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THE CORIOLIS ACCELERATION PLATFORM

A Unique Vestibular Research Device

W. Carroll Hixson and John J. Anderson

JOINT REPORT

NAVAL AEROSPACE MEDICAL INSTITUTE

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A Unique Vestibular Research Device

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Approved by

Ashton Graybiel, M. D.
Director of Research

Released by

Captain H. C. Hunley, MC USN
Commanding Officer

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PENSACOLA, FLORIDA

SUMMARY PAGE

THE PROBLEM

To develop a vestibular research device capable of generating precisely controlled linear and angular motion stimuli, acting singly or in combination, which have specific application to the investigation of the long-and short-term biological effects of aerospace acceleration environments.

FINDINGS

A combined linear and angular motion device, the Coriolis Acceleration Platform, has been developed which utilizes two independently controlled power servomechanism drive systems to generate acceleration stimuli originated as a result of rotation about an Earth-vertical axis, rectilinear translation along an Earth-horizontal axis, or their combination. For the study of the long-term effects of a rotating environment, the device is provided with a 20-ft diameter capsule which contains complete life-support and bioinstrumentation equipments for the exposure of four to eight men to continuous rotation for periods extending to thirty days or longer. The angular motion drive system is rated to produce capsule velocities to 33 rpm at angular accelerations ranging to 15 deg/sec^2. The linear drive system can be programmed to translate a single subject along a track structure fixed to the capsule and is rated to produce a peak linear displacement of 20 ft to either side of center, a peak linear velocity of 16 ft/sec, and a peak linear acceleration of 96 ft/sec (3 *g*).

ACKNOWLEDGEMENTS

The Coriolis Acceleration Platform was developed under joint USN-NASA sponsorship with financial support derived from NASA Order No. R-93. The KPT Manufacturing Company, Roseland, New Jersey, served as contractor for the project in which the principal subcontractors included the General Electric Company who furnished the drive motors and electrical controls, the Falstrom Corporation who performed the aluminum structural work, the Breeze Corporation who supplied the slip-ring assemblies, and the Dyson and Company who installed the device.

The authors wish to acknowledge the following Naval Aerospace Medical Institute personnel: Dr. Ashton Graybiel, director of research, who originated the concept for and defined the experimental objectives of a combined linear and angular motion vestibular research device; Drs. J. I. Niven, F. E. Guedry, Jr., and C. S. Harris for their contributions to the establishment of firm design specifications for the device; Mr. C. L. Browning, for his technical assistance during development of the device; and Mr. A. N. Dennis, Mr. C. A. Lowery, and Mr. D. H. Russell for their engineering technician support during the installation and final test phases of the project.

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INTRODUCTION

This report presents a brief description of the salient technical features of the Coriolis Acceleration Platform (CAP), a new and unique motion-producing vestibular research device, which was developed under joint USN-NASA sponsorship to study the biological effects of the acceleration environments encountered in the simulation and flight phases of manned spacecraft operations. The primary element of the device is a large rotating capsule which can be used to simulate the angular motion characteristics of spacecraft undergoing rotation so as to establish a gravity-like force field where complete life-support and physiological data-acquisition equipments are available for the exposure of four to eight men to continuous rotation for periods extending thirty days or longer. The device is unique in that two independently controlled power servomechanism drive systems are provided to generate preprogrammed acceleration stimuli due to the occurrence, singly or in combination, of Earth-horizontal translation and Earth-vertical rotation. With this capability biological performance in a given force field can be investigated in terms of the separate and joint contributions of the resultant linear acceleration and resultant angular acceleration components of the environment.

GENERAL DESCRIPTION

The over-all configuration of the device can be visualized from the sketch shown at the top in Figure 1 which is an artist's concept of the installation viewed in cutaway section. The main element of the device is a rotating superstructure which is housed in a circular, two-level, air-conditioned building. The superstructure, a photograph of which is shown at the bottom in Figure 1, is composed of a large capsule and a radial track turret which rest on a pedestal assembly installed at the center of the lower level of the building. A drive motor located inside the pedestal allows the entire device, capsule and track turret, to be rotated about an Earth-vertical axis. A second drive motor, installed within the track turret, permits a single subject (shown in shaded detail at the left of the capsule in the Figure 1 sketch) to be linearly displaced back and forth along the radial axis of the track turret. A domed structure attached to the roof of the building immediately above the center of the capsule houses a slip-ring assembly used for transmission of data to and from an adjacent control room.

The basic components of the device and their relative dimensions are sketched in elevation and plan in Figure 2. At the top may be seen the circular capsule, a totally enclosed room with an inside diameter of 20 ft and a floor-to-ceiling height of 9 ft 6 in., which is fixed to the upper surface of the radial track turret at floor level. The track turret, approximately 48 ft long and 5 ft wide, is bearing supported by the pedestal and in-line coupled directly to the shaft of a gearless 33-rpm, 18,000-lb-ft peak, DC torque motor housed in the upper base. The lower base of the pedestal contains a slip-ring assembly for high-level power and control circuitry, control and monitor velocity tachometers, and a rotary joint to furnish plumbing service to the capsule.

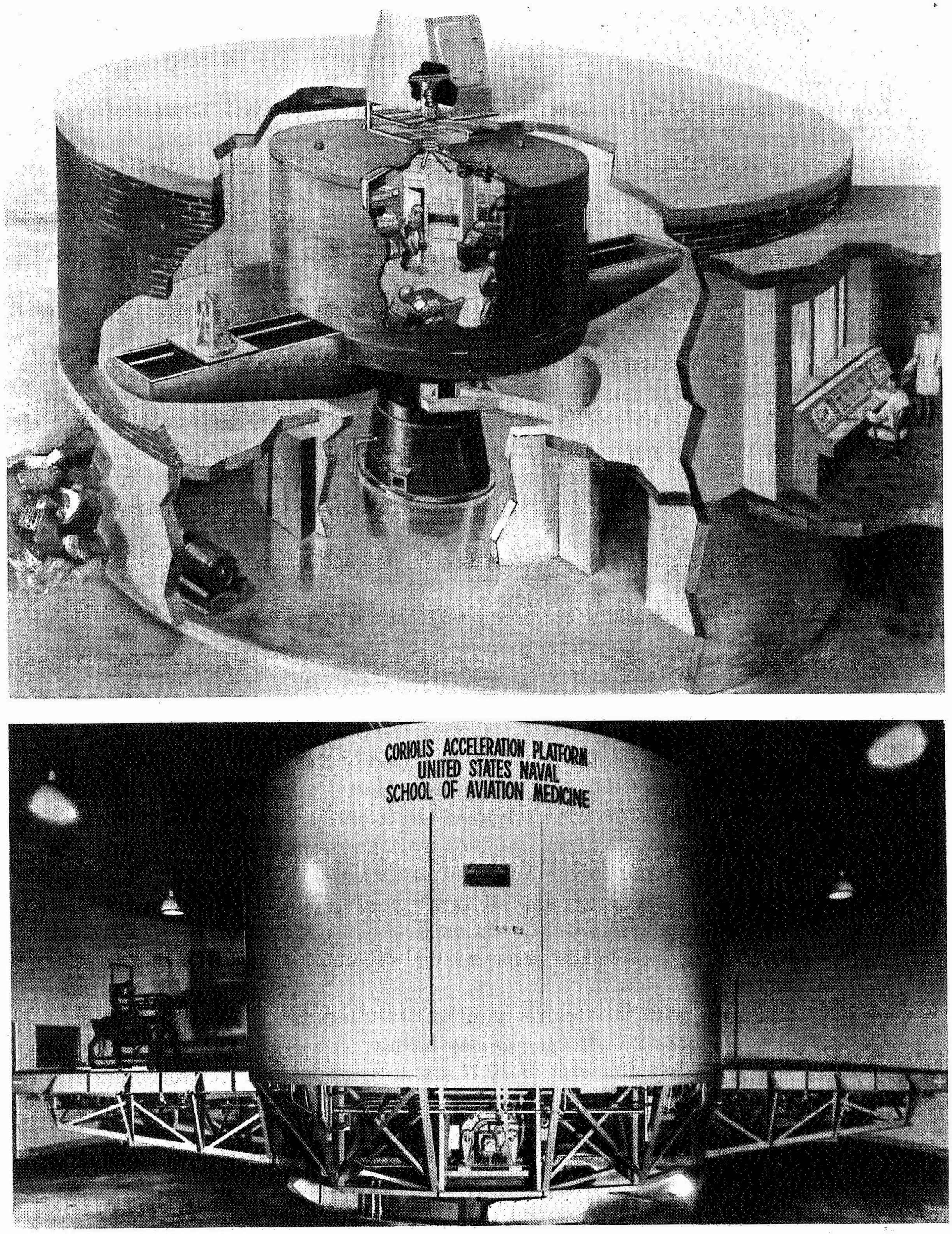


Figure 1

Artist's concept of the over-all Coriolis Acceleration Platform installation (top) and photograph of the actual rotating superstructure (bottom).

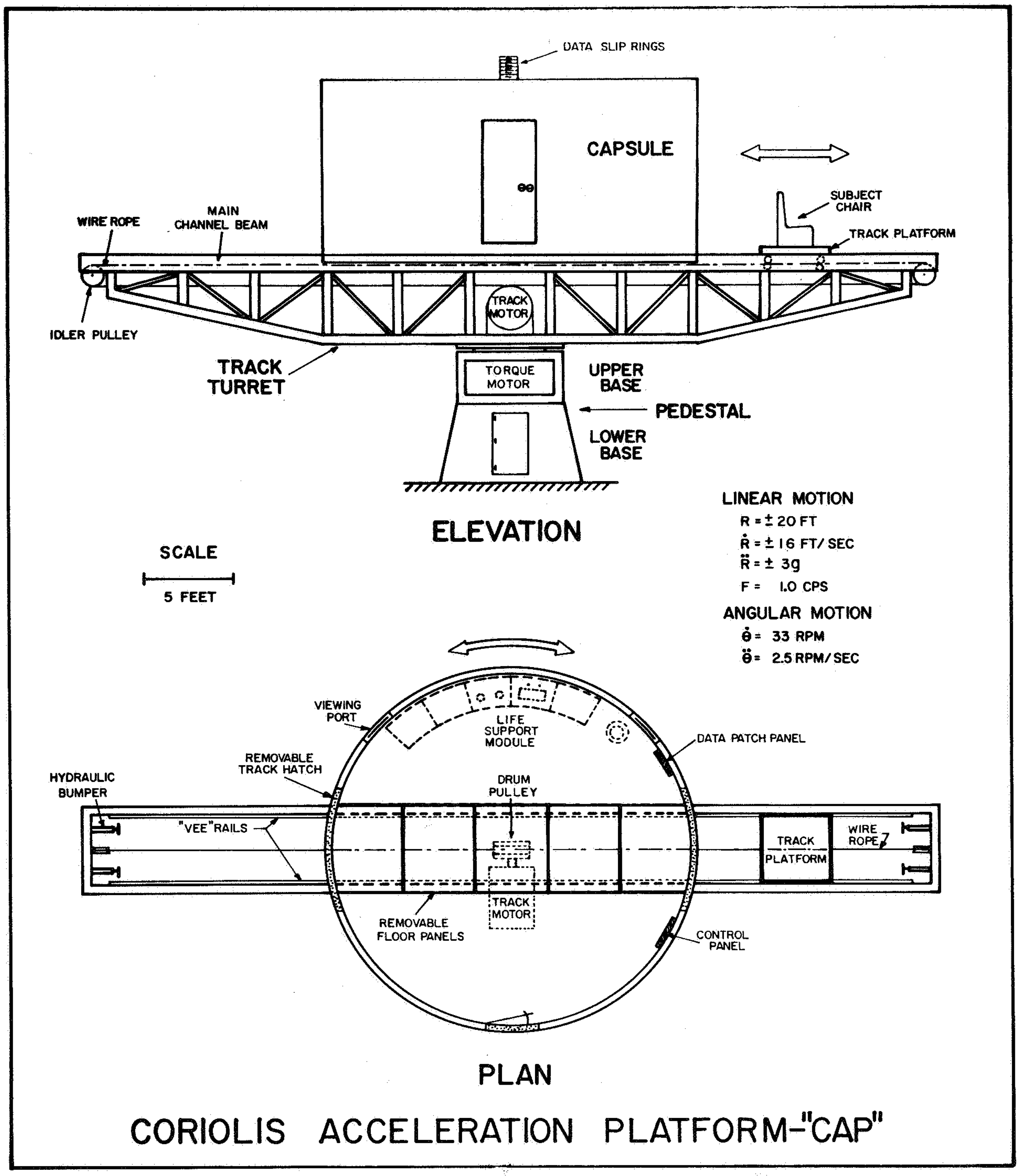


Figure 2

Elevation and plan view sketches of the Coriolis Acceleration Platform.

The DC torque drive motor is operated under closed-loop conditions where the overall rotary drive system describes a velocity-mode power servomechanism. With this system the entire device can be continuously rotated, CW or CCW, over a 0-to-33-rpm angular velocity range at a maximum angular acceleration of 15 deg/sec^2 with a maximum balanced payload of 5000 to 7500 lbs, dependent upon the form and duration of the programmed motions. Electronic control of the velocity-time profile of the angular motions is provided by a DC command signal which is made linearly proportional to the desired instantaneous angular velocity. The command signal can be obtained from a manually adjustable potentiometer; from various analog computer and function generator sources to produce, typically, ramp, triangular and sinusoidal velocity waveforms; or from actual vehicle angular motion data stored in analog form on magnetic tape.

The characteristics of the torque motor which led to its selection as the motive power source for the rotary drive system included a low full-scale output shaft speed, a relatively linear relationship between armature current input and shaft torque output, fast response time, a low acoustic noise level, and the ability to deliver full output under stall conditions. The last characteristic is particularly significant from the vestibular viewpoint, since smooth transitions in the direction of rotation can be accomplished with minimal "dead-band" or "jerk" effects. Since the motor is in-line coupled directly to its rotating superstructure payload, the problems of gear backlash are eliminated, resulting in a tight drive system with good dynamic response capabilities. The torque motor approach has also been applied in the concurrent development of the Periodic Angular Rotator (2), a small-scale vestibular rotator recently installed at this activity by the Engineering Experiment Station of the Georgia Institute of Technology.

For the production of linear motion stimuli a subject chair or carrier device can be fixed to a small track platform that is wheel-supported on "Vee" rails attached to the interior surfaces of two main-channel beams which extend over the full length of the track turret. Motive power to linearly displace the subject chair-track platform combination is furnished by a 100-hp, low-rpm, DC motor installed centrally in the track turret beneath the floor of the capsule. The track platform is coupled to the motor by means of a pretensioned wire rope that is reeved around and attached to a drive pulley fixed to the motor shaft, through idler pulleys installed at each end of the track turret, and terminated at the track platform to form a continuous loop as indicated in Figure 2. Data transmission between the track platform and the capsule is provided by a multiconductor electrical cable, routed parallel to the main drive rope, and a track slip-ring assembly which is chain-coupled to the output shaft of the track drive motor. Twin hydraulic bumpers installed at each end of the turret provide controlled deceleration of the track platform in the event of drive-system malfunction.

The linear drive system describes a closed-loop power servomechanism configuration similar to that used for the rotary drive system, except that it is operated in the position mode. With this system the instantaneous linear displacement of the track platform away from the center of the track turret is linearly proportional to the instantaneous amplitude and polarity of a DC command signal made analog to the desired position profile. With a 500-lb payload on the track platform, the drive system is rated to produce a peak linear displacement of 20 ft to either side of center, a peak linear velocity of 16 ft/sec, and a peak linear acceleration of 96 ft/sec^2 (3 g) where each rating serves as an independent limit for any combination of parameters. When programmed to produce continuous sinusoidal oscillations of the track platform along the track, the drive system has a maximum cyclic frequency rating of 1.0 cps.

In general, the research capabilities of the device derive from two distinct modes of operation. In the first mode a single subject is fixed to the track platform and the device programmed to produce static or time-varying linear displacements of the platform along the track either in combination with, or independent of, angular rotation of the entire device. In the second mode the track drive is inactivated, one or more subjects are placed within the capsule, and only rotary motions programmed.

In the first mode of operation the subject is usually seated in a chair assembly that is attached directly to the base of the track platform and which includes protective equipment for head, torso, and limb constraint. Photographs of two such custom-developed assemblies are shown at the top left and top right in Figure 3. The cubically shaped enclosure at the left can be positioned so that any one of its six surfaces may be attached to the base of the track platform to allow the preselection of the subject's orientation relative to the direction of motion along the track. The chair shown at the right provides similar variation of orientation but over a more limited range. An end view of the radial track, with the capsule hatches and floor panels removed to permit unrestricted travel of the subject over the full 40-ft length of the track, is shown at the bottom in Figure 3 where the subject chair may be seen in the background. The fence-like structure shown at either side of the track within the capsule serves a protective function for on-board operational personnel monitoring the motions of the track platform.

A typical application for the first mode of operation would be the exposure of a subject to pure linear-motion stimuli generated by programming periodic or nonperiodic time-varying displacements of the track platform along the Earth-horizontal track axis. A second application might be to statically displace the track platform a known distance from the center of the device and to program only angular rotation of the device, i.e., the simple fixed-radius centrifuge environment. A third application could involve the simultaneous occurrence of linear motion of the subject along the track and angular motion of the entire device and thus produce linear Coriolis acceleration stimulation from which the device's name derives. Most important, when angular velocity is held constant, sinusoidal track motions can be programmed which produce a constant magnitude, variable morphological direction, linear acceleration stimulus without attendant angular acceleration stimulation. To further expand the research capabilities of the device, a counter-rotating chair is being developed that will be attached to the track platform.

In the second mode of operation the capsule wall and floor panels removed for the linear motion track studies are reinstalled to make the capsule a totally enclosed, light-proof, experimental area. The ceiling of the capsule is structured to be self-supporting so that the interior of the capsule is obstruction free throughout. A photograph of the interior of the capsule taken during an experiment which required the installation of custom-developed floor and wall surfaces is shown at the top in Figure 4. For long-term

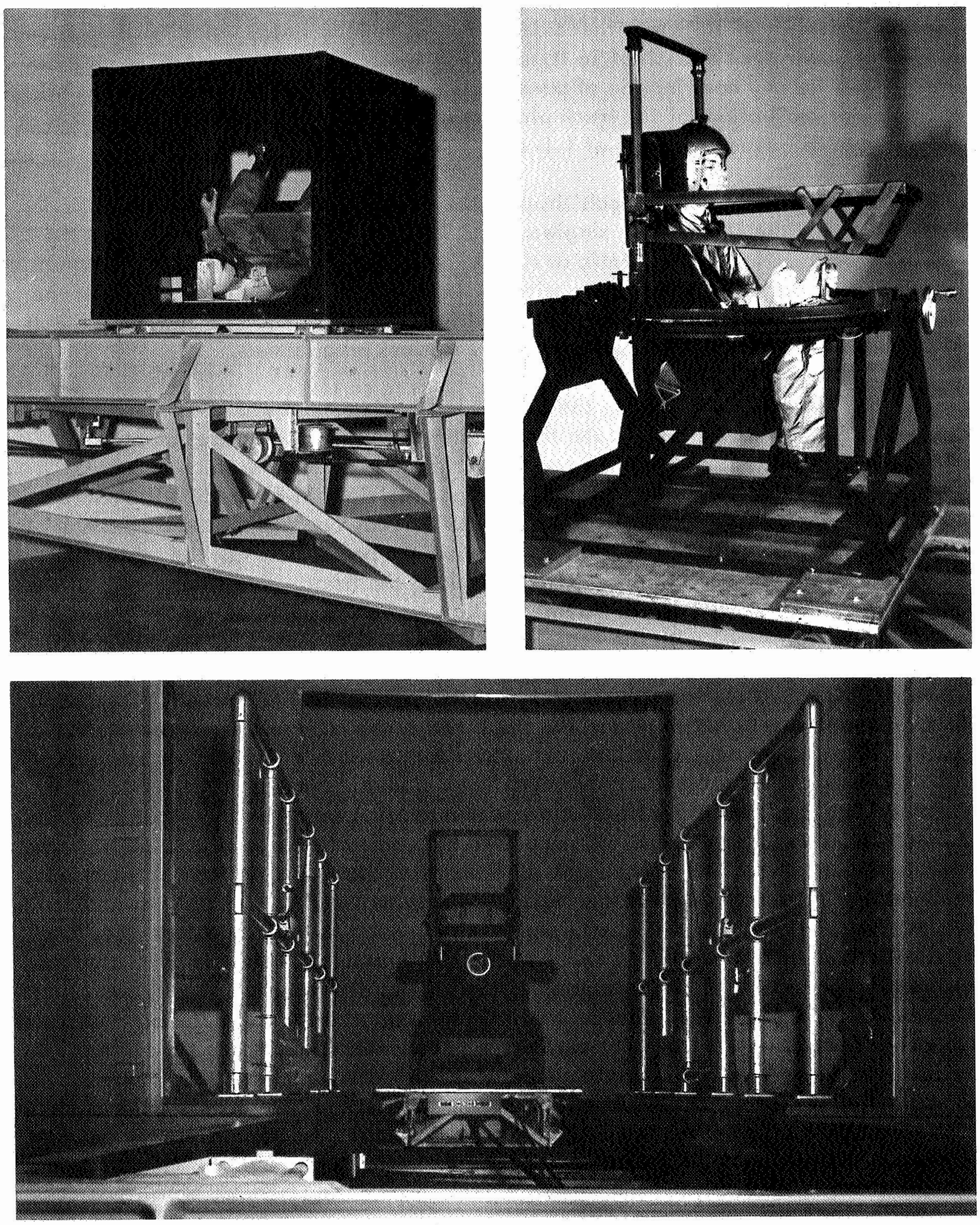
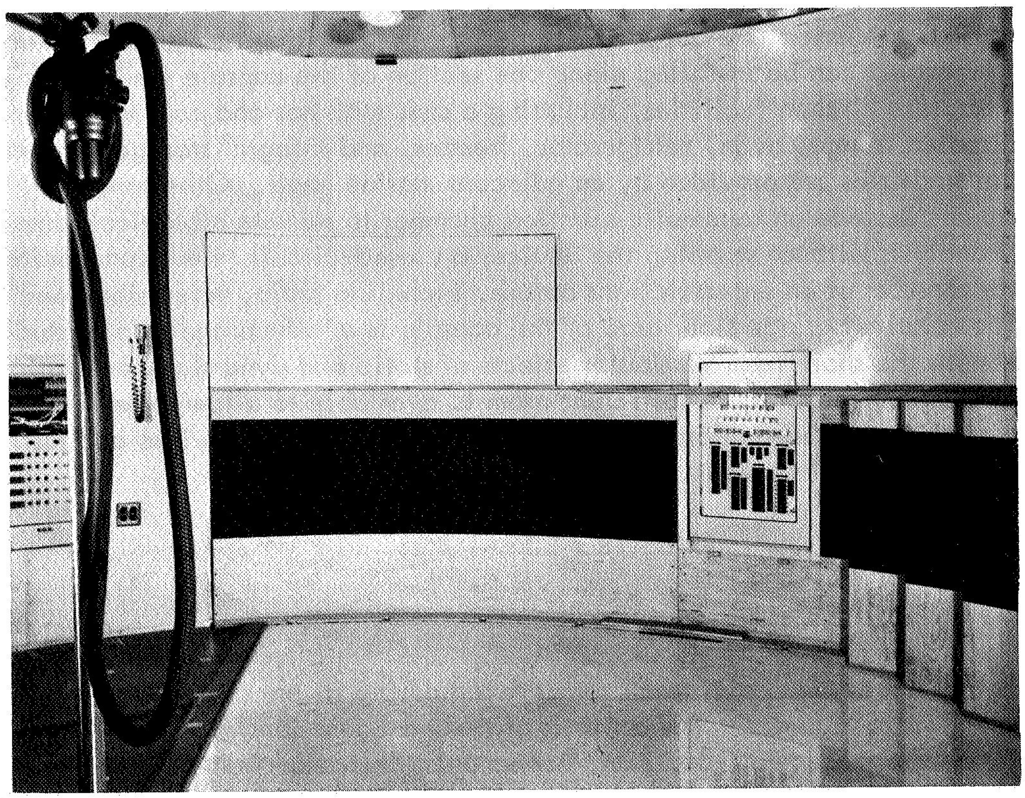


Figure 3

Two typical subject-carrier devices installed on the track platform (top). An end view of the radial track with capsule wall and floor panels removed to permit free passage of the subject-carrier through the capsule (bottom).



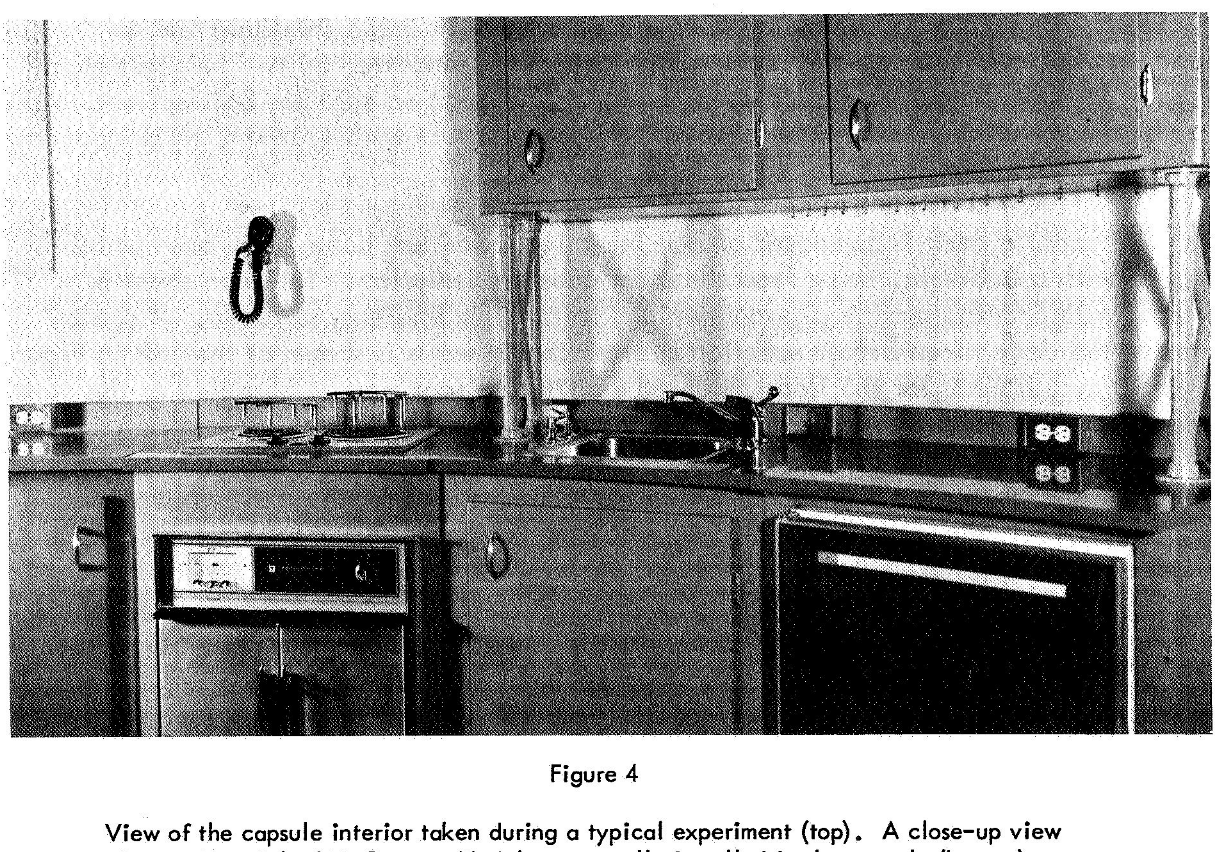


Figure 4

View of the capsule interior taken during a typical experiment (top). A close-up view of a portion of the Life Support Module as actually installed in the capsule (bottom).

studies a custom-designed Life Support Module (LSM), a portion of which is shown at the bottom in Figure 4, can be installed along one section of the capsule wall. This unit contains complete kitchen facilities, including a sink with hot and cold water service, garbage disposer, range, oven, refrigerator, freezer, and integral storage cabinets. On-board toilet facilities are provided by an adjacent marine head. Other ancillary features for such studies include an automatic ejection chamber to remove biological samples for laboratory analysis without stopping the device; a closed-circuit television monitor system; and various services of an entertainment nature, including radio, television, and telephone. The relatively large floor area of the capsule is of advantage also to studies concerned with the short-term vestibular effects of static and dynamic acceleration stimuli produced by rotation, as sufficient room is available to allow experimenters to make on-board visual observations during a given test and to use devices and instruments with laboratory scale dimensions.

TECHNICAL FEATURES

ROTATING SUPERSTRUCTURE

A photograph of the radial track turret taken during its on-site assembly to the pedestal is shown in Figure 5. The turret is of trussed-boom construction in which the main radial members are two type 12U7.41 channels fabricated from 6061-T6 aluminum which support the "Vee" rails. The remainder of the structure is mig-welded 5051-T6 aluminum, using 1/16-in. diameter 4040 shaved wire with argon shielding and a rectified DC power source. The deck of the capsule is supported by two hemispherical wings which are formed from aluminum structural "T" members that are bolt-spliced to the sides of the turret and isolated from metal-to-metal contact with 1/16-in. thick neoprene strips of 30-durometer hardness.

The capsule deck is composed of a 1-in. thick aluminum honeycomb base which is covered with a 0.017-in. thick lead sheet for acoustic isolation. The lead sheet is covered with 5/8-in. marine plywood which, in turn, is linoleum surfaced. A photograph of the deck taken before erection of the capsule walls is shown at the left in Figure 6, where cutout ports for the floor-mounted ventilation fans may be observed at the outer periphery. Also visible are the five radially mounted deck panels which can be removed when the track-drive system is operated. The grid-like arrangement of holes seen in the deck are 3/8-in., 16 UNF flush-mounted, threaded inserts which are used to secure research devices, equipment, and instruments that may be installed within the capsule during experimentation.

The structural members of the capsule walls are corrugated aluminum Vee-beams faced on both sides with 0.040-in. aluminum sheets. These members are joined with pop blind rivets using DK-153 gasket material between all metal surfaces at the riveted joints. The wall is formed with modular panels that were assembled and fitted at the time of manufacture and riveted together permanently at the installation site. A photograph of the interior of the capsule taken during final installation is shown at the right in Figure 6. The interior surface of the walls was then covered with three layers of

Figure 5

Photograph of the radial track turret taken during installation of CAP.

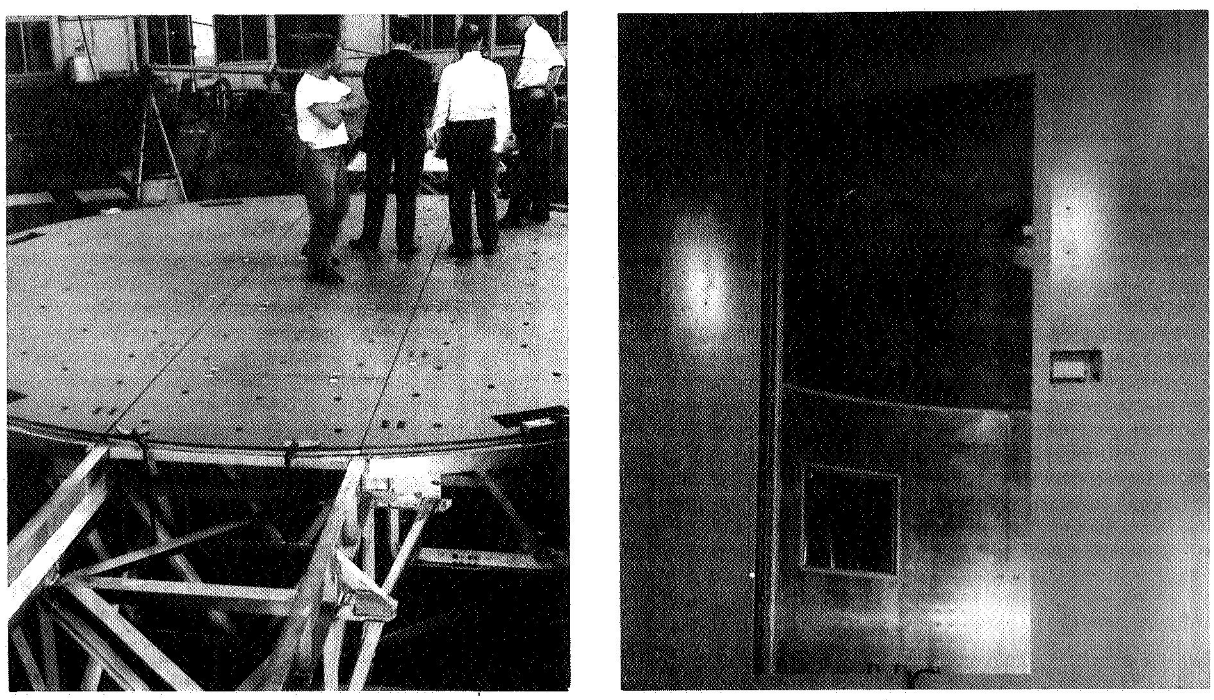


Figure 6

Photographs taken during factory assembly of the capsule floor to the radial track turret (left) and on-site erection of the capsule before installation of finish wall materials (right).

fiberglass insulation in 48-in. wide bolts that were adhesive applied sequentially in a cross-angle pattern to improve acoustical and structural characteristics. The outer layer was faced with green plastic, day lighting panels, composed of acrylic resin impregnated with glass fiber, which were riveted together to form a durable, washable, protective cover for insulation and provide a degree of resilience adequate to reduce the possibility of injury in the event a freely moving subject inadvertently impacts against the wall.

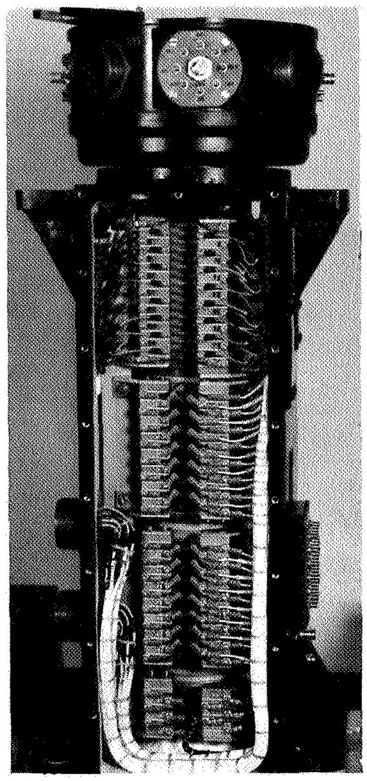


Figure 7

Upper slip-ring assembly.

The self-supporting capsule ceiling is composed of twenty-four 15^{o}-sectors of 0.040-in. thick sheet aluminum formed into a 2 1/2-in. deep trough with turned-in edges for rigidity. The sectors are bolted to each other and to a centrally located compression ring with a 30-in. inside-diameter ring to allow passage of ventilation air. The construction is such that the ceiling forms a cone of approximately 20-ft diameter and 5-in. height. For ambient lighting purposes twelve incandescent lamps are attached to the ceiling. Four pivot-mounted, high-intensity lamps are mounted centrally in the ceiling to provide lighting for photographic documentation purposes. The incandescent lamps, as well as the ventilation fans, are energized from a DC voltage source to minimize AC power-line interference while recording low-level electrophysiological data. A shielded slip-ring assembly, shown in Figure 7, is mounted directly above the center of the ceiling to provide electrical isolation from the high-level circuitry routed through the supporting pedestal of the capsule. This assembly provides 30 circuits for low-level physiological data, 60 circuits for low-level control and recording signals, and five video circuits. The ring and brush materials are coin silver and 75%-25% silver graphite, respectively.

PEDESTAL

The cylindrically shaped upper base of the pedestal serves as the main housing for the DC torque motor used to rotate the CAP superstructure. The motor stator is fixed directly to this housing, while the rotor is supported by a four-point ball bearing at the top and an annual ball bearing at the bottom. The upper end of the rotor is fastened to a large cylindrical ring to which the radial track turret is fixed. The lower end of the rotor is in-line coupled to a power slip-ring bank, a rotary joint, and a high rpm tachometer gear box, all of which extend into the lower base of the pedestal. These components can be seen in the photograph at the left in Figure 8 which was taken during assembly of the upper and lower bases of the pedestal. A photograph of the assembled pedestal is shown at the right in Figure 8; the open ports seen in the upper base terminate ductwork used in the forced-air ventilation system which cools the torque motor, and the

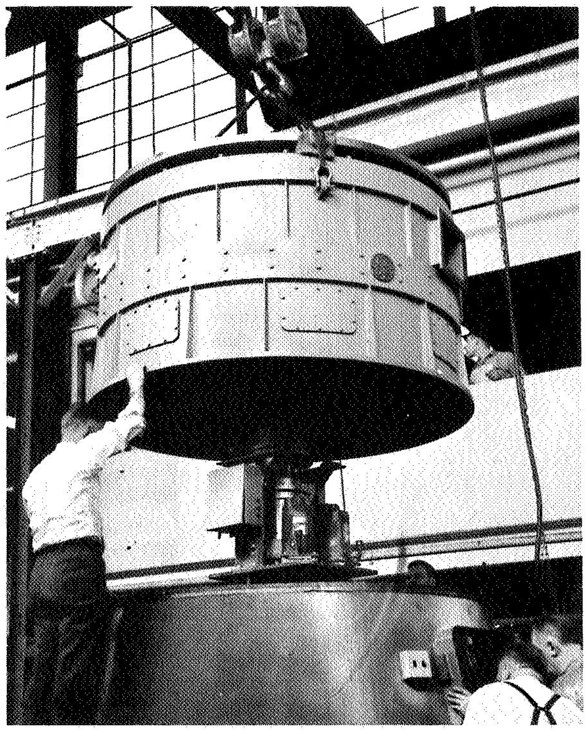
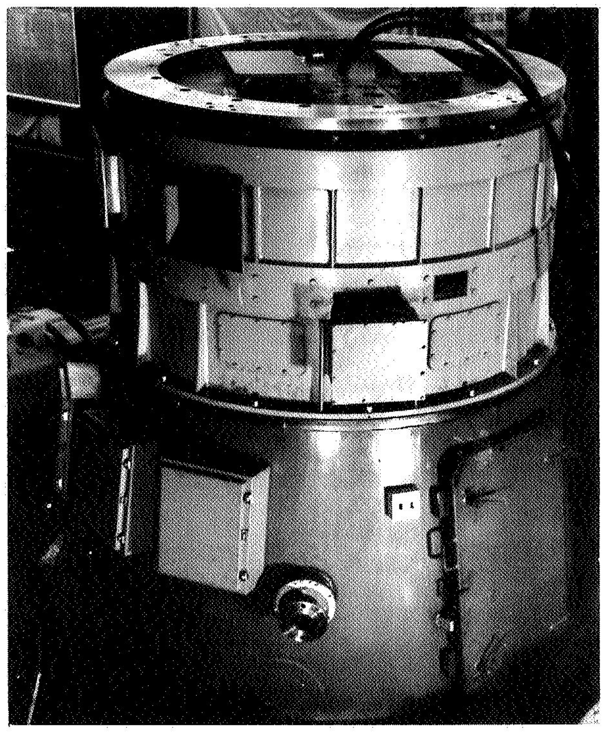



Figure 8

Photographs of the pedestal taken during (left) and following (right) assembly of the upper and lower base sections.

closed ports provide maintenance access to the torque motor brushes. The two electrical cables extending from the top supply armature current to the track drive motor installed within the turret proper. Also visible are three surface-mounted electrical boxes attached to the lower base which are used to terminate the power slip-ring circuits, and the outlet end of the rotary joint drainage line.

The interior components of the lower base can be seen in better detail in Figure 9, taken before final assembly. The power slip-ring assembly at the top provides two rings for the track motor armature, each rated at 300-amp continuous or 950-amp peak sinusoidal current at an oscillation frequency of 1.0 cps for a period not to exceed ten minutes; 6 rings rated at 150 amp, 240 VAC, used to supply AC power service to on-board experimental equipments; and 34 rings rated at 15 amp, 600 VAC, used for drive-system control circuits. The rotary joint located immediately beneath the slip rings contains two 1/2-in. inside-diameter lines for hot and cold water service and one 3-in. inside-diameter line for drainage service to the life-support module equipment located within the capsule. All three rotary joints are contained in a single housing to minimize bearings and couplings and to maximize shaft stiffness to the in-line mounted tachometer below. To minimize the possibility of leakage from the drainage line filtering into the water supply, the housing is provided with eighteen 3/4-in. weep holes to prevent water pressure buildup behind the water supply seals (Buna N. Material) in the event of drainage seal failure. Weep holes are also included at the rotary joint bearings to prevent water buildup within the bearings.

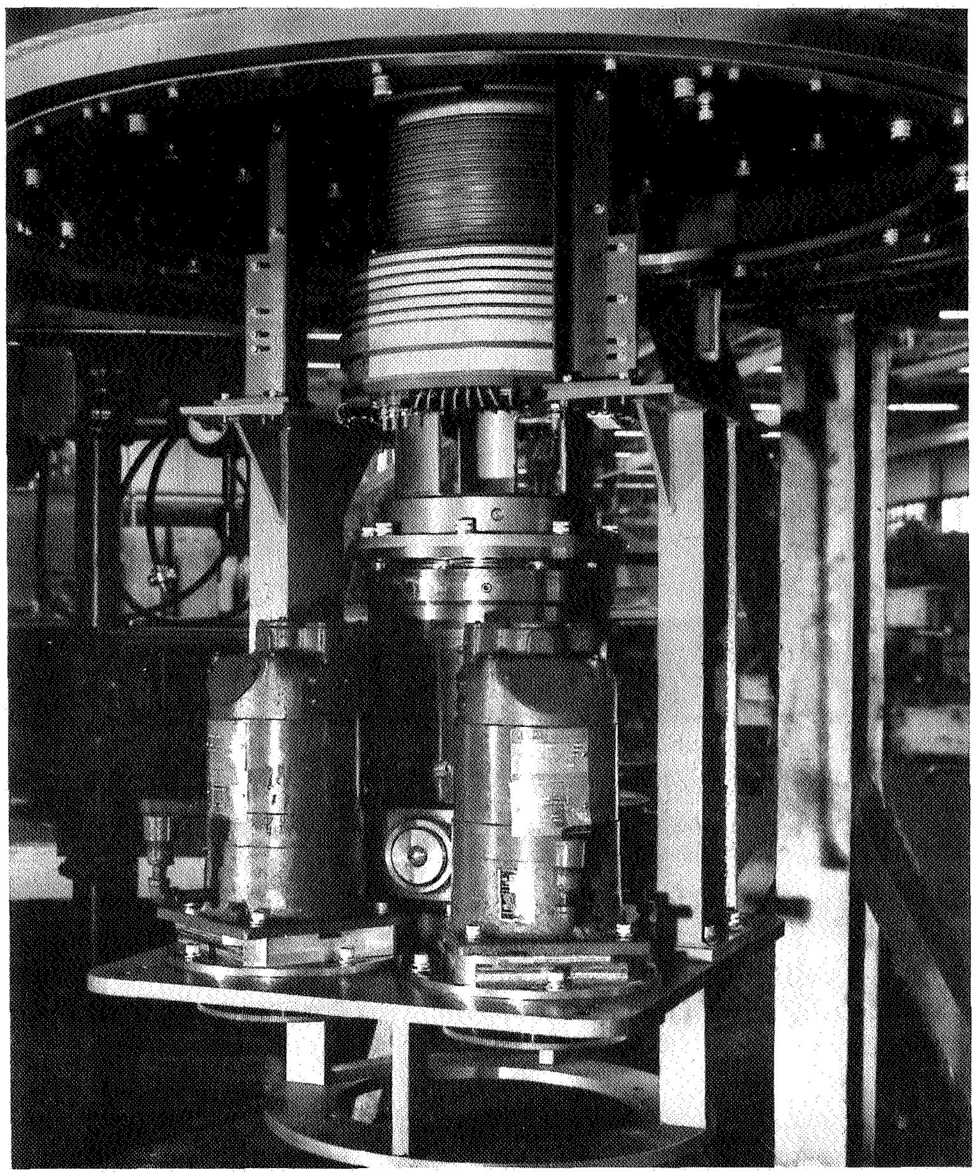


Figure 9

View of the interior components of the pedestal lower base.

The two high-rpm DC tachometers which are gear-coupled to the lower end of the rotary joint can also be seen in Figure 9. A low-rpm torque tachometer, not shown in this figure, is attached to the circular ring affixed to the base of the dual tachometer assembly. The lower end of the double-ended torque tachometer shaft is attached directly to a 600-tooth, 24-in. diameter, ferrous gear. This gear and a magnetic field sensing probe provide a digital measure of the capsule angular velocity which is converted to a decimal rpm read-out by means of a digital frequency-counter installed in the operator's console. Details of the power slip ring and the rotary joint are shown in Figure 10.

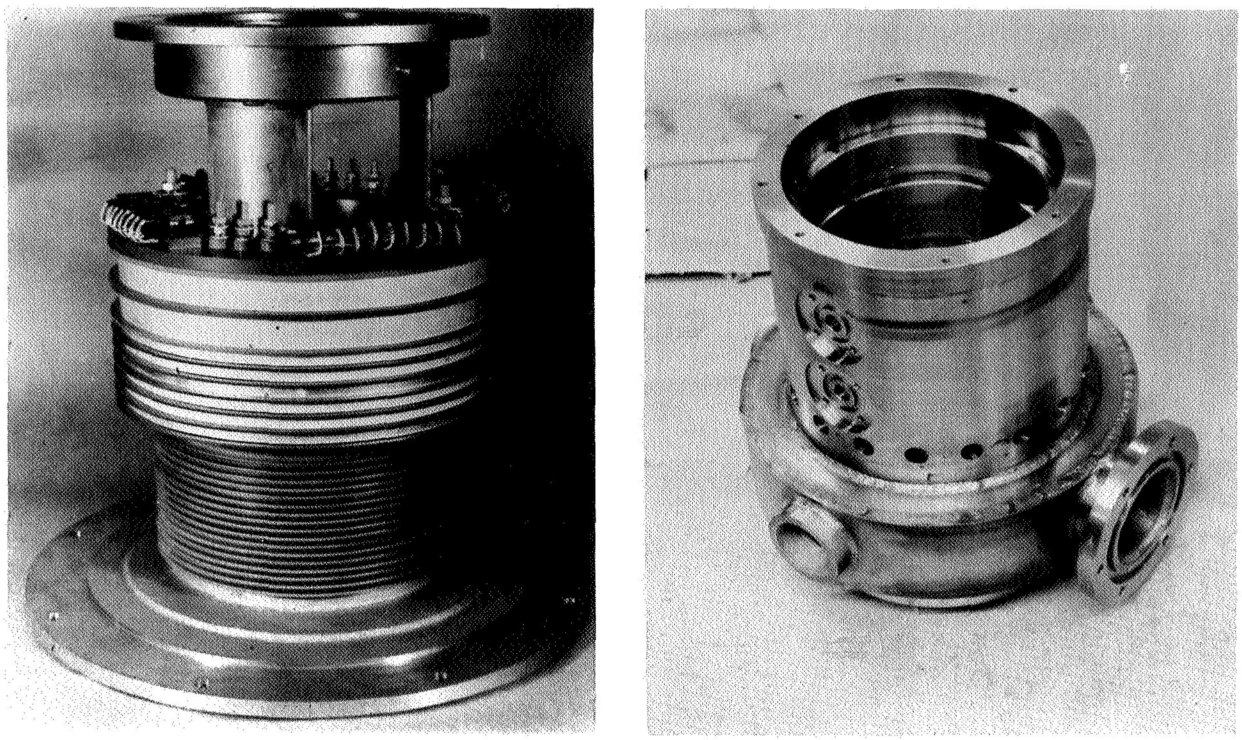


Figure 10

Close-up views of the power slip-ring bank (left) and rotary joint (right) before installation in the pedestal.

ROTARY DRIVE SYSTEM

The rotary drive motor (GE model MPF-28) is a 28-pole, 894-commutator segment, DC torque motor with electromagnetic field excitation that has a maximum speed of 33.3 rpm and is rated to deliver an output torque of 12,000 lb-ft. The motor is forced-air cooled and has a 174-volt, 435-amp armature rating and a 150-volt, 20-amp field rating. Under peak conditions the motor can withstand an 18,000-lb-ft torque, 196-volt, 680-amp instantaneous load. Photographs of the stator and rotor taken before assembly are presented in Figure 11.

Armature current of the torque motor is supplied from an 85-kw, 1750-rpm, 200-volt, 425-amp, shunt-wound DC generator with 80-volt, 12-amp field requirements. The prime mover for the generator is a 440-volt, 3-phase, 60-cps, 4-pole, 125-hp induction motor. An integral shunt wound, 4 1/2-kw, 250-volt, 18-amp exciter is included with the motor-generator set for dynamic braking purposes in case of power failure. The set is energized by means of a reduced voltage, auto transformer type of magnetic starter. A view of the motor-generator room, located in the lower level of the building, is shown at the top in Figure 12 where the track set is at the left and the rotary set at the right.

Variation of torque motor speed and direction is controlled by the magnitude and direction of the armature current supplied by the output of the generator which, in turn,

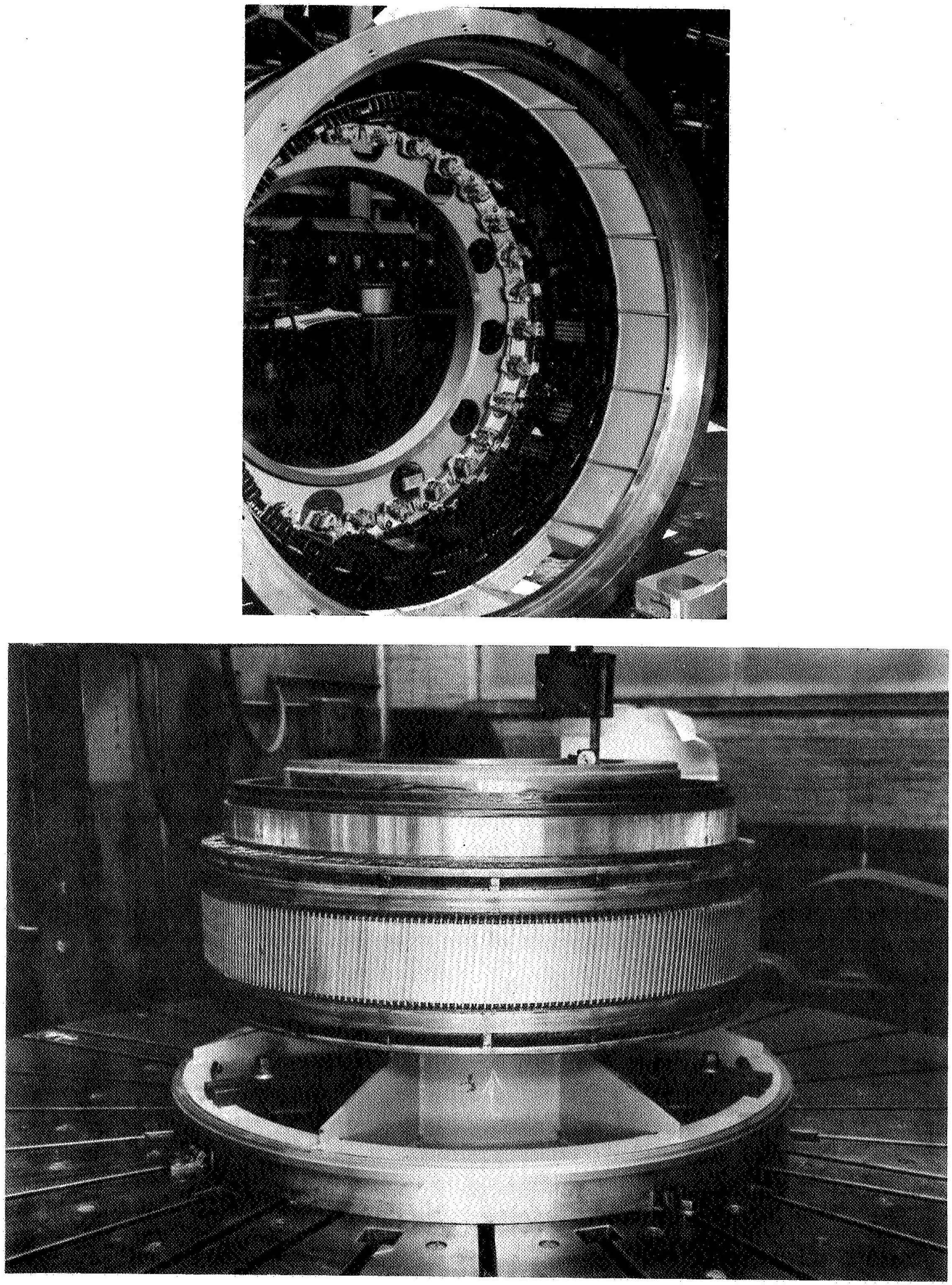
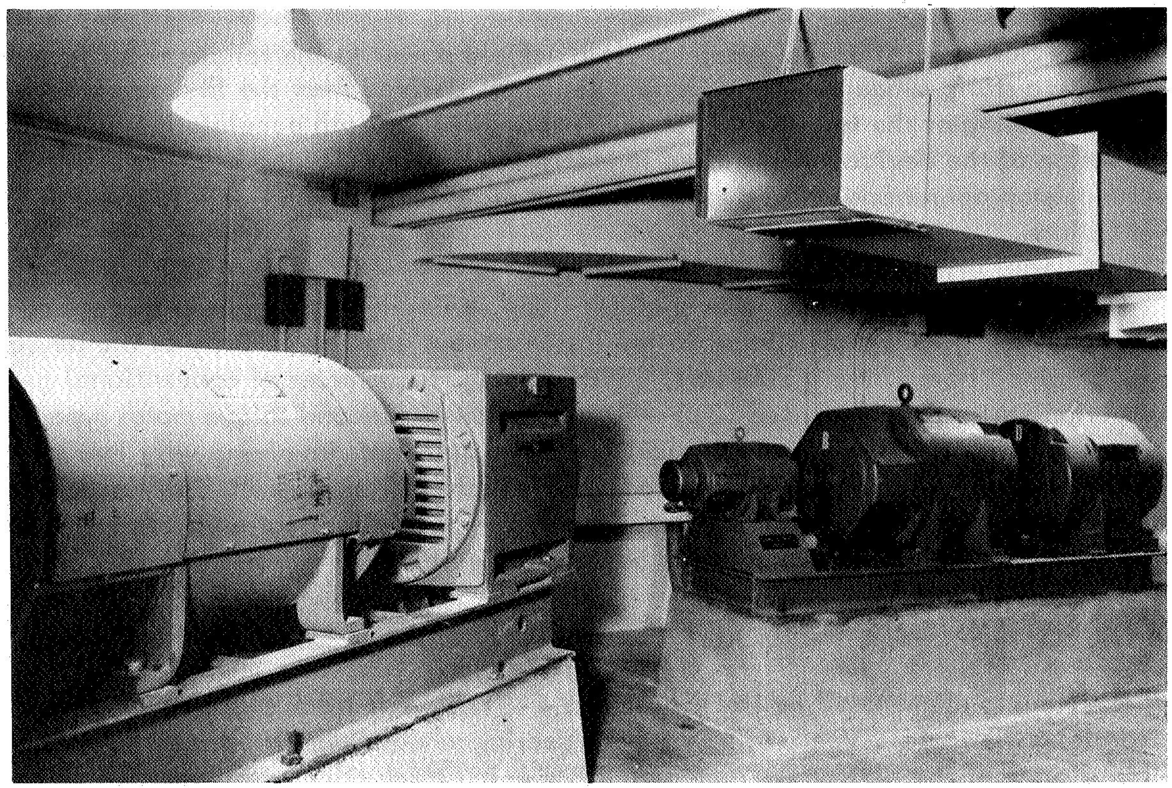


Figure 11

The stator (top) and rotor (bottom) of the rotary drive torque motor before assembly.



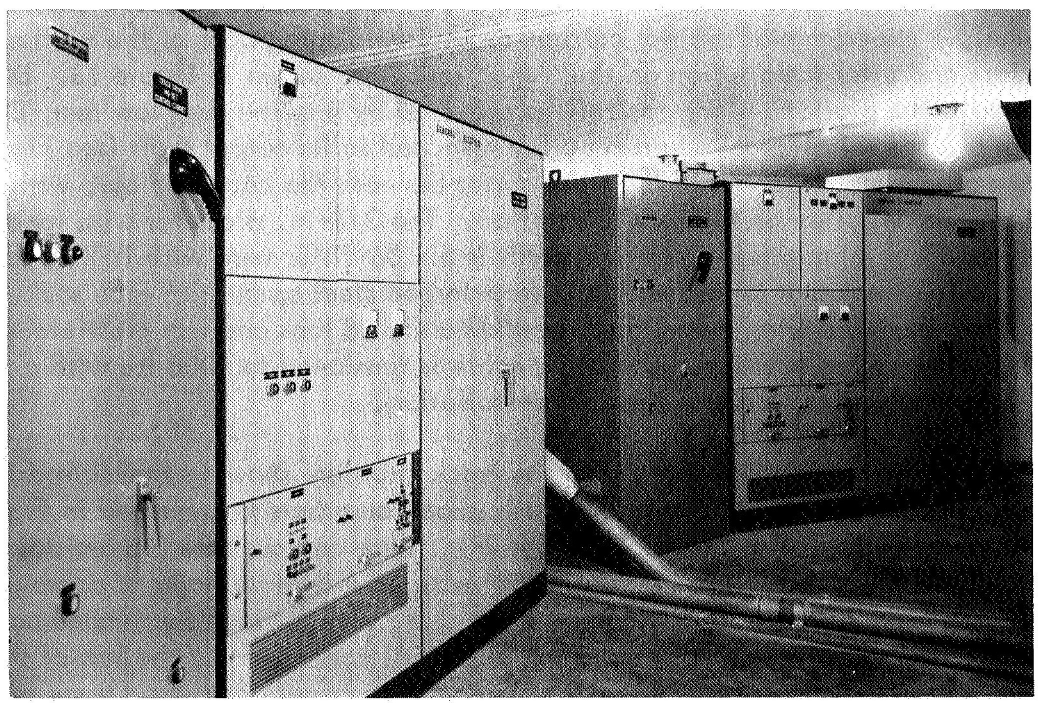


Figure 12

The motor-generator sets used for the linear and rotary drive systems are shown at the left and right, respectively, in the upper photograph. The electronic control equipments for the linear and rotary drive systems are installed in the three-module set of cabinets shown at the left and right, respectively, in the lower photograph.

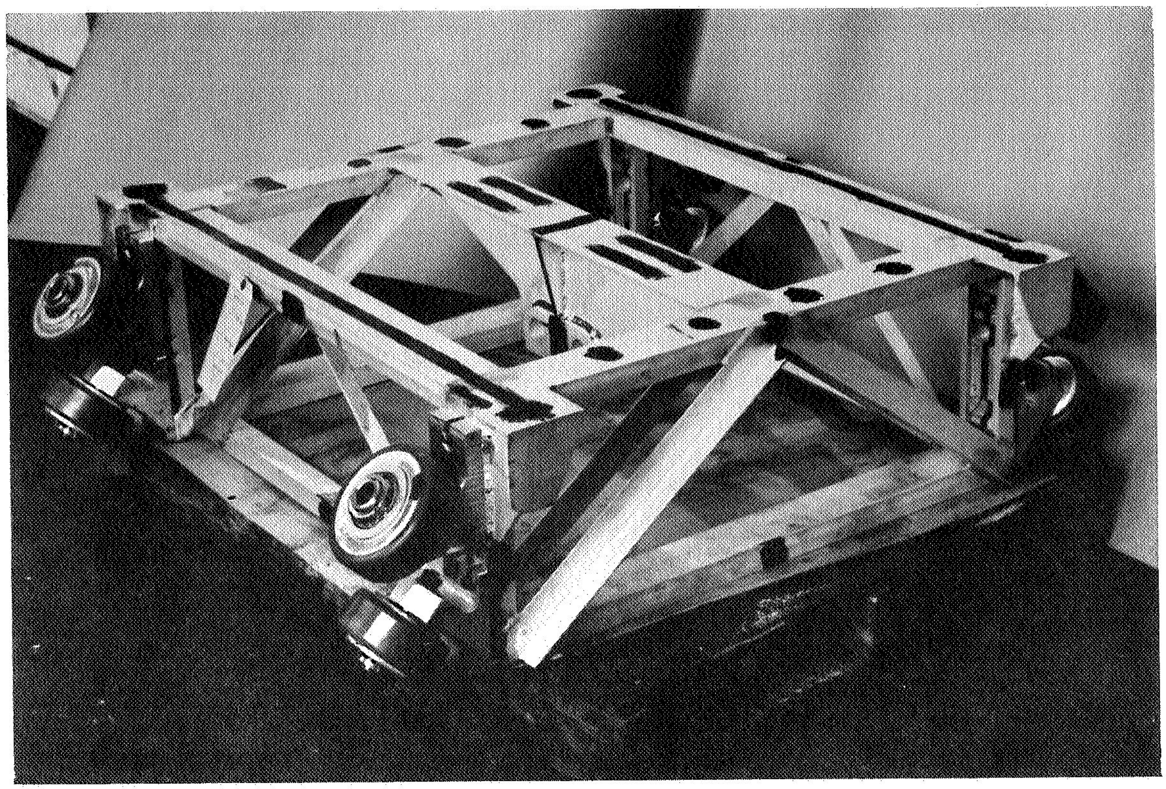
is varied by SCR control of the generator field. Field power to the torque motor is supplied by a static diode exciter. Current limiting, derived from the IR drop across a pole face winding of the torque drive motor, is provided for both acceleration and deceleration of the device. Controlled regenerative braking (15 deg/sec^2) is utilized for emergency stop operations while dynamic braking provisions are available in case of power failure.

The entire system is operated as a closed-loop, velocity-mode, power servomechanism. Feedback signals proportional to the instantaneous angular velocity of the device can be obtained from either a 200-volt, 1000-rpm, DC tachometer of conventional geared construction, or a direct-coupled 53.5-volt per radian per second torque motor type tachometer. The latter unit is usually utilized for experiments involving very low rotational rates. A third tachometer of the geared type is included to drive ancillary angular velocity monitor indicators and recorders. A photograph of the electronic control panels for the two drive systems is shown at the bottom in Figure 12.

TRACK DRIVE SYSTEM

The moving element of the track system is a 4-ft by 4-ft track platform which is guided along the radial "Vee" rails by 8 ball-bearing wheels fabricated from "Durathane." The top surface of the platform is covered with a 1-in. thick honeycomb core which has 3/8 - 16 UNC threaded inserts mounted on a 6 in. by 6 in. matrix to facilitate attachment of various experimental subject carriers or chairs. Photographs of the platform, taken before and after installation on the "Vee" rails, are shown in Figure 13. Drive power to move the platform along the rails is provided by a mill-type, low rpm, DC motor with a large spiral-grooved drum pulley attached to its output shaft (see Figure 14.) The motor is mounted within the track turret beneath the capsule floor, with the center of the drum pulley on the axis of rotation. The 3/4-in. diameter wire rope used to couple the track platform to the track motor is 6 x 36-filler wire with IWRG, regular lay, monitor AA steel that is fastened to a drop-forged steel open-wire rope socket. The rope has a minimum breaking strength of approximately 28 tons and was prestretched to 35 per cent of breaking strength. The drive cable is tensioned to 6000 lbs with a 12,000-lb hydraulic jack force in the CAP installation.

A close-up photograph of one end of the track structure showing the main drive cable, the idler pulley, and the twin hydraulic shock absorbers is presented in Figure 15. These absorbers have a 9 1/2-in. stroke and a 2-in. bore and are rated to provide a 3-g deceleration of the track platform for an impact with an initial velocity of approximately 12.3 ft/sec. A spring with sufficient force to hold the plunger in the extended position in a 9-g field is included on each absorber. The small cable seen at the left of the main drive cable in Figure 15 is used for electrical interconnection of the track platform to the capsule to permit the hard-wire acquisition of experimental data from the moving track platform. This cable is terminated at a track slip-ring assembly which is chain-coupled to the drum pulley attached to the drive motor. Ten physiological and twelve control circuits are provided with this system.



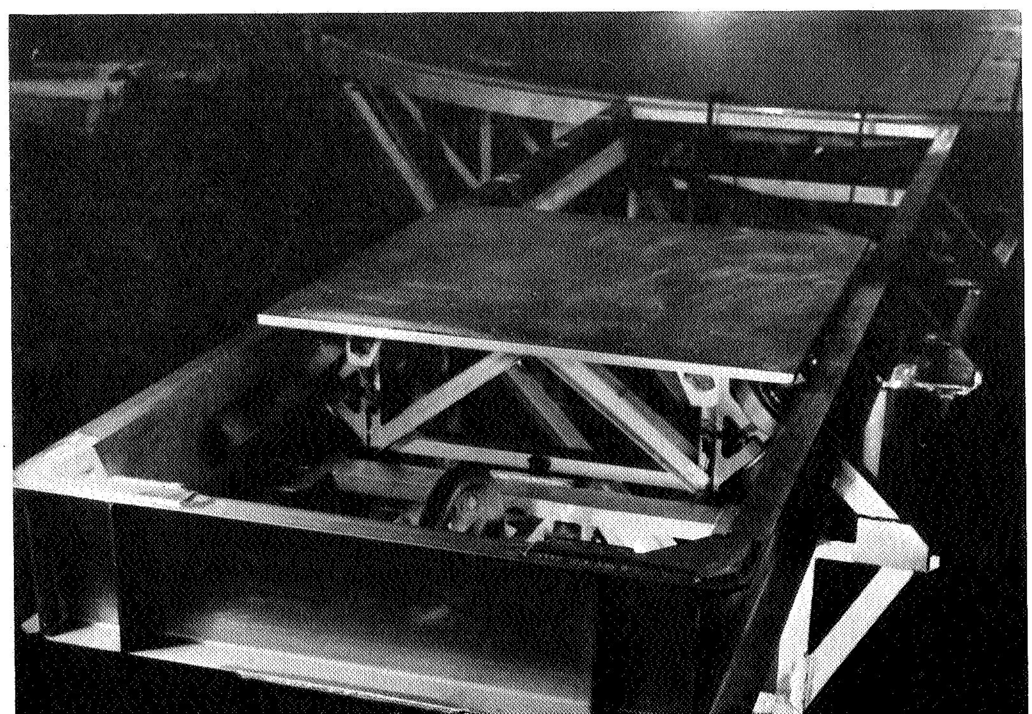


Figure 13

Photographs of the track platform taken before (top) and after (bottom) installation on the radial track turret "Vee" rails.

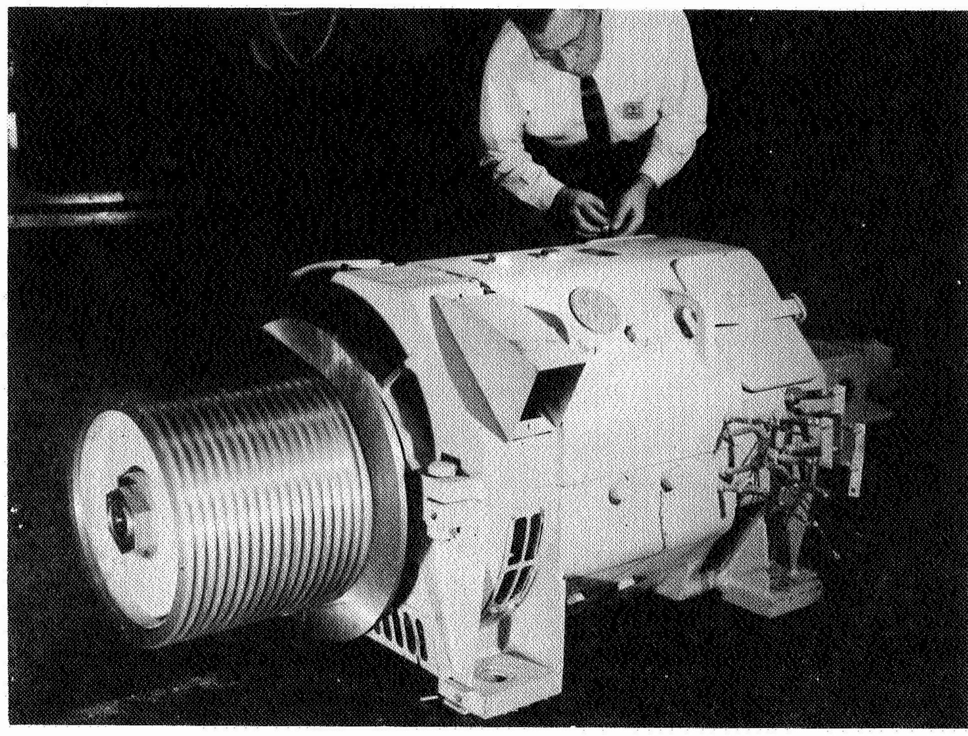


Figure 14

Preinstallation photograph of the track drive motor and the spiral-grooved drum pulley.

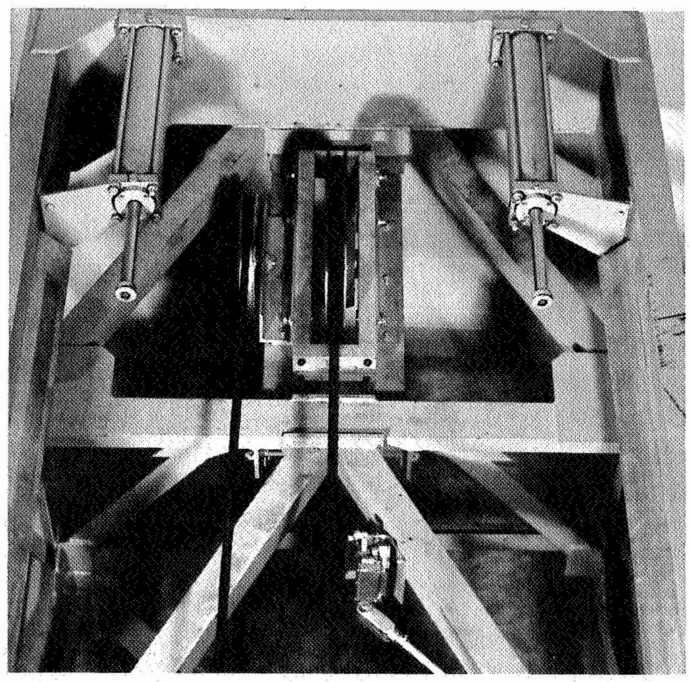


Figure 15

Close-up view of one end of radial track turret showing the drive and instrumentation cable pulleys and the twin hydraulic bumpers.

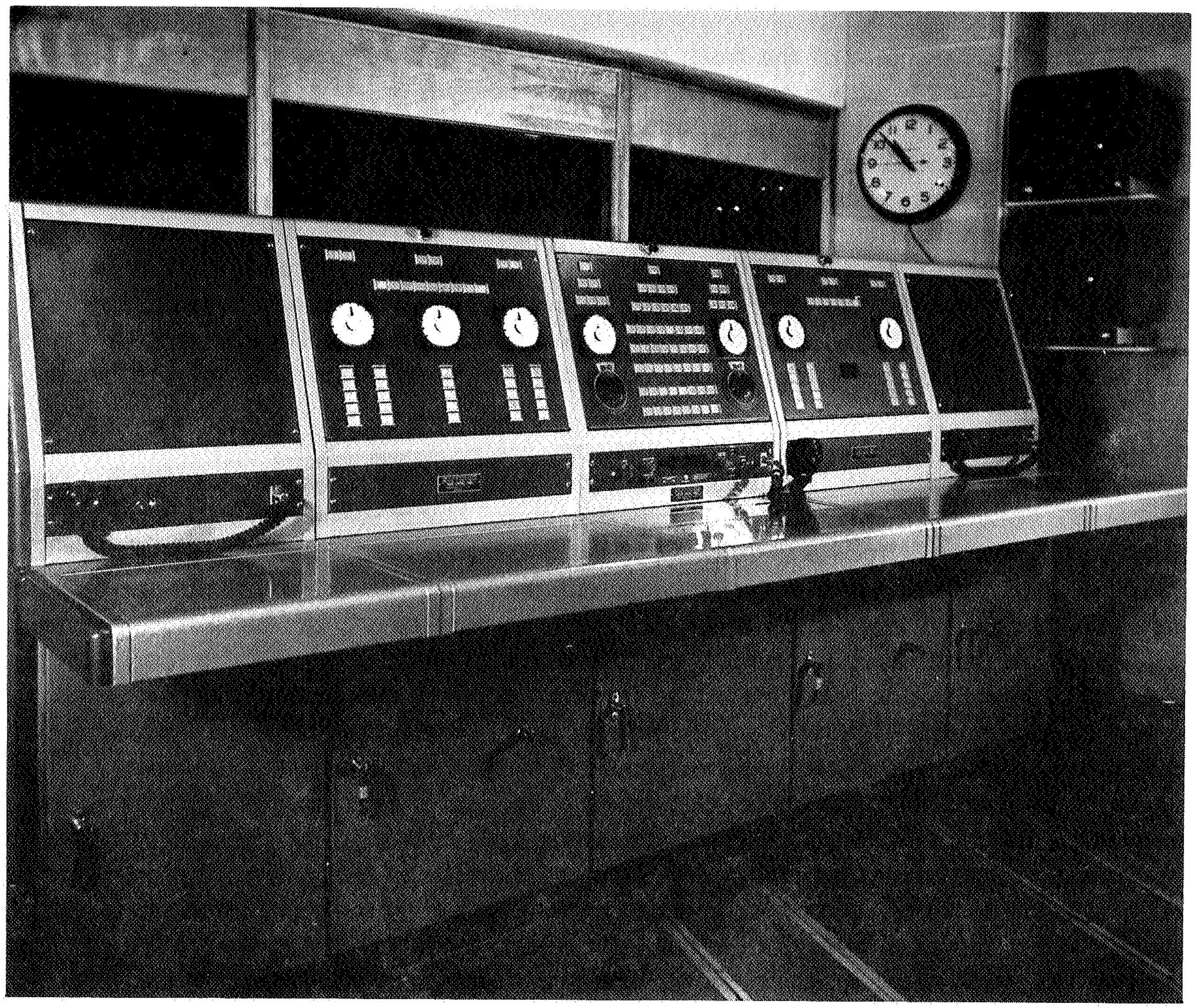
The main drive motor of the track system is a 100-hp, 500-rpm, 550-volt, 148-amp, shunt-wound DC motor with a normal 72-volt field excitation. For sinusoidal operation at high acceleration levels and peak motor speeds below 200 rpm, the field excitation can be increased to 120 volts for periods up to ten minutes to produce a 2360-lb-ft rms torque output. Armature current for the motor is supplied by a 100-kw, 1750-rpm, 400-volt, 25-amp, amplidyne capable of delivering 170-amp peak. The prime mover for the amplidyne is a 150-hp, 1800-rpm, 440-volt, 3-phase, 60-cps induction motor. A 3-kw, 125-volt, 24-amp, flat-compound wound exciter is coupled to the motor-amplidyne set to provide dynamic braking of the track platform motions in case of power malfunction. A reduced-voltage magnetic starter similar to that of the rotary drive is used to start the set.

The motor field excitation is supplied by a diode-bridge power source which provides 72 volts at 18 amps or 120 volts at 30 amps. Motor speed and direction are controlled by the amplitude and polarity of the amplidyne output current fed to the track motor armature. Amplidyne control itself is obtained from the output of a DC operational amplifier which amplifies the difference between an applied DC command signal made proportional to the desired track platform displacement and the output of a feedback potentiometer coupled to the shaft of the track motor. The feedback potentiometer is a 10-turn, wire-wound, liquid-filled, 5000-ohm unit. The system also utilizes rate feedback obtained from a tachometer direct-coupled to the track motor shaft. Current limiting during both acceleration and deceleration is derived from a dropping resistor in the armature circuit of the motor. A low-inertia disc brake fixed to the drive shaft is capable of maintaining the track platform and its rated payload fixed in position in a 3-g centripetal acceleration field. Magnetic proximity sensors, spaced at 4-ft increments to either side of center, are used in a safety limit system to automatically stop the track drive system if the track excursions exceed a given preselected maximum displacement.

CONTROL CONSOLE

A photograph of the console developed for operational control of CAP is shown in Figure 16. The console is composed of five sloped-front instrument cabinet modules which are installed in the control room immediately in front of the chamber observation windows. The blank-paneled modules located at the outer ends of the console are included as housing for ancillary equipments and instruments sometimes installed to meet the specialized requirements of a specific research program or experiment. Closed-circuit television viewing of on-board activities is provided by the two monitors seen at the right of the console which display video data derived from television cameras that may be installed within the capsule or on the track platform.

Independent, but correlated, control of the linear track drive system and the rotary capsule drive system is afforded by the panels installed in the sloped-front sections of the three center modules. The right center unit is identified as the Capsule Control Panel and contains all control switches and monitor devices associated with the setup and checkout of the electrical elements of the rotary drive system. The left center unit,



The CAP Control Console.

identified as the Track Control Panel, serves similar functions for the track drive system. The center module is identified as the Master Control Panel and houses all control elements required to actually start and stop the two drive systems. A fourth panel identified as the On-Board Control Panel, is installed inside the capsule and is used to assign on-board personnel certain operational responsibilities. In general, the selection of circuits to be controlled and monitored at these panels follows the functional concepts established in the design of the control console for the Human Disorientation Device (1).

The primary operator-controlled components mounted on the four panels are rectangular display-screen devices with translucent printed legend inserts that can be back-lighted to provide a visual indication of circuit on-off status. When the devices are required to perform a control as well as indicator function, they can be equipped with push-button multipole microswitches of either momentary or alternate action. If the control application requires electrical hold and reset action, a magnetic solenoid coil can be installed on the switch body which, when energized, maintains the switch in its activated position when the pushbutton is released. The physical arrangement of these various indicator-switch devices on the four control panels and the legends printed on their display screen inserts are shown in the layout drawings presented in Figures 17 and 18. The operational features of the CAP console can be briefly summarized by discussing the circuit function of each of the individual control devices. To facilitate this, the devices are numerically identified on each drawing and assigned a C, T, M, or 0 letter prefix to distinguish among units installed in the Capsule, Track, Master, and On-Board Control Panels, respectively.

In the Capsule Control Panel drawing shown at the top in Figure 17, it may be observed from the display-screen legends fixed to the C1-C6 row of indicator-switches that C1 and C2 are used to apply and remove the main 440-VAC input power to the entire rotary drive system; C3 and C4 start and stop the blower fans used to cool the torque drive motor installed in the pedestal; and C5 and C6 start and stop the rotary drive motor-generator set. The C7-C13 row immediately beneath contains display-type units which indicate the operational status of the primary electrical circuits of the rotary drive system. A failure in any of these circuits automatically stops the device and illuminates the related display screen to provide a visual indication of the malfunction source. Operator selection of one of five signal sources for command of capsule angular velocity is afforded by the C14-C18 column of indicator-switch, holding-coil devices. The coils are wired so that depression of one push button locks its integral momentary-action switch in the activated position and automatically releases the previously held push-button circuit. Similar hold circuitry is used for C19 and C20 which allow the selection of either of two tachometers as the signal source for velocity feedback. A conventional gear-type, high rpm tachometer, selected by C19, is used for capsule velocities above 10 rpm; for velocities 10 rpm and below, the C20 switch is depressed to select a gearless DC torque motor tachometer.

Push-button-hold circuitry is also used for the C24-C28 column of indicator-switches used to preselect an upper capsule velocity which, if exceeded, will automatically stop the device. This safety feature provides four preset and one adjustable over-speed limit where the specific selection of the limit is based on the maximum angular velocity to be programmed into the device during a given run. The meter at the left of the panel provides continuous visual monitoring of the amplitude and polarity of the command-signal voltage selected in column C14-C18. The meter at the right is used to monitor the instantaneous angular acceleration of the capsule when an appropriate angular accelerometer is installed aboard the device. An electrical reset counter, located in the center of the panel, provides a visual display of the total number of revolutions of the device.

The control and monitor functions of the Track Control Panel shown at the bottom in Figure 17 are of similar form: Indicator-switches T1-T6 are used to energize the track drive system; indicators T7-T15 identify the source of malfunctions which may occur within the track-drive electrical system; and the T36-T40 column of push-button switches shows the selection of one of five different signal sources to serve as the position command input to the track servosystem where a panel meter is provided to monitor the command signal

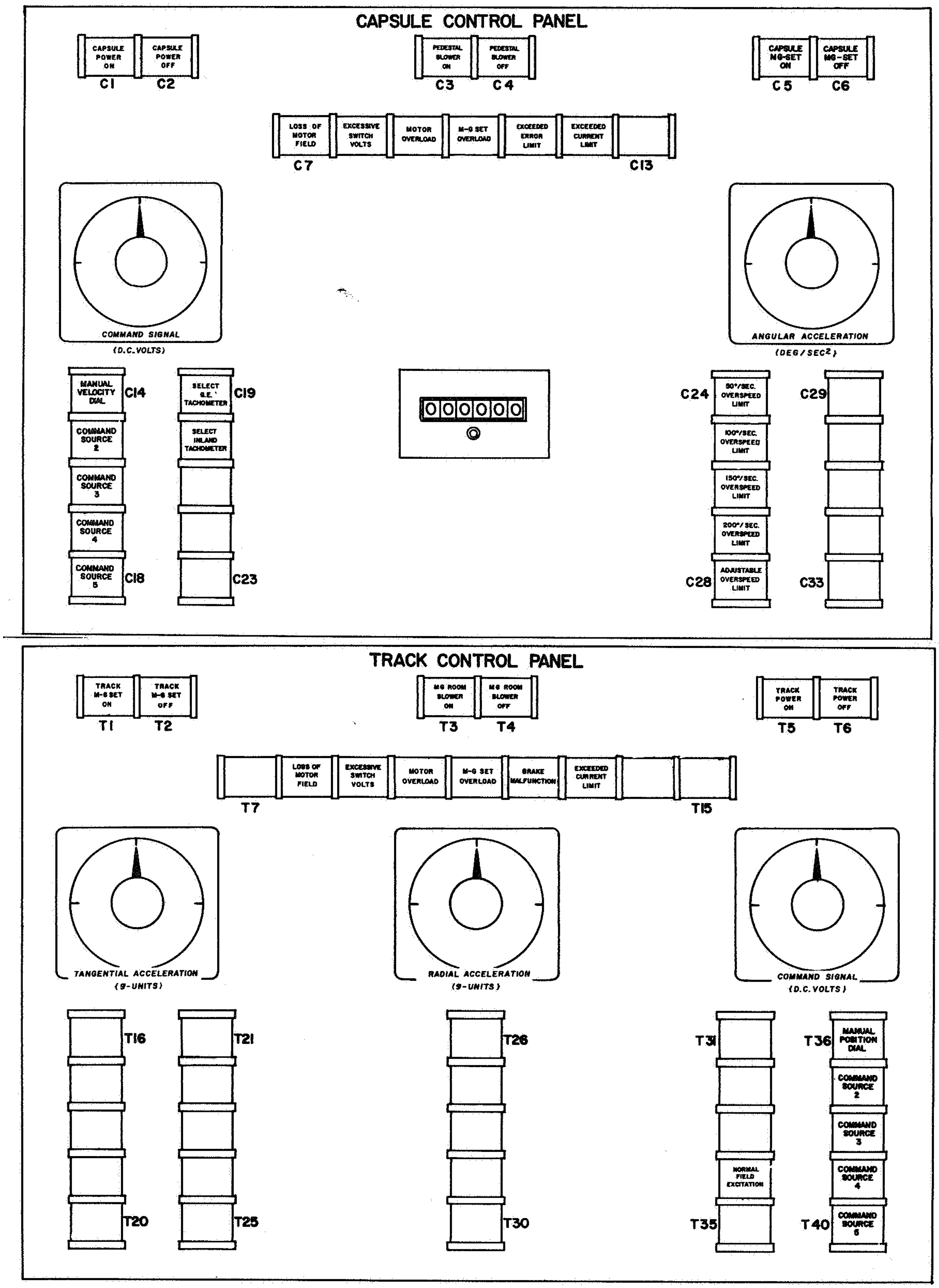


Figure 17

Front panel layout drawings of the Capsule Control Panel (top) and Track Control Panel (bottom).

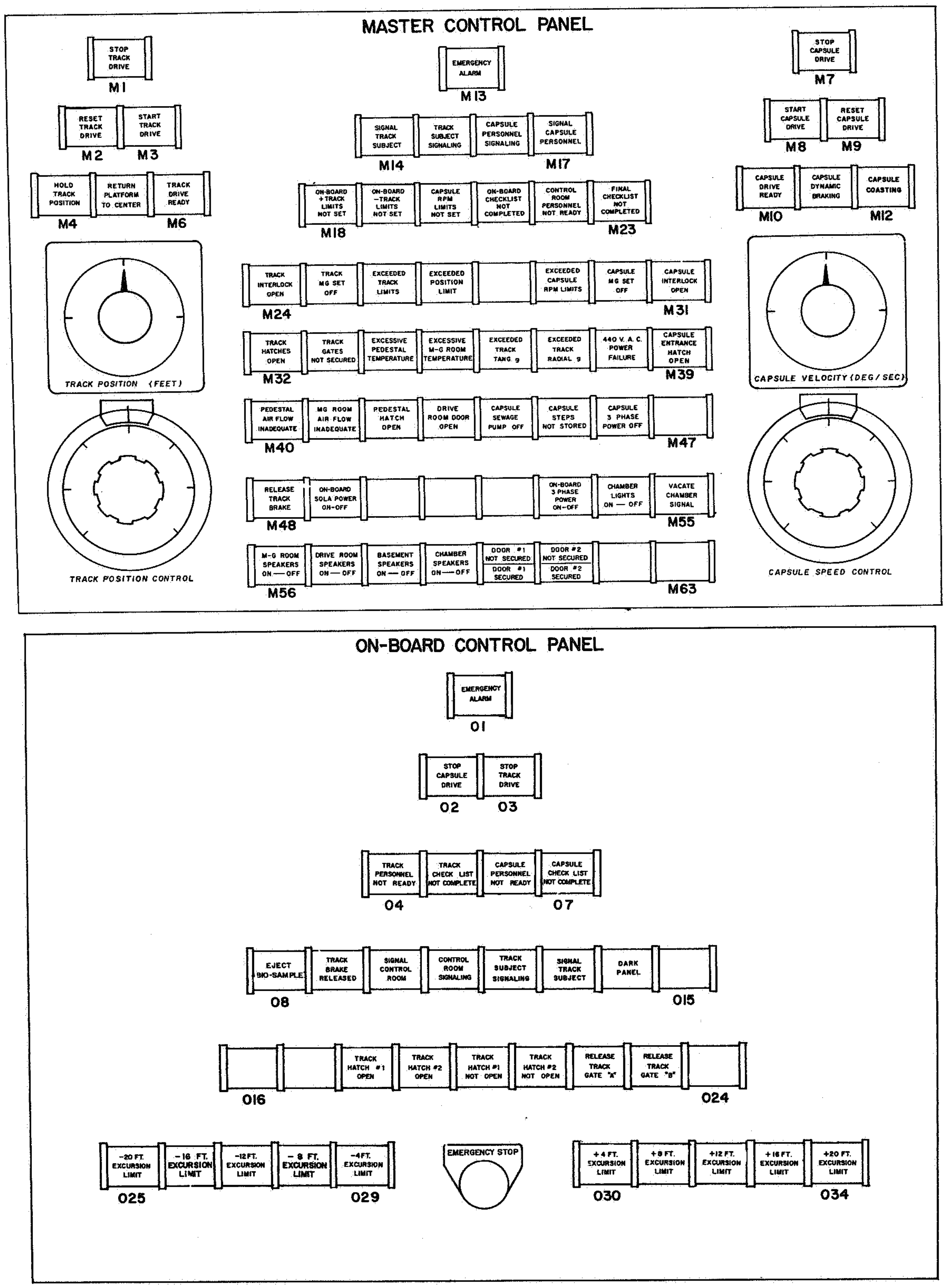


Figure 18

Front panel layout drawings of the Master Control Panel (top) and the On-Board Panel (bottom).

voltage. The meters at the left and center of the panel indicate the instantaneous linear acceleration of the track platform along, and at right angles to, the axis of linear motion when appropriate linear accelerometers are installed on the device.

Once the Capsule and Track Control Panels have been properly set up, all operational procedures originate at the Master Control Panel, shown at the top in Figure 18. The M1-M6 triangular grouping of indicator-switches at the upper left of the panel is the primary control element used to actually place the track platform in motion. The Track Position Control is a multiturn, center-tapped potentiometer with a calibrated dial which, when selected by the T36 command signal push button, allows the operator to position the track platform at any desired displacement from the center of the track turret. The meter located immediately above this potentiometer provides the operator with a visual readout of the actual displacement of the track platform where the displacement signal is obtained from a potentiometer attached to the output shaft of the track drive motor. Since this meter is physically adjacent to the command signal meter mounted on the Track Control Panel, the operator can readily adjust the Track Position Control so that the displacement command signal is equal to the actual displacement before the device is started. In the event this prerun adjustment is not made, error-limit circuitry prevents closure of the main loop to the track drive motor.

The components at the right on the Master Control Panel serve similar functions for the rotary drive system: Indicator-switches M7-M12 are used to start and stop capsule rotation; manual adjustment of capsule velocity is provided by the Capsule Speed Control potentiometer when the C14 velocity command signal push button is activated; actual capsule velocity is indicated by a meter which is driven by a monitor tachometer installed in the pedestal; and error-limit circuitry is included so that the capsule rotation cannot begin until the voltage of the selected command signal source is at its analog 0-rpm level.

Indicator-switch M13, located at the vertex of the central triangular grouping of control devices, is used to sound an acoustic warning alarm when the device is to be brought to a quick stop. The M14-M17 devices in the row immediately below are used for visual-signal type of communications between on-board and control-room personnel; M15 and M16 are illuminated by subject-operated switches while depression of M14 and M17 illuminates display indicators located aboard the device. This mode of communication finds particular application when deaf individuals serve as subjects. It is also of value when the experimental design of a given research program requires the elimination of voice transmissions during certain testing periods.

The M18-M23 switches serve a safety check-list function to be later discussed. The M24-M31, M32-M39, and M40-M47 control devices are, for the most part, display lamps which indicate the electrical status of various drive-system equipments and safety interlocks. The circuitry associated with these three rows of indicators is functionally arranged so that all devices are in the nonilluminated state when the system is properly set up for normal operation regardless of the mode of motion, i.e., whether the track and capsule drive systems are to be operated singly or in combination. In general, if any of these lamps are illuminated during the initial setup of a given drive system, the device cannot be started. However, once the device has been placed in motion, failure of a given circuit may or may not stop the device, depending on the nature of the malfunction. For example, if the capsule entrance-hatch interlock circuit opens while the capsule is rotating, the device will be brought to a stop immediately and indicator M31 illuminated. When a malfunction occurs which offers no hazard to the on-board personnel or which will not result in immediate equipment damage, the pertinent indicator lamp will be illuminated but the device will not be stopped. An example would be illumination of M41, indicating that the ambient temperature of the motor-generator room exceeded some preset maximum limit. If the malfunction occurred before rotation was initiated, the control circuits would not allow the device to be started. However, once rotating, the same malfunction would illuminate M41 but not stop the device.

The bottom two rows of control devices, M48-M55 and M56-M63, are comprised primarily of indicator-switches used to operate and monitor the status of various ancillary equipment and circuits. Switches M56-M59 can be used to mute loudspeakers installed in various off-board locations when voice transmission to these areas is not required. Units M60 and M61 are used to indicate the open or closed status of the two chamber-entrance doors. These doors have solenoid-activated lock mechanisms that maintain the doors in the locked position unless energized by operator depression of M60 or M61. Interlock circuitry prevents the operator from opening these doors while the device is rotating and automatically stops the device if the doors are opened inadvertently through some other action.

The On-Board Control Panel, shown at the bottom in Figure 18, serves a dual function: It provides capsule personnel with certain limited control and monitor capabilities relative to the two drive systems; and it requires their active participation in a safety check-list program which must be performed before device motion can be initiated. The 02 and 03 push buttons allow either of the two drive systems to be independently stopped. Simultaneous shutdown of both drives is afforded by the Emergency Stop push button at the bottom center of the panel. Participation in the safety check-list operations arrives in the 04-07 row of indicator-switches. In the 08-015 row, 08 operates a solenoid assembly that automatically releases a biosample container inserted in an ejection-chute chamber that is flush mounted in the floor of the capsule; 09 is used to release the track brake to allow the manual movement of the track platform when the device is not in motion; 010-013 are utilized in the visual signaling system; and 014 allows on-board personnel to turn off all panel lights when experimentation requires a darkened capsule. The 016-024 row indicates the status of the various on-board safety interlock circuits. When the safety fence is erected inside the capsule during track operations, ush buttons 022 and 023 are used to open the electrically locked gates installed in the fence to provide access to the subject-carrier installed on the track platform.

The 025-029 and 030-034 rows of control devices are indicator-switch assemblies with magnetic holding coils wired so that only one circuit in each row can be activated at a given time. These switches are used to select a given value of track displacement at either side of center which, if exceeded, will automatically stop the track platform motions. The position of the track platform is sensed by magnetic proximity transducers fixed to the upper surface of the track turret and spaced at 4-ft intervals. Heavy-duty microswitches at either side of center, activated by physical contact with the base of the track platform, are mounted at the outer ends of the turret as a safety back-up measure to ensure opening of the track main loop and the application of dynamic braking before impact into the hydraulic absorbers occurs.

Before an experimental run can be started on CAP, the following conditions must be met: Initially, all lamps in the C7-C13 and T7-T15 rows must be off, indicating that the electrical elements of the capsule and track drive systems are ready for operation. The 016-024 row of lamps must be off, indicating that the on-board safety interlocks are in the safe condition. At the Master Control Panel the M24-M47 lamps must be off, indicating that the drive systems are properly set up, certain power and drainage services are afforded to the capsule, and that all safety interlocks throughout the system are properly engaged. At this point all machine elements of the system are ready for operation. However, before any form of motion can be started, the control and on-board operators must verify that all safety check-list procedures that can be performed only by the man element of the system have been completed. This operation is afforded by the M18-M23 and 04-07 push buttons at the two control stations which utilize magnetic hold coils to establish a certain sequential operating procedure. The coils are wired so that each push button, once depressed, is held locked in the energized position where the locking action cannot take place unless the preceding switch in the sequence has been engaged. These indicator-switches, normally illuminated, are sequentially activated by both operators. When all lamps have been turned off, either form of motion can be initiated.

Though activation of these switches cannot establish that the related check-list procedures have been performed, they serve at least as a reminder to the operators that the procedures denoted by the legends should be performed. In effect, depression of a given switch represents an electrical signature by the operator that he has performed this specific check-list operation. The hold coils are released whenever the main loop of either drive system is opened so that the check-list operation must be repeated before the device can be restarted.

One last feature of the CAP control system which received especial design attention involved the various methods provided to stop the rotary motions of the capsule. Under routine conditions the console operator brings the device to rest by manually reducing the velocity command signal to zero level. Switch M7 is then depressed which opens the main loop to the torque drive motor. However, when operational requirements are such that the device must be brought to a stop as fast as possible, illuminated Emergency Stop push buttons installed at the very top of the center three console modules may be depressed. Activation of these push buttons automatically programs a command signal into the system which decelerates the device to rest at a 15-deg/sec^2 rate. This form of stop, utilizing the full power capabilities of the system, is automatically initiated whenever any of the primary safety interlocks are opened, e.g., the capsule entrance hatch or the CAP chamber entrance doors. Once the capsule is brought to a stop M7 is depressed to open the main loop to the drive system.

A second form of stop is provided when a malfunction occurs in the drive system proper or its related overload circuits. For such malfunctions the main loop circuit to the drive motor is opened and the capsule goes into a coasting state in which several minutes are required to reach zero speed from the top angular velocity of 33 rpm. This mode was provided because many experiments involve on-board personnel who are freely moving about the capsule and performing various tests and would not always be in a posture favorable to a quick stop. With the coasting stop little change in velocity occurs at the instant of malfunction so that there is minimal hazard to personnel. During this coasting phase the device can be brought to rest at a faster rate by depressing switch M11 which activates dynamic braking circuitry. Dynamic braking can be applied even during loss of main power service to the drive system as the main motor-generator set contains an exciter unit to supply field excitation to the main drive motor. This feature was included because certain experimental studies involve the short-time exposure of a subject to linear acceleration fields of relatively high level with body orientations not optimal to prolonged exposure. In such cases, when a power failure occurs, a dynamic-brake rather than coasting stop can be used to minimize subject-exposure time. Similar dynamic braking features are included for the track drive system.

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The report presents a brief description of the Coriolis Acceleration Platform, a new combined linear and angular motion-producing vestibular research device developed to study the biological effects of aerospace acceleration environments. The primary element of the device is a 20-ft diameter capsule equipped with various life-support equipments to study the long-term effects of continuous rotation. A low rpm, direct-coupled, DC torque motor operated in a closed-loop, velocity mode, power servomechanism configuration rotates the device in either direction at angular velocities extending to 200 deg/sec at accelerations ranging to 15 deg/sec^2. A second drive system can be programmed to produce time-varying rectilinear translations of a single subject along a track structure fixed to the capsule where this form of motion can occur singly, or in combination with rotation of the entire device. Peak ratings of the linear drive system include a radial displacement of ±20 ft, a linear velocity of ±16 ft/sec, and a linear acceleration of 96 ft/sec^2 (3 g).

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