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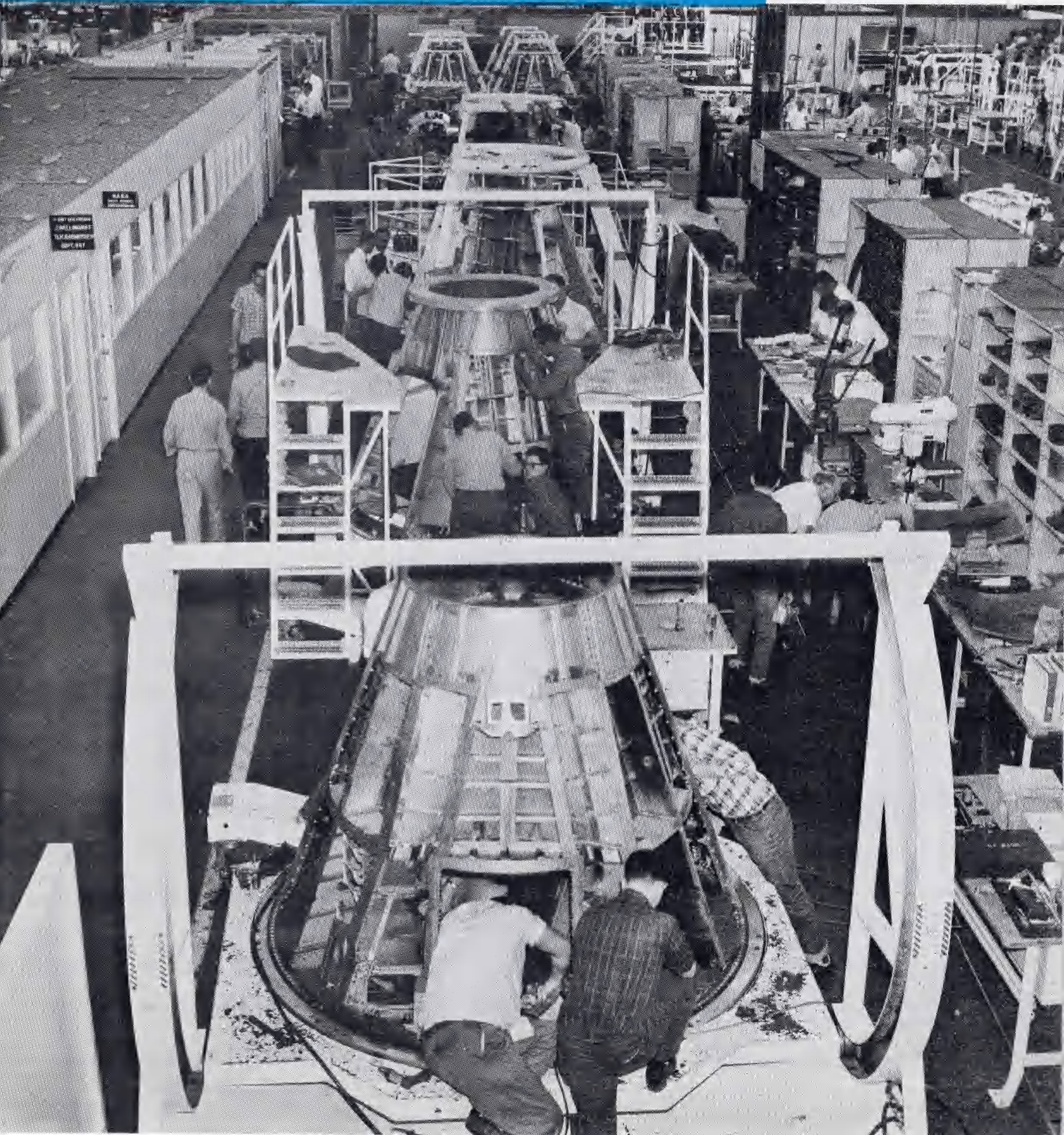
SPECIAL REPORT:

Gemini Design, Manufacturing

Gemini Production Line



Reprinted From AVIATION WEEK & SPACE TECHNOLOGY

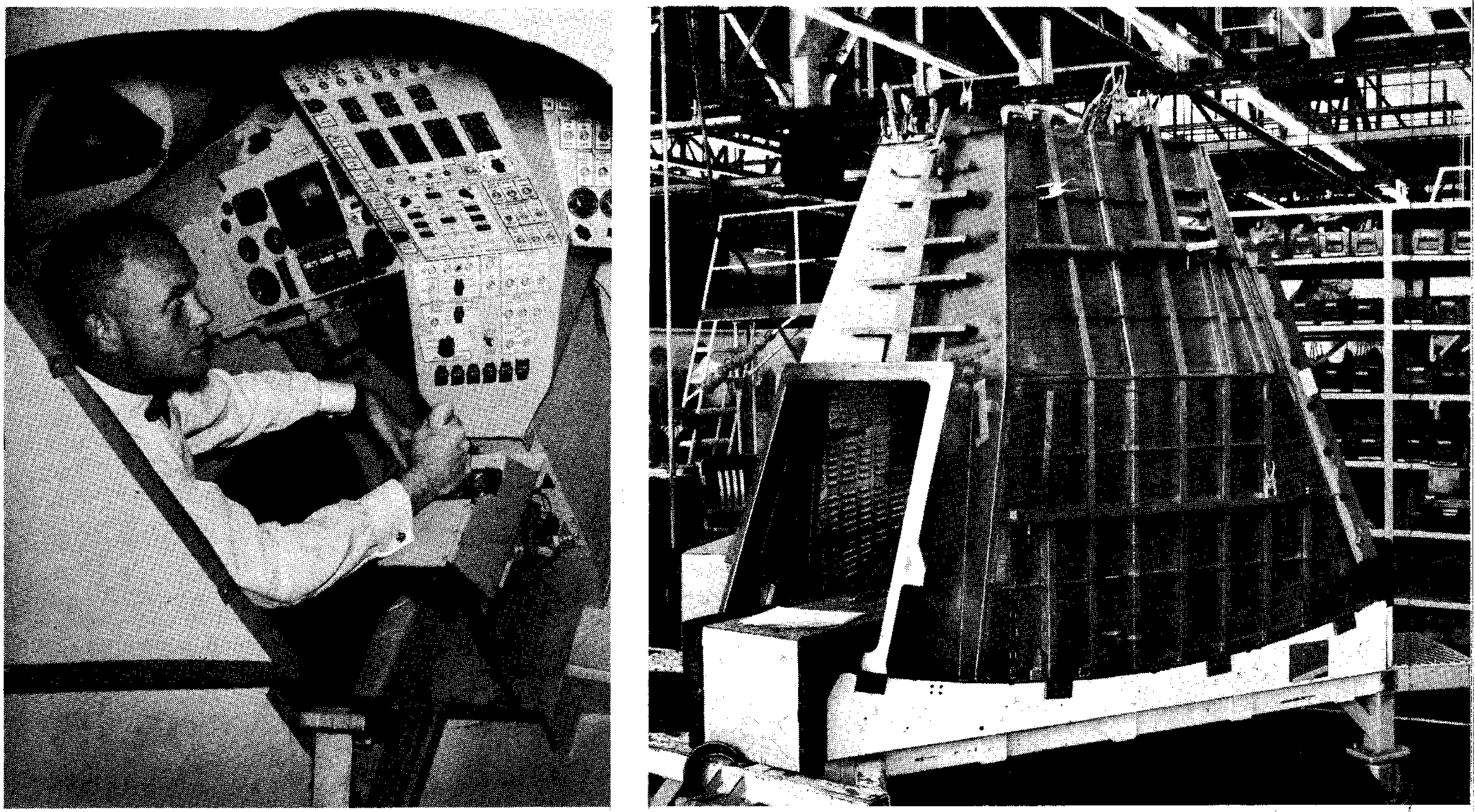
By

TITANIUM METALS CORPORATION OF AMERICA

233 Broadway, New York 7, N.Y.

COVER: Four of the five Gemini crew modules on McDonnell Aircraft Corp.'s production line at St. Louis are shown in various stages of fabrication. The crew module, a titanium pressure vessel, is the re-entry portion of the two-man spacecraft and will be mated with an equipment adapter, a retrorocket adapter and a rendezvous and radar module.

SPACE TECHNOLOGY



ASTRONAUT JOHN GLENN sits in Gemini trainer, above left. Right is a partly completed manned pressure vessel on the production line at McDonnell Aircraft Corp., in St. Louis. Cockpit floor, including forward panel, is at left.

Gemini Design Keyed to Mission Flexibility

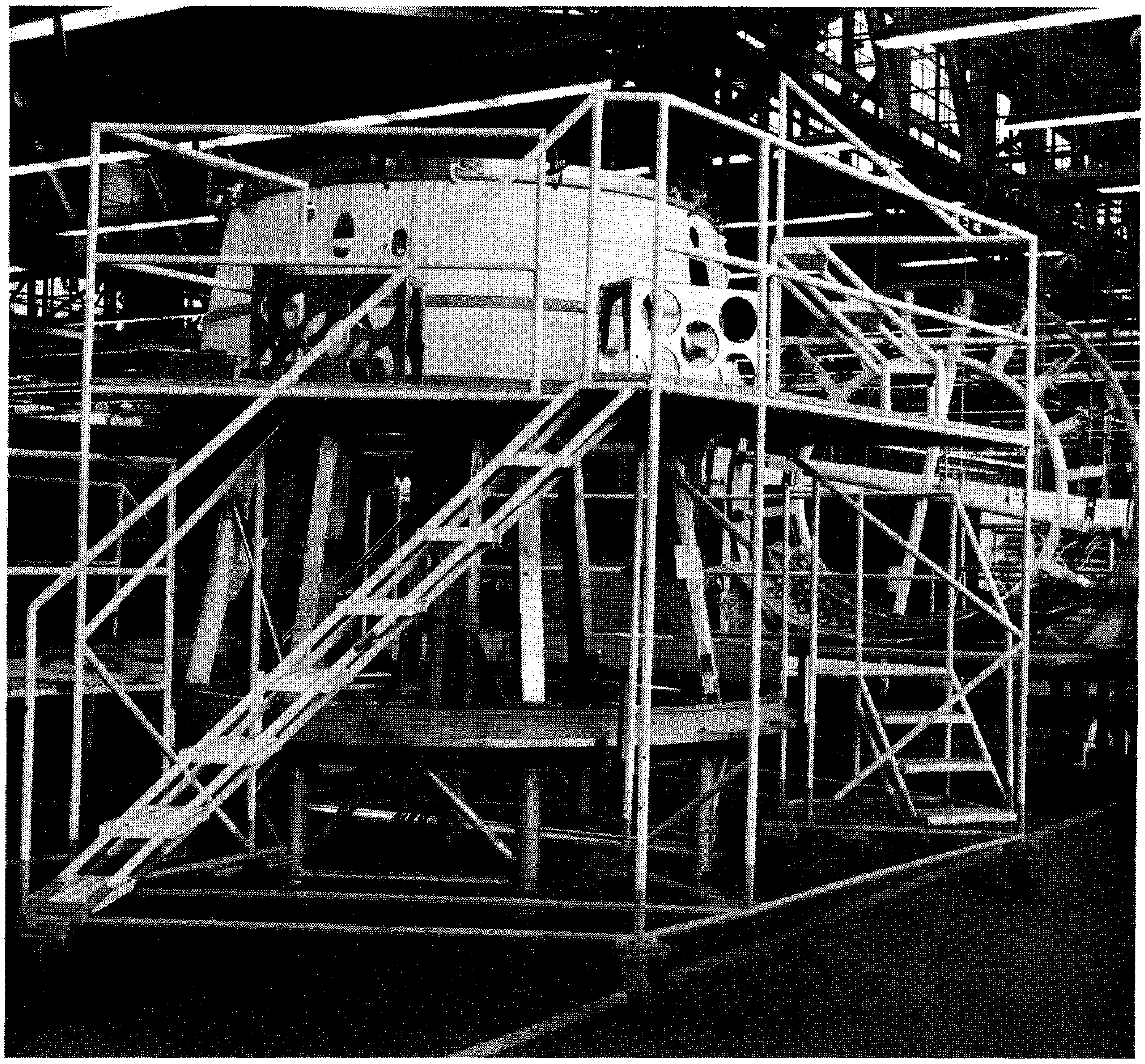
By George Alexander

St. Louis—Aircraft technology is the foundation for design, manufacture and testing of the two-man Gemini spacecraft but it is overlaid with the experience gained by McDonnell Aircraft Corp. and the National Aeronautics and Space Administration during the course of the Mercury spacecraft program.

McDonnell has designed Gemini as it would an aircraft. The pressure vessel is a cockpit. Remainder of the spacecraft is a fuselage in which fuel is stored and systems are installed. Systems are accessible for maintenance through aircraft-type panels and the entire spacecraft has been built with the goal of high utilization rates always in mind. Gemini can accommodate a variety of systems and missions.

At present, NASA has programed only two missions for Gemini—rendezvous and long-duration flight (AW May 6, p. 22). Air Force, which will participate in the program (AW Jan. 28, p. 26), has indicated that it will use the spacecraft for rendezvous-inspection of other, possibly hostile satellites and shuttle transport to permanent space stations.

Gemini will be operated like an aircraft. Its two-man crew will use the on-



ADAPTER MODULE of the Gemini spacecraft consists of two sections, retrograde and equipment, but is built as a single unit in this jig at McDonnell's St. Louis facility.

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How Gemini Will Dock With Agena

National Aeronautics and Space Administration may attempt to fly a Gemini spacecraft on a direct-ascent, co-planar trajectory with an orbiting Agena D stage in their first rendezvous and docking mission. Rendezvous cube, that imaginary volume in space where the two vehicles would meet, would be the apogee point of Gemini's orbit, approximately 160 naut. mi.

This rendezvous plan, one of several under consideration, would impose a launch window measured in seconds on the Gemini-Titan 2 vehicle. The Gemini spacecraft would have to be launched a little less than 1 hr. before Agena—placed in a 160-naut.-mi. circular orbit the day before—passed through the calculated cube. Perigee, or orbital injection point, of Gemini would be 87 naut. mi.

Also under consideration for the first rendezvous mission is a direct-ascent trajectory flown by Gemini, co-planar or nearly co-planar with Agena, in an expanded cube that would provide a larger launch window for the manned vehicle. Gemini would approach apogee no more than 10-15 deg. of revolution distant from Agena and use its propulsion system to catch the stage.

Gemini's rendezvous system consists of a Westinghouse Electric Corp. L-band radar, an array of four spiral antennas (AW Oct. 22, p. 72), and an International Business Machines Corp. digital computer. Interferometer radar signals are translated by the computer into range, rate and elevation data and displayed to the crew every 100 sec. in digital form and on an indicator with three needles for X, Y and Z axes. Effective range of the radar is expected to be about 250 mi.

Based on ground station tracking data and the pilot estimates of the situation, a decision is reached by the spacecraft crew and the Integrated Mission Control Center on the optimum point to begin the chase leg of rendezvous. More factors are involved than relative positions of the vehicles. Rendezvous initiation at one point might require four or five ignitions of the on-board propulsion system to close with Agena, but if delayed for several orbits when the orbital planes are converging it might be effected with only two ignitions.

When the decision is made, the spacecraft commander commands the computer by tapping out a coded signal on a 10-key keyboard to give him the orientation and magnitude of the velocity vector that must be added to Gemini to place it on a collision course with the target. The computer, using the radar data, does so and displays the vector in digital form, on the X-Y-Z axis indicator and on the Delta-V indicator. This last device gives the individual components of the vector.

The commander then fires his thrusters, which provide a velocity increment of 1.0 ft./sec./sec. longitudinally and 0.5 ft./sec./sec. laterally, until the required velocity vector has been added. He then shuts down the propulsion system and awaits further instructions from the IBM computer.

These corrections are issued automatically after chase has begun, and the magnitude of each should be successively less, both in attitude and acceleration. First correction will be on the order of 100-150 fps.; the second under 50 fps.

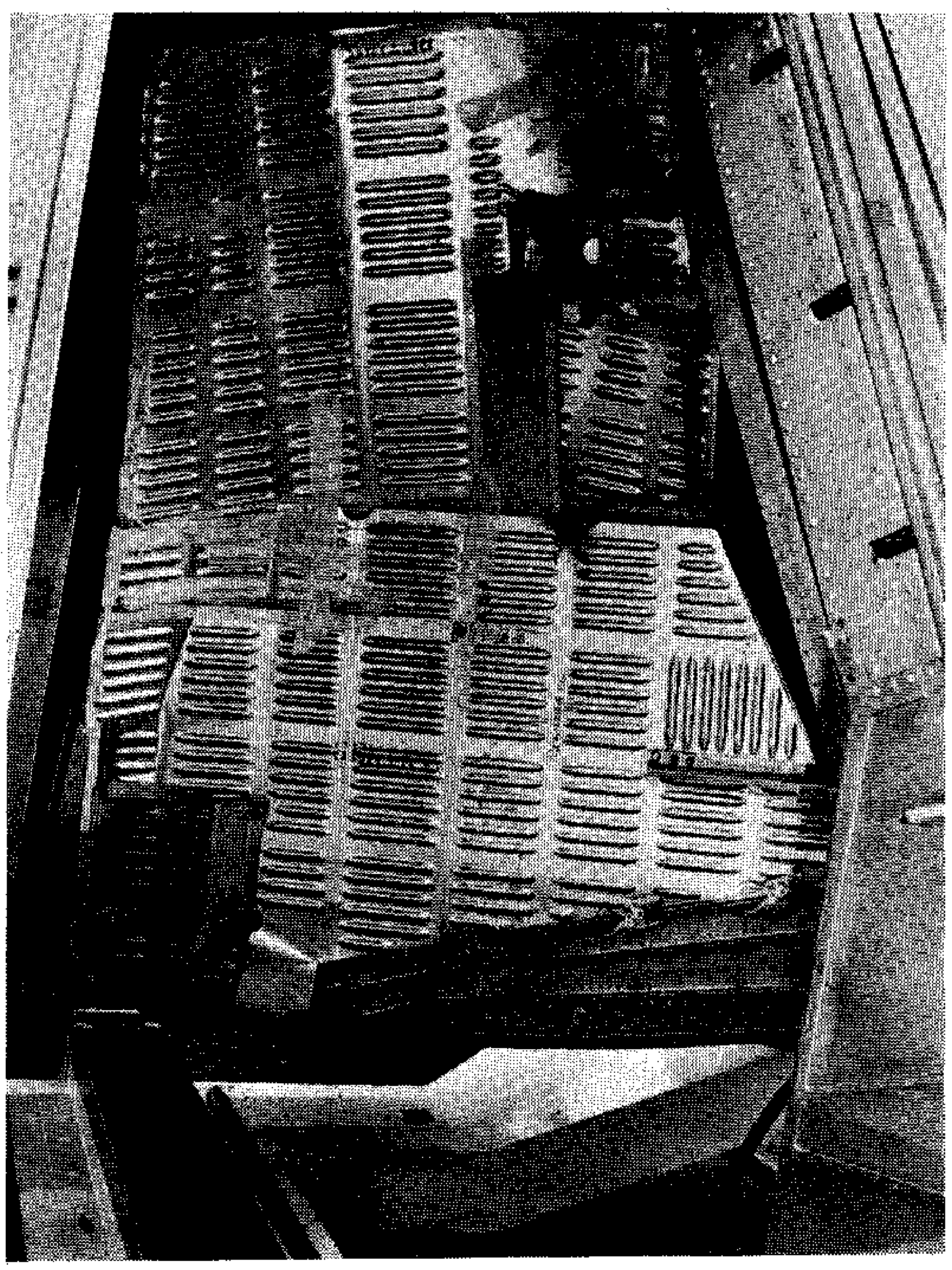
Terminal leg of the chase, will be flown visually by the Gemini crew—a distance as low as 2 mi. or as high as 20 mi.—using two high-intensity flashing lights aboard Agena for homing. Before docking to the stage, the spacecraft commander will determine Agena's status, indicated by five front-lighted dials, registering the safe "off" position of the main Agena engine, the amount of burning times remaining on the main engine and secondary propulsion system (AW Apr. 29, p. 19), the amount of gas left in the attitude control system, and the remaining lifetime on the batteries.

If all indicators are positive, the spacecraft commander aligns the docking bar, a 14-in. telescoping rod mounted on Gemini's rendezvous and radar module, with the center of a notched cone in the Agena adapter section. Tolerance is ±1 ft. or 10 deg. on any axis. Flickfiring the thrusters, the commander will close on the Agena at a forward rate of 1.5 fps. and a lateral rate of 0.5 fps.

As Gemini's nose enters the Agena adapter cone, coated with a dry-film lubricant, three boat hook type latches will trip and snap into receptacles on Agena. When the latches seat, three mechanical links on the aft end of the cone will retract and pull both Gemini and the Agena adapter sleeve against three hard points on the Agena stage. Solid docking will be indicated by a panel light.

After firing four small ullage rockets, two 16-lb. or two 200-lb. thrust rockets clustered around the main Agena engine, to seat Agena's propellants at the pump head, the Agena main engine will be fired. Thrust can be used in this attitude as retro-thrust to reduce orbital height, or the Agena-Gemini combination can be rotated end-to-front and the Agena engine thrust used to increase orbit altitude.

When all fuel aboard Agena is expended—Lockheed is modifying Agena for a 5-day orbital duration—the Gemini crew will activate the release of the pull-down mechanism and the cone will snap back to its original deployed position. Should the latches fail to retract at this point, the crew can fire small explosive squibs to break the bond.



BEADED TITANIUM inner skin of double-walled pressure vessel is shown through personnel hatch.

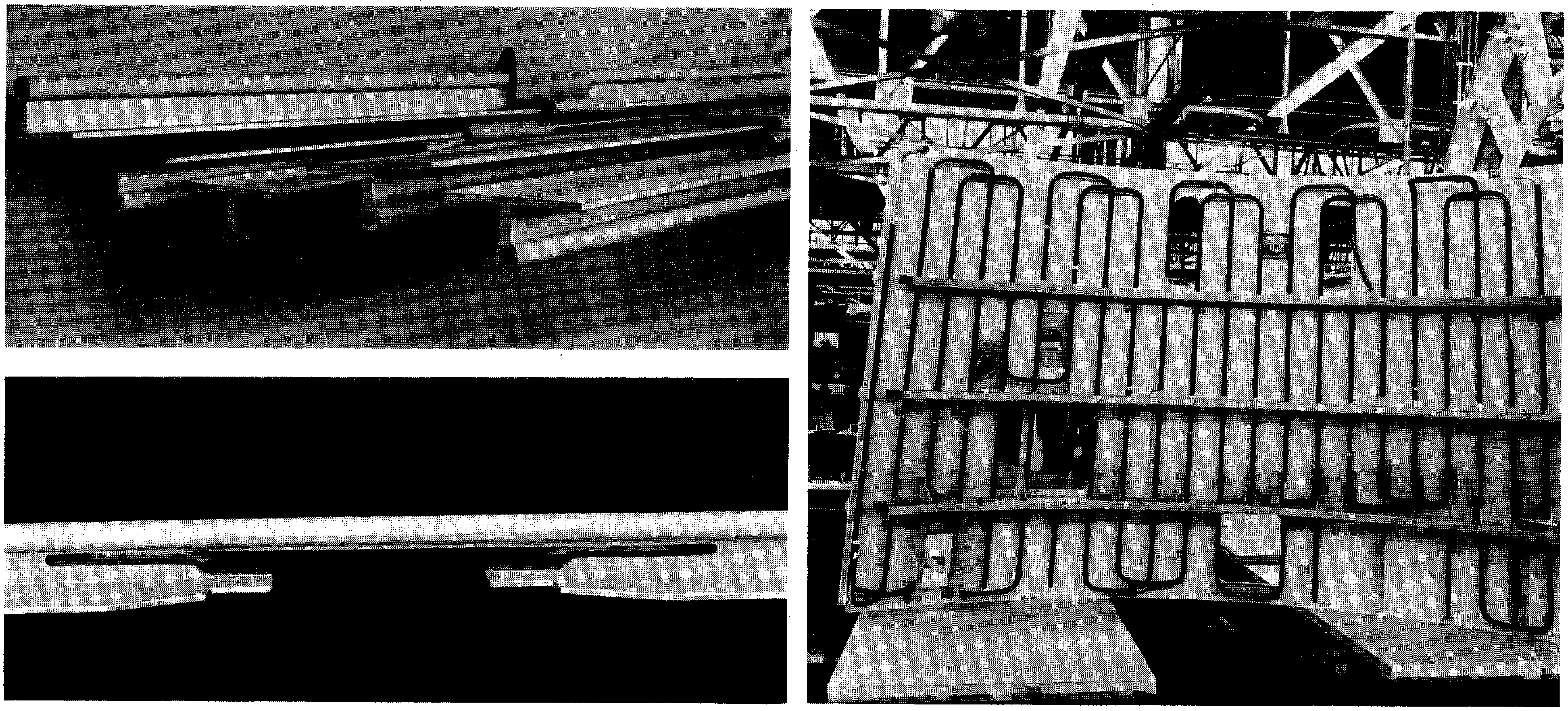
board propulsion system to fly to points in space dictated by mission objectives. It will re-enter the atmosphere with positive lift and land on a tricycle gear. Even the assigned roles of the two astronauts reflect those of an aircraft crew. The astronaut in the left-hand seat is the spacecraft commander and the man in the right-hand seat is the co-pilot/navigator.

Superficially, Gemini and Mercury are similar and the two-man spacecraft bears the imprint of its one-man predecessor in many respects. In reality Gemini is so advanced that it represents a new spacecraft, not a modified Mercury. In Gemini, the primary control mode is the human brain, not a sequencer.

The difference between a research and development manned capsule—Mercury—and an operational manned vehicle—Gemini—can be illustrated by the difficulty in replacing a part or subsystem on the former. "It seemed," said one McDonnell engineer, "that every time we had to replace something on Mercury, it was always on the bottom [of the capsule]."

To get at the carbon dioxide absorber canister in Mercury's life support system necessitated the removal first of approximately 10 items of plumbing and structure. All the other systems, which may have been satisfactorily operative prior to removal, then had to be reinstalled and re-validated.

When replacement of this canister became necessary during one of the many delays in getting John Glenn's MA-6 capsule airborne, it took three 8-hr. shifts to accomplish the task. A



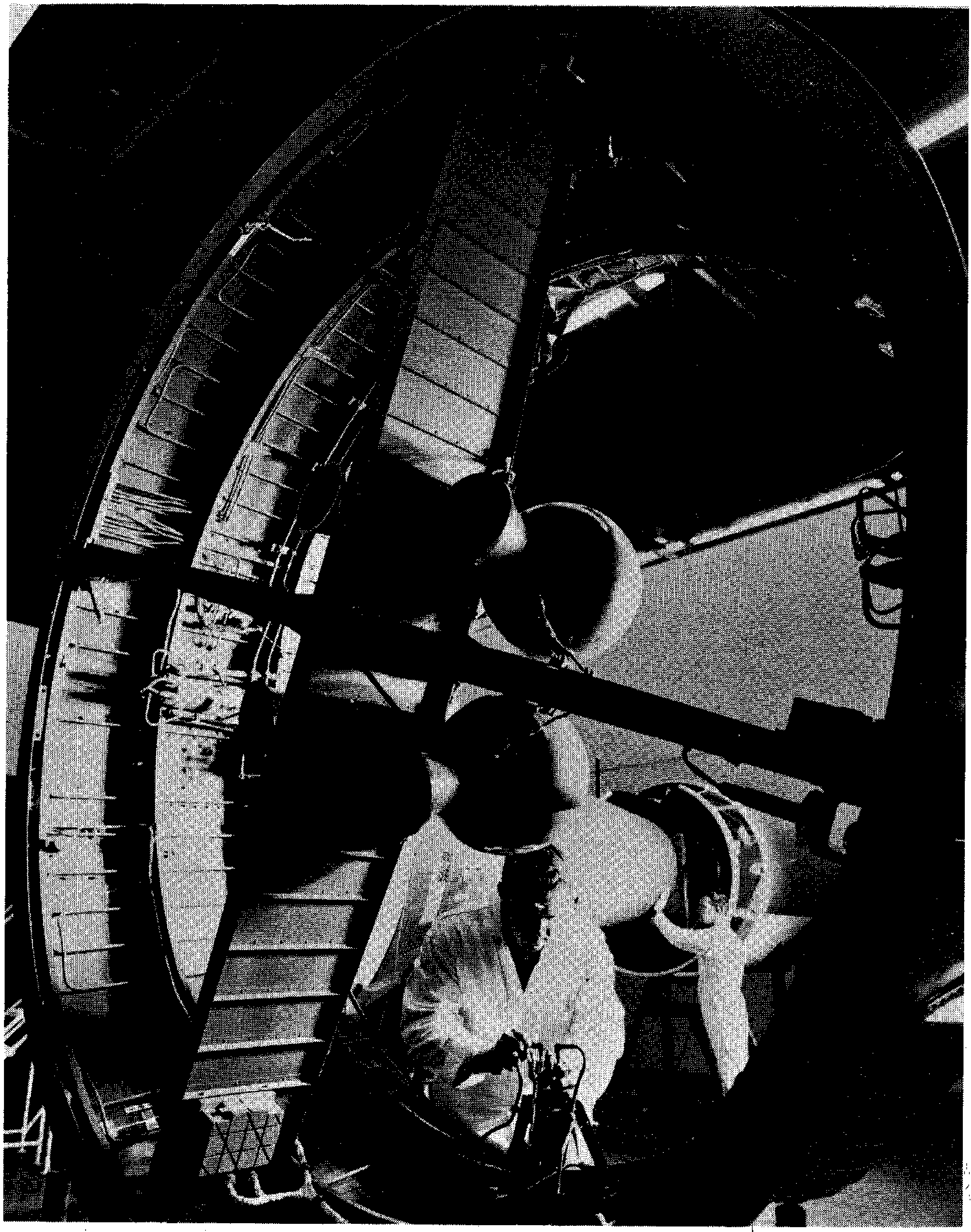
ADAPTER STRINGERS are delivered to McDonnell as 60-ft. long magnesium alloy extrusions (top left) then machined at intervals to leave only the tubing (bottom left). Gemini adapter module (right) is both equipment storage unit and radiator.

contributing factor to this lengthy operation, aside from the stack-upon-stack arrangement of systems within the capsule, was that only one man could work within the capsule at any time.

Although there is at present no complete Gemini spacecraft upon which to conduct a comparable operation, such a task is expected to require no more than a few hours. The reason is that the lithium hydroxide canister, as part of a life support system package, is directly accessible through a hatch at the external base of the two-man capsule. Several technicians, working side by side, will be able to open the hatch and remove the complete package. A new life support package can be inserted, mounted and connected, and the hatch refastened. Later, at the factory, the discarded package can be opened, a fresh canister inserted, and the entire unit used for a future flight.

Accessibility to equipment through hatches on the external airframe has been a cornerstone of Gemini's design (AW July 2, p. 94). It also is one of several reasons why Gemini has been a more difficult design and manufacturing effort than Mercury and why it has a more complex structure. Building a single conical vessel which serves both as pressure vessel and equipment bay is easier than it is to build specific structures for certain groupings of equipments—and a separate pressurized hull for pilots—and to integrate all these pieces into a balanced spacecraft.

Modularity has gone hand in hand with accessibility. All systems have been packaged and mounted as such on the structure, and they are easily removed and replaced. Since rendezvous mis-



McDONNELL TECHNICIAN adjusts lines in Gemini retrorocket ring.

sions impose tight launch window restrictions on Gemini, McDonnell and NASA realized they could not waste hours on the launch stand looking for a burned-out component or loose wire in a subsystem. Instead the complete subsystem is designed for removal. A new one can be installed and repairs made to the malfunctioning unit at the factory.

McDonnell engineers say that the concept of modularity frequently has been misunderstood to mean that each system is wholly contained within one package. In fact, some systems are scattered over the spacecraft in two or three separate packages. What the concept does mean, they emphasize, is that components are grouped in logical sets, mounted on common chassis and attached to support racks on the structure.

Structurally, Gemini also is composed of modules. From front to back, they are:

- **Rendezvous and radar.**
- **Re-entry control.**
- **Cabin, including** the manned pressurized hull.
- **Adapter,** which consists of two separate sections, retrograde and equipment.

Forward Module

The rendezvous and radar module, the forward element of the Gemini spacecraft in launch configuration, houses the rendezvous radar, the stabilizing drogue parachute and the paraglider. In addition, it contains an ultra-high-frequency (UHF) stub antenna, a male-type electrical connector and three latch receptacles; these last two items are devices involved in docking with the Lockheed Agena stage.

The module itself is a truncated cone, 30 in. in diameter and 37 in. long, atop a short cylindrical base, 9 in. deep and 38 in. in diameter. It is divided into fore and aft compartments by a transverse plate 9 in. below the top of the cone.

In the forward compartment, further subdivided by a longitudinal plate, are two cavities—the larger for the Westinghouse Electric Corp. rendezvous radar and the smaller for the drogue parachute. Both are delivered to McDonnell in flight-ready canisters and are inserted, including canisters, into their appropriate bays.

Aft compartment is a 9-cu.-ft. cavity and the North American Aviation, Inc., paraglider is stowed there. Like the radar and drogue chute, the paraglider comes folded within its own container and, after insertion, needs only to be connected to the spacecraft's electrical harness. Because of development problems (AW Jan. 28, p. 55), the inflatable wing will not be ready for initial Gemini flights and will be replaced for these by a single 84-ft. diameter parachute.

Paraglider container has a slightly flattened face on one side that leaves a well in the aft compartment for the retracted nose skid of the landing gear system. Bulk of the nose gear is contained within the second module, however.

Construction of the rendezvous and radar module is of titanium throughout, with the exception of the external heat-resistant beryllium shingles. Basic frame of the module is a semimonocoque structure of 10 stringers and four formers. On the inner side of the frame, the skin is of single thickness, 0.032-in., smooth titanium panels, seam-welded to the stringers. Beryllium shingles comprise the external skin of the module and are held in place by beryllium retainers so that this external surface expands and contracts uniformly under the heat load of re-entry and the cold soak of space. Retainers are bolted to the stringers, with an intervening layer of insulation to preclude heat transfer into compartments.

Re-entry control system module is an 18-in. deep, 38-in. diameter cylindrical unit and primarily houses the attitude control system used only during re-entry. Besides the bulk of the nose skid landing gear, it also contains the tank of gaseous nitrogen, pressurized at 1,200 psi., which is used to inflate the paraglider.

Re-entry control system consists of two redundant and identical rings, identified as A and B, of eight 25-lb. thrust engines each. Each ring is pressure-fed from its own separate and independent set of propellant tanks and either ring is adequate by itself to satisfy the control requirements.

Paired Thrusters

Configuration of the eight thrusters in each ring is a pair of opposite-facing engines every 90 deg. around the circumference. Thrusters are paired, those two jets which give the same rotation being fired together. The clockwise-firing thruster at 90 deg. is coupled with the clockwise-firing engine at 270 deg. to produce roll. For yaw, the counterclockwise-firing thruster at 270 deg. would be coupled with the clockwise unit at 90 deg. Thrust vector line of each thruster is tangential to the circumference of the module.

Propellant tanks are bladders within cylindrical titanium casings. Propellants —monomethyl hydrazine and nitrogen tetroxide—are positively expelled by gaseous nitrogen at 3,000 psi. in spherical tanks and ignite hypergolically in the thrust chambers. Chambers are ablatively cooled.

Re-entry control system normally will not be activated until about 5 min. before the Gemini crew intends to re-enter the atmosphere. Primary control of this system rests with the digital computer in the inertial guidance system because of the difficulty pilots would have trying to move a control stick under the high g-forces of re-entry. It is one of the few automatic systems that is aboard Gemini.

Construction of the re-entry control module is similar to that of the rendezvous unit. Basic frame consists of eight stringers and four formers. Inner skin panels, seam welded to the stringers, are of 0.032-in. smooth titanium and the external beryllium shingles are mounted on beryllium retainers. Six propellant and gas-pressurization tanks—three for each ring of thrusters—are cantilevered off the aft end of the module. When all modules of Gemini are mated—or stacked,—these tanks protrude into the 19-in. deep space between the top of the cabin module airframe and the top of the pressurized hull.

Most difficult Gemini module to design, McDonnell engineers say, was the cabin because of the greater load concentrations expected. Mercury's loads, aside from the bending moments induced by the escape tower, primarily are columnar and compressive. In addition to normal dynamic loads, Gemini also will be subjected to tension and bending loads from ejection of the pilots' seats in the event of an abort, or from deployment of the paraglider and landing shocks. In addition, the bracing that takes out these concentrated loads also is required to support other structural elements.

Externally, the cabin module is a truncated cone, 90 in. in diameter at the base, 38-in. in diameter at the top and 75 in. tall. The pressurized hull, or cockpit, is an irregularly shaped structure within this symmetrical airframe and resembles a blunted wedge. Airframe of the module is built around the pressure vessel, although one entire cockpit wall and part of another are common to both.

Pressurized hull begins to take form when the hatch section and the floor are joined together by six titanium longerons, four cornerposts and two centerposts. Aft cornerposts, where the cockpit is deepest, are about 65-in. long each. Centerposts are about 50 in. long and the forward cornerposts, where floor and hatch join the firewall, are about 35 in. long. All joints are fusion welds.

Side walls consist of four double-skin titanium panels, two panels to a wall. Inner skin of each trapezoidal panel is beaded and the outer skin smooth; both are 0.010 in. thick and are seam welded wherever the crown of a bead contacts the smooth skin. Vertical and horizontal titanium stiffeners, spaced about 6 in. apart and spot welded to

Gemini Power Systems

St. Louis—Electrical power for Gemini on-board systems will be drawn from two parallel fuel cell modules, under development by General Electric's Direct Energy Conversion Operation, Lynn, Mass.

There are 32 individual cells, connected in series, to a stack and three stacks, in parallel, to a module, or section. Sections are in parallel to the dual 22- and 30-v. main bus. Each stack delivers approximately 350 w.; total system has a peak power capacity of about 2,100 w., of which a little more than a third is used normally. Efficiency is about 50%, according to McDonnell.

Fuel cell system weighs about 550 lb., of which about 200 lb. are supercritical hydrogen and oxygen, the fuels with which the cells operate. Fuels are fed into separate chambers on opposite sides of the cell (AW Apr. 9, 1962, p. 54) and pass through catalytic electrodes. Electrodes sandwich the GE-developed ion exchange membrane, key element of the cell.

Hydrogen atoms dissociate, giving up electrons to the anode and ions to the membrane. Ions travel through the membrane to the cathode, where they combine with dissociated oxygen and returning electrons to form water molecules. This reactant product is pure and is drawn off by wicks for storage and eventual consumption by the crew.

Fuel cell system has pilot controls for off-on power, water transfer to the cabin reservoir and emergency shutdown. Pilots will periodically shut down the cells to purge impurities which might otherwise interfere with the reactance process.

In addition to the cells, the Gemini spacecraft also carries four parallel 45-amp.-hr. silver-zinc batteries, weighing about 20 lb. each, to supply power to the main bus after jettison of the adapter module. Fuel cell system is contained within the adapter module, which is dropped prior to re-entry. There also are three high-discharge rate, 12-amp. hr. batteries, weighing 8 lb. each, to provide power for control circuits and pyrotechnic devices. All these batteries, supplied by Eagle-Picher Co., are mounted in equipment bays on the side of the cabin module.

There are about 14 mi. of electrical wiring in the Gemini spacecraft, compared to about 7 mi. on the Mercury capsule. Wire bundles are assembled and checked on a three dimensional board to make sure that all wires, pins and connectors have been correctly put together. These 3-d boards are dummy duplicates of spacecraft sections and the wire bundles are bent and routed as they would be on the spacecraft. On Mercury, the bundles were laid out straight and flat on 2-d boards and were not bent until they were installed on the capsule.

From the 3-d boards, the bundles go to a tube-and-cable mockup, a full scale dummy Gemini. The bundles are installed connected and tested to determine that the routing is correct and that there is no cross-feed between wires. All connections between electronic packages and cables are of the crimped-pin type; there are no soldered connections above component level, as there were in several instances on Mercury.

These manufacturing and test methods, coupled with the fact that all bundles are routed on the outside of the spacecraft where two or more technicians can gain access to them, has reduced the time of installation about 90% compared with Mercury.

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the smooth side of the panels, make these flat walls load-bearing members as well as pressure containers. Panels are seam welded to the frame.

Large and small pressure bulkheads are, respectively, the rear wall and firewall of the cockpit. The large bulkhead is an elliptical dome, 90 in. in diameter, of double-skin (beaded and smooth) titanium construction. An extensive cross-pattern of titanium stiffeners is spot welded to the beaded side of the dome. Two 45 in. long machined aluminum rails, upon which the ejection seats are mounted, (AW Apr. 29, p. 65), are bolted to the smooth, or pressurized, side of the dome with an angle of 24 deg. between their centerlines.

Small pressure bulkhead, or firewall, is 56-in. from the aft dome and is a flat keystone-shaped plate of double-skin titanium construction. It too is stiffened fore and aft. It is seam welded to the cockpit frame, unlike the large bulkhead, which is bolted to the frame.

Hatch section is the complete overhead of the cockpit and also comprises about a fourth of the external airframe surface. The section consists of a common sill and two hatches, the sill a trapezoidal frame of 0.5 in. thick chemically milled titanium with a centerpiece dividing the frame into two hatchways.

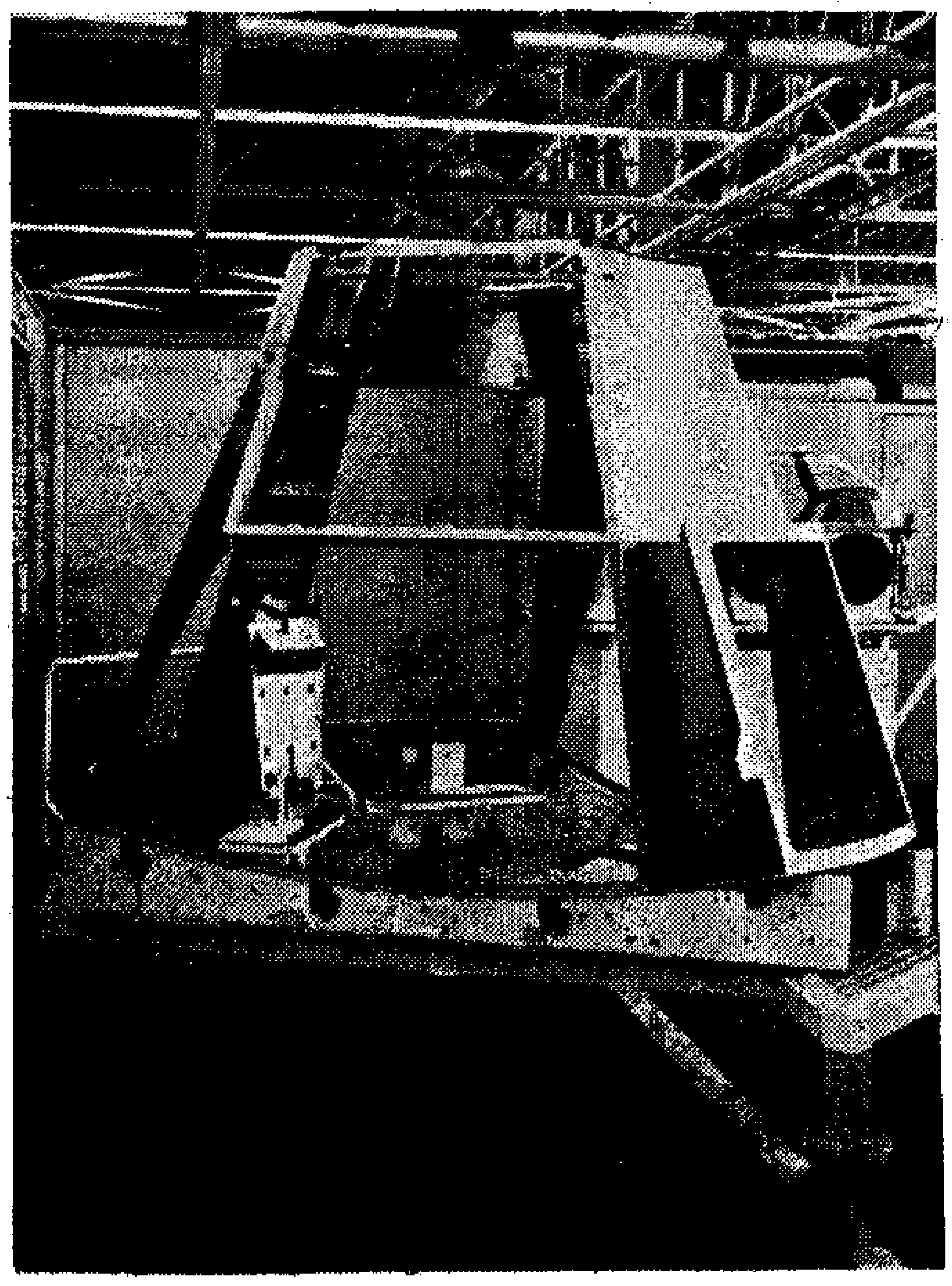
Around the perimeter the sill is grooved, and the groove is filled with a silicon rubber sealant. A tongue-type extrusion of the hatches fits this groove and, when the hatches are closed and dogged down properly, a pressure-tight seal for the cockpit is formed. Each hatch, swinging on four hinges, is secured by 10 dogs, all of which, for normal ingress-egress, are manually controlled by a ratchet wheel centrally located on the inside of the hatch.

Each hatch is approximately 34 in. wide at the base, 26 in. wide at the top and 43 in. long—compared with the 28—20-in. width and 25-in. length of the single Mercury entrance hatch. In the middle of each hatch is a cutout for a teardrop-shaped pilot observation window about 71 sq. in. in area. A 5 in. deep, 20 in. wide scoop runs forward of the window for greater field of vision. In comparison, Mercury's single window is more than 200 sq. in. in area and is flush-mounted in the sloping side of the capsule.

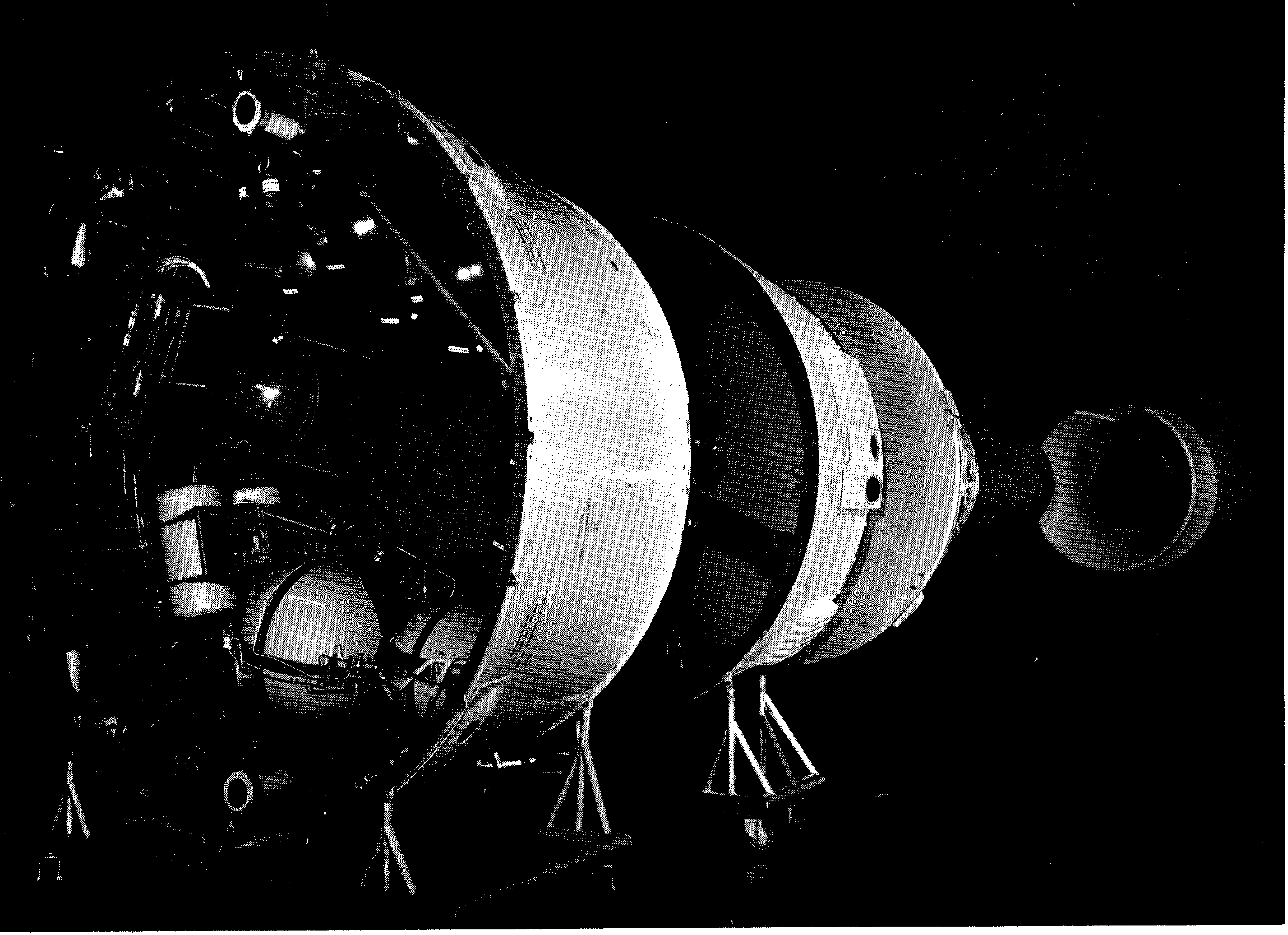
The window in each Gemini hatch consists of three panes of glass, the outer and middle panes of Vycor, developed by Corning Glass Works, and the inner pane of tempered glass. Inner and middle panes are held by a common three-tined fork frame and the outer pane by an independent two-tined frame. Frames are bolted to stiffeners on the outer, non-pressurized side of the hatches.

Cockpit floor consists of two sections, a forward 28 in. long, 58-32 in. wide trapezoidal panel upon which the pilots' feet rest and an aft 28 × 24 in., hatch, directly below the seat pans of the two pilot couches. This hatch is stepped out approximately 10 in. from the forward panel to become part of the external airframe, and opens into a compartment in which the cabin environment control system (ECS) package is installed.

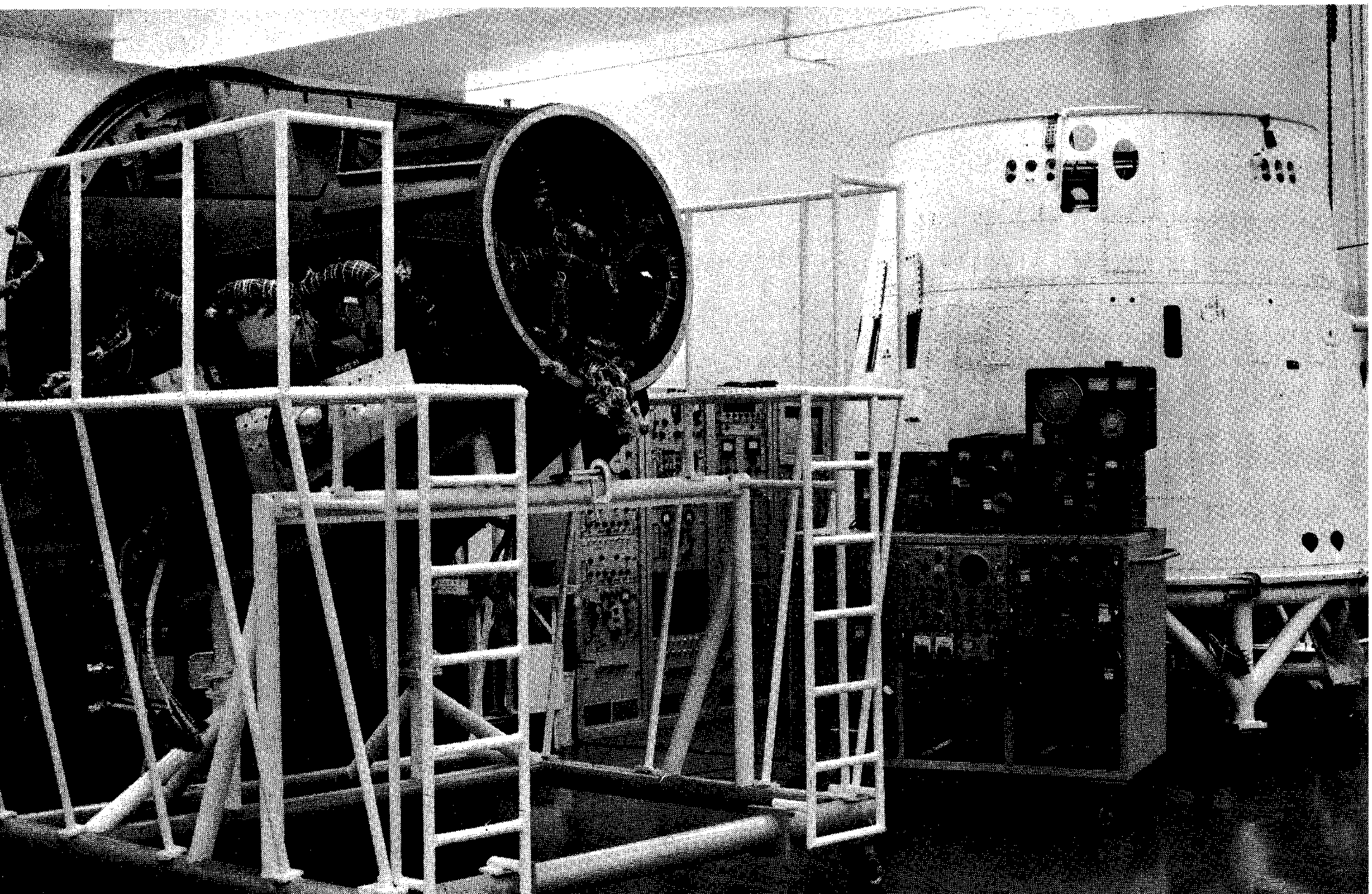
Because the pressure vessel is not symmetrically conical, six narrow triangular titanium shear webs are seam welded at right angles to the flat side walls of the



OVERHEAD HATCH frame (left) and floor (right) of the cockpit are joined by four cornerpost and two centerpost longerons. Environment control system access hatch is located at right.



GEMINI SECTIONS, above, are the equipment adapter, left, which houses maneuvering fuels, fuel cells and cooling pumps and radiators, retrorocket adapter section and crew compartment of re-entry module. Extreme right is Agena docking cone. Below is compatibility test unit in the systems assembly white room. It is a nonflyable Gemini used to verify design and installation of all Gemini systems.



cockpit to provide shaping and attachment points for the external airframe. Titanium ribs, at right angles both to the webs and the walls, complete the skeletal conical structure.

External airframe is composed 75% of hatches, since the skeletal structure surrounding the cockpit divides this internal volume into eleven unpressurized compartments, which serve as equipment bays for the packaged systems. There are five bays on each side of the cockpit's flat walls and two bays directly below the forward floor panel. All are closed by hatches.

Bay hatches are of the same general construction—smooth 0.10 in. titanium inner panels seam welded to fore-and-aft stiffeners and beaded Rene-41 nickel alloy outer shingles bolted to the stiffeners, with an intervening layer of insulation between shingle and stiffener. Hatches closing the pressure vessel have double-skin inner panels. All hatches are approximately 1 in. thick in cross section.

Aside from the two elongated hourglass-shaped bays bracketing the environment control system hatch, where the main landing gear skids will be housed, McDonnell and NASA are still considering several ways of distributing packages in the equipment bays.

Whatever the distribution, all electronics packages in these bays will be mounted on cold plates, with an interstitial layer of jelly—containing silver particles—between package and plate. These plates are of three-layer aluminum sandwich construction, with two separate and independent fluid systems circulated between layers. Fluid is a commercially available Monsanto Chemical Co. product and there is about 25 lb. of the liquid in each loop.

Packages are so designed that heat travels toward the cold plates. Silver-impregnated jelly distributes the heat evenly to the plate surface and the fluid picks it up there. Heat then is carried through tubing to the adapter module, immediately below the cabin, where it is transferred to the skin of the module and radiated into space.

McDonnell is building the heat shield for Gemini, using a company developed ablative material. McDonnell engineers say that although the shield has a 45% greater frontal area than the Mercury shield, it weighs only 4% more.

The elliptical shield is separated from the large pressure bulkhead by a ⅜-in. thick layer of insulation. Circumference of the shield is flared slightly to provide an attachment flange. This flange butts squarely against the base of a U-shaped bracelet ring around the base of the cabin. Bolts are driven down through the trough of the U into the shield's flange to secure the two units.

Cabin module is nested on an L-shaped steel ring in the top of the adapter module. Three 1 in. wide titanium straps, buried among the cable bundles jumping the interface between modules, lock the cabin and adapter together during flight. By contrast, Mercury used a steel clamp ring to secure itself to its adapter. Gemini's nesting ring and tie-down straps will save about 40 lb. over a comparable-sized clamp ring.

Adapter module, consisting of two sections but built as a single unit, serves both as a radiator and an equipment-storage section. It is a truncated cone, 90 in. tall, with a 120 in. diameter base, and 90 in. diameter top. Separation plane between the two sections—retrograde and equipment—is about 55-in. from the base.

Stringers in the adapter serve a dual purpose. They stiffen the structure and they carry the tubing of the circulating fluid-coolant system. Stringers have a T-shaped cross section, with a 0.25 in. diameter tube on the bottom of the shank. They are delivered to McDonnell as 60 ft. long extruded units.

At 34-in. intervals, the T section is removed from the extrusion for a distance of about 6 in., leaving only the tube section. The tube then is bent to a U shape in the cutout area. In this way, McDonnell makes 18 separate stringers but only one continuous tube from a single piece of material. Four 60-ft. pieces are required to make the 72 stringers in the retrograde section of the adapter. Tubes are joined with flared fittings at the junctures of the four pieces.

Fluid circulating through the cold plates in the equipment bays of the cabin module is ducted to one of two jump-off points one for each system, at the base of the module. There, the tubing is routed outside into a faired tunnel across the interface and then brought back inside into the top of the adapter.

PRESSURE BULKHEAD which forms rear wall of the Gemini cockpit shows mountings for the aluminum rails on which ejection seats rest. Rubber guards are for plant use.

Moving down the length of the retrograde section in the hollow stringers, the heated fluid transfers its heat through the T section to the module's external magnesium skin. Upon cooling, the fluid is pumped into the cabin module again.

Surface area of the adapter is about 190 sq. ft. With the exception of some hatches, this entire surface is used as a radiator. Magnesium was chosen as the skin for this module because of that metal's good heat transfer characteristics.

Construction of the retrograde section is mostly of magnesium alloy. External skin panels are of 0.032 in. magnesium alloy and the extruded stringers are also magnesium alloy. The four circumferential formers, however, are of aluminum alloy for greater structural rigidity.

Retrograde section houses four Thiokol Chemical Corp. solid propellant retrorockets, each rated at 2,500 lb. thrust. The 13-in. dia. spherical motors are mounted independently on a four-legged aluminum spider beam within the conical section. For re-entry, the motors would be ripple-fired and their burning times overlapped. They would be fired in salvo to separate the spacecraft from the Titan 2 launch vehicle, if an abort situation arose during the boost phase of flight at altitude.

Six thrusters, two 85-lb. and four 100-lb. thrust units, are also located on the retrograde section. They are part of the Orbital Attitude and Maneuvering System (OAMS).

Equipment section of the adapter module also is a magnesium alloy construction in the external skin panels and the stringers. There are 88 stringer/coolant lines and five circumferential formers in this part of the module. Formers are of titanium, instead of aluminum as in comparable rings in the forward part of the module.

Equipment section, which is closed by a thermal curtain on its broad end to prevent solar radiation on cryogenic systems located there and by a glass fiber shield on the forward end to protect those same systems against retro-rocket exhaust, houses:

- **Fuel cell system.**
- **OAMS tankage and control,** and 10 thrusters.
- **Electronics.**
- **Environment control system.**

Each of these systems is packaged on support frames as integral units and is suspended from the skin structure. Access to the systems installed within the adapter module is limited, once mated to the Titan 2 launch vehicle, because of the radiator structure on the inner skin. Unmated, however, the packages are easily pulled off and replacement systems installed.

The Orbital Attitude and Maneuvering Systems (OAMS), as the name implies, is the on-board propulsion system which will make Gemini a genuinely operational spacecraft. The Mercury capsules' orbital parameters were determined by its Atlas booster. Gemini, propelled by OAMS, will have the capability of correcting its orbit to desired or pre-determined parameters and will be flown much like a high-performance aircraft.

The OAMS system consists of 16 thrusters:

- **Two 100-lb. thrust engines,** located 180 deg. apart on the aft rim of the adapter module, provide forward acceleration.
- **Two 85-lb. thrust engines,** located 180 deg. apart on the forward end of the retrograde section of the adapter, provide deceleration.
- **Four 100-lb. thrust engines,** located 90 deg. apart on the forward end of the retrograde section, provide lateral displacement of the spacecraft. Their thrust vector lines are perpendicular to the spacecraft's center line.
- **Eight 25-lb. thrust engines,** located every 45 deg. apart on the aft rim of the adapter, provide pitch, roll and yaw control to the spacecraft. Thrust vector lines of these eight engines are tangential to the spacecraft. These engines are always fired in pairs, like the thrusters in the re-entry control system.

All 16 thrusters are pressure-fed from common propellant bladder tanks—nitrogen tetroxide and monomethyl hydrazine. Helium is the pressurizing gas and represents a weight savings of approximately 20 lb. over a comparable amount of nitrogen. For the short two-day rendezvous mission, where the Gemini crew will attempt to meet and mate with an Agena stage, the OAMS propellant tankage will be augmented with duplicate tanks of fuel, oxidizer and pressurizing gas. For the long duration—above three days—missions, only one set of tankage will be used. Extra set of tanks adds about 700 lb. and partly explains the heavier (7,800-lb.) weight, of the short-duration configuration over the long-duration (6,800-lb.) configuration.

The eight translational thrusters of OAMS—the six 100-lb. and the two 85-lb. thrust engines—will be controlled by the spacecraft commander only, using a maneuverable stick on the instrument panel before him. The stick, with a ball knob, resembles the choke on an automobile. Pushing the stick straight in causes the decelerating 85-lb. thrusters to come on. Gemini, unlike Mercury, flies small end first, in the same direction as the pilots face.

Four 100-lb. thrusters around the retrograde section are fired singly and displace the spacecraft in the direction of thrust. For example, if during a rendezvous attempt, the spacecraft commander observed that the Gemini was misaligned only laterally with the Agena, he would fire either the thruster on the port or starboard beam to move the spacecraft into position.

At one time, NASA and McDonnell considered the addition of a duplicate OAMS control stick socket on the copilot's side, so that the single stick could be plugged in on either side of the panel and used by either pilot, but this idea was dropped.

Attitude is controlled by a side-arm stick mounted on the console between the pilots. Either pilot can use it; the commander with his right or the copilot with his left. There are five control modes for attitude:

- **Direct.** This corresponds to the fly-by-wire mode of Mercury. Movement of the stick triggers a direct electrical impulse to the valving on the appropriate 25-lb. thrusters. It is a manual mode, and whatever energy is put into the spacecraft must be taken out by countermovements of the stick, once the desired attitude has been achieved.
- **Rate.** Second of three manual modes, this method is very similar to the rate command system of Mercury. Movement of the side-arm stick triggers thrusters corresponding to the direction of the control movement. However, when the pilot has the spacecraft oriented as he desires, he simply releases the stick and the system automatically damps out any further turning rates.
- **Pulse.** Third manual mode, the pulse system causes the thrusters to fire in short bursts of .06 deg./sec. As in the direct mode, the pilot must take out whatever he puts in, after he has achieved the desired attitude.
- **Horizon scan.** One of two automatic modes, this system uses inputs from infrared horizon scanners on the forward end of the cabin module to align the spacecraft within ±5 deg. in pitch and roll. It is comparable to an aircraft's automatic pilot.
- **Re-entry.** Used only during re-entry, this automatic mode translates guidance system signals into commands for the thrusters in the re-entry control module (the adapter section is jettisoned prior to re-entry). It damps out undesired pitch and yaw moments and generates a steady roll rate of 20 deg./sec. when the correct re-entry trajectory is achieved.

There is no direct mechanical linkage between the side-arm stick and the thrusters, as there was in Mercury. Pilot will select one mode at a time with a rotary switch, turning it to the appropriate stop for the desired mode. This will preclude two modes being in operation at the same time, as happened on Scott Carpenter's MA-7 flight.

Side-arm stick travel is 10 deg. in any direction. In any mode other than rate command—where a flick will cause the thrusters to come on—the stick must be moved at least halfway to the stop limit before the thrusters fire. There is no proportionate scaling of stick motion to thrust level—the engines either are on at their nominal rated values or off.

An unusual feature of Gemini's on-board propulsion system is the absence of any screws or bolts in fittings. All propellant and pneumatic lines, of stainless steel, are joined by brazed sleeves wherever one line connects to another. Components, such as valves, regulators, filters, solenoids, etc., are welded together in packages; all OAMS control components are contained in five such packages. If a valve should stick or a regulator fail during checkout of a spacecraft, the sleeves immediately upstream and downstream of the package containing the faulty part would be opened and the complete package removed. A replacement package would then be installed and the sleeve connectors rebrazed to seal the system once more.

Environment control system is divided into two packages, one in the cockpit and the other in the adapter. Major elements of the ECS include the oxygen reservoirs, oxygen purification, personnel cooling, water management and egress oxygen/cooling.

Gemini carries two breathing oxygen reservoirs, a 104-lb. tank of supercritical and a 15-lb. tank of gaseous oxygen. Large tank, the primary reservoir, is located within the adapter module and would be used only on long-duration flights. Smaller tank, called the secondary reservoir, is located within the cockpit and would be used on both long and short duration missions. It provides breathing oxygen during re-entry.

Oxygen supply, purification and suit cooling are all on a single loop. Pilots' suits are connected in parallel to the loop, however, and fitted with individual regulators so that each man may set flow rates according to his own desire. With the face plates of their helmets closed, exhaled breath is vented through a suit outlet and ducted through a compressor to the purification module. There, lithium hydroxide reduces carbon dioxide, charcoal filters remove odors and wicks absorb any moisture. Purified gas then passes through a heat exchanger (a finned unit around which the Monsanto coolant fluid circulates), where it is cooled. Downstream of the exchanger, the recycled oxygen is mixed with fresh oxygen and then ducted back into the suits. When the face plates of the helmets open, the cycle would be the same except that exhalation would be into the cabin and the inlet on the compressor would be opened to draw in the gas.

Cockpit Pressure

Gemini cockpit, according to present NASA plans, will be pressurized to 5.1 psi. with 100% pure oxygen. Cabin and suit pressurization systems are separate but inter-connected.

Drinking water is drawn from a 16-lb. capacity tank within the cockpit. It always contains at least 13.5 lb. of water and is partially filled prior to launch. After launch, the fuel cell—as a reactant product—delivers approximately a pound of water for every kw. hr. and this is ducted into the storage tank by the pressure differential between the two systems. Mouthpiece fits a plug in the pilot's faceplate to allow drinking even if the plate should be closed.

As part of the total water management system, body perspiration not evaporated by suit cooling will be drawn off by wicks and dumped into a storage tank in the cabin module. Urine also will be dumped into this refuse tank. Liquid stored in this tank can, if necessary, be used for augmentation of the coolant system.

An egress oxygen/cooling system is built into the pilots' ejection seats. In the event of ejection, the system is triggered and provides the pilots with breathing and cooling oxygen, as well as pressurizing their suits.

Inertial guidance system of Gemini consists of a stablized platform built by Minneapolis-Honeywell Co. and a digital computer developed by International Business Machines Corp. During the boost phase, this inertial system is a back-up guidance unit to the radio-inertial system under adaptation from the Mercury/Atlas vehicle to the Gemini/Titan 2 (AW Sept. 3, p. 38).

After separation of the spacecraft from the Titan 2—accomplished by firing the two 100-lb. thrust OAMS engines on the rim of the adapter module—the IBM computer will check the orbital insertion parameters. If lower or higher than planned values, the spacecraft commander will use the OAMS thrusters to place his vehicle in the desired position.

Primary function of the guidance system is to lead Gemini to its Agena target vehicle in rendezvous missions. The Westinghouse L-band rendezvous radar, an array of four spiral antennas (AW Oct. 22, p. 72), provides angular and range data to the computer on the relative positions of spacecraft and stage.

Inertial guidance system also plays a major role during re-entry. All through orbital flight, the computer constantly determines the latitude and longitude of the spacecraft and predicts future plots so that the crew will know which possible landing sites are available in emergency.

If the crew is interested in a particular landing field, it will enter the coordinates of the site into the computer, which then determines whether the site is within reach or whether the capsule must be maneuvered to a new heading.

Computer not only indicates the vectors of the maneuver, but also gives a target time for firing the retrorockets. This use of the guidance system is called the orbit navigation mode.

At the time of retrofiring, the computer is supplied with this data from ground stations:

- **Orbit parameters,** as determined by ground tracking stations.
- **Coordinates** of the landing site.
- **Relation** between the orbital plane and the plane of the landing site.

Using this data, the computer then predicts the range distance to the site, based on a zero-lift trajectory, and computes the position of the spacecraft in relation to the site coordinates. The difference between the prediction and the computation is an error signal output, which the computer sends to the re-entry control system to fire selected thrusters.

Attitude of Gemini during re-entry is such that the pilots are head-down, looking at the earth, with their backs to the direction of flight. The spacecraft's center of gravity, offset 1.5 in. from the vehicle's center line, is located in the area of the ECS system, that side of the capsule facing toward space during re-entry. Its placement causes the spacecraft to trim out at an angle of 16 deg. from horizontal.

Firing of the thrusters causes the center of gravity to be rolled back and forth over a 180-deg. arc but the cg is always maintained on the upper, or space-oriented side. Positive lift control is thus provided; letting the capsule roll more than 180 deg. would place the cg on the earth side and result in negative lift.

Displacing the center of gravity off the center flight path line results in the spacecraft banking in that direction to a degree proportional to the displacement. In this way, out-of-place misalignments between re-entering capsule and its landing site can be corrected to coplanar.

This offset center of gravity can only extend the range of a re-entering Gemini; it cannot shorten it. For this reason, the computer introduces a bias in the time of retrofiring so that the crew must use the lift of the offset center of gravity to reach the landing site. Maximum life occurs when the center of gravity is perpendicular to the flight path trajectory. Zero lift occurs when the spacecraft is in a steady roll.

Landing footprint of Gemini, i.e., the extent to which it can be maneuvered during re-entry to reach one or more landing sites, is 450-naut.-mi. long and 90-naut.-mi. wide.

Re-entry begins with the jettison of the adapter module. This is achieved in two steps. First, a shaped charge between the retrograde and equipment sections is fired; this not only severs the airframe, but also cuts and pinch-seals all coolant and ECS lines between the two sections of the module. This same charge also drives a series of razor-sharp blades, called guillotines, through electrical bundles and OAMS propellant lines. Signal to activate the charge is delayed about 0.5 sec. to allow a switch to shut off the current flow downstream of the charge and thus prevent short circuiting.

About 5 min. later, with the equipment section now well behind, the spacecraft is turned around by the crew to a heat-shield first attitude and pitched up to the proper angle. The Thiokol retrorockets are ripple-fired to slow the craft. Explosive squibs cut the titanium straps holding the cabin module to the retrograde section and also drive two guillotines to cut the wire bundles, coolant lines and ECS lines in the tunnels bridging the interface between modules. Retrograde section then is jettisoned, completing the second phase of adapter jettison.

Spacecraft Re-entry

The spacecraft then re-enters the atmosphere and, once the correct ballistic trajectory to the landing site is attained, goes into a 20 deg./sec. roll at about 60,000 ft. A small mortar is fired by the crew, opening the top of the drogue chute canister and deploying this small stabilizing parachute.

At about 50,000 ft., the rendezvous and radar module is released from the re-entry control module by explosive bolts and the drogue chute pulls the entire module clear of the spacecraft. In so doing, it also dumps the folded paraglider from its bucket-like glass fiber container.

Attached at the nose and tail by clamps to the forward end of the re-entry control module, the full 30-ft. length of the glider emerges as a U-shaped loop. Tail clamp on the dorsal side of the module is released first. The end of the paraglider travels toward the base of the spacecraft and pulls its associated cabling free from the 1.5-in. deep trough which runs the length of the cabin module between the hatches. Cables are laid in this covered trough prior to flight.

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