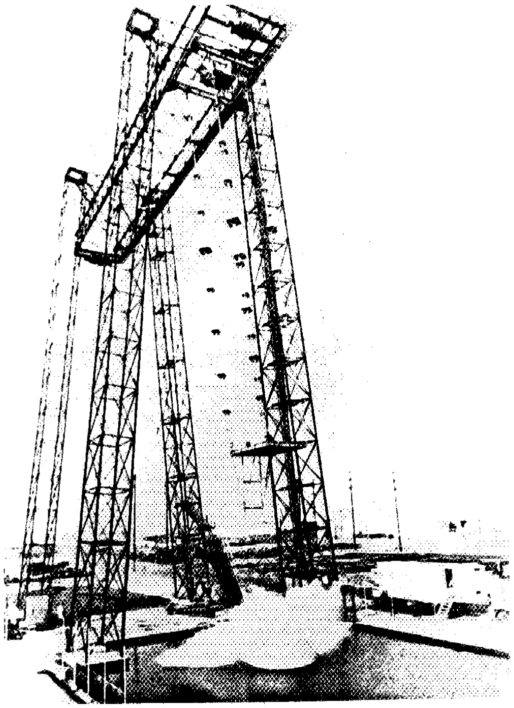
P-284

Environmental (vacuum) chamber at Downey

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.

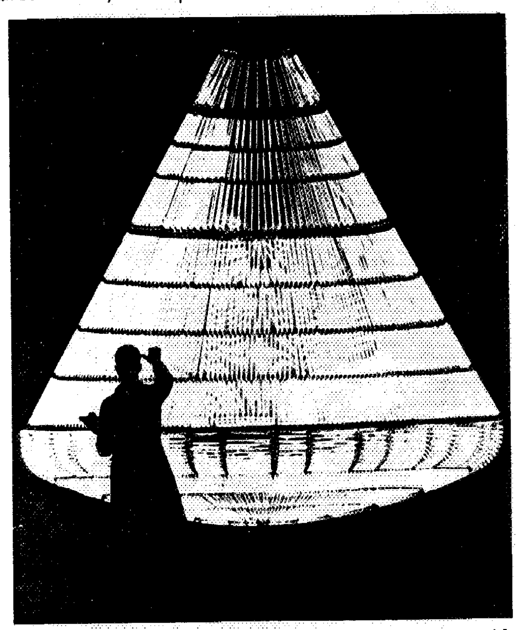
Impact Test Facility—This four-legged tower contains a pendulum that was used to swing a full-scale instrumented CM at controlled speeds and angles, dropping it into a water tank or on a special land impact area to simulate parachute landings. Drop tests provided information on how impact affects the 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

P-286

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.

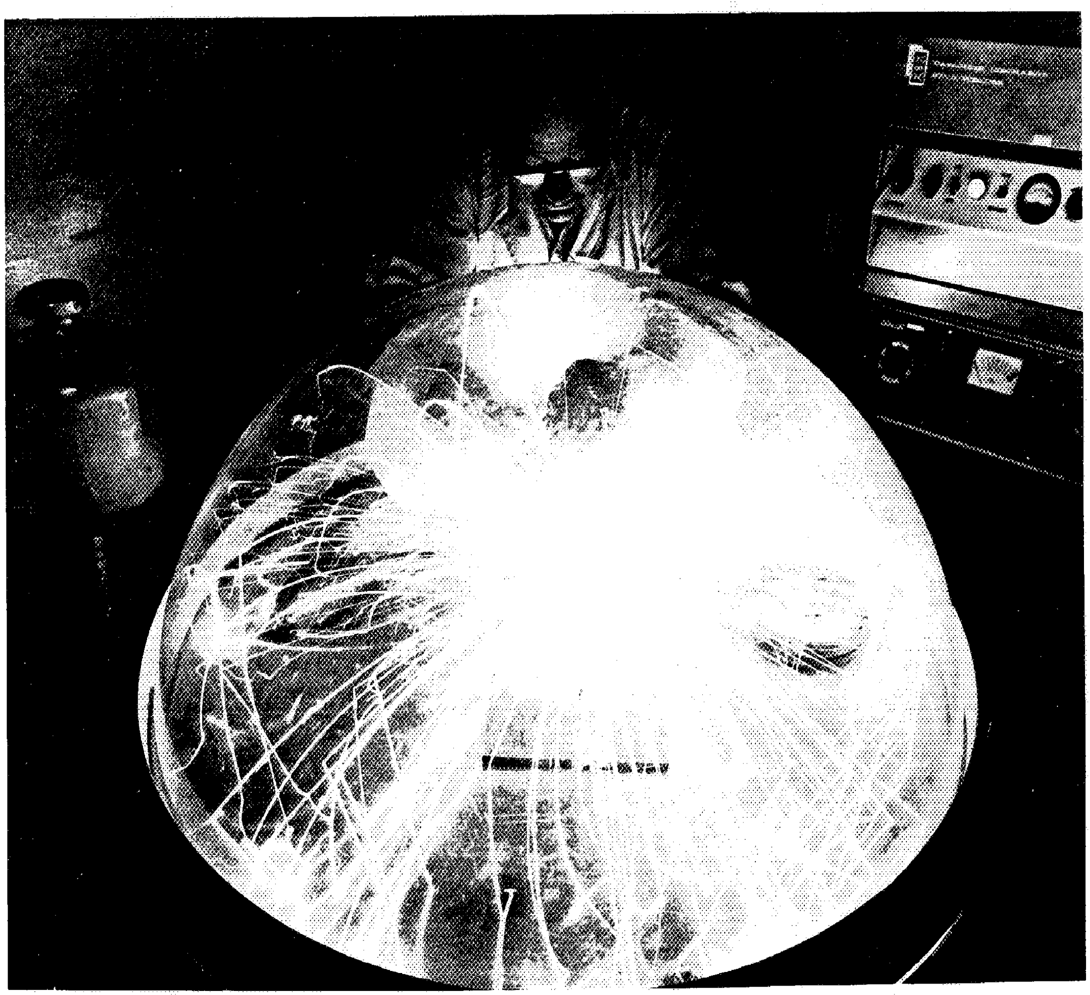
Plasmajet Test Facility—Approximately 1,000 plasmajet tests are conducted on ablative specimens, simulating radiative and convective heat fluxes. Heat fluxes from 5 to 800 British thermal units per square foot per second and gas stream enthalpies from 5,000 to 25,000 British thermal units per pound are 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



P-287

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.

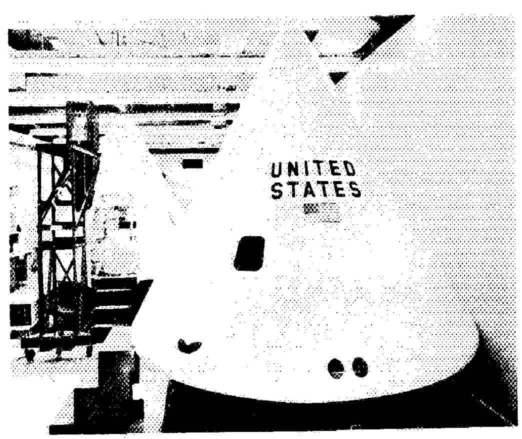
Special equipment for the training program includes spacecraft evaluators at Downey and mission simulators at the Manned Spacecraft Center in Houston and at Kennedy Space Center.

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.

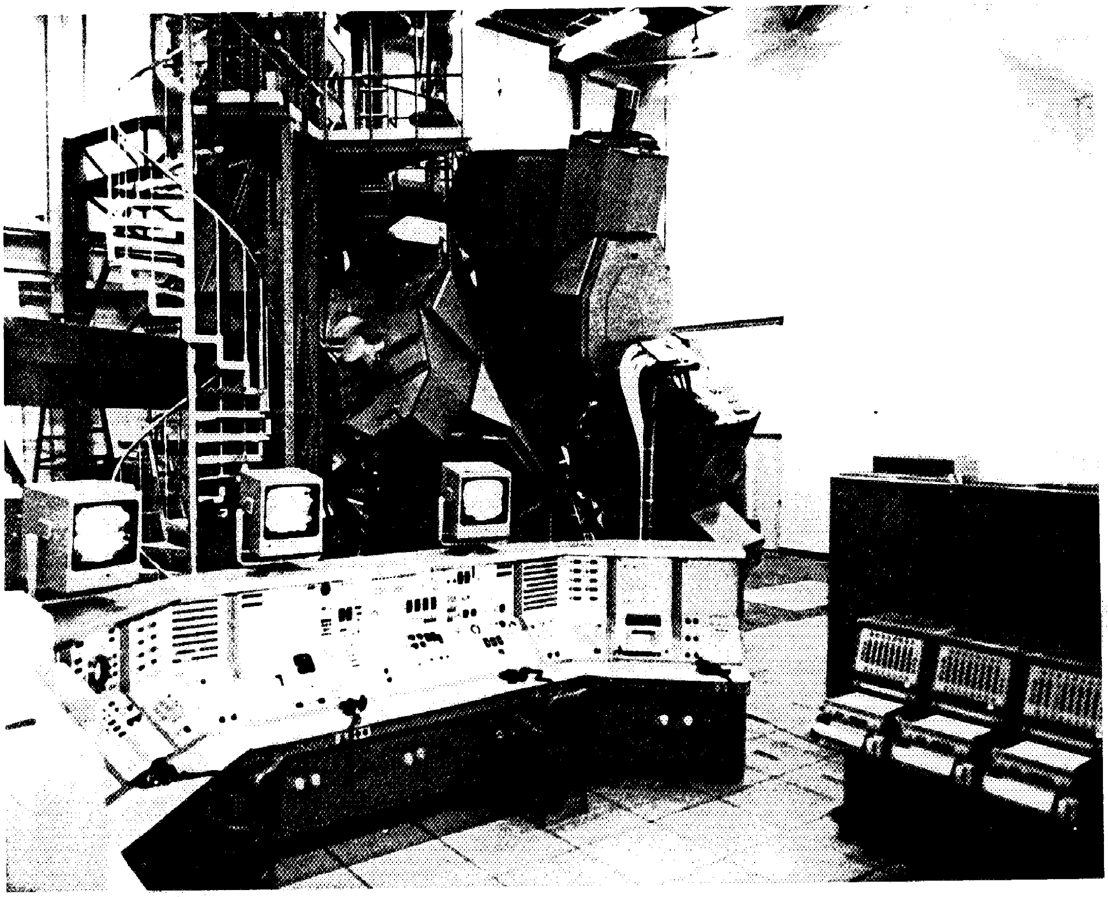
Peripheral equipment includes an earth, stars, and sun as they would appear to the astronauts. The earth, a six-foot globe in which landmarks are scaled to an accuracy of within three miles of their actual position as seen from space, revolves in a manner to simulate its own revolution and the orbit 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

P-288



P-289 *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.

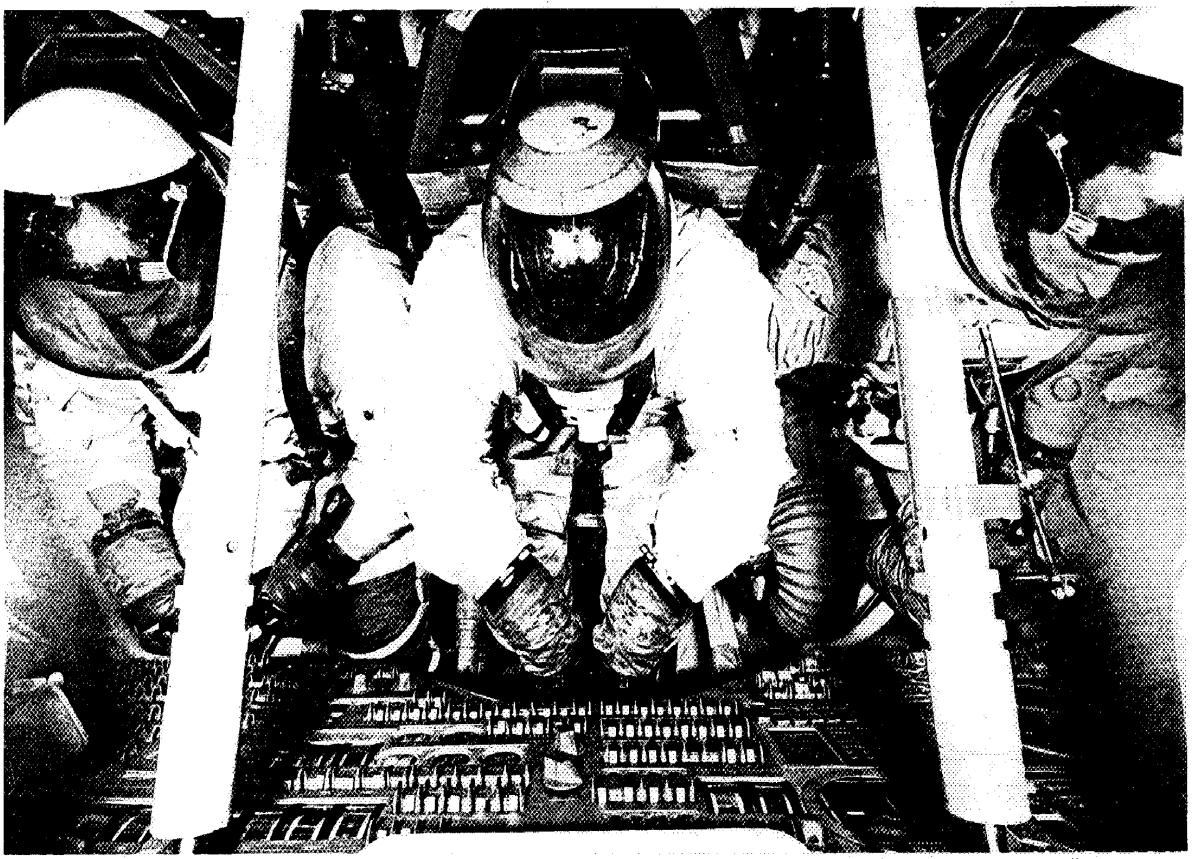
An entire lunar mission—except for lunar descent and ascent—can be simulated. Visual and acoustic effects are simulated; everything, in fact, except the sensations of weightlessness and the gravitational forces of launch and earth re-entry. (Training for the lunar descent and ascent is performed in the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



P-290

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

APOLLO MANUFACTURING

The variety and complexity of components in the Apollo command and service modules and the degree of reliability and quality demanded for each imposed many fabrication problems.

Solution of these manufacturing problems required application of skills in such areas as advanced electronics, fire retardant organics, plastics and cryogenic insulation, welding and brazing, adhesive and diffusion bonding, and machining, plus design and development of many tools and fixtures.

In fact, almost all of the tools and fixtures used in fabrication and assembly of the command and service modules were designed especially for the Apollo program.

For the Apollo spacecraft there are five major manufacturing assemblies: the command module, service module, lunar module, launch escape subsystem, and the spacecraft-LM adapter. All but the LM are assembled by North American Rockwell. The CM, SM systems, and launch escape subsystem are at Downey, Calif. The SLA and basic SM structure are produced at North American Rockwell's Tulsa (Okla.) Division. The LM is produced by Grumman Aircraft Engineering Corp., Bethpage, N.Y.

In the original basic mastering programs, conventional airframe mastering techniques were used. Tooling specialists soon realized, however, that while plaster model masters had been satisfactory for constructing aircraft, they could not maintain the tolerances required for critical space hardware. So the technique was conceived of fabricating control masters, masters, and assembly tools from like materials, compatible with the end hardware: for example, aluminum masters and aluminum tools for the aluminum hardware and steel masters and steel tools for the steel hardware. Basic tolerances could be integrated into these tools and were not nullified by differential expansion during operations involving the application of heat. Mainly because of this improved tolerance control, some heat shields have been delivered without any defective weld despite the 718 feet of weld in the crew compartment heat shield and the difficult access to some areas.

Many welding innovations have been developed during the program. One of these was the use of a pressurized portable clean room that enclosed a total weld station to maintain temperature and dust particle control. Another was the development of closed-circuit television for monitoring and controlling manufacturing operations. Miniaturized weld skates were developed for use in inaccessible areas.

One of the most important innovations was an induction brazing method in which a small unit can be moved as far as 600 feet away from its bulky generator. The small unit is used to join stainless steel fluid system components in remote and relatively inaccessible areas of the spacecraft.

In the portable brazing tool, a radio frequency current flows through coils and produces a high-frequency magnetic field around the work piece. This magnetic field produces the induction heating (up to 2,000 degrees) needed for brazing. The brazing substance is a gold alloy inside the sleeve which joins the two ends of a conduit.

Most of the spacecraft plumbing joints are induction-brazed stainless steel. This successful joining process offers a number of advantages. The joints are light (compared with mechanical joints), strong, and low cost. X-ray examinations have determined that more than 97 percent of these braze joints are acceptable. In addition, this system permits joining of tube stubs having widely different wall thickness.

The boost protective cover is an example of problems solved on the program. It is a multi-layer, resin-impregnated fiberglass assembly 11 feet tall and 13 feet in diameter, weighing approximately 700 pounds. It fits over the command module like a glove.

Originally it was concluded that the protective cover would be a standard configuration adaptable to all spacecraft. As the program progressed, however, it was apparent that each cover must be tailored to each heat shield.

In the process, heat shields are mounted on a holding fixture and a mixture of resin and fiberglass blown against the shield to produce a fiberglass female mold identical to the heat shield. Through a series of carefully controlled casting operations, a full-size plaster master is constructed to reproduce the outer moldline of the heat shield.

The plaster simulators match so exactly the actual heat shield that the finished boost protective cover is inspected for a match with the simulator rather than the actual heat shield, eliminating hundreds of hours of inspection and other operations for the spacecraft.

The unified hatch for the command module is probably the most carefully engineered and manufactured door ever built. A system of 12 linked latches seals the door shut.

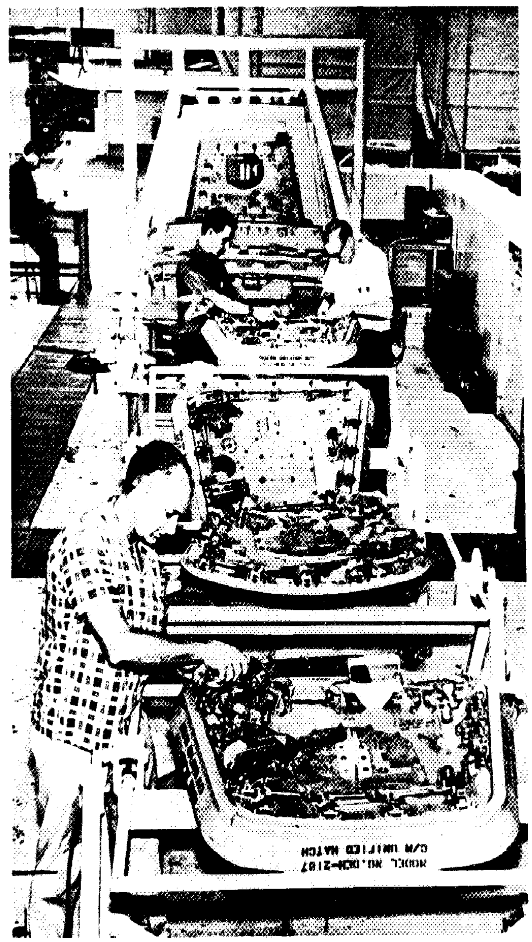
Many advanced technologies were used to produce this hatch, both in tooling and in the various tool fabricating and assembling areas. One noteworthy innovation was the conversion of an existing fixture to machine three complex components: edge ablators which fit around the periphery of the door and the hatch opening, and the ablator which attached to the inner crew compartment door. In all, about 150 new tools were designed and built for the hatch.

A major element of the environmental control subsystem is the coldplate, a mounting plate through which coolant flows to prevent overheating of electronic components. Originally, coldplates were machined, ladder-type cores that were eutectic-bonded between two face sheets. These were difficult to bond and the rejection rate was prohibitive.

To overcome the problem, a pin-fin configuration was developed which could be machined by electrical discharge and which immeasurably reduced fabrication complexity yet proved more effective in heat dissipation. In addition, heated platens with precise thermal controls were developed to provide the degree of heat, pressure, and flatness necessary to diffusion-bond the coldplates. Although required to function at a pressure of 90 psi, the coldplates now being produced are being tested at 1000 pounds without any evidence of failure.

One of the severest requirements of the Apollo program was for a heat shield that would withstand the intense aerodynamic heating experienced during entry from a lunar mission.

The heat shield is fabricated of a special stainless steel honeycomb sandwich manufactured by the Aeronca Co., Middletown, Ohio, and serves as the outer structure of the vehicle. The shield is assembled from 40 individual panels produced by



P-291

Unified hatch in final assembly

means of a special electric-blanket brazing process. The brazing material used to join the steel skins to the honeycomb is a silver-copper-lithium alloy in a nickel matrix. Each panel is subjected to X-ray inspection after brazing to assure quality.

The ablative (heat-dissipating) material is a phenolic-filled epoxy compound developed and applied by the Avco Corp.'s Space Systems Division, Lowell, Mass. The ablative material is dielectrically heated and injected with specially developed guns into each of more than 370,000 cells in the glass-phenolic honeycomb bonded to the outer surface of the three heat shield sections. Each section is X-rayed to assure that all cells are completely filled, then cured in specially designed ovens. For machining the various thicknesses required of the contoured shields, computers operate machining heads of giant lathes. Pore sealer is applied as the final process, and thermal paint is applied to the heat shield.

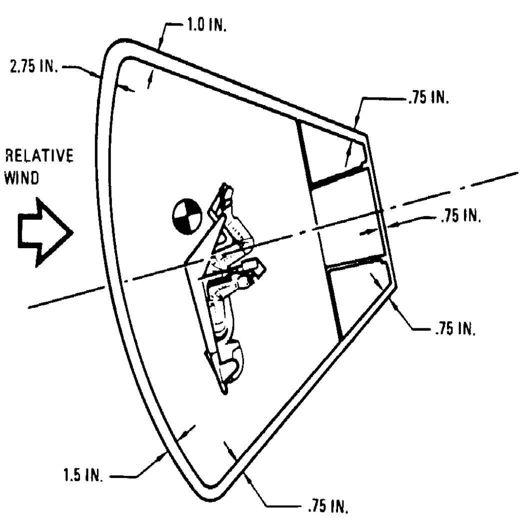
COMMAND MODULE

The basic command module structure consists of a nonpressurized outer shell (the heat shield) and a pressure-tight inner shell for the crew compartment. The inner compartment is formed of aluminum honeycomb sandwich while the heat shield is formed of stainless steel honeycomb sandwich. The space between the inner and outer structures is filled with a special fibrous insulation (Q felt).

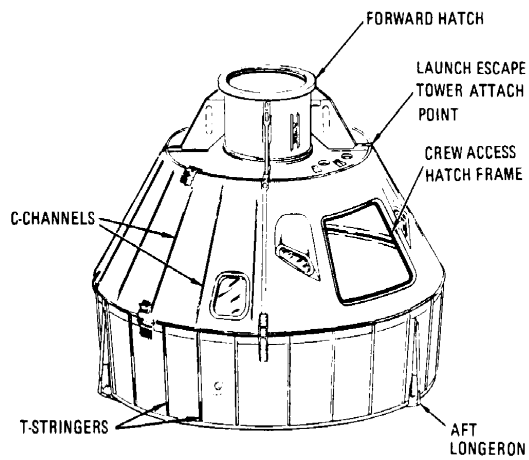
ASSEMBLY

The heat shield structure consists of three basic assemblies: the forward, crew compartment, and aft sections. The complete assembly envelops the the inner crew compartment and provides thermal protection during entry.

The forward assembly of the heat shield consists of four conical-shaped honeycomb panels, one machined aft ring, one forward bulkhead, and four launch escape tower leg fittings. The section is assembled in the following sequence. The tower leg fittings are installed, trimmed, and welded to each of the four honeycomb panels. The panels are installed in a fixture which accommodates all four panels; the panels are trimmed longitudinally, then butt-fusion welded. The welded panels, forward bulkhead, and aft ring are placed in another fixture for circumferential trim and weld. The aft ring and forward bulkhead inside ring are finish-machined after welding. The completed assembly is fit-checked



P-292 *Thickness of CM ablative material*



P-293 *CM inner structure*

to the inner crew compartment and crew compartment heat shield, and then removed for application of ablative material.

In addition, the forward heat shield assembly has an outer access door. This door consists of two machined rings that are weld-joined to a brazed honeycomb panel. The inner ring and outer ring are machined after welding. The door closes the forward end of the access tunnel of the crew compartment. It provides thermal and water-tight protection and may be opened from inside or outside.

The crew compartment heat shield is formed from numerous brazed honeycomb panels, numerous machined edge members which provide for door openings, and three circumferential machined rings joined by fusion welding. The panels and rings are installed in a series of jigs for assembly, trimming, and welding. The welded sections are placed in a large fixture for precision machining of the top and bottom rings. The assembly is fit-checked with the inner crew compartment and the forward and aft heat shields, then removed for application of ablative material.

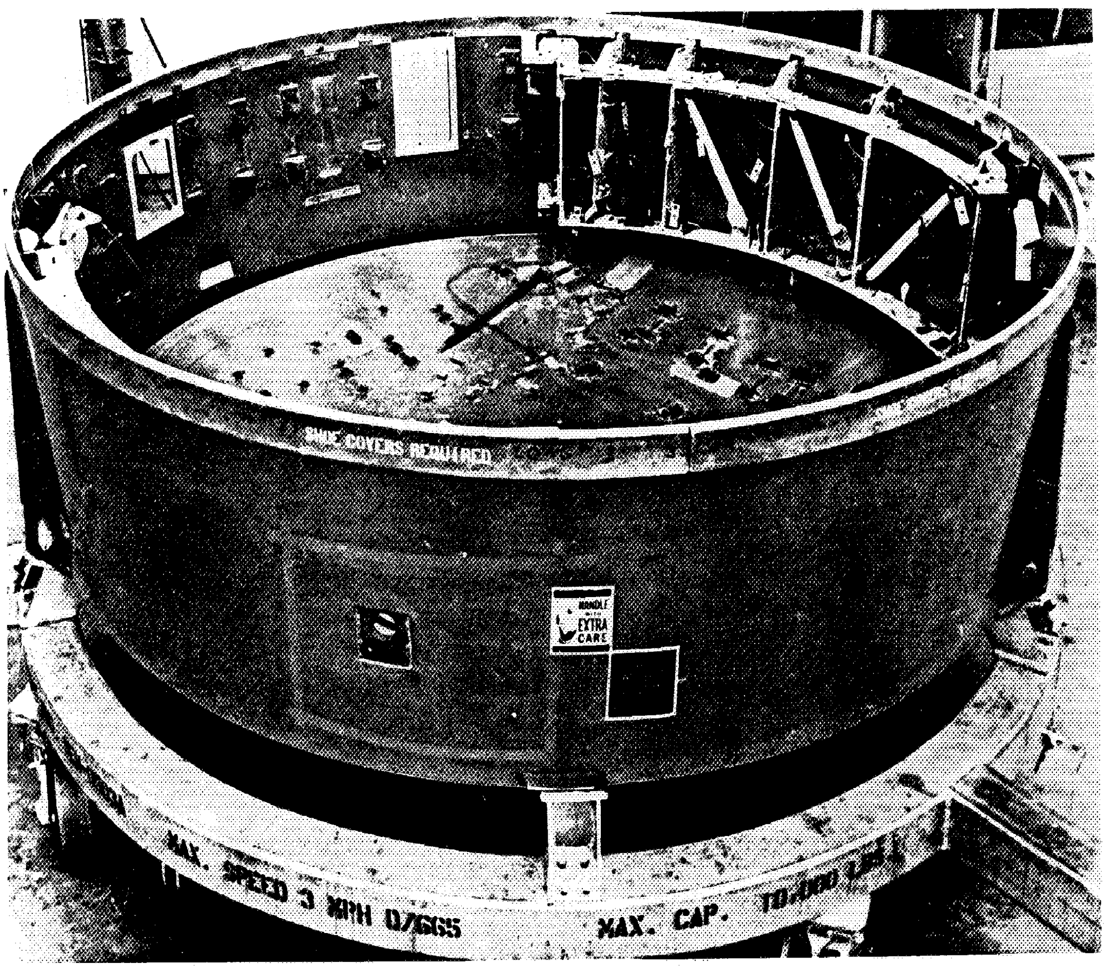
The aft heat shield consists of four brazed honeycomb panels, four spotwelded, corrugated, sheet metal fairing segments, and one circumferential machined ring. The honeycomb panels are joined laterally by fusion welds. The four fairing segments are attached to the honeycomb panels and machined ring using conventional mechanical fasteners. Holes for inner and outer structure attachment points and tension tie locations are cut through the assembly. The complete section is fit-checked with the crew compartment heat shield, then removed for application of ablative material.

The inner crew compartment is built in two assemblies: the compartment structure and the system support structure. The compartment structure is made of aluminum and is fabricated in two sections. The forward section consists of an access tunnel, a forward bulkhead, and a forward sidewall. The aft section consists of an aft sidewall, an aft bulkhead, and a circumferential machined ring. The two sections, when joined, form the spacecraft's pressure vessel.

The forward section welded inner skin is fabricated from panels, four machined longerons, window frames, a machined circumferential girth ring, and fittings. Aluminum honeycomb core and outer face sheets are thermally bonded to the inner skin and cured in a giant autoclave (similar to a giant pressure cooker). Attachments and fittings are then bonded to the structure for installation of the system support structure, wiring, tubing, and other equipment. The access tunnel, which is bonded to the forward bulkhead, includes a forward ring for mounting the docking ring, the pressure hatch cover, and external frames which absorb loads from parachute deployment and the recovery sling.

The aft section welded inner skin is fabricated from panels, machined ring, and fusion-welded bulkheads. Aluminum honeycomb core and outer face sheets are thermally bonded to the inner skin and cured in a giant autoclave. External frames and internal attachments are bonded to the structure for the system support structure.

The inner crew compartment is completed when the forward and aft assemblies are circumferentially trimmed and fusion welded at the girth ring. The final assembly operation is the bonding of aluminum honeycomb core fillers and facing sheets.



P-294

"Egg crate" fixtures developed to locate exactly the CM interior components

The system support structure, which is added after completion of the inner structure, consists of the main display console and the structure for the equipment bays. The bays are fabricated of sheet and machined aluminum panels and vertical frames. Each equipment bay is assembled outside and then transferred into the inner compartment through the crew access hatch. Basically, the final assembly of the command module involves the installation of the heat shield over the inner crew compartment and the mechanical attachment of the two structures. Fibrous insulation (Q felt) is installed between inner and outer structures.

"Egg crate" fixtures were developed for more accurate and efficient installation of CM interior components. These curved tooling structures simulate a bay of the spacecraft and give workers the precise location for brackets, stringers, and other mountings. The attachments are located with the jig, and fixed in place with metallic tape and the egg crate is removed. Then the devices are bonded to their locations. The egg crate tool is used again to determine whether any of the components have moved during bonding. The largest of the egg crate jigs covers about one-quarter of the inside circumference of the CM.

Engineers say the egg crate jig is more flexible in use and more accurate than the "wrap-around" tool that was used for the same purpose but covered the entire circumference of the inside of the module. The old tool was much bulkier and less adaptable for close tolerance work.

SUBSYSTEM INSTALLATION

Subsystems are installed in a giant clean room in Downey. When structural assembly of the command module is complete, it is moved from the main manufacturing area to the clean room. There it goes through an outer airlock and is mounted on a special machine which vacuum-cleans and tumbles it, removing all dust and other particles. After this cleaning operation, it goes through an inner airlock to a station in the clean room for installation of subsystems.

Workers entering the room must pass through an air shower and clean their shoes with an electric buffing machine before entering the anteroom. There they don clean smocks and head coverings and pass through the air shower again before entering the clean room proper.

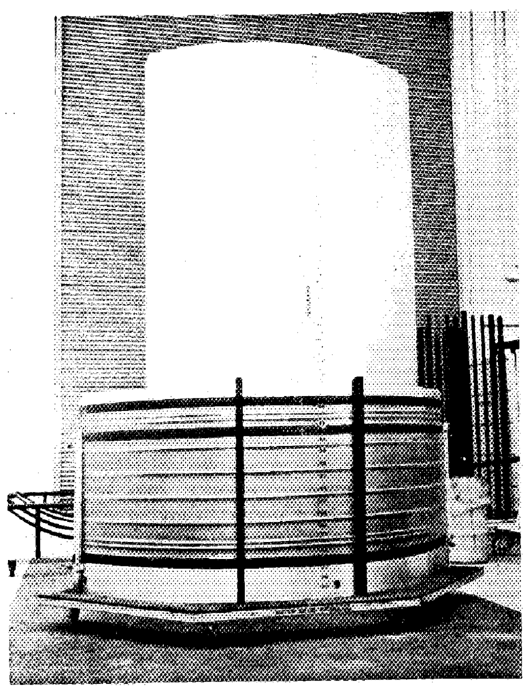
Even the workers clothing is restricted. Wool is prohibited (too much lint) and leather soles may not be worn. Workers entering the command module must remove everything from their pockets, and even rings and tie tacks, to assure that no foreign material will be left in the module. They also must put on special "booties" to protect the crew compartment. A hatch guard is stationed at the entrance to each command module to check each worker in and out.

Tools used by the clean room workers in installing the spacecraft's wiring and subsystems are issued in specially-designed, fitted boxes. These boxes are checked at the beginning and end of each shift to account for every tool and item of equipment.

When subsystem installation and the many testing operations are completed, the module is moved to another part of the clean room for the acceptance checkout tests described in the section on Checkout and Final Test.

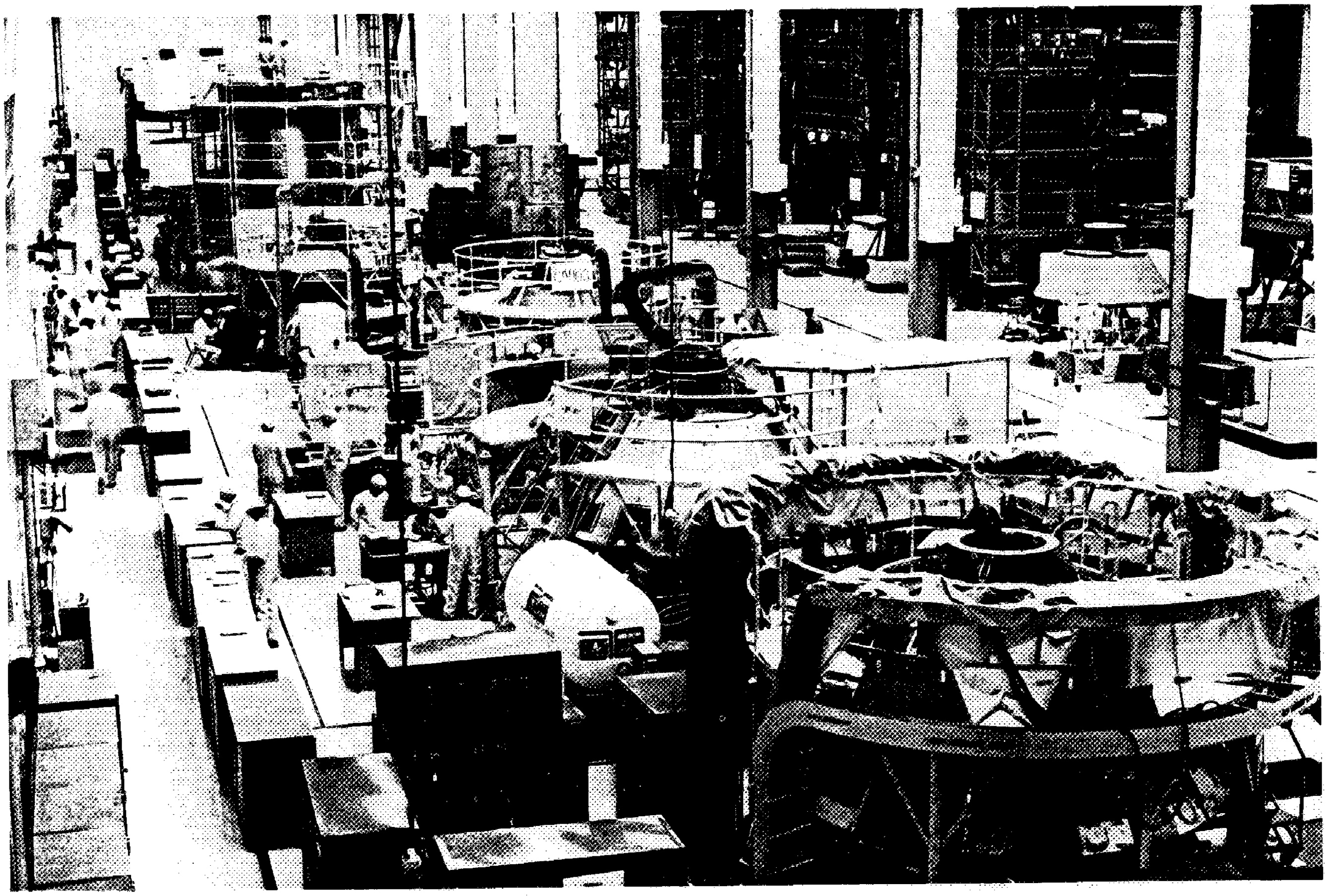
SERVICE MODULE

This is a cylindrical structure consisting of forward and aft honeycomb sandwich bulkheads, six radial beams, four outer honeycomb sandwich panels, four honeycomb sandwich reaction control system



P-295

SM radiator panel after assembly in Tulsa



P-296

Subsystems are installed and checked in command and service modules at Space Division's clean room, Downey, Calif., then shipped by air to Kennedy Space Center, Fla.

panels, aft heatshield assembly, and a payload fairing and radiator assembly.

The outer sector panels are 1 inch thick, and made of aluminum honeycomb bonded between aluminum face sheets. The radial beams, made from milled aluminum alloy plates, separate the module into six unequal sectors around a center section. Maintenance doors are located around the exterior of the module for access to equipment in each sector.

Radial beam trusses on the forward portion of the SM provide the means to connect the CM and SM. Alternate beams (Beams 1, 3, and 5) have compression pads for supporting the CM. The other beams (Beams 2, 4, and 6) have shear-compression pads and tension ties. A flat center section in each tension tie contains explosive charges for SM-CM separation. The six radial beams are machined and Chem-Mill etched (made thinner by chemical action) to reduce weight in areas where there will be no critical stresses.

These beams and separation devices are enclosed within a fairing 26 inches high which seals the joint between the CM and SM. Eight radiators which are part of the spacecraft's electrical power subsystem are alternated with ten honeycomb panels to make up the fairing. Each EPS radiator has three tubes running horizontally to radiate, to space, excess heat produced by the fuel cell powerplants. Two of the four outer honeycomb panels have radiators to dissipate heat produced by the spacecraft's environmental control subsystem. These ECS radiators, each about 30 square feet, are located on opposite sides of the SM.

After its assembly is complete, the service module is mated with the command module for a fit-check and alignment. The modules are then de-mated and the service module follows the same procedures as the command module for installation of subsystems in the clean room.

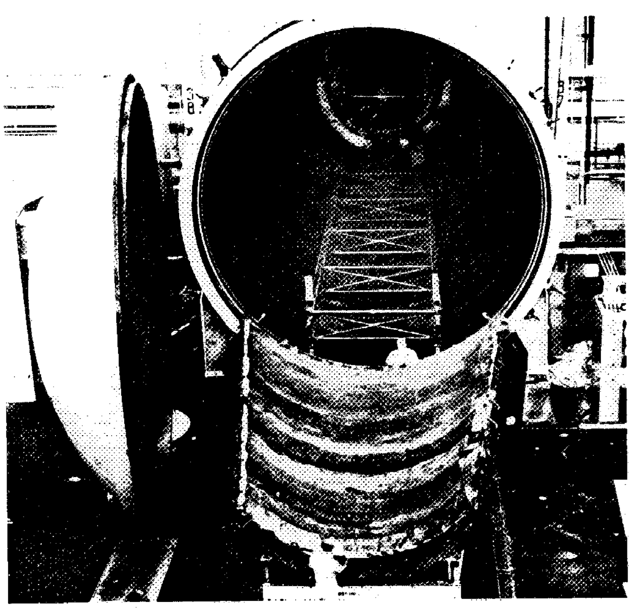
SPACECRAFT-LM ADAPTER
(SLA)

This structure is a tapered cylinder constructed of eight 2-inch-thick aluminum honeycomb panels (four aft and four forward) joined together with inner and outer doublers. The four forward panels, each about 22 feet tall, are hinged at the bottom. The aft panels are each about 7 feet tall. Other major components of the SLA include devices to separate it from the SM, fold back and jettison the forward panels, and separate the LM from the SLA.

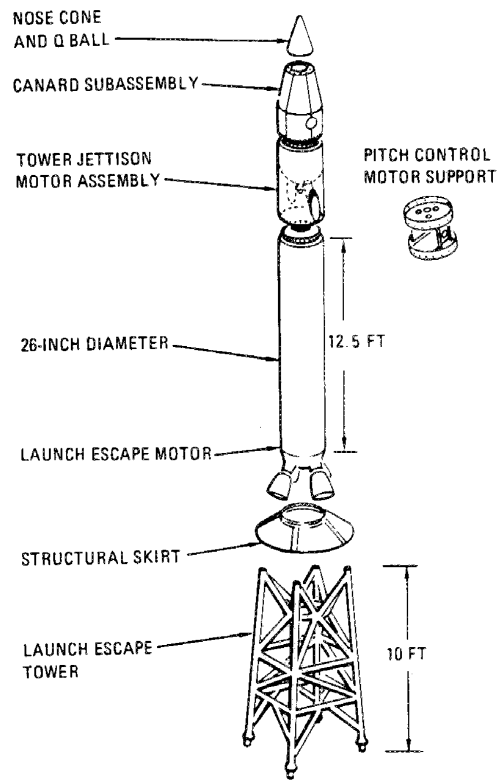
The bonding of the skin to both sides of the honeycomb panels is done in one of the largest autoclaves in the aerospace industry. This autoclave, at North American Rockwell's Tulsa Division, is a huge pressure heater, 20 feet in diameter and 40 feet long, with a heat capacity of 500 degrees and a pressure capability of 110 psi. An epoxy adhesive is used to bond the parts. The autoclave is large enough to accommodate one of four large SLA forward panels at a time. The autoclave also is used to bond all of the service module panels

LAUNCH ESCAPE ASSEMBLY

The basic structure consists of a Q-ball instrumentation assembly (nose cone), a ballast compartment and canard assembly, a pitch control motor, a tower jettison motor, the launch escape motor, a structural skirt, and a latticed tower.



SLA panel is prepared for bonding in giant autoclave
P-297



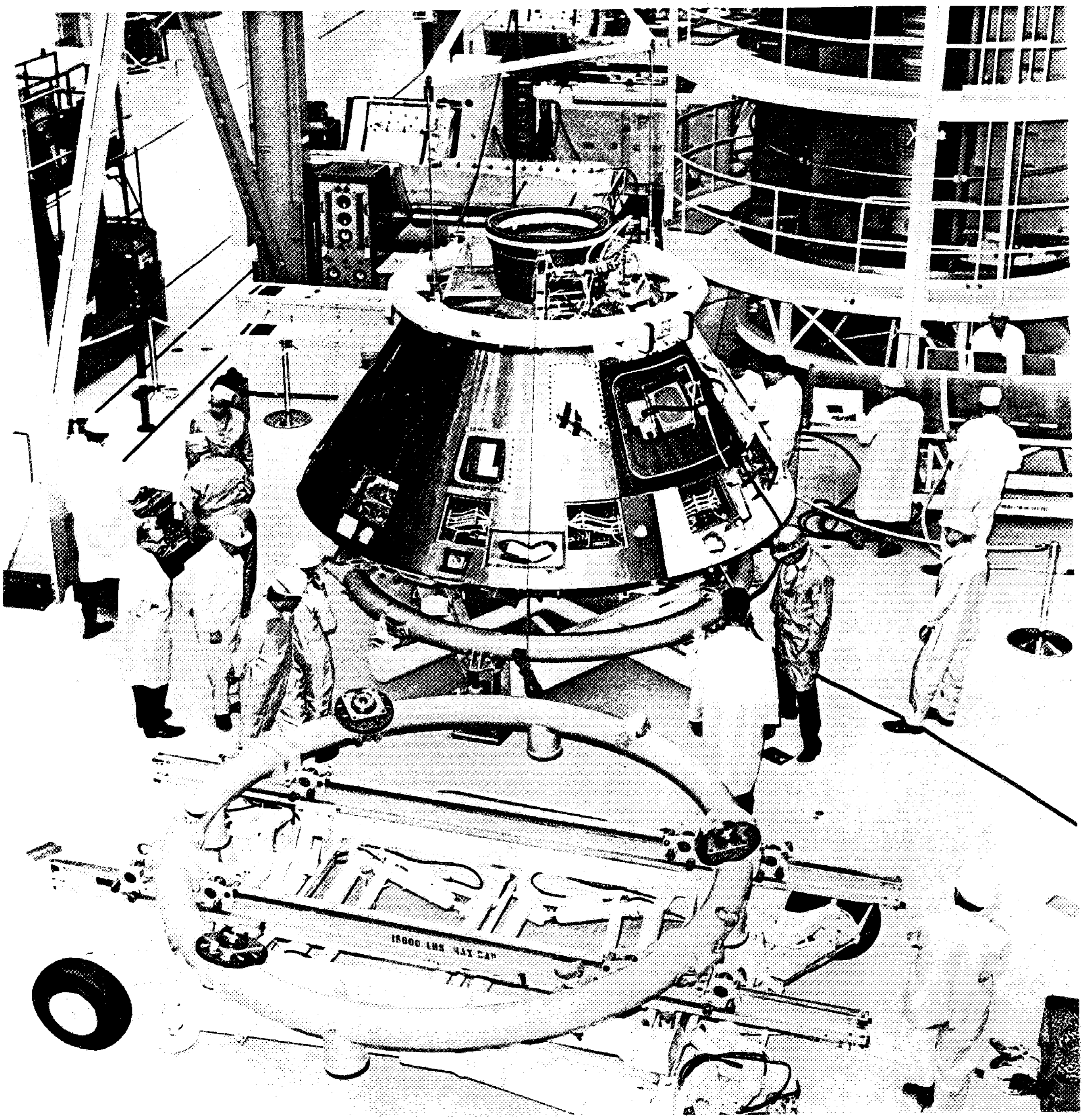
P-298 *Major launch escape subsystem structure*

The nose cone is a little more than 13 inches in diameter at its base and tapers to a rounded apex. Its total height also is a little more than 13 inches. Its skin is made of Inconel (a heat-resistant nickel alloy) and stainless steel riveted together. The cone has four ports to permit the electronic instrumentation inside it to measure pressure changes and the angle of the launch vehicle.

The ballast compartment also is constructed of Inconel and stainless steel and contains lead weights. Two canard subassemblies, each consisting of a thruster, actuating arm, and deployable surface, are faired into the ballast compartment surface.

The pitch control motor assembly is made of nickel alloy steel sheet skins riveted to ring bulkheads and frames. The case for the tower jettison motor is made of high-carbon chrome-molybdenum steel forged.

The launch escape motor is 15 feet long and has a case made of steel. The structural skirt is made of titanium, as is the tubing of the launch escape tower.



P-299 *Command module, nearing completion in Downey clean room, is put on fixture to be moved to new station*

CSM SUBCONTRACTORS

More than $1,078,000,000 has been funded by North American Rockwell's Space Division to Apollo subcontractors and suppliers throughout the United States. Funding to subcontractors with contracts in excess of $500,000 (values are approximate):

Company	Product	Value
Accessory Products Co. Whittier, California	Helium transfer unit, valves, and assemblies	$ 3,469,567
Aerojet General Corp Space Propulsion Division Sacramento, California	Service propulsion engine	99,780,000
Aeronca Manufacturing Co. Middletown, Ohio	Stainless steel honeycomb panels	15,411,779
Air Products & Chemical Co., Inc. Allentown, Pa.	Liquid hydrogen storage units	599,523
Amecom Division Litton Systems, Inc. College Park, Maryland	C-band (Block I) and S-band antennas	2,348,600
Applied Electronics Corp. of New Jersey Metuchen, N.J.	Pulse-code modulation systems	1,185,000
Astrodata, Inc. Anaheim, Calif.	Integrated computer complex	783,000
Avco Corp. Space Systems Division Lowell, Mass.	CM ablative heat shield	47,272,900
Avien, Inc. Woodside, N.Y.	2-gigacycle deep-space antenna	2,628,000
Beckman Instruments, Inc. Scientific & Process Instruments Division Fullerton, Calif.	Data acquisition system and water conditioning	2,838,000
Beech Aircraft Corp. Boulder, Colo.	Cryogenic gas storage system	30,855,876
Bell Aerosystems Company Division of Textron, Inc. Buffalo, N.Y.	Positive expulsion reaction control subsystem propellant tanks	23,084,000
Bendix Corp. Davenport, Iowa	Instrumentation	552,000
Borg-Warner Controls (Formerly Electroplex) Los Angeles, Calif.	Modules and amplifiers	706,781