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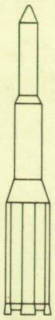

THE MERCURY-REDSTONE PROGRAM

by

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PROJECT MERCURY

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SUMMARY

The Mercury-Redstone program is reviewed as to its intended mission and its main results. The progressive results of unmanned, animal, and manned flights of this over-all Project Mercury ballistic training program are presented. A technical description of the major spacecraft systems is presented with some analysis of flight performance.

Performance of the spacecraft with and without pilot input is discussed. The influence of the astronaut as an operating link in the over-all system is presented, and relative difficulties of manned versus unmanned flight are briefly commented upon.

The program provided information on man as an integral part of a space flight system, demonstrating that man can assume a primary role in space as he does in other realms of flight. The Mercury-Redstone program demonstrated that the Mercury spacecraft was capable of manned space flight, and succeeded in partially qualifying the spacecraft for orbital flight.

INTRODUCTION

The Mercury-Redstone program, the first step in the United States effort of manned space flight, was successfully completed on July 21, 1961 with the achievement of the second manned flight. Project Mercury, initiated to investigate man's capabilities during space flight, utilized the subject program to obtain limited ballistic space flight over and above the environments reached with the present high performance aircraft.

This program was an integral part of the over-all research, development and training activities necessary for the future accomplishment of manned orbital flight. The program followed the early research and development phase of Big Joe and Little Joe flights and led into the forthcoming phase of orbital manned flights.

The Mercury-Redstone program provided qualification flight tests of the spacecraft and its component systems and the integration of man as a primary element of these systems. The first flight was an unmanned flight, the second carried a primate, and the third and subsequent flight was manned. This philosophy was adopted early in the program and was adhered to as will be discussed later.

In this manner, it was possible to learn from each preceding test and to build upon the experiences so provided (ref. 1). This was the underlying philosophy in the Mercury-Redstone program and indeed is the underlying philosophy in the NASA Manned Space Flight program.

TEST OBJECTIVES

In the fall of 1958, the Space Task Group, a unit of the National Aeronautics and Space Administration located at the NASA's Langley Research Center, Hampton, Virginia, came into existence with specific responsibility for putting a manned satellite into orbit with subsequent safe recovery. During the 12 to 18 months preceding formation of the group, members of the Langley staff had conducted experimental and theoretical studies into problems of manned space flight. Within the framework of the program concepts there was a need for early astronaut training flights so as to better integrate the pilot with the task, and obtain baseline data for the study of man's capability in a space environment (ref. 2).

The Redstone booster with moderate performance was selected for this part of the program due to its background of launching experience and reliability. This then, was the initial step to manned space flight.

The test objectives of the Mercury-Redstone program can be generally summarized as: (a) the familiarization of man with brief space flight, and (b) the partial qualification of the spacecraft for orbital flight. However, it should be noted that most of the elements necessary for conducting manned orbital flight were exercised and improved upon throughout this flight test history.

Detailed flight test objectives for each of the respective flights are enumerated in table I.

TEMPORARY STUDY PANELS

With the definition of the spacecraft in the latter part of 1958 and commitment of launch vehicles to the Project Mercury program in early 1959, engineering had to integrate the spacecraft with the three launch vehicles to be utilized: Little Joe, Redstone, and Atlas (fig. 1). The mechanical and electrical interface, with each of the respective launch vehicles, placed upon the spacecraft a desired versatility in these areas. However, variations had to be minimized if inputs from one flight program to another were to be valid data. Therefore, it was necessary for the specified orbital spacecraft to be changed in limited ways.

In February 1959, the Space Task Group and the Development Operations Division of ABMA (the nucleus of the present George C. Marshall Space Flight Center) formed temporary study panels to aid in centralizing technical coordination between Space Task Group, McDonnell Aircraft Corporation, and Development Operations Division.

Originally, six panels were formed. These panels were as follows:

Panel 1 - Design coordination, ground tests, scheduling and shipping, fabrication and check-out

Panel 2 - Booster and spacecraft check-out procedures at Huntsville

Panel 3 - Operations, flight safety, pilot safety, emergency procedures, recovery operations, pad and ground safety, countdown, impact area selection, external instrumentation and communications, blockhouse measurements and displays

Panel 4 - Trajectories, aerodynamics and loads

Panel 5 - Countdown procedures at Cape Canaveral

Panel 6 - Supporting ground tests

After approximately 12 months operation, it was possible to reduce the panels to three, so that the panel organization appeared as follows:

Panel 1 - Design coordination, interface problems, scheduling and check-out at Huntsville

Panel 2 - Operations, pilot safety, range safety, external instrumentation and communications, emergency procedures, recovery operations and measurement displays

Panel 3 - Trajectory, aerodynamics and loads

These panels functioned mainly as temporary study panels and were active up to the point of the project becoming operational. At various times, a complete coordination group consisting of reports from all the panels to NASA-STG Management would be called, from which the desired control decisions would be formulated. It was found that the panels were an effective means for "across-the-board" coordination of such a large project. Subpanels were maintained for solution of specific problems as required.

SPACECRAFT DESCRIPTION

Figure 2 is a sketch of the Mercury spacecraft with and without its escape system. The launch configuration shown on the left of this figure is approximately 26 feet in height. The maximum diameter of the spacecraft is $74\frac{1}{2}$ inches.

The spacecraft configuration is characterized by certain features: the blunt reentry face, the conical afterbody, the cylindrical recovery compartment, and the antenna canister. The heat shield and retropack can be seen at the reentry face of the configuration. Three solid-propellant retrorockets are used to initiate the descent from orbit by producing a velocity decrement at approximately 440 feet per second. These retrorockets were fired during the Mercury-Redstone ballistic flights for flight qualification of the system and for the purpose of exercising pilot manual control of spacecraft attitude during retrofiring.

Three solid-propellant posigrade rockets are integrated in the retropack and are used to separate the spacecraft from the booster at the desired time. A "popgun" effect occurs during posigrade firing which effectively increases the normal separation velocity and results in a rate of separation of 28 feet per second. This "popgun" effect is caused by the exhaust gases trapped in the adapter which exert a back pressure on the heat shield.

The escape system used with the spacecraft for Project Mercury consists of a solid-fuel rocket motor of 58,500-pound thrust and is attached to the spacecraft by a tubular tripod structure. The three primary legs of the tripod are attached to the face of the parachute canister and straddle the antenna canister.

The tower escape system shown on the figure is capable of pulling the spacecraft away from the immediate vicinity of the booster at any time prior to tower jettison. The escape motor can be ignited by astronaut action, by the booster abort system, or by ground command. The escape system has been exercised many times in qualification tests and in fact, the first production spacecraft was the subject of an escape test at Wallops Island, Virginia.

The inward sloping surfaces of the cone tend to minimize the afterbody heating and the extensions to the cone enhance both the static and dynamic stability. The outer wall of the conical afterbody and antenna canister consists of overlapping shingles. This type of construction allows for expansion in all directions. The metal shingles are made of René 41 nickel-base alloy which dissipates the reentry heat by radiation. The characteristic black surface is the result of high-temperature oxidizing which increases the emissivity of the surface, thereby limiting spacecraft heating during reentry. These spacecraft conical section shingles are 0.016-inch thick and will sustain temperatures in the 1,600° F to 1,800° F range.

The inner-wall structure in the region of the conical portion of the afterbody constitutes the pressure vessel or cabin and is constructed of two layers of thin-gage commercially-pure titanium. The layers are 0.010-inch thick and are welded together to form a single sandwich structure. The inner layer is flat-rolled and the outer layer has been stiffened with corrugations approximately 3 inches in length and $\frac{1}{2}$ inch in width. Figure 3 is a photograph of the spacecraft under construction at the manufacturer, the McDonnell Aircraft Corporation in St. Louis, Missouri, and shows this inner-wall structure. The recovery-compartment outer wall is constructed of a series of beryllium plate elements unrestrained for thermal expansion.

The Mercury-Redstone ballistic flights resulted in only a mild heating environment compared with that of an orbital reentry. Peak stagnation-point heating rates were less than 5 Btu/ft^2/sec, whereas an orbital entry peak rate exceeds 50 Btu/ft^2/sec. The total heat input experienced on the approximately 1-inch-thick beryllium heat shield was 150 Btu/ft^2 for these ballistic flights compared to some 7,500 Btu/ft^2 for orbital reentry. This relatively mild environment resulted only in a 25° to 30° rise in temperature. Afterbody temperatures were between 300° F and 400° F during exit.

Figure 4 indicates the relative position of the astronaut, observation window, the side egress hatch, and internal arrangement of various equipment. The astronaut is shown in a semisupine position with his back toward the heat shield. The large window and side egress hatch are two modifications that have been made to the spacecraft since its initial design.

This window enables the astronaut to have a greater viewing area than the original side-port windows that were installed on the earlier spacecraft including spacecraft no. 7 utilized on MR-3. The window is fabricated from Vycor glass panels capable of withstanding reentry temperatures. It provides a field-of-view of approximately 30° in the horizontal plane and 33° in the vertical.

Another viewing device, the periscope, is shown in figure 5. The periscope is manually and automatically extendable and retractable and provides an 8-inch circular display of the earth for astronaut visual reference of altitude, attitude and retrograde angle. At low magnification, the periscope provides a field-of-view of the earth's surface approximately 1,900 nautical miles in diameter and at high magnification, approximately 80 nautical miles in diameter. The periscope viewing screen is in the center of the cockpit instrument panel, figure 6.

A prime item of equipment in the spacecraft is the contoured couch, figure 7, which evenly and uniformly distributes the g forces on the astronaut during exit and reentry. Tests have been made utilizing this couch in which accelerations reached values as high as 25g on a profile representing reentry with no injury to the occupant.

Major Spacecraft Systems

The basic philosophy of the pilot's role in the Mercury system is that, where feasible, he shall have a backup and override function for all of the major spacecraft systems. This approach to the pilot's task permits the maximum utilization of the pilot as an aid to system reliability and mission success.

Control system.- The control system is shown in figure 8 and is composed of an automatic system and a manual system. The manual control system utilizes a manual proportional control and a rate command mode. Both the automatic and the manual control systems command inputs to the reaction control system which uses hydrogen peroxide as the propellant. The two systems are completely independent of each other.

The automatic stabilization and control system (ASCS) is shown installed in the spacecraft in figure 9. The ASCS consists of sensors, the amplifier calibrator, and horizon scanners. The sensors include roll, pitch, and yaw directional-gyros, roll, pitch, and yaw rate-gyros, and an 0.05g accelerometer switch. Two horizon scanners at right angles scan earth and space to detect the infrared horizon between space and the earth's atmospheric troposphere. Thus, they establish the true vertical direction to the earth below and provide pitch and roll references. These units provide a 118° conical scan of the horizon in the pitch axis and roll axis and transmit attitude correction signals to the automatic stabilization and control system attitude gyros.

The primary component of the ASCS is the amplifier-calibrator. As shown on the block diagram, figure 10, the amp-cal receives inputs from sensors and sequencing devices as shown on the left of the figure and generates outputs to displays and reaction controls as shown on the right.

Manual control systems provided for the spacecraft are as follows:

(a) Manual control by the use of the manual proportional hydrogen-peroxide valves

(b) Manual control by the use of "fly-by-wire"; the pilot has control through the control stick which operates solenoid valves in the automatic control system.

(c) The rate command system; the rate command system damps the commanded rate to $\pm 3^{\circ}$ per second. With no manual command, it damps the rates to zero, $\pm 3^{\circ}$ per second. This system operates solenoid valves in the manual control system.

The automatic system alone was utilized on the MR-1A and MR-2 flights. The automatic system, fly-by-wire, and manual proportional control systems were used on the MR-3 flight; the automatic system, the manual proportional, and rate command systems were used on the MR-4 flight.

The reaction control systems utilized in the spacecraft are independent of each other (fig. 11). One system is utilized by the ASCS which includes operation of the fly-by-wire mode. The other system is utilized by the rate command and manual proportional control system.

Each reaction control system employs hydrogen peroxide as the thrust-producing agent. The hydrogen peroxide is forced under pressure to the thrust chambers where it is decomposed by a silver catalyst. The hydrogen peroxide is stored in a bladder-type bag which is contoured to a tank that encloses it. Nitrogen, stored at 2,250 psi in a spherical tank, is reduced to 450 psi for pressurizing the hydrogen-peroxide tank space between the outer shell and the bladder. Hydrogen peroxide is thus forced through small holes into a transfer tube that extends the full length of the tank assembly inside the bladder.

The thrust chamber assembly consists of a stainless-steel cylinder containing a metering orifice, a distribution disc followed by a catalyst bed of silvered screen, and nozzle. A theoretical specific impulse of about 160 pound-seconds is produced by the decomposing hydrogen peroxide. The decomposition products are superheated steam and oxygen at a temperature of $1,380^{\circ}$ F.

The automatic reaction control system, shown on the left side of the figure, consists of 12 hydrogen-peroxide thrust chambers of fixed thrust levels and their associated valves, lines, tank, pressure regulator, and pressurization bottle. The 12 automatic reaction control system jets are divided into four roll jets (two 1-pound, two 6-pound), four pitch jets (two 1-pound, two 24-pound), and four yaw jets (two 1-pound, two 24-pound). The 1-pound jets are low torque, and the 6-pound and 24-pound are high torque. A 32-pound supply of hydrogen peroxide is available for the automatic system.

The manual reaction control system, shown on the right side of figure 10, consists of six hydrogen-peroxide thrust chambers which may be operated either as fixed thrust chambers by the rate stabilization control system or variable thrust chambers by the manual control system. Both systems, however, are similar as shown in the figures. A $23\frac{1}{2}$-pound supply of hydrogen peroxide is available for the manual system.

The manual selector control valve can either be switched to supply hydrogen peroxide through the manual control valves or through the solenoid control valves of the RSCS. In the rate command mode, the control stick displacement is proportional to angular rate as described earlier, while in the manual control mode, the control stick displacements are proportional to the angular accelerations.

The hand controller is the final item in the control system and is shown in figure 12. Yaw is accomplished by a rotary motion of the handle; roll by a lateral left-right motion of the handle, and pitch by a fore-and-aft motion.

Environmental Control System.- The environmental control system (ECS) provides the spacecraft cabin and the pilot with a 100-percent oxygen environment for breathing, ventilation and pressurization gas required during the flight. This system is completely automatic, but in the event that the automatic control malfunctions, manual override controls can be actuated by the astronaut.

The ECS consists of two individual control circuits, the cabin circuit and the suit circuit. Both systems are normally operated simultaneously. The suit circuit is isolated from the cabin circuit when the astronaut closes the faceplate on his helmet and can operate independently of the cabin circuit. An emergency mode is supplied in the event that the suit circuit fails. A schematic of the ECS is shown in figure 13.

During ascent, cabin pressure is maintained near atmospheric pressure up to an altitude of about 27,000 feet after which it is maintained automatically at 5.1 psia.

The cabin gas is circulated by the cabin fan through the cabin heat exchanger. Pressurization of the cabin is maintained at 5.1 psia above 27,000 feet by oxygen flow from the cabin pressure control valve through the suit pressure regulator. In the event the cabin pressure should exceed 5.5 psia, pressure relief is provided through the cabin pressure relief valve. During descent, when 20,000 feet is reached, the outflow-inflow snorkel valves automatically open, thus allowing external air to be circulated through the suit circuit to the cabin, and then overboard.

The suit circuit fan circulates gas from the suit, through the solids trap, CO_2 and odor absorber, heat exchanger, and water separator.

Under normal operation, pressure in the suit circuit is maintained at 5.1 psia by the combined action of the suit pressure regulator and the cabin pressure regulator. During ascent or descent, the suit pressure regulator also approximately equalizes suit internal and external pressures below an altitude of 27,000 feet.

Solid foreign matter is removed by the solids trap. Carbon dioxide and odor are removed by an absorber which contains lithium hydroxide and charcoal.

Heat is removed by the suit heat exchanger. Water is supplied to the heat exchanger from the coolant tank which is pressurized by a separate oxygen supply. The astronaut can manually adjust the coolant flow to maintain the desired temperature within the suit circuit.

The water separator is a filter-type sponge that collects moisture from the suit circuit. A piston compresses the sponge 30 seconds every 30 minutes and the water obtained is collected in a tank. On the MR-3 flight, the water separator was inoperative, but was operative for the MR-4 flight. During a short ballistic flight, this feature was not necessary.

The oxygen supply comes from the normal oxygen bottle and is reduced from a stored supply pressure of 3,000 psi in two stages to 5.1 psi in the suit circuit. In the event that the normal oxygen system malfunctions, a secondary supply of oxygen, which is in parallel with the normal supply, would automatically be cut into the circuit. The secondary oxygen supply is also reduced from 3,000 psi.

Oxygen supply pressure will be increased to 7,500 psi for use in the later orbital spacecraft, as the 3,000 psi supply is not adequate for the longer mission.

In the postlanding phase, provisions are incorporated for the suit circuit fans to operate for several hours following landing. The suit fan draws ambient air through a snorkel fitting into the spacecraft. After circulation through the suit circuit, the air is discharged overboard.

Landing system.- The landing system is composed of a drogue stabilization parachute, a main recovery parachute, and a reserve parachute. The drogue chute is a 6-foot, conical-ribbon chute and is actuated at 21,000 feet to aid the stability of the spacecraft; the main chute is a 63-foot, ring-sail chute with alternate international orange and white gores, and is actuated at 10,000 feet. The reserve chute is identical to the main chute and is actuated by the astronaut if required.

The storage and diagram of actuation of the main and reserve parachute system is shown in figure 14, where it can be seen that the ejection of the antenna fairing deploys the main chute. The reserve chute, if needed, is deployed by manual firing of a pilot chute.

The Mercury parachute system has been exercised 88 times including research and development tests as well as Mercury flight tests with only one failure. A sharp corner on a surface in the recovery compartment caused this failure which has subsequently been eliminated.

Electrical system.- The Mercury spacecraft consists of d-c power supplied by silver-zinc batteries and a-c supplied by solid state inverters which are fed by the d-c supply. A schematic of this system is shown in figure 15.

Four 1,500 watt-hour batteries are connected in parallel. The failure of one or more batteries does not disable the system, but merely reduces the total available power of the main system. Should a failure occur in the main system, a standby battery with a capacity of 1,500 watt-hours can be inserted in the main battery system. Standby battery actuation can be accomplished automatically or manually. On all Mercury-Redstone flights, this standby battery has been paralleled with the main system.

To insure reliable operation of the pyrotechnic system, each device uses a completely isolated power supply as well as the main power. The isolated-battery power supply consists of one 1,500-watt-hour battery which has sufficient capacity to provide power to the pyrotechnic actuated systems and to provide the power source for the recovery beacon and the voice communications systems.

The a-c power is supplied by conversion of d-c power through utilization of one 250-volt-amp inverter and one 150-volt-amp inverter, and one 250-volt-amp standby inverter. The a-c system provides power for the ECS fans, ASCS and RSCS attitude and rate control gyros, the horizon scanners, rate indicating system, humidity indicator, cabin lighting, and maximum-altitude sensor. The standby inverter can automatically assume the load of either of the main inverters in the event of malfunction. The standby inverter can also be switched into the system by the pilot.

The electrical circuits in the spacecraft are protected by appropriate fuses to reduce fire hazards and undesirable power loss. Redundant circuits and components are used in all sequencing and switching modes. The circuits contain the necessary interconnects to achieve the desired operation.

A ground umbilical disconnect assembly is used for the spacecraft. Two methods may be used to disengage the plug and receptacle; an omnidirectional lanyard-operated release mechanism or a solenoid-operated release mechanism.

Communications system.- The spacecraft communications system has four purposes. These are:

(a) Voice communication

(b) Data transmission to the ground

(c) Spacecraft flight control by ground command signal

(d) Tracking and recovery

Figure 16 shows the location of this equipment in the spacecraft. The various subsystems of the communications system are described below.

Two telemetry transmitters are used in the Mercury spacecraft to convey instrumented information to the ground stations.

Command receivers initiate the proper action aboard the spacecraft when any one of the following ground commands are received:

(a) Abort command

(b) Satellite clock reset

(c) Retrorocket sequence

The C-band beacon is compatible with the FPS-16 tracking radar system used in the Mercury network. The S-band beacon is compatible with the SCR-584 Mod II radar and the Verlort long-range radar.

Voice communication was provided for the astronaut throughout the mission. A dual headset and microphone is contained within the pilot's helmet. Either of the two voice links, HF or UHF, can be selected by the astronaut. Each of the two voice links has duplicate transceivers for increased reliability.

HF reception is available through the main HF voice communications system during launch and orbit phase. HF voice transmission can be used only after spacecraft separation. UHF reception and transmission is available throughout the entire mission.

The command receivers provide an emergency ground-to-spacecraft voice link prior to landing. Also, telemetry transmitters can be keyed to send C-W messages to the ground stations.

During transmissions, an onboard tape recorder recorded the voice output to the transmitters.

The primary HF voice link is an amplitude-modulated unit having a 5-watt output. This unit will operate through exit and through reentry until the drogue parachute housing is jettisoned at 10,000 feet; at this point, the HF voice will be permanently cut off.

The primary UHF voice link is an amplitude-modulated unit having a 2-watt output. The unit operates throughout the flight as a transmit-receive unit until drogue housing jettison at 10,000 feet, at which time the UHF transmits an RF carrier for D/F mode. However, the astronaut can also use this UHF link to transmit and receive.

The secondary HF link is identical to the primary HF link except that the secondary has a power of 1 watt. The secondary link is not operative until the postlanding antenna is fully erected. The secondary UHF link is identical to the primary link, except that it has 0.5-watt output.

The recovery beacon is a HF/UHF, CW/pulse modulated unit containing a SARAH rescue beacon and the SEASAVE beacon. The SARAH beacon has a transmitting power of 15 watts and the SEASAVE beacon, 1 watt.

There are four separate spacecraft antenna systems. These are main antenna, descent antenna, postlanding antenna, and radar beacon antenna.

The main antenna is formed by isolating the drogue parachute housing from the remainder of the spacecraft. The result is a structure that acts like a discone antenna in the frequency band of 225 megacycles and 450 megacycles, and as a center-fed dipole at 15 megacycles. The main antenna is used during launch, orbit, and part of the reentry phase of the mission.

The descent antenna is a spring-loaded fan-monopole which swings erect at 10,000 feet when the main antenna canister is jettisoned, and begins radiating most of the signals formerly carried by the main antenna.

The postlanding antenna is a telescoping 16-foot whip-antenna that is squib-actuated 60 seconds after impact.

The C- and S-band radar beacon antenna systems each consist of three helical antennas flush-mounted in the skin of the spacecraft.

LAUNCH VEHICLE DESCRIPTION

The Mercury-Redstone launch vehicle was based on the Army's Redstone missile which was designed and developed by Marshall Space Flight Center scientists and technicians prior to their transfer to NASA.

A view of the launch vehicle spacecraft combination is shown in figure 17. Modifications were incorporated to adapt the rocket to this special role, with major emphasis on increased reliability. The Redstone booster was selected for the manned ballistic space flight role because of its significant record of reliable flight in a launching history which extends over the past 9 years.

A view of the Mercury-Redstone spacecraft combination, as compared with the standard Redstone and Jupiter-C boosters, is shown in figure 18.

The over-all height is 83 feet, compared to the 69 feet of the standard Redstone. The body of the rocket is 70 inches in diameter. The lift-off weight is approximately 66,000 pounds, including the 2-ton Mercury spacecraft.

Several modifications were made to the Redstone booster. The rocket's tank section was elongated by about 6 feet to increase the fuel and liquid oxygen capacity. This was sufficient to increase the burning time by some 20 seconds. The Redstone booster was similarly elongated for its role in the launching of the early Explorer satellites. That version of the booster was known as Jupiter-C (ref. 3).

The engine used was the latest Redstone engine design Rocketdyne (A-7). Using alcohol and liquid oxygen, the thrust level of the engine is 78,000 pounds. Provisions were built into the engine to allow for the additional burning time.

A new pressurized instrument compartment (upper section) and spacecraft adapter section were designed. This compartment contained the booster control system. Unlike the standard Redstone, this compartment does not separate from the booster after burnout; instead it descends to the earth attached to the propulsion unit.

The Mercury-Redstone launch vehicle, as compared to the Redstone missile, has a well-tested, less complex control system which provides a simpler and more reliable operation. The gyro-table assembly is the old LEV-3, first used on the V-2, then on early Redstone missiles. The system uses an autopilot which minimizes the drift during powered flight. Carbon vanes located in the jet exhaust of the propulsion unit coupled with air vanes are used as control surfaces to maintain proper attitude.

The automatic abort system serves to give an advance warning of a possible impending catastrophic development. An electric signal is employed which would cause the following actions, in sequence: termination of the thrust of booster, separation of the spacecraft from the booster, and activation of the spacecraft's escape rocket which would propel the spacecraft to a distance of several hundred feet within 1 second. The abort system senses and is activated by: unacceptable deviations in the programed attitude of the booster, excessive turning rates, loss of thrust, or loss of electrical power. In addition to the automatic activation, the spacecraft escape system could be activated by the pilot in the spacecraft, and manually in the launching blockhouse and the NASA Mercury Control Center.

Special emphasis on reliability was placed in the booster program. Most of the reliability effort was centered on new components; those which are peculiar to the Mercury-Redstone launch vehicle. This program was conducted by the Marshall Space Flight Center and the Chrysler Corporation. Reliability tests were conducted on individual components, subsystems and systems. Test conditions included excessive vibrations and extreme temperatures. Engineers of the Chrysler Corporation designed and operated a special "rock and roll" device, which subjected the entire instrument compartment of the Mercury-Redstone launch vehicle to environmental stress, including vibration, heating, cooling, and loads. This latter phase was devoted primarily to checking out the abort system to insure that it would operate properly on demand and could not be activated accidentally.

Marshall Space Flight Center personnel conducted structural tests on the Mercury-Redstone launch vehicle configuration which assured the structural integrity of the vehicle. Units of the vehicle were submitted to considerably higher stresses and strains than those encountered in flight.

In addition to the acceptance firing of the engines, each completed booster was static-fired prior to its shipment to the launch site. During these static firings, a detailed measuring program gave assurance of proper performance of the engine. Also captive-fired was a complete Mercury-Redstone configuration, including a research model of the spacecraft previously tested during a Little Joe research and development flight to evaluate the dynamic structural response of the elongated tank section, instrumentation compartment and adapter region. Also noise measurements were made.

Separation tests were also made with the spacecraft Marman clamp ring. This device is used to hold the spacecraft onto the booster adapter. The purpose of these tests was to develop a retention device between the clamp ring and booster to prevent the separated segments of the clamp ring from colliding with the spacecraft after separation during the ballistic free-flight.

FLIGHT PLAN

The nominal flight plan is shown in figure 19. The flight plan presented is that of the MR-3 and MR-4 flights. As shown, the range was approximately 260 nautical miles, and slightly over 100 nautical miles altitude, with a weightless period of about 5 minutes.

For these flights, the sequence of major events was as follows: At T-35 seconds, the spacecraft umbilical was pulled and the periscope was retracted. At lift-off, the sequence timers were started. During the boosted phase of the flight, the flight-path angle was controlled by the booster control system. At booster cutoff, the tower clamp ring was released and both the escape and pylon jettison rockets fired to remove the tower. Ten seconds after booster cutoff, the adapter clamp ring was separated, and the posigrade rockets were fired to separate the spacecraft from the booster. The periscope was extended; the ASCS provided 5 seconds of rate damping then oriented the spacecraft to its normal orbiting attitude ($14\frac{1}{2}^{\circ}$ from the horizontal in the case of MR-3; 34° for MR-4).

The retrosequence was initiated 30 seconds before apogee. Retrofire began at apogee which occurred at approximately T+310 seconds. Sixty seconds after retrofire began, the retropack was jettisoned and the spacecraft was oriented to reentry attitude. Thirty seconds later, the periscope was retracted. When the axial load factor reached 0.05g, the ASCS switched from a reentry-hold mode to a rate-damping mode and initiated a constant roll rate of about 10° per second to reduce touchdown dispersion. When the spacecraft descended to 21,000 feet, the drogue parachute and radar chaff were deployed and the periscope was extended. The rate damping and 10° per second roll rate were maintained until the antenna fairing was ejected at 10,000 feet. At antenna fairing separation, the following events occurred: (a) deployment of the main parachute, (b) ejection of a SOFAR bomb, (c) turning on the UHF recovery beacon, (d) jettison of the remaining hydrogen peroxide in the reaction control system, and (e) arming the deployment of the landing bag. Upon landing, the main parachute was automatically disconnected through circuitry controlled by an impact switch. This impact switch together with an interlocking rescue aids switch enabled the astronaut to jettison the reserve parachute, deploy dye marker, turn off instrumentation, and activate the rescue beacon, HF recovery transceiver and the recovery flashing light.

During the MR-3 and MR-4 missions, the astronauts controlled the attitude of the spacecraft after turnaround to reentry as shown. During the MR-3 mission, the retrorockets were fired by an onboard timer, while during MR-4, the retrorockets were fired by the astronaut.

The planned and achieved flight parameters for MR-3 and MR-4 are shown in figure 20. As shown, the agreement with planned parameters was excellent.

FLIGHT HISTORY

The Mercury-Redstone program consisted of five flights. These flights are presented chronologically with the launch dates and highlights from each flight in the following discussion.

MR-1 Attempted Launch

The MR-1 attempted launch utilizing an unmanned spacecraft was made on November 21, 1960. The attempted launching of MR-1 resulted in: (a) shutdown of the booster, (b) firing of the escape rocket motor and separation of the escape tower from the spacecraft, and (c) the accomplishment of complete spacecraft design sequence following tower jettison.

The countdown on MR-1 had proceeded smoothly with no problems. At the firing signal, the booster engine started and accomplished lift-off, but in the process of lift-off, one of the two tail plugs that supply power to the booster pulled out sooner than the other. The plug still connected allowed a period of reverse current flow, or feedback, for approximately 40 milliseconds, which energized the booster-cutoff relay which gave a cutoff signal to the spacecraft. Upon the initiation of what appeared to the spacecraft to be a normal booster engine cutoff signal, the spacecraft sequencing system performed the normal functions of (a) tower jettison, (b) arming the parachute barostat switches, the functions of which began immediately since the spacecraft was below normal actuation levels. Consequently, the 42,000-foot barostat[1] initiated firing of the drogue parachute, the 10,000-foot barostat triggered the antenna fairing mortar which fired the fairing from the spacecraft, which in turn, deployed the main parachute.

Normal sequence functions which would have occurred during a normal mission included the firing of the capsule-adapter explosive bolts, the posigrade rockets and the retrorockets. These sequences were blocked by the presence of a 0.25g sensor which was subjected to 1g at all times.

The spacecraft was not damaged in any way. The booster, however, had risen approximately 4 inches and settled back, causing some local deformation and was, therefore, returned to the Marshall Space Flight Center.

MR-1A – Launch of Unmanned Spacecraft

A new booster was shipped from Marshall for the MR-1A mission. MR-1A was launched on December 19, 1960, using the same spacecraft.

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[1]On later flights this barostat was changed to a 21,000-foot unit.

This was the first flight of the Mercury-Redstone series. The flight was successful. The spacecraft achieved an altitude of 116.6 nautical miles and a range of 207 nautical miles. The reentry deceleration was 12.4g, which was somewhat higher than planned because of slight booster overspeed. As a result of this flight, a design change was made in the booster velocity cutoff sensor which would give greater cutoff accuracy.

MR-2 — Launch of Spacecraft With Primate Occupant

The MR-2 flight was made on January 31, 1961. This was the second flight in the series. The occupant aboard was a chimpanzee named Ham.

A booster malfunction occurred on this flight. The burning rate of the engine was greater than normal because of faulty engine thrust regulation. Propellant depletion was reached 0.5 second before velocity cutoff arming and the abort system thrust-chamber pressure switch disarming. Thereupon, the chamber pressure switch initiated a spacecraft abort just prior to normal cutoff.

The higher-than-normal booster thrust combined with escape motor firing produced a greater-than-normal exit velocity. This velocity and lack of retrorocket firing resulted in a range of 363 nautical miles, a maximum altitude of 136 nautical miles, a period of weightlessness of about $6\frac{1}{2}$ minutes with a maximum reentry deceleration of 14.6g.

The flight was successful, however, in that the primate occupant of the spacecraft withstood the flight with no ill effects, continuously performing his given tasks.

During this flight, however, two malfunctions occurred in the spacecraft. The landing bag did not operate properly; the heat shield struck the bottom of the spacecraft puncturing the lower pressure bulkhead, and later broke away from the spacecraft, allowing the spacecraft to lay over on its side. As a result of the punctures and laying over on its side, the spacecraft took on a large amount of water.

The second malfunction that occurred was the loss of cabin pressure. The air inlet valve opened during ascent at about 18,000 feet so that the cabin did not maintain pressure; however, the suit-circuit mode performed as designed providing a satisfactory environment for the chimpanzee.

MR-BD — Booster Development

The MR-BD flight was made on March 24, 1961. This flight utilized a nonoperative research and development type spacecraft. It was made to investigate the corrections made to the booster as a result of the problems brought to light on the MR-2 flight. The flight was successful and showed that all problems had been corrected.

MR-3 – Launch of Manned Spacecraft

The first Mercury manned space flight was successfully accomplished on May 5, 1961, with Alan B. Shepard, Jr. as the pilot (ref. 4). All systems performed satisfactorily for the flight and all phases of the flight were highly successful. The spacecraft achieved an altitude of 101 nautical miles, a range of 263 nautical miles, and was in weightless flight for slightly over 5 minutes.

MR-4 – Launch of Manned Spacecraft

The MR-4 flight was made on July 21, 1961, with Virgil I. Grissom as the pilot. The flight was successful. After landing, however, due to premature actuation of the side hatch, the spacecraft was lost, but the pilot was rescued after having spent a short period in the water. The spacecraft achieved an altitude of 103 nautical miles, with a range of 263 nautical miles, with a period of weightlessness of about 5 minutes.

The MR-4 flight was the final flight made in the Mercury-Redstone program. It was considered that all test objectives had been achieved and additional flights would contribute little to the over-all Mercury program.

FLIGHT RESULTS

There are various problem areas and questions concerning space flight that require resolving before extensive space flight exploration is made. To some degree, the Mercury-Redstone program provided answers and information in several of these areas. These were:

A. Launch procedures

B. Spacecraft system behavior

C. In-flight monitoring

D. Effect of a weightless condition on man

E. Pilot performance during space flight

F. Recovery operations

There follows a discussion of the contributions made in each area.

Launch Procedures

Considerable study and planning were devoted to launch procedures prior to the first Mercury-Redstone flight. The main problems were: (a) time the astronaut is in the spacecraft prior to launch, (b) loxing procedures, (c) integrating the spacecraft count with the booster count, and (d) gantry requirements.

There was a continuing effort to reduce the time the pilot was in the spacecraft prior to launch. An early goal was to insert the pilot at T-90 minutes, but this goal could not be met. Consequently, all counts had a T-123-minute insertion time. It was understood that in most cases, holds would lengthen this time. On both manned flights, the pilots were in the spacecraft a relatively long time before launch. In the case of MR-3, the pilot was in the spacecraft for a total of 4 hours and 14 minutes prior to launch. On MR-4, the pilot was in the spacecraft for a total of 3 hours and 22 minutes prior to launch. In both cases, these extended periods were due to holds. Astronaut insertion actually started on schedule at T-123 minutes.

The amount of time the astronaut was in the spacecraft in both MR-3 and MR-4 had no deleterious effect on his physical well-being. Shown in figure 21, for example, is a plot of pulse rate of the pilot for MR-4 during countdown. The pulse rates for the MR-3 mission are presented in reference 4. As shown, the pulse rate exhibited a generally constant level with peaks occurring at various critical periods during the count. Later questioning of the pilots indicated the hold was considered somewhat long; however, this appeared to be due to wanting to "get on with the job," rather than any physical impairment.

During all counts except for the MR-BD and MR-4 flights, loxing was accomplished at around T-385 minutes. On the MR-4 operation, loxing was delayed until T-180 minutes so that a later and consequently more accurate weather forecast could be made. This procedure worked out very well, and if the Mercury-Redstone program had continued, it possibly would have been utilized for the remainder of the program.

When the booster is loxed and a scrub is called, a draining-off and a drying-out period is necessary so that at least a 48-hour recycle time is required. Also, if there are many scrubs, the cycle of loxing and deloxing has harmful effects on the vehicle, and it is questionable as to how many times this operation can be repeated.

A considerable amount of effort was expended early in the program in integrating the spacecraft and launch vehicle counts. The count was finally arranged into two parts with a rest period between. This resulted in the same efficient team conducting the operation throughout all of its aspects.

The first part of the count extends from T-640 minutes to T-390 minutes; the second part of the count resumes the next day at T-390 and proceeds on to T-0. The amount of interval between the two parts could be varied, but in all cases was within approximately 24 hours of each other. There follows an abbreviated outline of the count.

MERCURY-REDSTONE COUNTDOWN

PART I – T-640 to T-390

T-640	Start count Remove covers and sealing tapes Warm up telemeter ground stations Verify complex is on critical power Apply capsule power and begin systems tests
T-490	Start fuel loading
T-450	Complete capsule systems tests
T-440	Finish fuel loading
T-390	End Part I of count

PART II – T-390 to T-0

T-390	Begin second part of count
T-385*	Start lox loading
T-350*	End lox loading
T-270	Move service structure to edge of pad
T-250	R/F tests begin
T-230	R/F tests completed
T-225	Return service structure to position around vehicle
T-205	Static-fire spacecraft control system thrusters
T-140	Astronaut arrive at pad
T-123	Astronaut insertion begins

PART II – T-390 to T-0 – Concluded

T-120	Start booster hydrogen-peroxide loading
T-115	Suit purge
T-100	End booster hydrogen-peroxide loading
T-90	Install spacecraft hatch
T-85	Purge spacecraft
T-75	Spacecraft pressure check
T-55	Move service structure to edge of pad Position cherrypicker for emergency egress
T-25	R/F systems ON
T-22	Spacecraft abort system ARMED
T-15	Transfer spacecraft to internal power
T-9	Move service structure to launch position
T-7	Command receivers ON
T-4	Check all stations for "ready" status
T-2.5	Arm destruct package Move cherrypicker to launch position
T-35"	Firing command Umbilical drop Periscope door close
T-14"	Boom drop Ignition Main stage
T-0	Lift-off

*As discussed previously, the time for loxing was moved to T-180 for the MR-4 mission.

These launching procedures were proven sound and operations were very smooth with all the Mercury-Redstone missions. Constant and continual improvements were made in the count throughout the program. The final count, as accomplished on the MR-4 mission, which is essentially as outlined except for the change in loxing, was a very smooth and satisfactory count.

Prior to the integration of man with rocket launchings, there had been little requirement for an extensive upper surface working area to accommodate a great deal of critical work after mating. With the Mercury-Redstone program, it soon became apparent that there must be a closed area for considerable and lengthy work on the spacecraft at the upper level. Also, there was a requirement to keep the spacecraft in a state of "white room" cleanliness as well as keeping technicians in a satisfactory working environment.

As a result of these requirements, there evolved a white room enclosure as shown in figure 22. This structure separated down the middle when the service structure was opened as shown in figure 23, and moved back with the gantry with no restrictions. It provided an air-conditioned, filtered-light environment for technicians and engineers working on the spacecraft. The temperature was kept at around 75° F winter and summer with relative humidity of about 55 percent.

In general, this enclosure proved to be very satisfactory. It is considered that a working area of this type is a mandatory item for manned launches.

It is considered that the Mercury-Redstone program contributed to a better understanding of the requirements for manned spacecraft launching procedures.

Spacecraft System Behavior

The Mercury-Redstone program provided information concerning basic system behavior for spacecraft in suborbital flight. The main results obtained can be summarized with the statement that the complete spacecraft system generally performed as it was designed. There were some specific exceptions to this which will be discussed.

It was shown, however, that the basic Mercury spacecraft system was sound and that it could function properly under actual space flight operating conditions. There follows a discussion of the results obtained concerning the systems of the spacecraft as demonstrated by the Mercury-Redstone program. The discussion will be broken down as follows: (a) control system, (b) environmental control system, (c) mechanical systems, (d) electrical systems, and (e) communications systems.

Control system.- Operation of the automatic stabilization and control system was satisfactory for all flights. The turnaround maneuver following separation was accomplished by the automatic system successfully in all flights except MR-2 which was in the abort mode.

The pilots succeeded in controlling the motions of the spacecraft with the manual control system on the MR-3 and MR-4 flights.

The main problems associated with both the automatic and manual control systems were associated with the reaction control system. There have been evidences in all flights except MR-4 of thruster leakage. The addition of screens upstream of the valves and thrusters have evidently improved the leakage problem. Although there was no evidence of thruster leakage on MR-4, there was a condition which may have accounted for the feeling of sluggishness as attributed to the control system by Astronaut Grissom on the flight. Full stick deflections did not always produce maximum spacecraft turning rates during the MR-4 flight. Figure 24 shows a plot of the expected rates and the measured rates where it can be seen that a rate of only $\frac{2}{3}$ of the specified rate was obtainable. This problem is believed to be caused by a mechanical linkage arrangement in the control system that makes it impossible to maintain a consistent stick position versus thruster output. This linkage arrangement possibly precluded full open position of the manual proportional hydrogen-peroxide valves, hence less than full thrust was provided. Because of the loss of the spacecraft, the exact cause of the reported sluggishness of the control system cannot be determined.

Astronaut Grissom utilized the rate command control system during the MR-4 flight for the first time. It was determined that the rate command mode was especially effective in providing damping during reentry.

The results of the Mercury-Redstone program concerning the control system can be summarized as follows: the control system was effective in controlling the sequencing of the spacecraft by the automatic system and in controlling the motions of the spacecraft manually. There have been evidences of leakages in the hydrogen-peroxide system. However, these leakages have continued to diminish as the flight program progressed. The rate control mode appears to be very effective during reentry.

Environmental Control System (ECS).- The Mercury-Redstone program has demonstrated that the environmental control system has functioned as designed. Two failures were noted which will be discussed.

A failure in cabin pressurization occurred on the MR-2 flight in which the primate was the occupant. During exit, approximately 1 minute after launch, during the period of maximum vehicle vibration, the air inlet valve opened and caused the cabin pressure to decay to approximately ambient through the negative pressure relief valve and then through the open air inlet valve. The altitude corresponding to this time was about 18,000 feet. However, when this failure occurred, the suit circuit performed as designed and maintained design conditions for the duration of the flight.

This malfunction occurred because of a mechanical discrepancy. The air inlet valve is designed such that a snubber prevents the hand control linkage from striking the tripping mechanism of the valve. In assembly of this valve into the spacecraft, the snubber interfered with the linkage mechanism so that the snubber was removed. Vibration of the spacecraft and booster during the maximum dynamic pressure region was sufficient to cause the freely-floating linkage mechanism to strike the valve-triggering mechanism with enough force to actuate the valve. It has since been demonstrated by ground tests that without the snubber the valve can be triggered by vibration.

The valve was redesigned and there has been no further problem. In addition, there has been a check valve installed between the negative pressure relief valve and the air inlet valve so that even if this latter valve should become actuated, cabin pressure would not be lost.

The second problem that has occurred in the ECS occurred on the MR-4 flight. There was present a leak rate in the oxygen supply system such that the usage rate appears to be about six times greater than that which a man could possibly demand. This leakage could have been either in the cabin or suit circuit; it could have been either at a joint or in a valve. A similar leak was noted in the MA-4 orbital flight which was later considered to be a partially opened valve. This problem is presently under study.

Except for these two discrepancies, the ECS functioned as designed. Figure 25 shows the cabin, suit, and ambient pressures for MR-4 which are typical of all Mercury-Redstone flights, except for the MR-2 flight. Suit and cabin temperatures were maintained within expected limits. Figure 26 shows the variation in suit temperatures for the MR-2, MR-3, and MR-4 flights. The initial suit inlet temperatures were selected as shown. Cabin temperatures did not exceed 110° F.

It can therefore be summarized that the ECS for the Mercury spacecraft was adequate for the Mercury-Redstone flights. The system requires further investigation to determine the source of the excess oxygen decay rate. With the correction of this, the system should be adequate for manned orbital flights.

Mechanical systems.- The mechanical systems on the Mercury spacecraft can be grouped into the following: (a) landing and recovery system, (b) landing-bag system, and (c) explosively-actuated side egress hatch.

The landing and recovery system has been highly satisfactory. Parachute deployment has occurred at planned altitudes and specified descent velocities of 28 to 30 feet per second were always achieved.

The SARAH beacon proved most effective as a location aid. In the case of the MR-2 flight, which overshot the landing point considerably, contact was received from the SARAH beacon at ranges from 97 to 135 nautical miles before the spacecraft landed. After landing, contact was reestablished with the SARAH beacon at ranges from 50 to 20 miles depending on the aircraft location and airborne receiver equipment.

The landing bag system was added to the spacecraft in a later stage of its development primarily to attenuate the shock of possible land impact and consists of a skirt extension between the heat shield and the spacecraft itself (fig. 27). The skirt is extended by release of the heat shield 12 seconds after main parachute opening and utilizes a cushioning effect when the spacecraft hits the water. It was utilized for the first time on the MR-2 flight in which the primate was flown.

The results of the first flight operation in the Mercury-Redstone program with the bag were not satisfactory. As was mentioned earlier, the heat shield struck the bottom of the spacecraft, puncturing two holes and later through the action of the waves, the steel restraining straps were fatigued so that the heat shield broke away and allowed the spacecraft to turn over on its side. Through a combination of water entering the holes in the bottom and water coming in through the recovery compartment, thence through the cabin pressure relief valve, the spacecraft took on a large amount of water, on the order of 800 to 1,000 pounds, such that when the spacecraft was actually recovered, the water was up to the couch level of the primate. Figure 28 shows the condition of the spacecraft just prior to recovery. The primate occupant was, however, fully protected in his enclosed water-tight couch so that he was recovered sound and in good condition.

The remedies applied to subsequent spacecraft involved the protection of the underside of the spacecraft from puncture damage from the heat shield, mainly by applying aluminum honeycomb in large areas, and the "dedaggering" and potting solidly of all sharp projections (fig. 29). Also a fiber-glass protective shield was installed between the honeycomb and the heat shield. This concept of protecting from puncture damage was tried, utilizing drop tests of spacecraft no. 5, previously flown on the MR-2 mission, in waters near Langley Field, Virginia. The protection outlined above provided a satisfactory solution to the puncture damage. At the same time, work in utilizing restraining cables to hold the heat shield was accomplished, so that it could be assured that the heat shield would be retained for an adequate time period after the spacecraft lands, even if the supporting straps should fatigue. All this was demonstrated prior to the MR-3 flight.

This is the one example, however, that showed that the seaworthiness of the spacecraft was below expectation, and work had to be done to improve it. The Mercury-Redstone program contributed materially to the solution and to the identification of this problem.

The third mechanical system to be discussed in connection with the Mercury spacecraft is the explosively-actuated side egress hatch. This hatch was flown for the first time on the MR-4 flight.

This hatch is attached to the door sill with 70, $\frac{1}{2}$-inch titanium bolts. A small hole is drilled in each bolt shank to provide a weak point. Mild detonating fuse (MDF) is installed in a channel between the outer and inner seal around the periphery of the hatch. When the MDF is ignited, the resulting gas pressure between the inner and outer seal causes the bolts to fail in tension. The MDF is ignited by a manually operated igniter.

The igniter requires an actuation force of 5 to 6 pounds when the safety pin is out and 40 pounds when the safety pin is installed. The igniter can be actuated from inside the spacecraft by means of a plunger, or from the outside by means of a lanyard. When it is actuated by a lanyard from the outside, the shearing of the pin is required so that a steady 40-pound pull is required.

On the MR-4 flight, the hatch fired prematurely during the post-landing period. Astronaut Grissom has stated that after removing the igniter cover and pulling the safety pin, he was resting in the spacecraft awaiting helicopter hook-on when the explosive charge suddenly fired, blowing the hatch away. An emergency situation was thereby precipitated. No suitable explanation of why the hatch was actuated has been found.

Extensive tests have been conducted on the hatch to determine possible causes of premature actuation. To date, no duplication of the premature actuation can be made. There are presently in progress environmental tests which will subject the complete hatch assembly to orbital flight conditions. Also, new operational procedures have been outlined that include not removing the cover and safety pin until helicopter hook-on has been made with the spacecraft.

To summarize the mechanical systems experience on the Mercury-Redstone program, it can be stated that the landing and recovery systems functioned as planned for the spacecraft. A problem was discovered and solved in the landing-bag system. The problem with the explosively actuated side egress hatch is under extensive study.

Electrical power system.- The electrical power system, has, in general, worked satisfactorily for all missions. The main source of trouble was in the inverters. It was only through the ability of the pilot to switch to the standby inverter that temperatures considered to be excessive were averted. It was shown that the inverters need some cooling medium. Later spacecraft will have cooling plates installed beneath the inverters.

Another source of problems with the electrical power system has been "spikes" or "glitches" caused when squib circuits fire. Figure 32 presents a typical history of a-c and d-c voltages and current during a flight. This time history was obtained on the MR-4 flight after the latest modifications had been applied to the electrical system.

It was deduced that a "glitch" with concurrent voltage drop caused a reset of the 60-second timer after retropack release on the MR-3 flight, and thus the cockpit telelight did not indicate retropack release. Although Astronaut Shepard had visually observed that the retropack had separated, he pulled the manual override, which activated the light. A modification was made to the electrical system on spacecraft no. 11 for MR-4 to protect these time-delay relays from voltage transients. The modification consisted of replacing a number of the normal squib fuses with 1-ohm resistor squib fuses. This added resistance in the squib circuit limited the current drain, and consequently attenuated the voltage spike that occurred during squib firing. These 1-ohm fuses cause the main bus voltage to drop only $1\frac{1}{2}$ volts, as shown in the figure. However, without the 1-ohm fuse, similar shorts in the squib circuits can cause a potentially dangerous drop of around 10 volts in the main bus. It is considered, therefore, that the addition of these 1-ohm fuses has added to the reliability of the electrical system.

The electrical power system has been modified and redesigned continuously throughout the Mercury-Redstone program as the various problems have arisen. The major problem areas have been recognized, and it is felt that corrections in progress will assure an adequate system.

Communications system.- The results of the communications system as obtained by the Mercury-Redstone program has been essentially satisfactory. UHF voice communications have always been good to and from the Mercury Control Center, as well as to recovery aircraft operating in the down-range area. Mercury Control Center tapes have been made of both flights in which the astronaut's voice is recorded very clearly.

The same is not true, however, for HF. No satisfactory HF communications have been made. However, it is considered that marginal transmission conditions due to poor antenna pattern peculiar to the Mercury-Redstone flight plan have prevented adequate tests of the HF system on the Mercury-Redstone program. The recent MA-4 flight provided good HF communication results.

The tracking beacons have operated satisfactorily thus far and have given good results.

The SARAH beacon has performed exceptionally well. Very little experience has been had with the SEASAVE beacon because of the short recovery time involved.

Telemetry has been excellent thus far. The quality of the data has been good, both Cape and down-range, which allowed very good and prompt evaluation of the flight data.

In summary, it can be stated that the communications system, including the tracking beacons and telemetry, has been good. The UHF two-way voice link and the SARAH beacon have been especially valuable tools in the operation.

In-flight Monitoring

The requirement for in-flight monitoring and control of the Mercury spacecraft was established early in the program. This operational concept was based largely on flight safety problems associated with manned orbital flight. The Mercury network has been constructed and is now in operation.

The facilities and stations for this Mercury network are as follows:

Site 1 - Cape Canaveral, Mercury Control Center

Site 2 - Bermuda

Site 3 - Atlantic Ocean Ship

Site 4 - Canary Islands

Site 5 - Kano, Nigeria

Site 6 - Zanzibar

Site 7 - Indian Ocean Ship

Site 8 - Muchea, Australia

Site 9 - Woomera, Australia

Site 10 - Canton Island

Site 11 - Hawaii

Site 12 - Southern California

Site 13 - Guaymas, Mexico

Site 14 - White Sands, New Mexico

Site 15 - South Texas

Site 16 - Eglin AFB, Florida

The Mercury Control Center located at Cape Canaveral, Florida is the command center for Mercury missions. An illustration of the interior of the Mercury Control Center is shown in figure 31. The Control Center is responsible for the flight operation from lift-off through reentry to recovery. During the flight operation, the stations are manned with STG flight controllers to provide real-time evaluation of the flight.

The requirements for controlling and monitoring the flight on Mercury-Redstone missions were limited and only the Mercury Control Center contributed actively to the operation. On various occasions, however, Bermuda and the Atlantic and Indian Ocean Ships stationed in the recovery area operated to provide exercise for these facilities and real-time information during the reentry and recovery phases.

The results of the operation of the network, and in particular the Mercury Control Center, did point out several items which are noted as follows:

(a) The Mercury Control Center provided a central point for over-all mission control. This was a particular advantage in the prelaunch and recovery phases of the mission when the Operations Director was able to remain abreast of the operation at all times.

(b) The Mercury-Redstone missions established that the concept of operation and operations procedures were feasible and capable of providing real-time information for adequate flight control.

(c) The capability and reliability of a major portion of the equipment was determined. Some changes resulted, particularly in the communications area. The most important gains, here, were in the ability to obtain trajectory – computer-orientated information. Communications procedures to be used during powered flight were also exercised and proven under actual flight conditions.

(d) One of the few failures that occurred with the spacecraft during the Mercury-Redstone program was established in real-time. This failure occurred during the MR-2 flight. During the exit phase of the flight, during the period of maximum dynamic pressure, the inlet snorkel valve was prematurely actuated as described in an earlier section. The systems monitor at the console observed this pressure drop and was able to report this pressure drop in real-time. Therefore, the Operations Director was advised of the situation and knew that there had been a failure in the primary system, but that the secondary system was holding. Had this been an orbital flight, an abort would have been commanded. The value of this monitoring capability was thus established very early in the program.

In summary, it can be stated that the concept of in-flight monitoring in real-time has been proven sound by the use of the Mercury-Redstone program. Further, it has proven to be a valuable training exercise for the flight controller teams, so that when manned-orbital flight operations occur, the proficiency of these teams will have been enhanced.

Effect of a Weightless Condition on Pilot

One of the questions concerning man's operation in space flight has been the effect of his weightless condition. Various schemes have been considered and proposed for simulating a weightless condition on earth, but they have met with little success. Therefore, the question of man's behavior under weightless conditions has continued to be a popular as well as a scientific question.

The Soviet Union's two manned orbital space flights have contributed the over-all answer to this question; that is, there are no gross harmful effects, for both pilots appeared to be well after the flight.[2] The detailed results of the behavior of the Soviet Cosmonauts under weightless conditions, however, have not been made generally available.

Therefore, the Mercury-Redstone program provided for the United States the first opportunity to observe man under a brief 5-minute period of weightless flight. Maximum use was made of this period of weightlessness, in the continuous biomedical and performance information obtained during both the MR-3 and MR-4 flights.

Figure 32 shows the pulse rate for the MR-4 flight with the comparative ranges obtained from centrifuge simulation on the Mercury-Redstone mission for the MR-4 pilot, Astronaut Grissom. (An envelope

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[2]Recent reports indicate that on the 17-orbit mission, the pilot felt nausea sometime in his flight following prolonged weightlessness.

was constructed from 5 selected centrifuge conditions; pre-run, exit, cut-off, retrofire, and reentry.) It can be noted that a pulse rate of 165 beats per minute occurred at around spacecraft-separation time. This pulse rate was not maximum, however, in that the pulse rate peaked at 171 beats per minute at around retrofire time. The lowest pulse rate noted during weightless flight was 143 beats per minute. Although pulse rates were higher than in the centrifuge program, this can be explained by the fact that the pilot was undergoing the actual experience rather than a training run.

Reference 4 presents similar data for the MR-3 flight.

In both flights, the ECG (Electrocardiogram) displayed no abnormal rhythm or disturbance and appeared normal.

Body temperatures remained nearly constant at a normal level during the flights. Vision appeared to be good in both cases. No disorientation or semicircular-canal distrubances were recognized, except in one brief instance on MR-4 when there was a brief tumbling sensation that occurred at the turnaround maneuver. This disturbance cleared promptly and was not associated with nausea or altered vision. In neither flight did the pilots report dizziness.

There is no attempt in this paper to go into medical detail on the findings associated with weightless flight, but it has been determined by the medical evaluation that there were no harmful effects that could be attributed to the brief 5-minute weightless condition.

Debriefing and interrogation of both pilots has indicated that they barely noticed they were in a weightless condition, and in fact, the first indication that Astronaut Shepard had on the MR-3 flight was that he saw a washer floating by his eyes.

Although this weightless condition only lasted 5 minutes, it is reassuring to have detailed subjective and objective data from the Mercury Astronauts' experience in zero gravity. Mercury orbital flights will permit the United States to obtain detailed astronaut performance information, a necessary step in providing data that can be extrapolated to flights of longer duration.

Pilot Performance During Space Flight

An objective of the Mercury-Redstone program was to provide a demonstration of man's ability to perform effectively under conditions of space flight.

To achieve this purpose, a well-defined program of flight activities for each astronaut was established prior to each flight. This program was practiced repeatedly on ground simulators. From these training devices, data on the astronaut performance was obtained. This baseline data could then be compared with the astronaut performance in flight.

In order to obtain a maximum of information within the limited time available on these ballistic flights, a very full program of activities was scheduled. The astronaut was in control of the vehicle attitude from after spacecraft turnaround after separation to reentry. During this time, the astronaut had to maintain normal spacecraft attitude and carry out a program of test maneuvers, and in addition, he communicated with the ground, monitored the spacecraft functions and made observations outside the vehicle. Despite this very full program, the large majority of all planned activities was carried out by both pilots.

The general quality of the performance of the astronaut under the conditions of the space flight was generally within that demonstrated on the fixed-base simulator where no flight stresses were present. An example of astronaut ability to control attitude on the Mercury-Redstone flights is given in figure 33. This figure shows the accuracy with which the astronaut maintained vehicle attitude during the retrofire period on the MR-4 flight. A comparison is given of the attitude control during the flight with the envelope of 10 trainer runs made prior to the MR-4 flight. As this figure shows, the astronaut was able to hold the attitudes of the spacecraft well within the envelope of trainer runs and well within the attitude permission limits. The performance of this critical maneuver by both astronauts during the Mercury-Redstone flights was well within the requirements for a safe reentry from orbital flight.

While the opportunities for viewing the ground were limited by the short time of flight and the amount of cloud cover which was present during both flights, Astronauts Shepard and Grissom were able to make a number of observations of value to the coming manned orbital program. They provided some information on the size of landmarks which could be seen from orbital altitude and the general coloration of land and water as seen from orbital altitude. They also described the appearance of the horizon and evaluated the use of the horizon as an attitude reference. Astronaut Grissom reported watching the tower jettisoning and separating from the spacecraft. Both pilots observed parts of the retropackage after separation. Astronaut Grissom reported contrails during the reentry. Their space flight experience also allowed them to evaluate their training experiences and the training equipment. This has led to a general confirmation of the value of the simulators and the adequacy of the training program.

The experience with the Mercury-Redstone flights has demonstrated that adequate training for short space flights was performed using ground-based simulation. Such training appears adequate to permit the pilots, even on first exposure to space flight, to perform within operational requirements. It therefore appears that elaborate and exotic training equipment was not necessary. Within the limits of the short flight times of the Mercury-Redstone operations, there was no evidence that environmental conditions of space flight had influenced the pilot's ability to operate the vehicle. On the basis of this limited experience, it has been reaffirmed that man will be an effective and essential component of future space vehicle systems.

Recovery Operations

Recovery support for the Mercury-Redstone program has been excellent and has served to demonstrate the adequacy of the techniques employed. When the Mercury program was originally conceived, water landing was made a prime design criterion. This meant, of course, that water recovery from open seas was a part of the normal operational plan. Support of the Department of Defense was therefore requested for recovery operations along with many other phases of Project Mercury. The Navy was assigned over-all responsibility by DOD and detailed plans were established in consonance with NASA requirements.

A large amount of training was implemented by the DOD units and much testing of the recovery equipment and procedures was accomplished by the NASA and the DOD. In general, the NASA requirements were met through use of existing operational units suitably augmented for the Mercury missions. Training missions were accomplished so that the operations procedures for recovering the spacecraft were well organized prior to the first Mercury-Redstone flight.

A typical recovery force deployment for a Mercury-Redstone flight is shown in figure 34. This figure shows surface craft and aircraft positioned along a flight corridor with the primary recovery units in the primary landing zone. Also shown is the landing point of the Mercury-Redstone No. 4 spacecraft as compared to the predicted point.

Two problems have been brought to light in the over-all recovery effort of the Mercury-Redstone program. Both of these problems were spacecraft faults. One was associated with the heat shield and landing bag and was described in an earlier section of this paper. The other problem occurred on the MR-4 flight, and caused the loss of the spacecraft.

The incident that caused the loss of the spacecraft was the premature actuation of the explosively-actuated side egress hatch. The helicopter, which was the prime recovery unit at the time, was following established procedures in the hook-on of the spacecraft when the hatch suddenly actuated and Astronaut Grissom immediately egressed into the water. The crew continued to try for spacecraft recovery, as Astronaut Grissom appeared to be in no difficulty at the time. The weight of the water-filled spacecraft was greater than the lifting capability of the helicopter so that release of the spacecraft was required. While the attempt was being made to lift the spacecraft from the water, a second helicopter moved in to retrieve Astronaut Grissom. Astronaut Grissom was in the water about 3 to 4 minutes.

Other than this incident, which fortunately turned out to have a happy ending, the recovery operations for the Mercury-Redstone program have proceeded exceedingly smoothly. For example, on the MR-2 flight when the spacecraft overshot its target by 118 nautical miles, recovery by helicopter was made 2 hours and 40 minutes after landing, which deposited the spacecraft onboard an LSD 51 minutes later. This recovery operation afforded an opportunity to exercise recovery in an area other than the primary landing area.

In summary, it can be stated that operations during the Mercury-Redstone program by the recovery forces have demonstrated that water landing and recovery by helicopter and ship is practicable and that present techniques are satisfactory.

CONCLUDING REMARKS

The Mercury-Redstone program has provided initial information on pilot capability and systems operation in space flight. The following conclusions are indicated:

(a) Satisfactory launch procedures have been determined for manned spacecraft.

(b) The Mercury-Redstone program provided answers concerning basic system behavior for spacecraft in suborbital flight. The main result obtained can be summarized as the complete spacecraft system performed as it was designed.

(c) The feasibility and importance of in-flight monitoring and control have been established.

(d) The effect of weightlessness on a pilot during ballistic space flight has been studied and appears to be of no consequence to his physical condition.

(e) Pilot performance is good during limited space flight; he is able to perform many tasks capably and well.

(f) The recovery techniques as defined for Project Mercury have been demonstrated to be sound and have been satisfactory for the Mercury-Redstone program.

This program provided information on man as an integral part of a space flight system, indicating that man can assume a primary role in space as he does in other realms of flight.

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2. Committee on Aero. and Space Sci.: Project Mercury: Man-In-Space Program of the National Aeronautics and Space Administration. Senate Rep. No. 1014, U.S. Govt. Printing Office, 1959.

3. Hoelker, R. F.: Launching of Explorer I. Selected Topics on Ballistics. AGARDograph 32, Pergamon Press (New York, 1959), pp. 74-87.

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TABLE I

MERCURY-REDSTONE MISSIONS AND TEST OBJECTIVES

Mission	Launch date	Objectives
MR-1A Unmanned	December 19, 1960	(a) Qualify the spacecraft-booster combination for the Mercury-Redstone mission which includes attaining a Mach number of approximately 6.0 during powered flight, a period of weightlessness of about 5 minutes, and a deceleration of approximately 11g on reentry. (b) Qualify the posigrade rockets (c) Qualify the recovery system (d) Qualify the launch, tracking, and recovery phases of operation (e) Qualify the Automatic Stabilization and Control System, including the Reaction Control System
MR-2 Primate aboard	January 31, 1961	(a) Obtain physiological and performance data on a primate in ballistic space flight (b) Qualify the Environmental Control System and aeromedical instrumentation (c) Qualify the landing bag system (d) Partially qualify the voice communication system (e) Qualify the mechanically-actuated side hatch (f) Obtain a closed-loop evaluation of the booster automatic abort system
MR-BD Booster Development Flight	March 24, 1961	(a) Investigate corrections to booster problems as a result of the MR-2 flight. These problems were as follows: (1) Structural feedback to control system producing vane "chatter" (2) Instrument compartment vibration (3) Thrust control malfunction
MR-3 Manned	May 5, 1961	(a) Familiarize man with a brief but complete space flight experience including the lift-off, powered flight, weightless flight (for a period of approximately 5 minutes), reentry, and landing phases of the flight. (b) Evaluate man's ability to perform as a functional unit during space flight by: (1) Demonstrating manual control of spacecraft attitude before, during, and after retrofire (2) Use of voice communications during flight (c) Study man's physiological reactions during space flight (d) Recover the astronaut and spacecraft
MR-4 Manned	July 21, 1961	(a) Familiarize man with a brief but complete space flight experience including the lift-off, powered, weightless (for a period of approximately 5 minutes), atmospheric reentry, and landing phases of the flight. (b) Evaluate man's ability to perform as a functional unit during space flight by: (1) Demonstrating manual control of spacecraft during weightless periods (2) Using the spacecraft window and periscope for attitude reference and recognition of ground check points (c) Study man's physiological reactions during space flights (d) Qualify the explosively-actuated side egress hatch

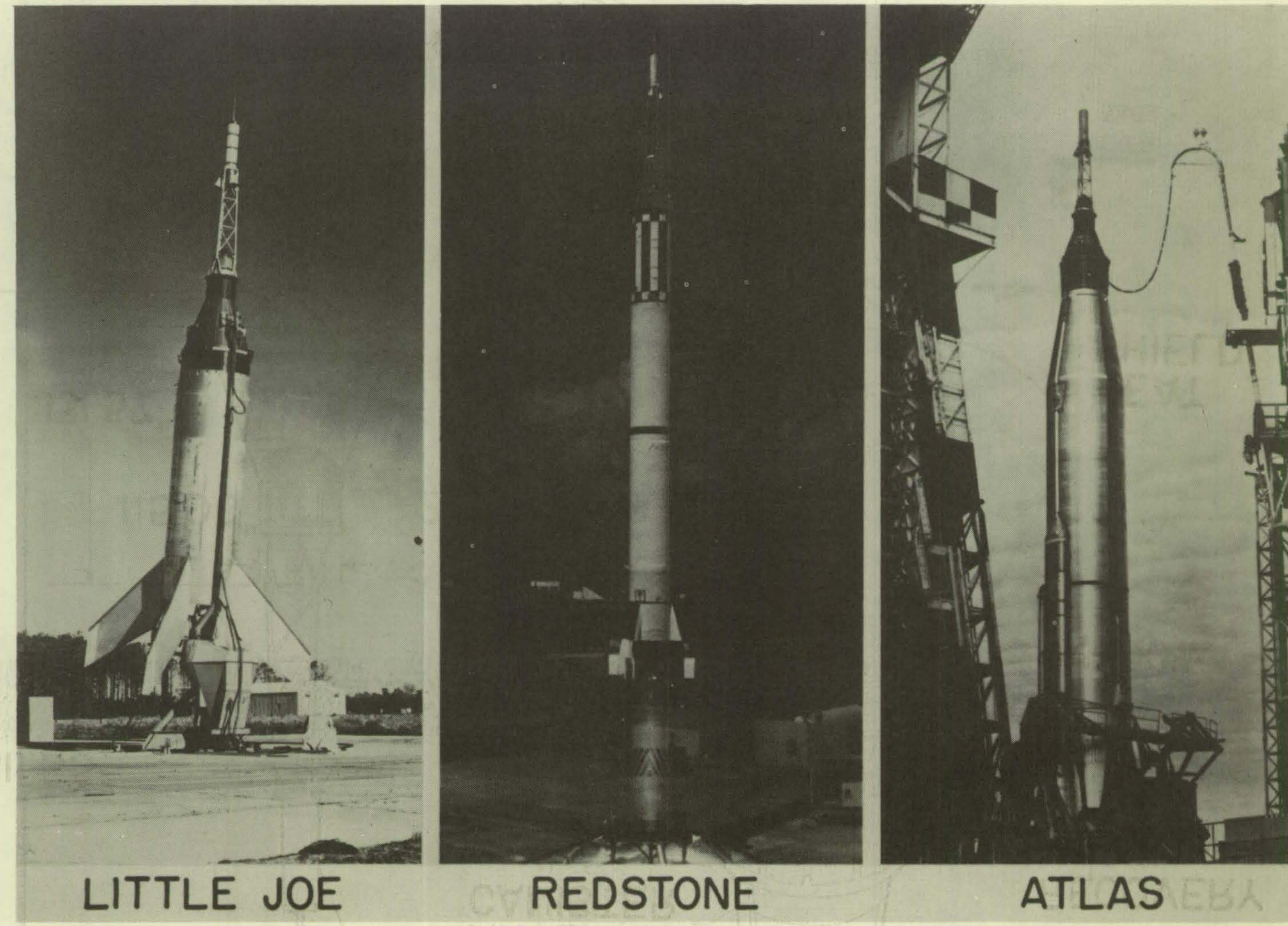

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Figure 1.- Project Mercury launch vehicles with spacecraft.

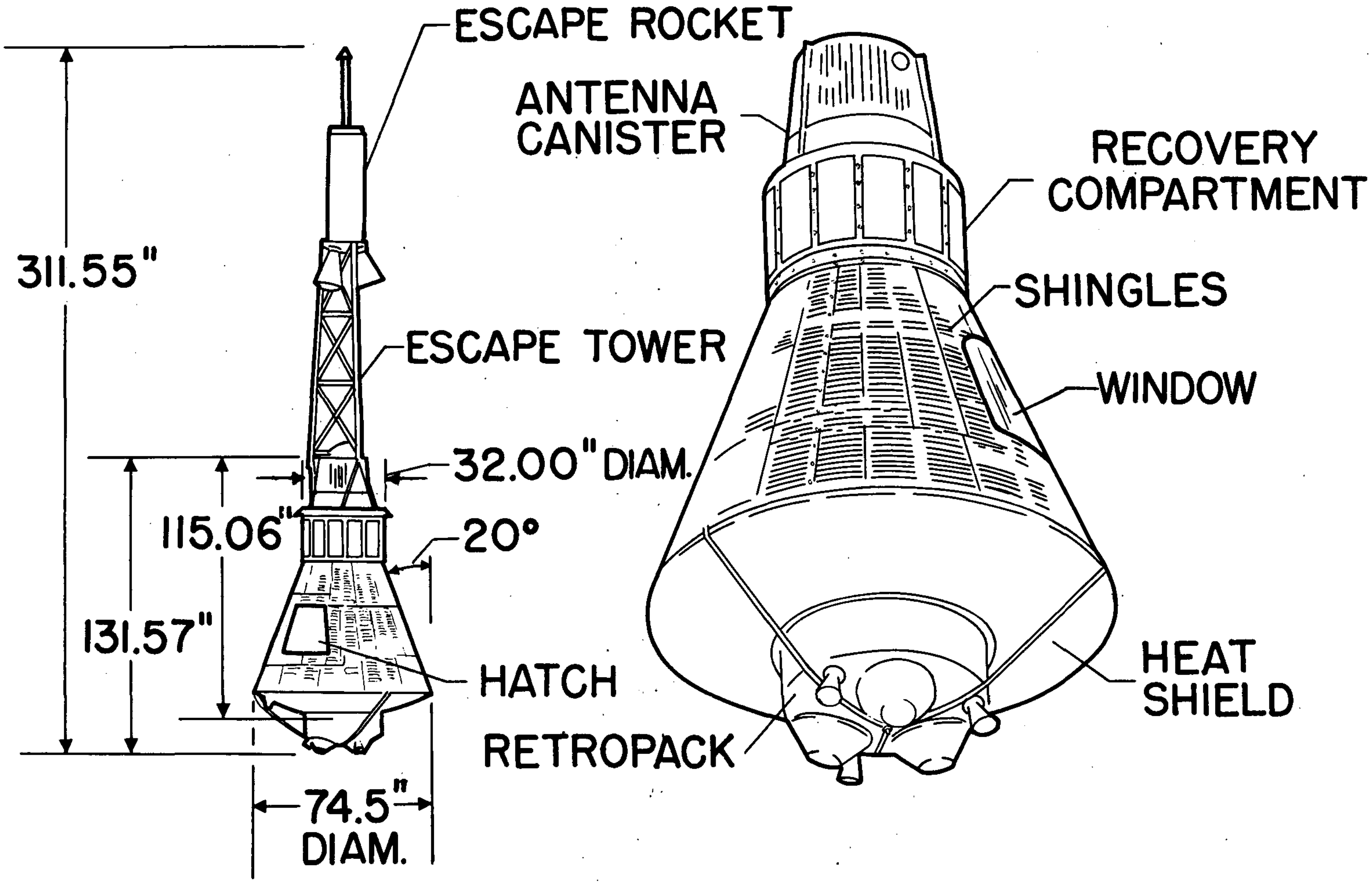

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Figure 2.- Spacecraft and escape-system configuration.

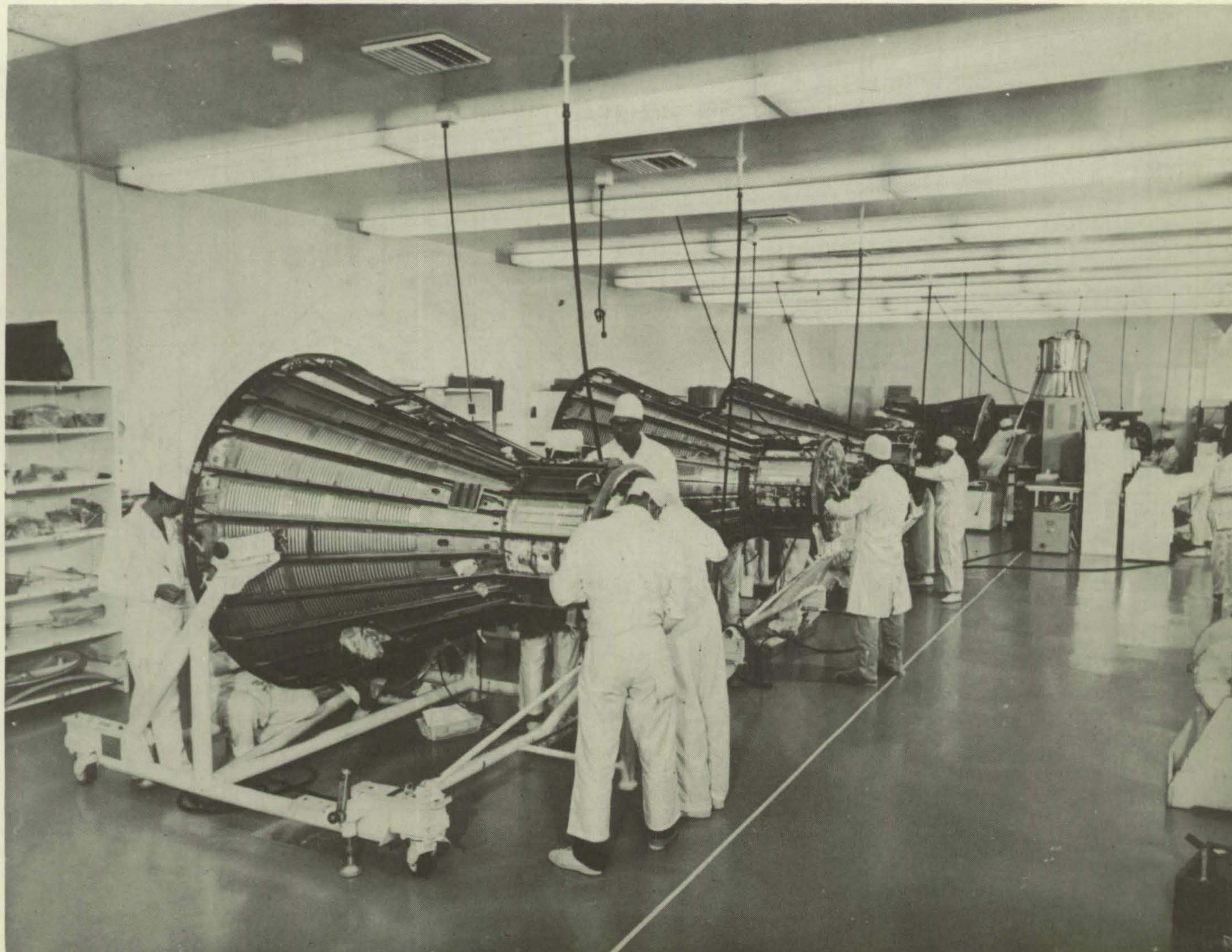

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Figure 3.- Photograph of spacecrafts in final assembly.

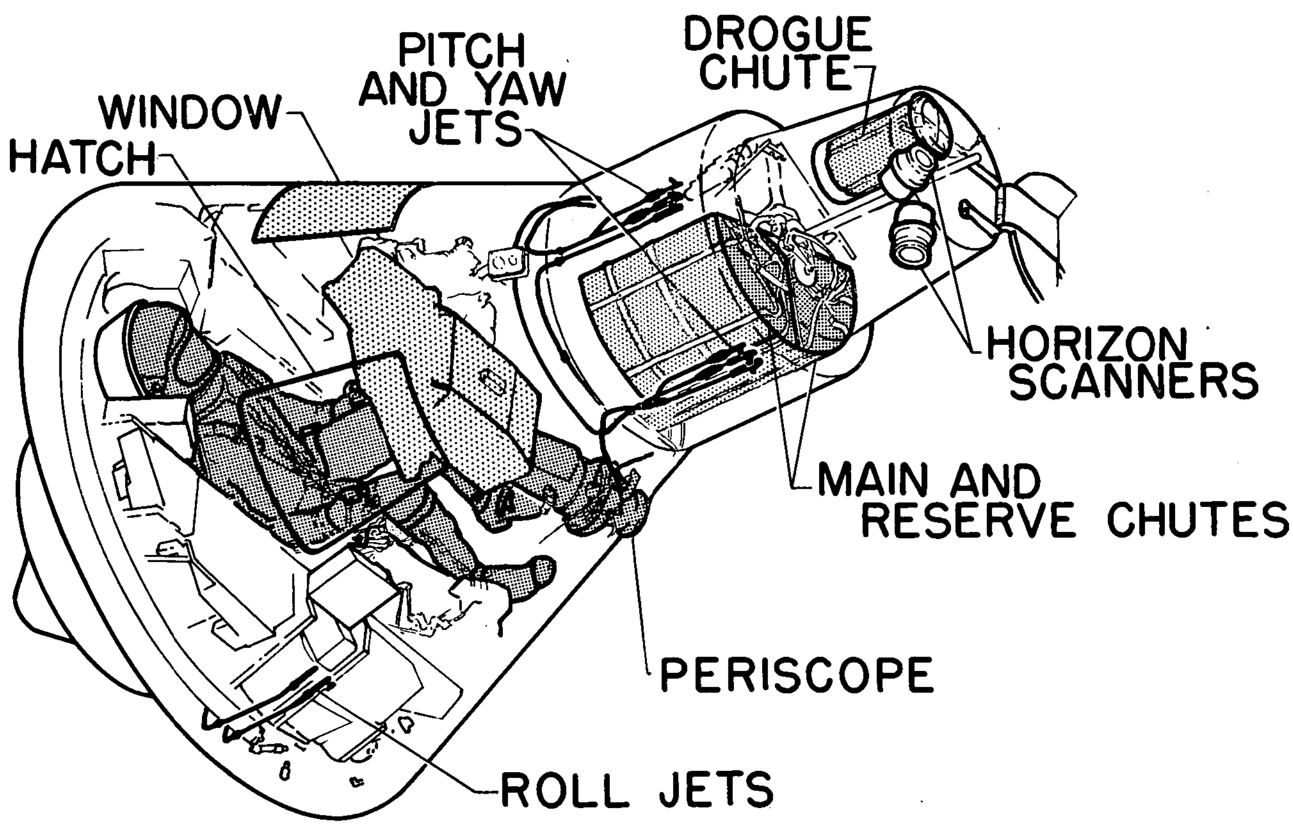

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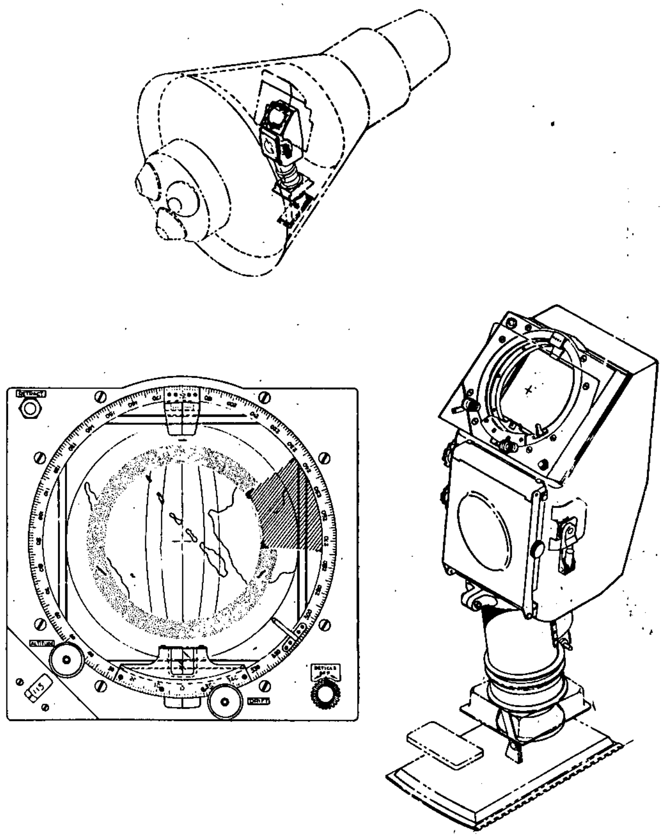
Figure 4.- Illustration of the spacecraft internal arrangement.



FUNCTION:

NAVIGATION INSTRUMENT

1. ATTITUDE
   (a) ERECTING ATTITUDE GYROS AS BACKUP TO SCANNERS
   (b) ORBIT, RETRO, AND REENTRY REFERENCE
2. EARTH POSITION
3. DRIFT ANGLE
4. ALTITUDE
5. SUN, MOON POSITION

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Figure 5.- Periscope and internal arrangement in spacecraft.

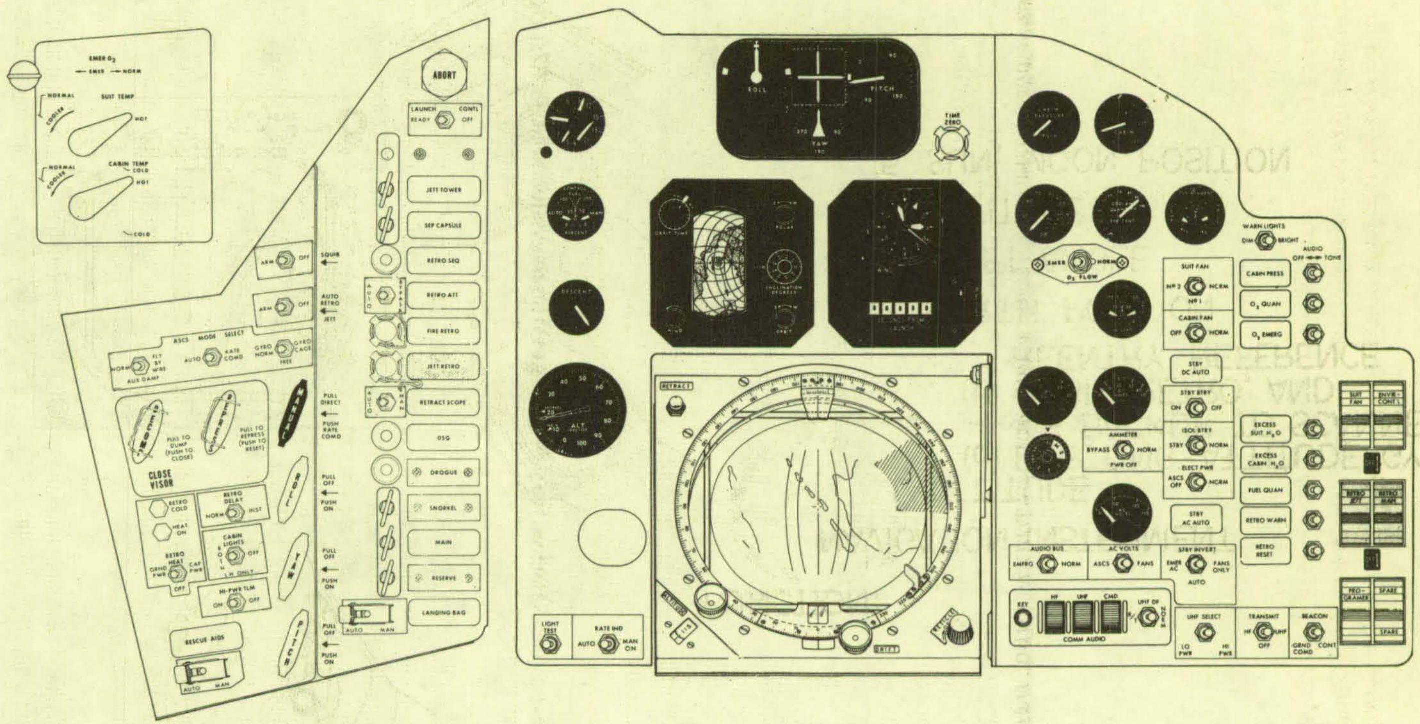

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Figure 6.- Main instrument panel and consoles for MR-4 spacecraft.

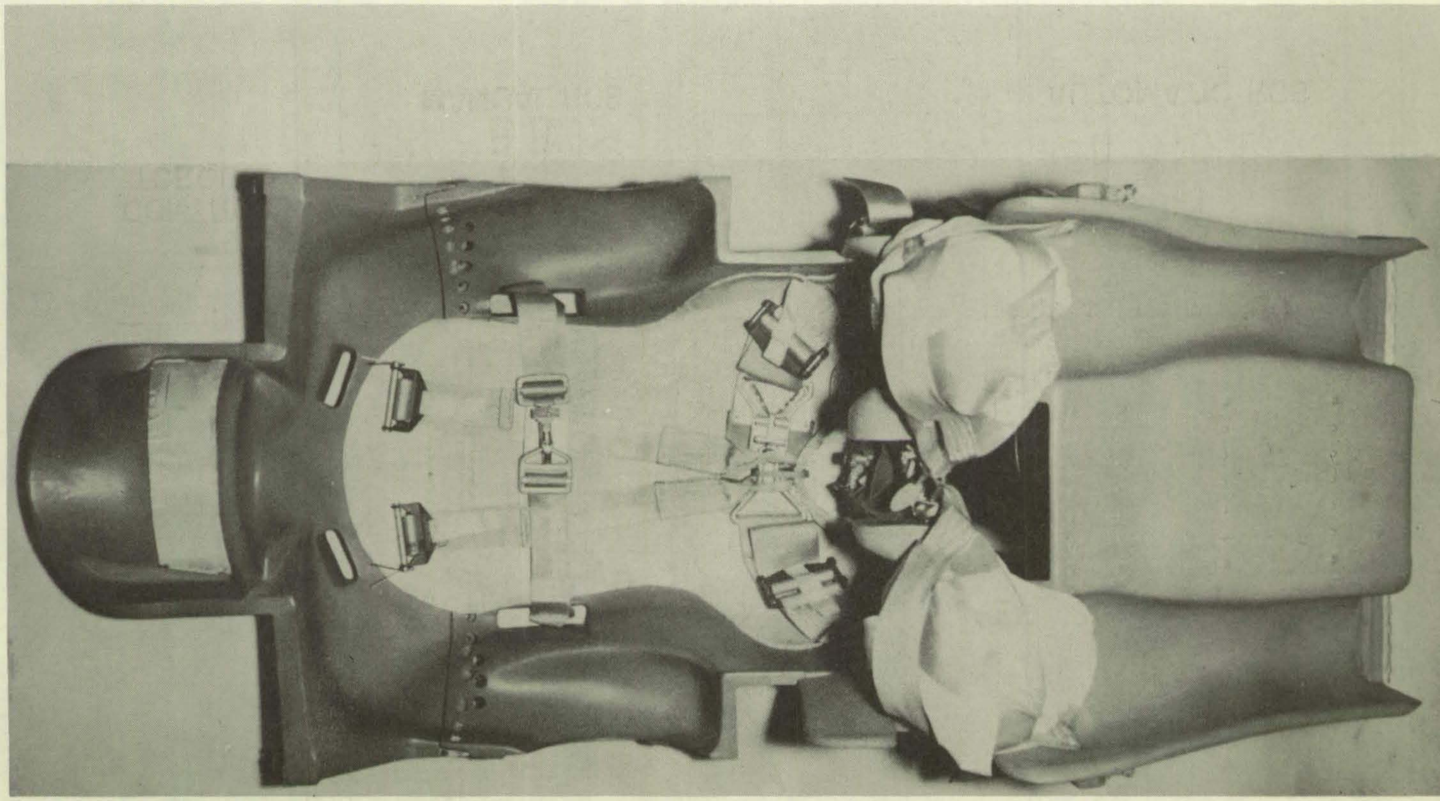

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Figure 7.- Astronaut's support couch.

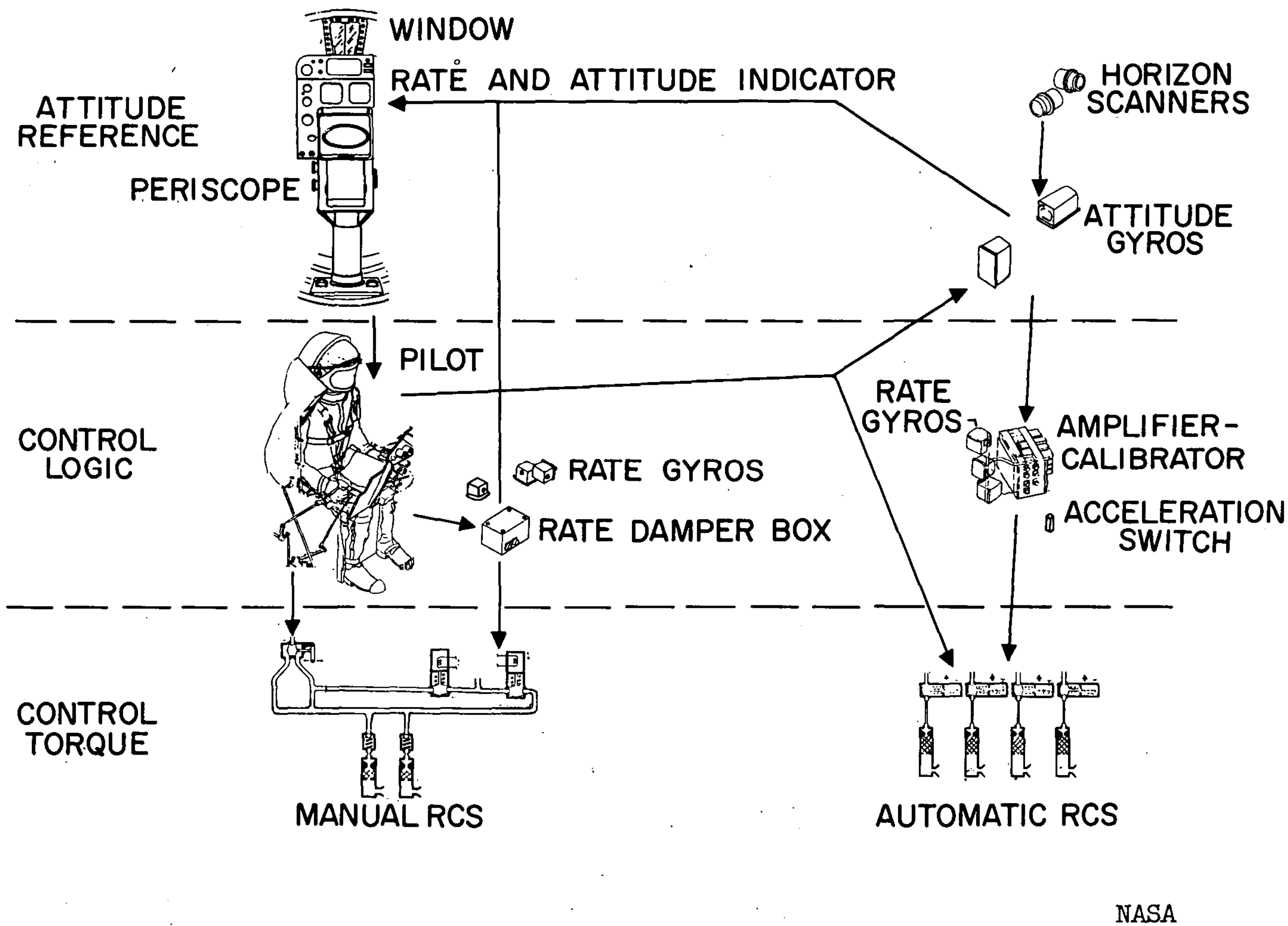

Figure 8.- Spacecraft attitude control system arrangement.

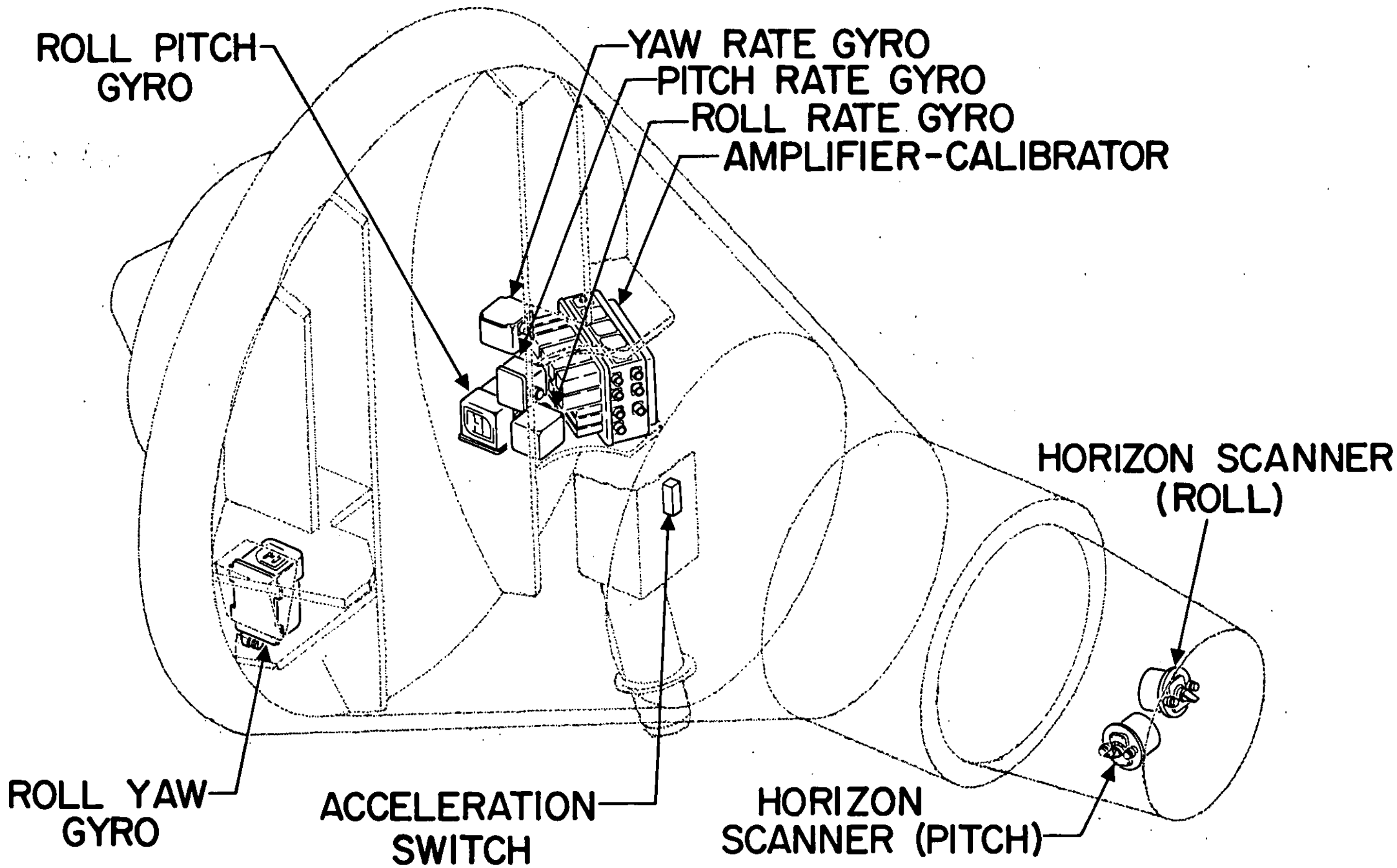

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Figure 9.- Automatic stabilization and control-system installation.

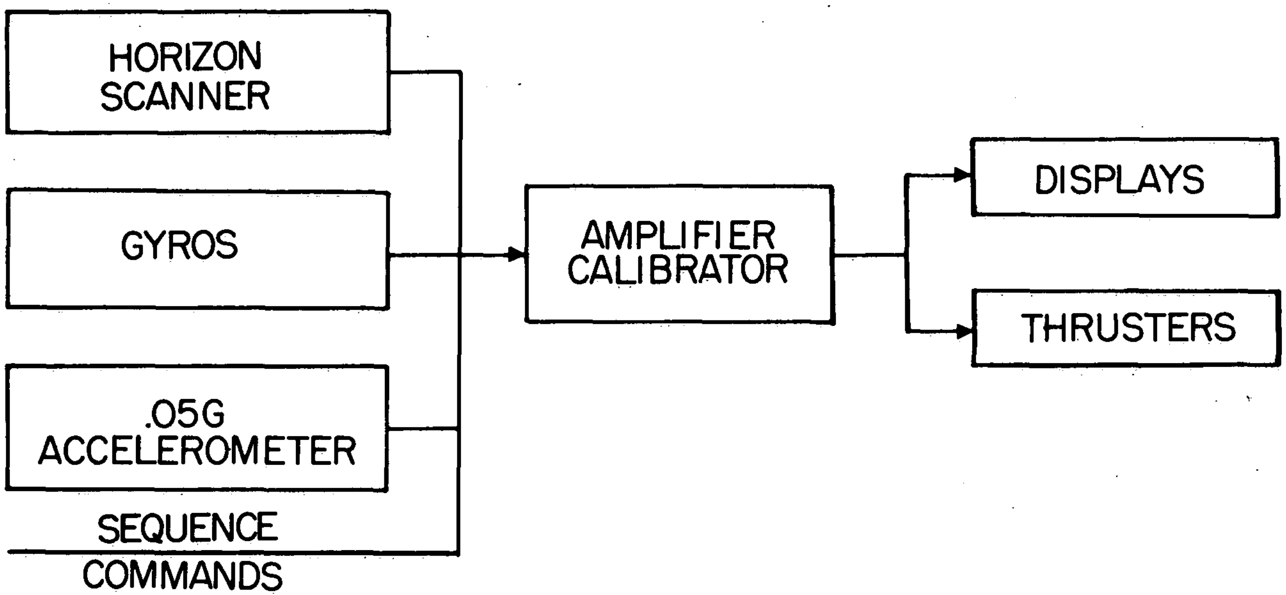

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Figure 10.- ASCS schematic block diagram.

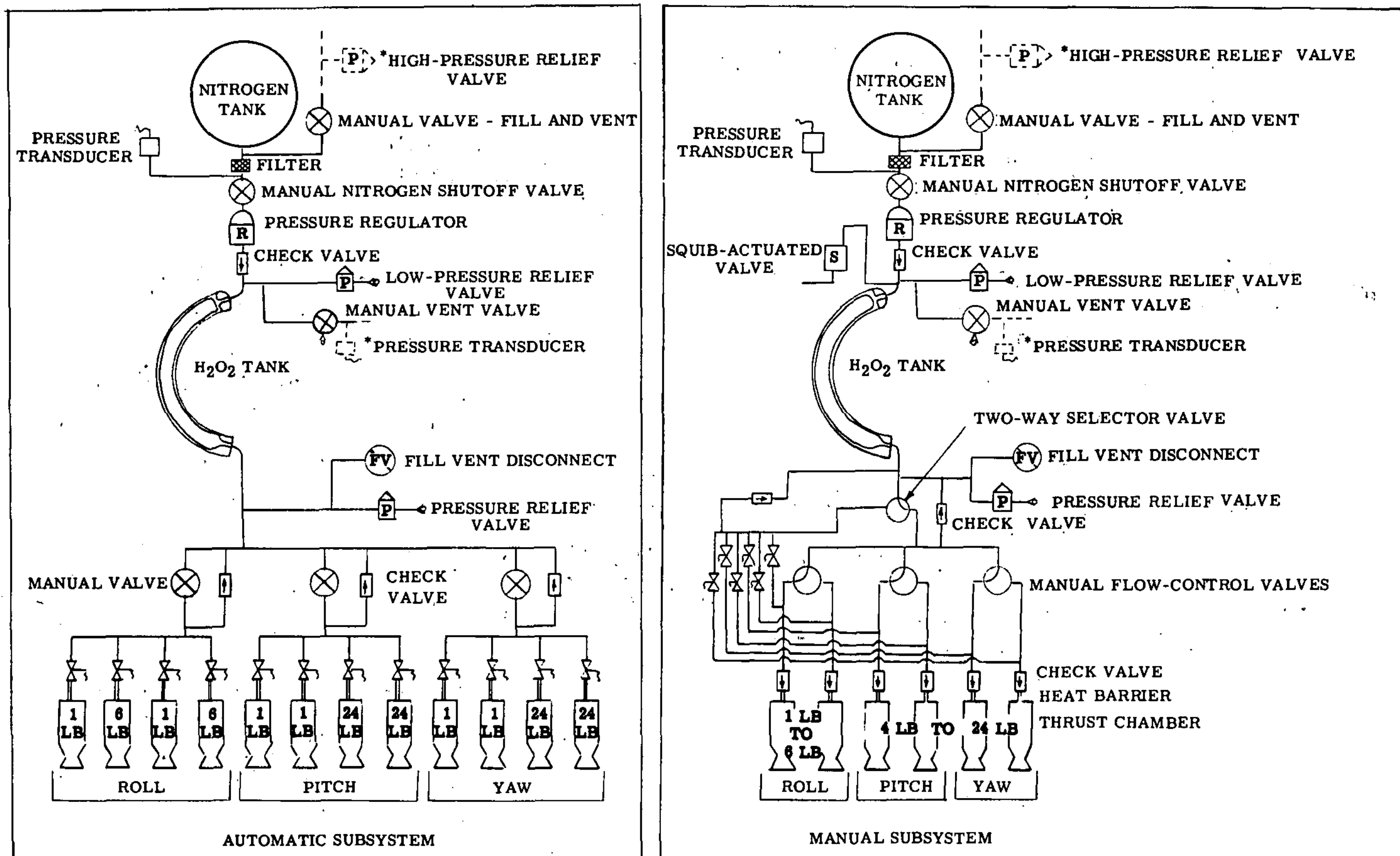

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Figure 11.- Reaction control system schematic.

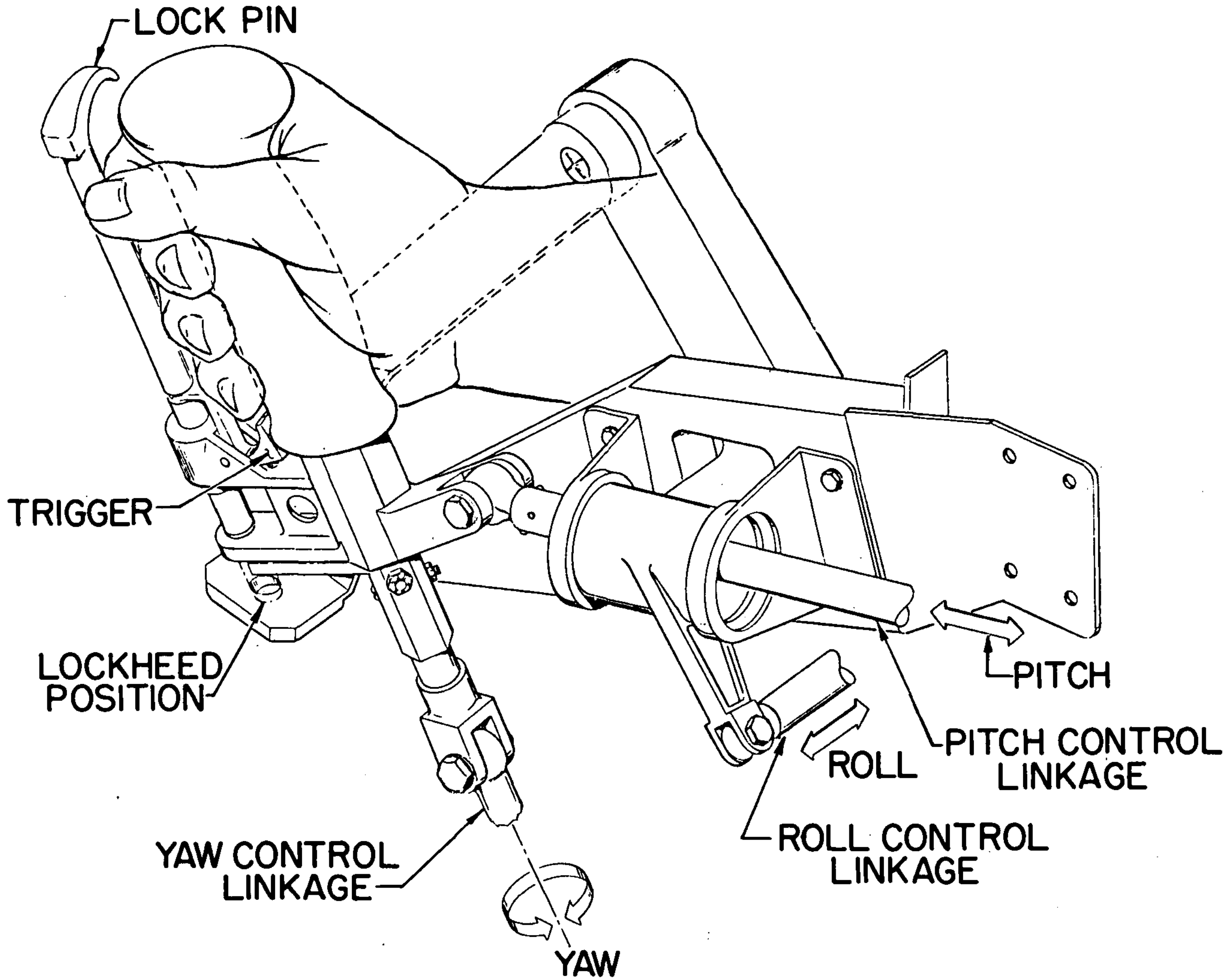

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Figure 12.- Three-axis hand controller.

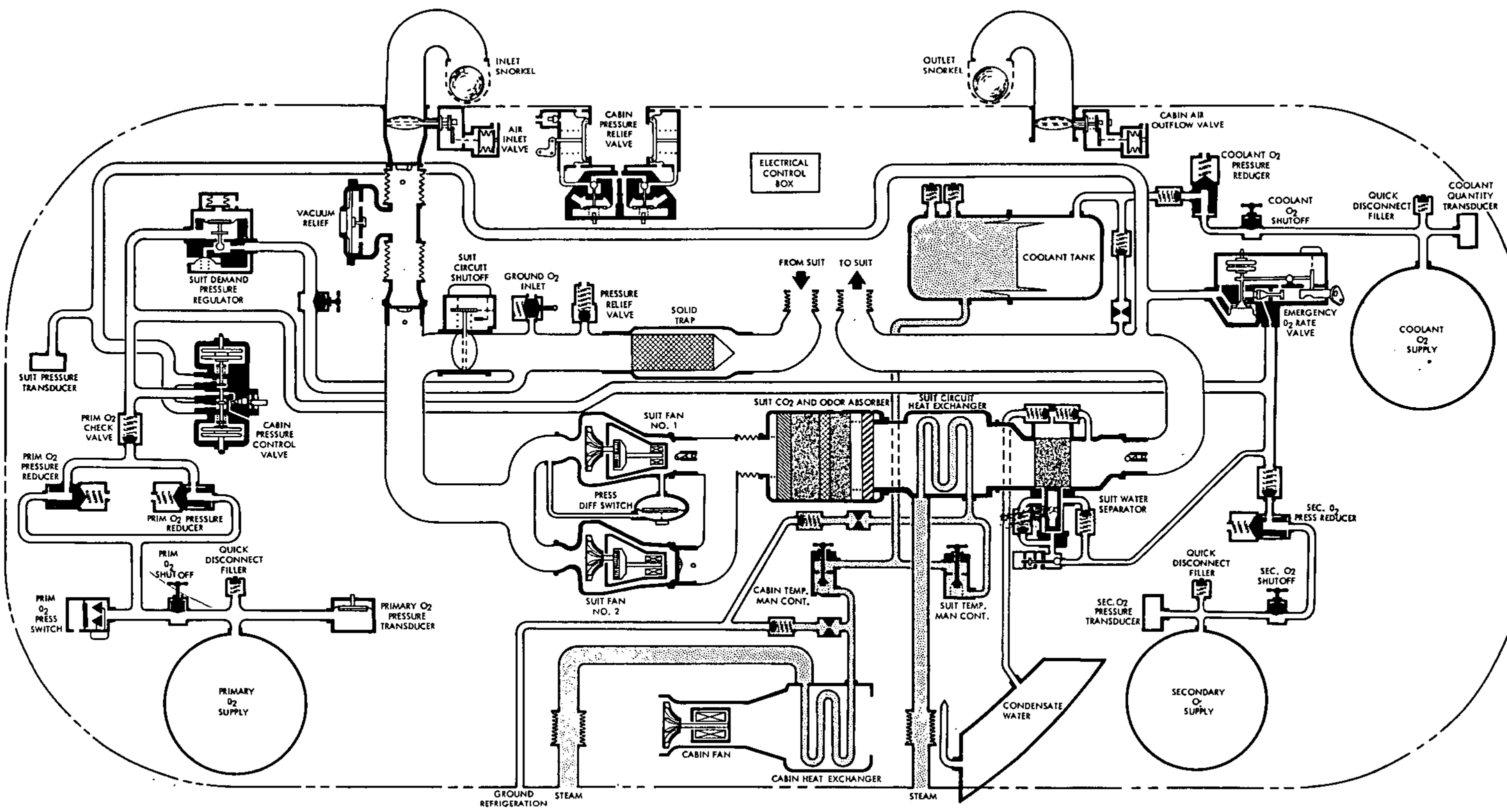

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Figure 13.- Environmental control system schematic.

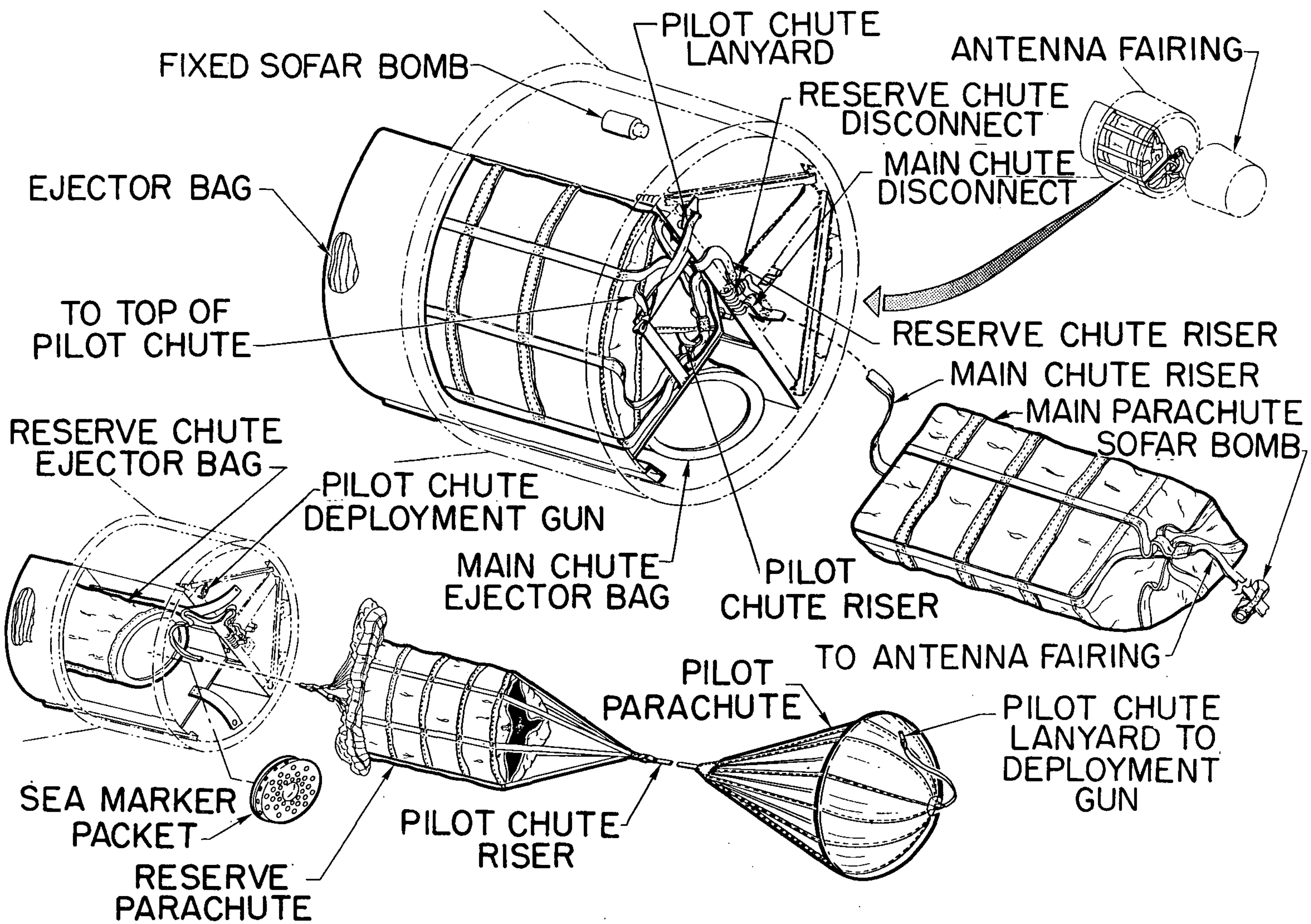

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Figure 14.- Main and reserve parachute system.

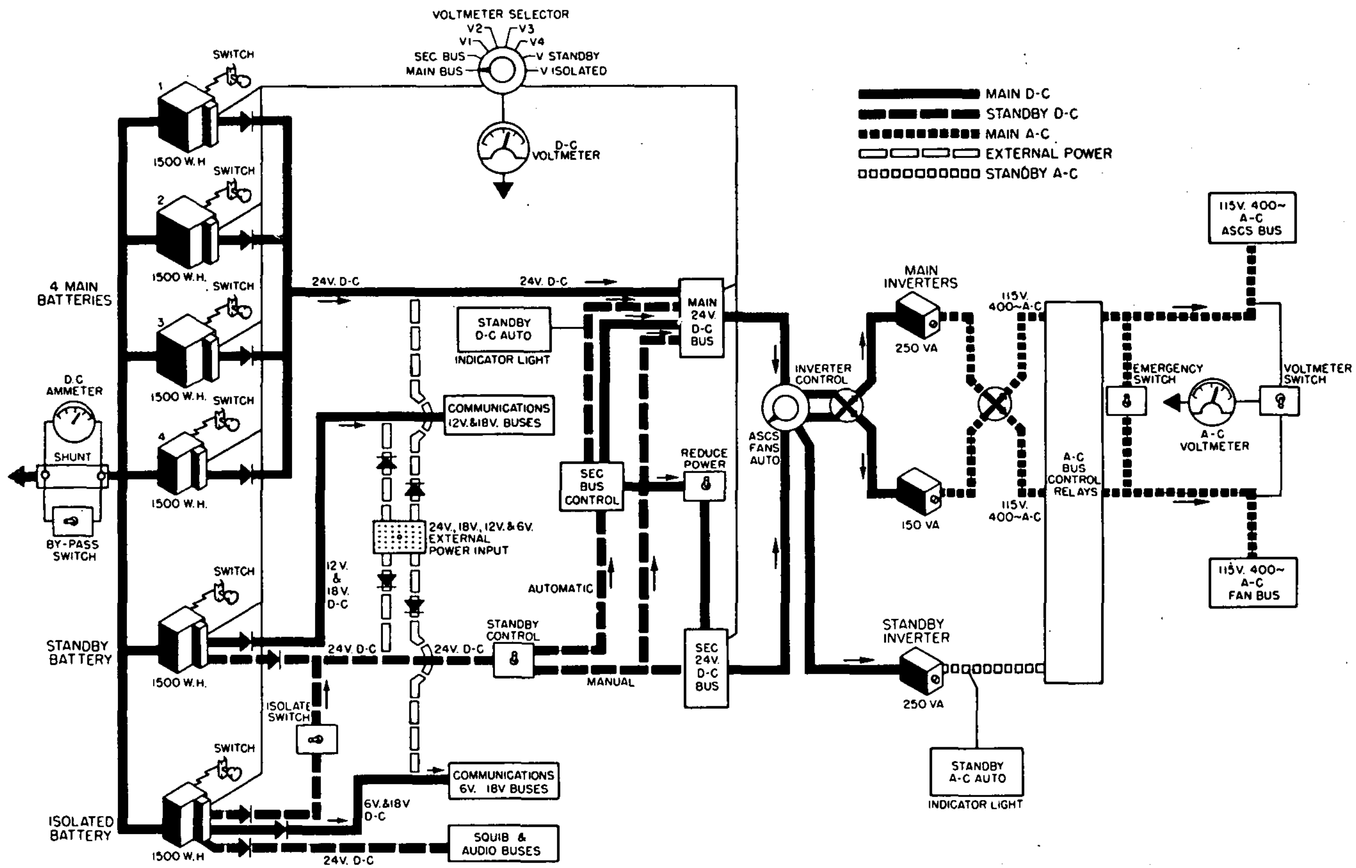

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Figure 15.- Schematic of electrical power system.

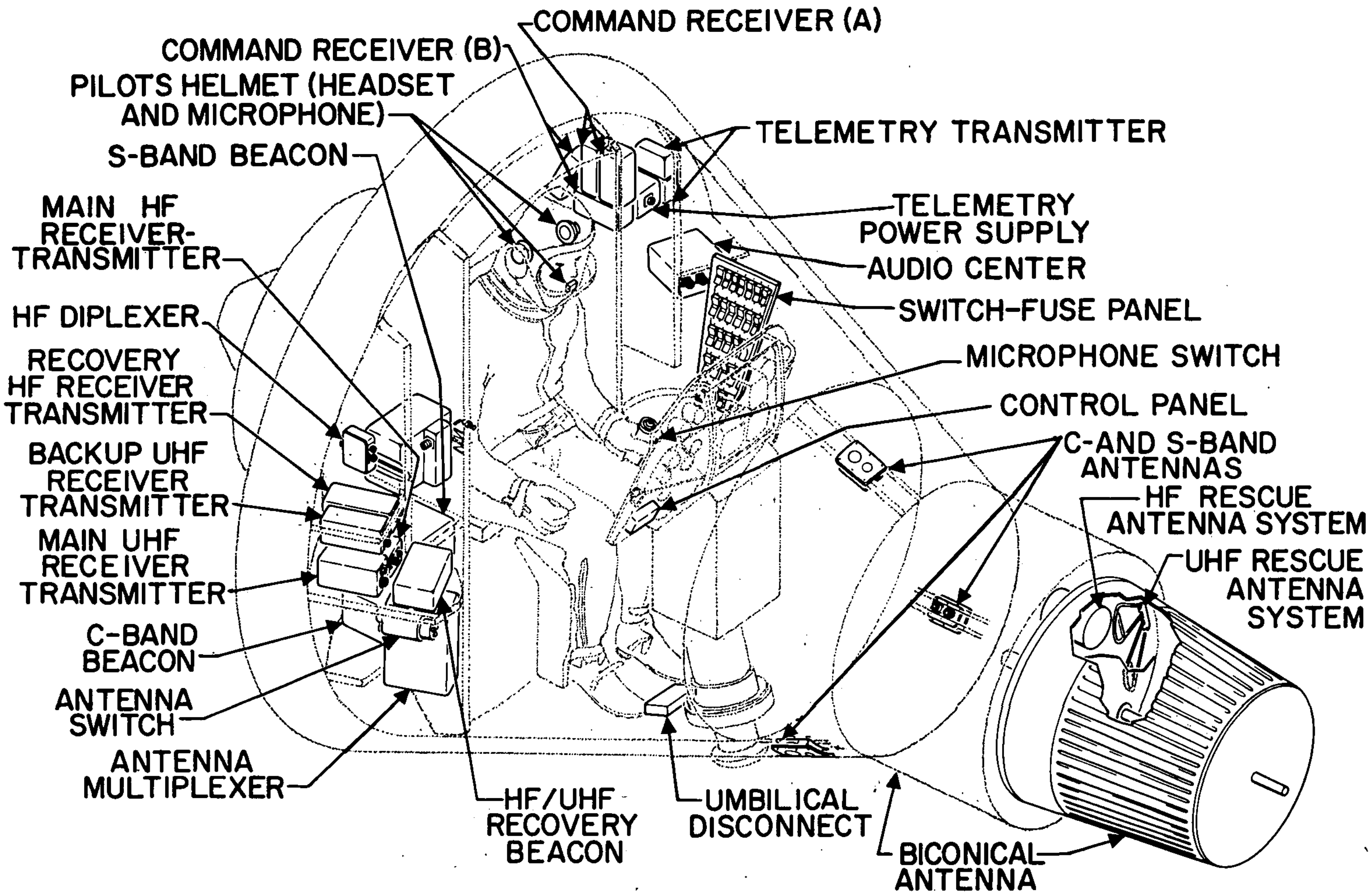

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Figure 16.- Communications, telemetry, and tracking equipment.

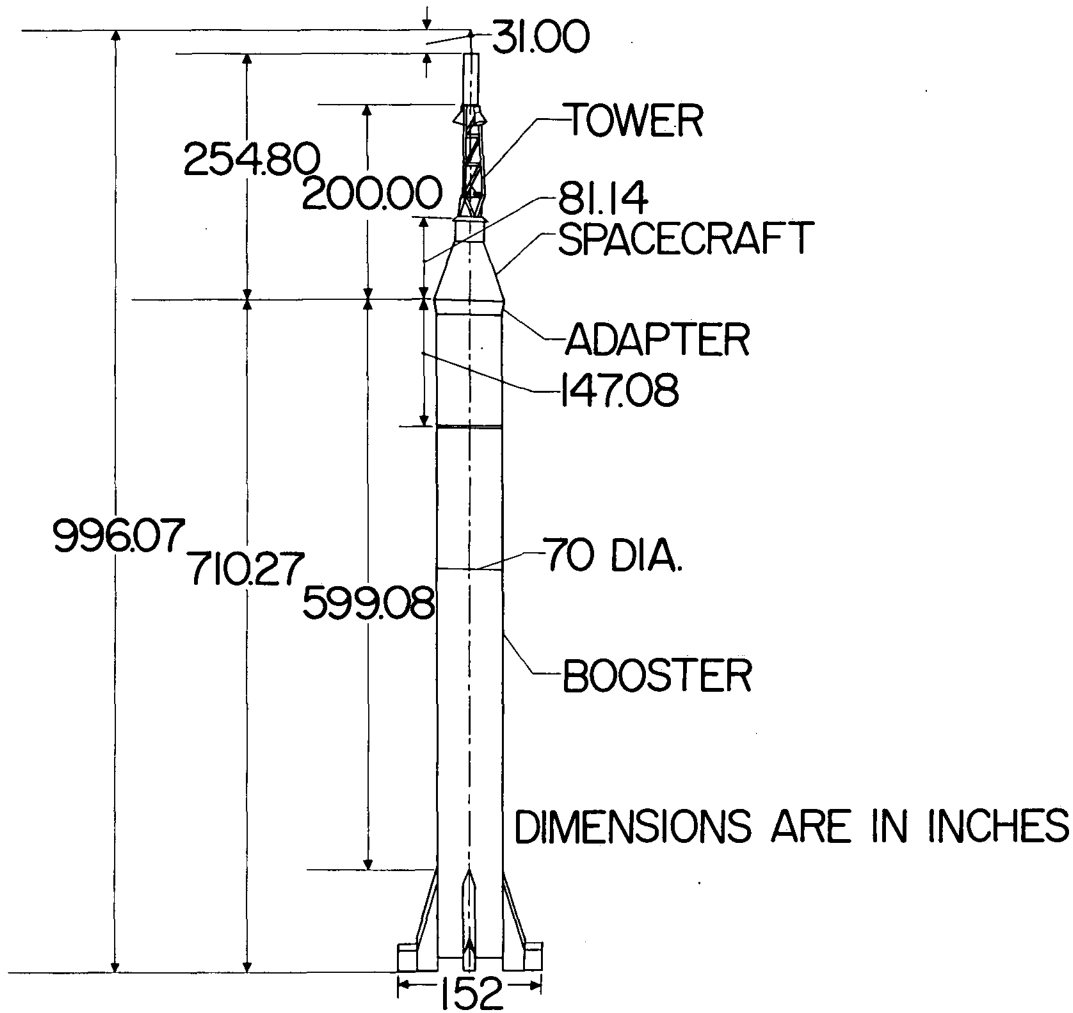

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Figure 17.- Mercury-Redstone spacecraft booster configurations.

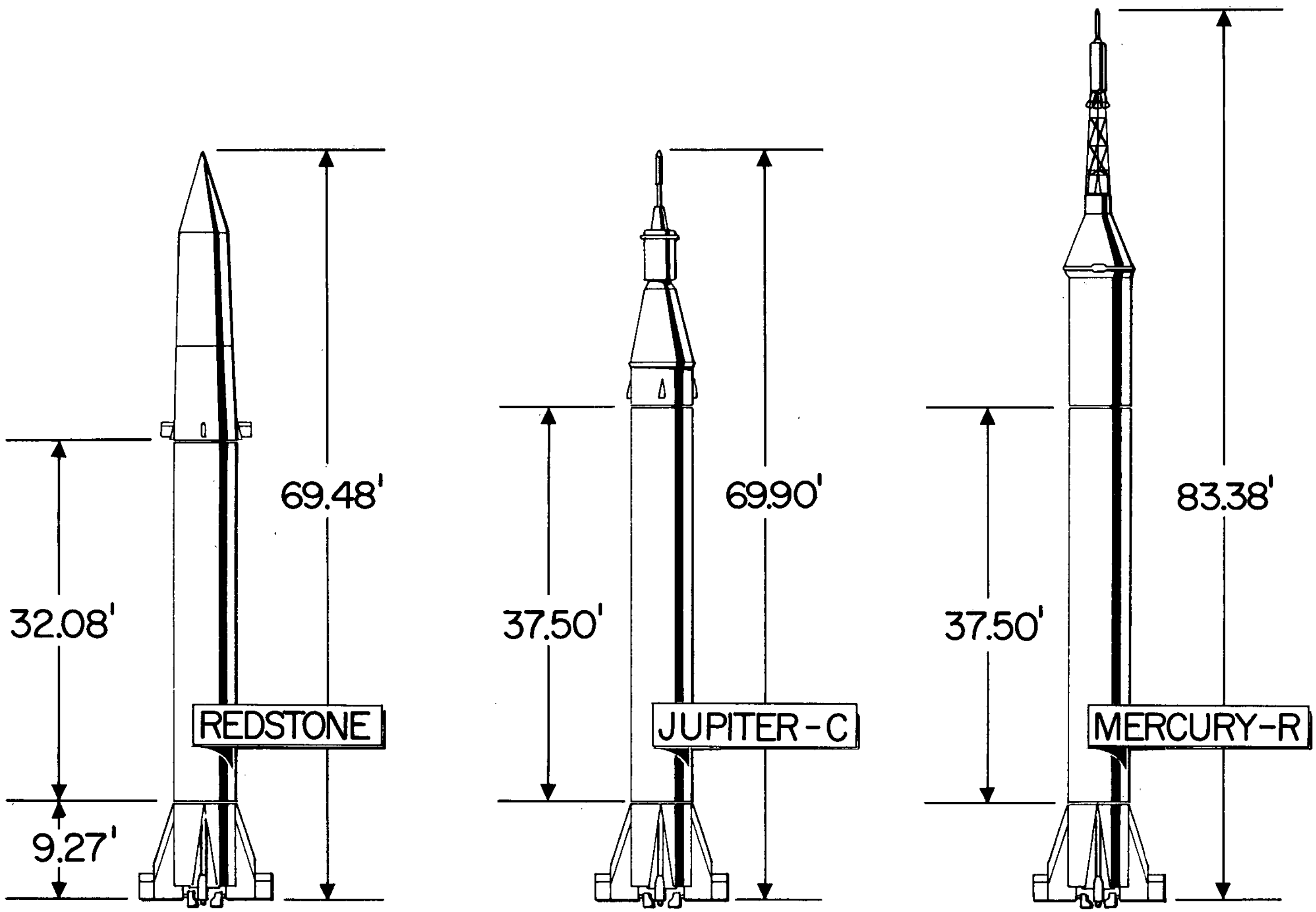

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Figure 18.- Configuration comparison of Redstone vehicles.

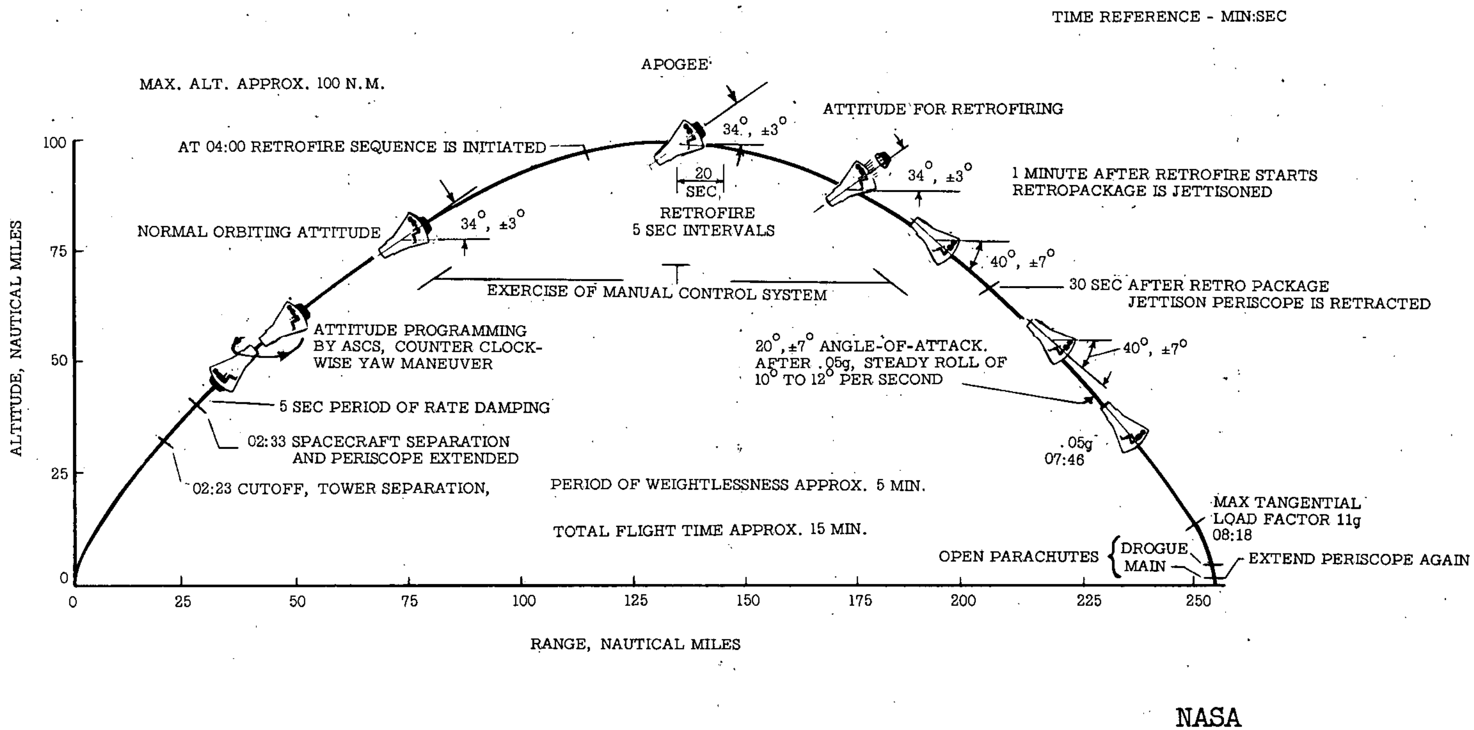

Figure 19.- Mercury-Redstone flight plan.

QUANTITY	PLANNED	MR-3	MR-4
RANGE, N. M.	258	263.1	262.5
MAXIMUM ALTITUDE N. M.	101	101.2	102.8
MAXIMUM EXIT DYNAMIC PRESSURE LB/SQ FT	598	586	605.5
MAXIMUM EXIT LONGITUDINAL LOAD FACTOR, G	6.3	6.3	6.3
MAXIMUM RE-ENTRY LONGITUDINAL LOAD FACTOR, G	10.9	11.0	11.1
PERIOD OF WEIGHTLESSNESS MIN:SEC	05:00	05:04	05:00
EARTH-FIXED VELOCITY FT/SEC	6380 (MR-3) 6540 (MR-4)	6414	6561
SPACE-FIXED VELOCITY FT/SEC	7302 (MR-3) 7499 (MR-4)	7388	7516

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Figure 20.- Comparison of actual and planned flight parameters.

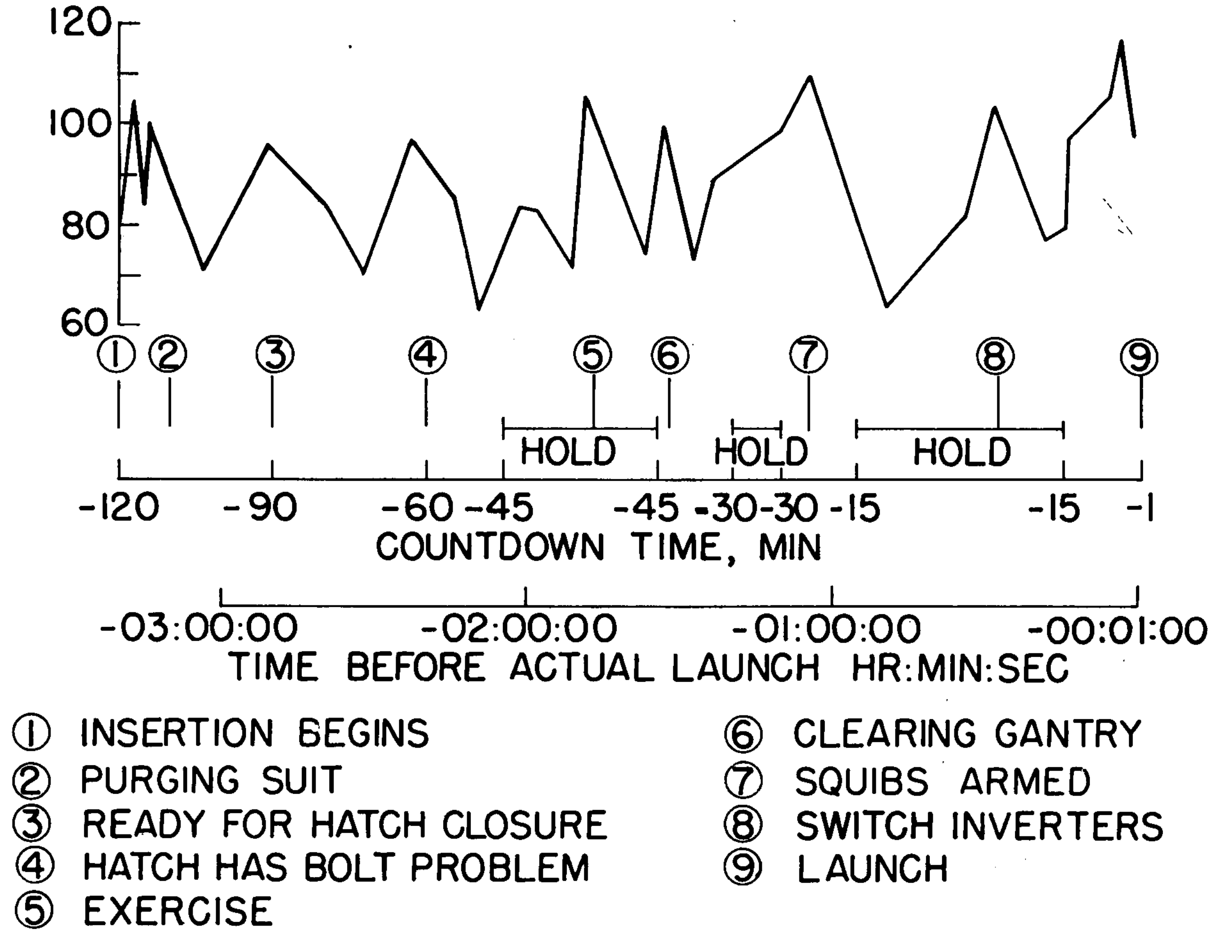

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Figure 21.- Pulse rate for MR-4 during countdown.

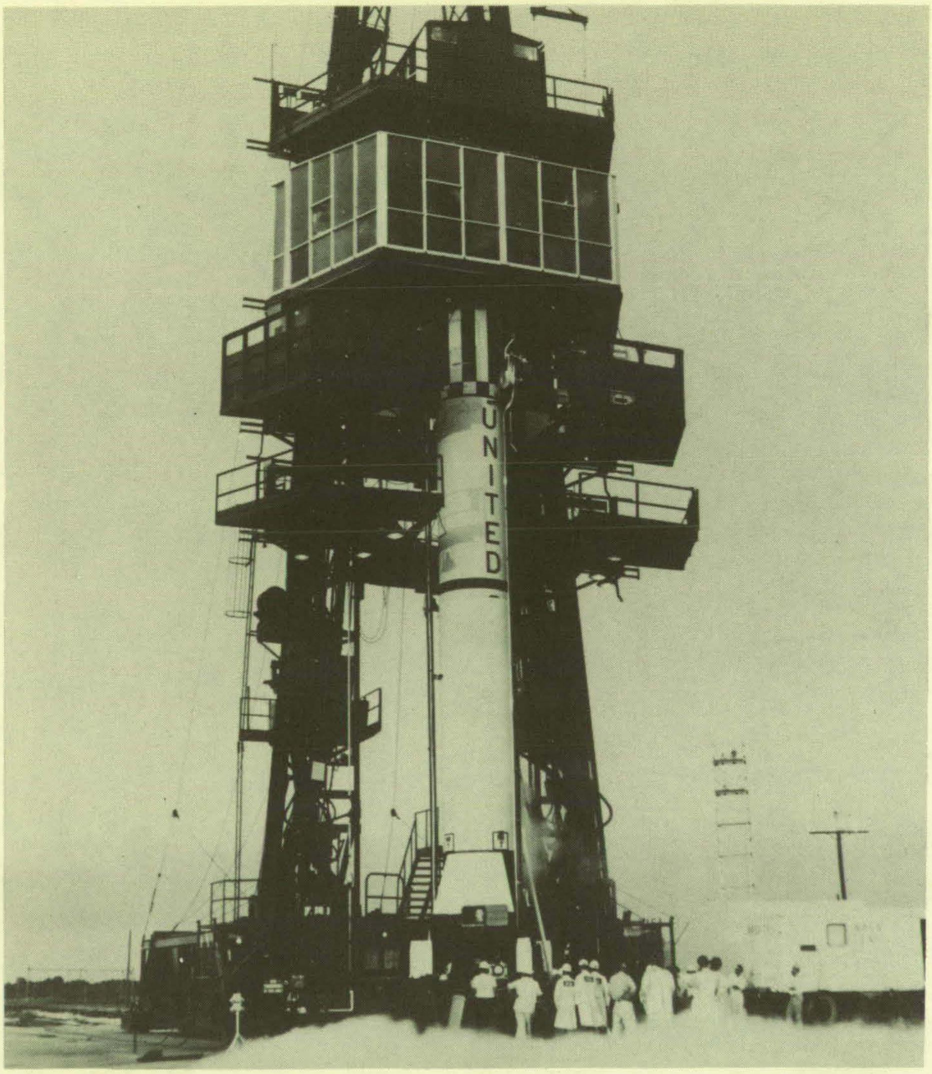

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Figure 22.- Photograph of spacecraft in white room enclosure.

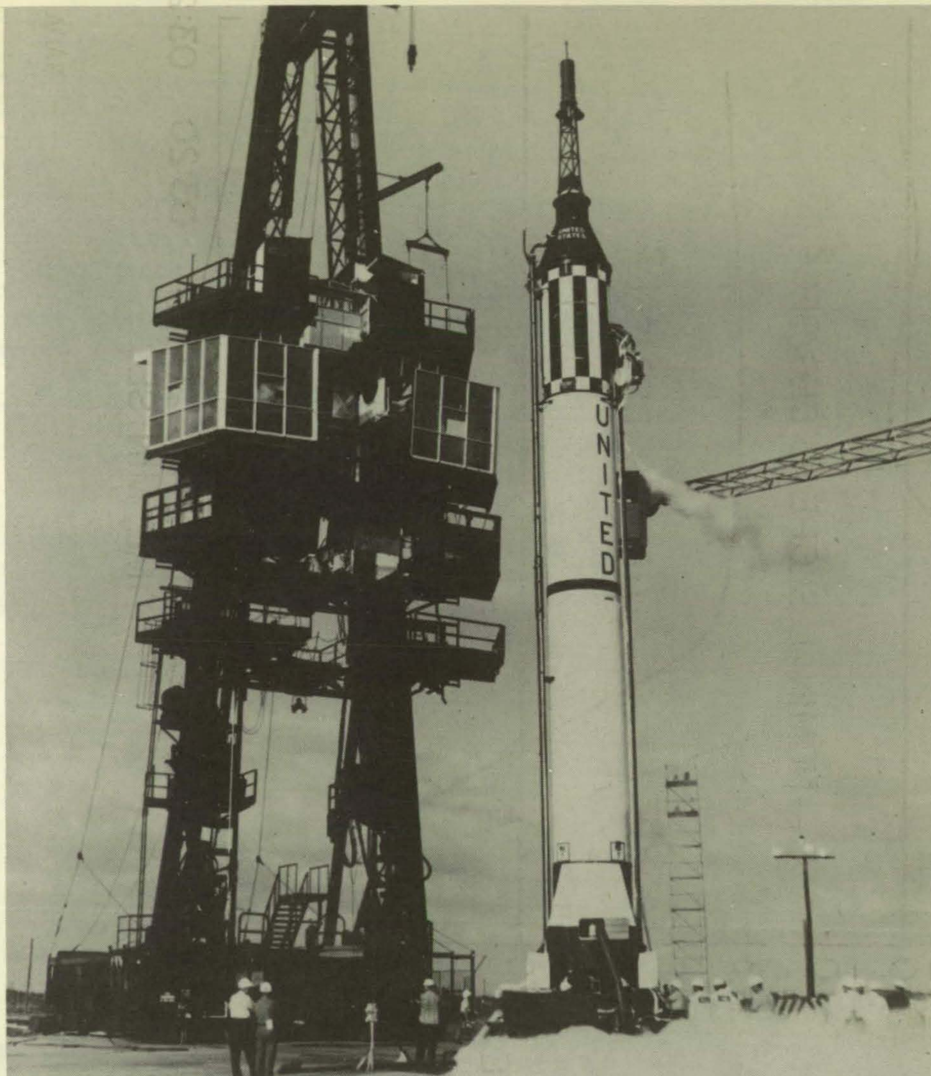

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Figure 23.- Photograph of white room enclosure open and gantry moved back.

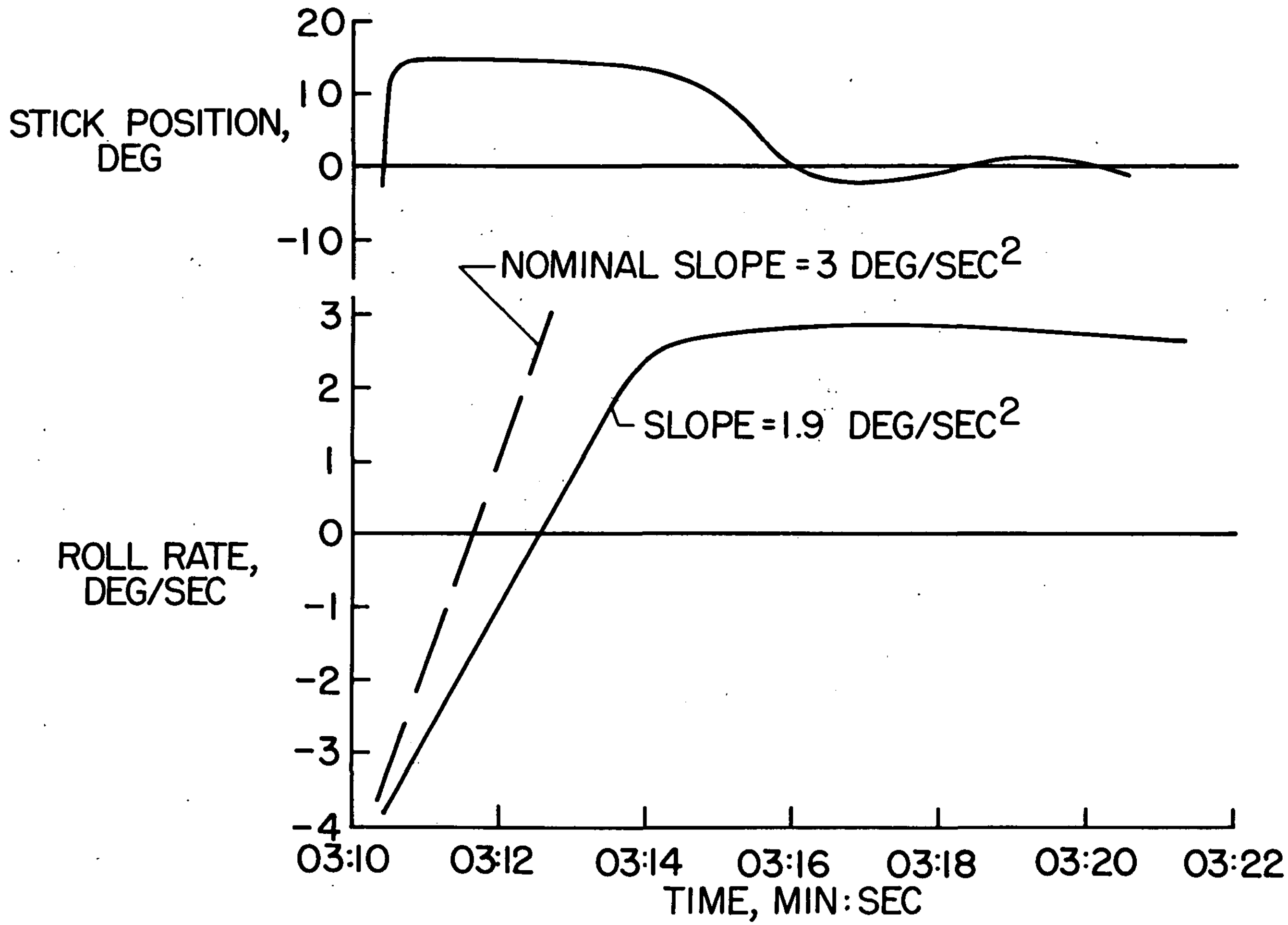

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Figure 24.- Example of manual proportion control response.

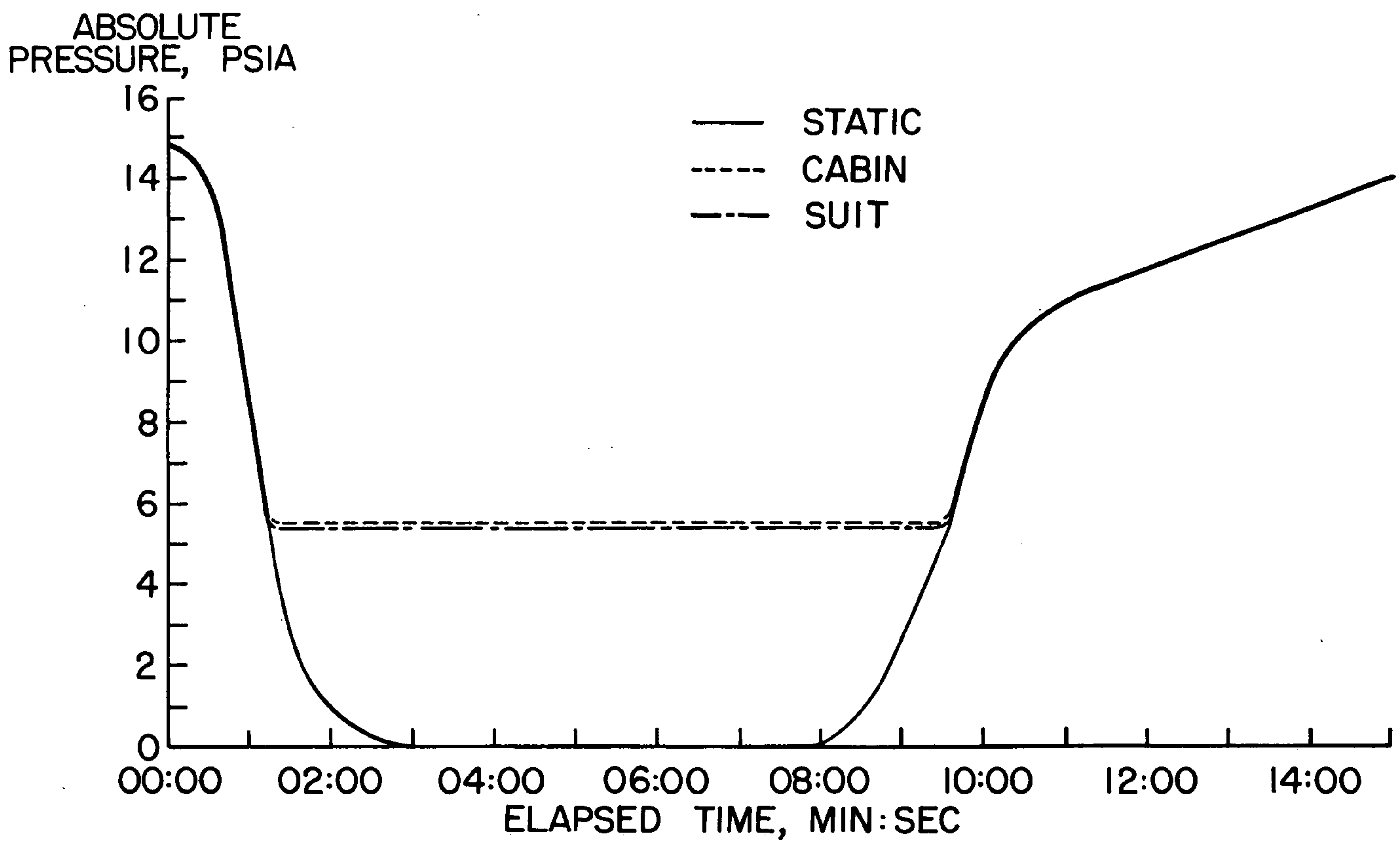

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Figure 25.- Variation of static, cabin, and suit pressure.

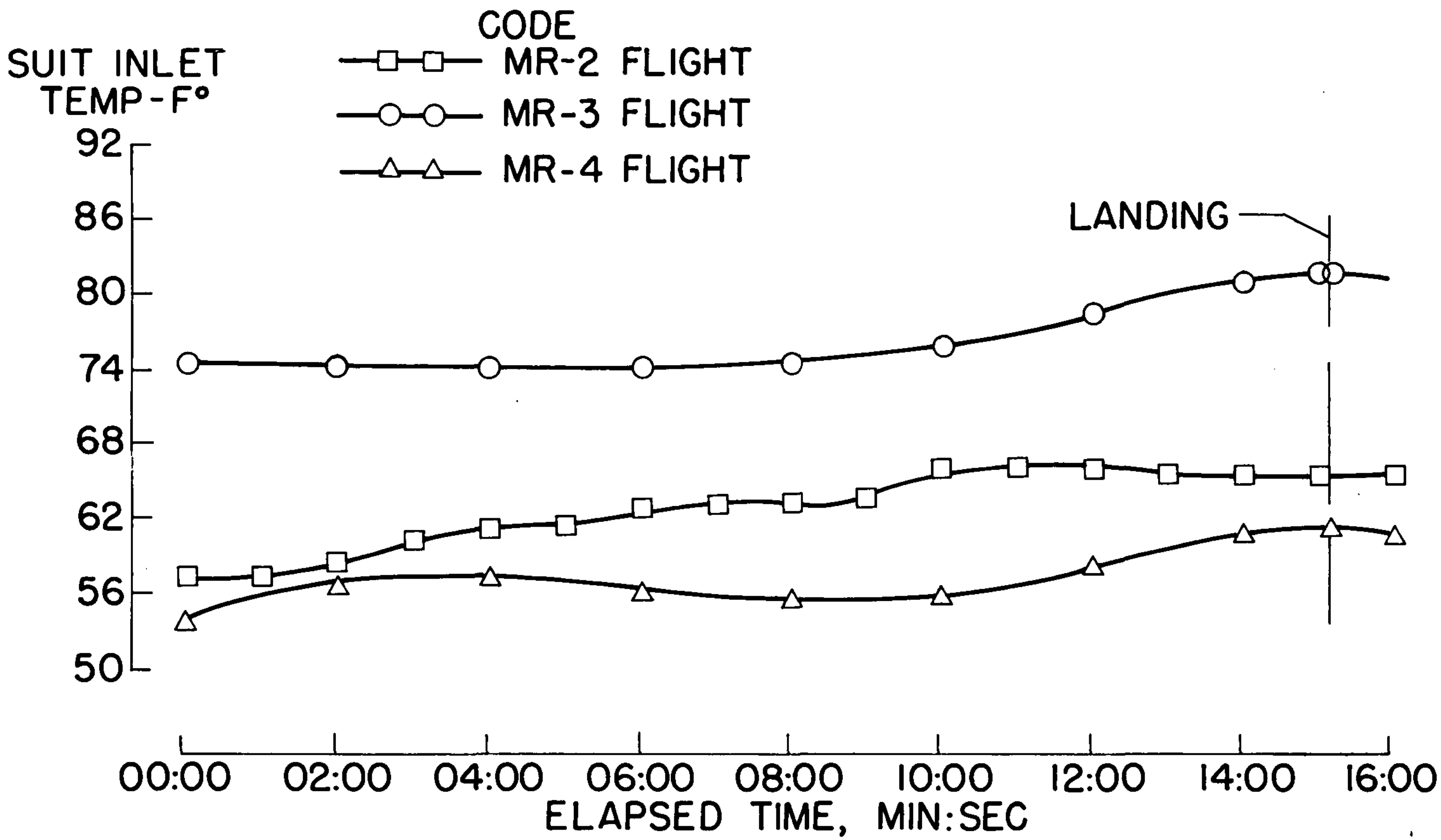

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Figure 26.- Variation of suit inlet temperature with time.

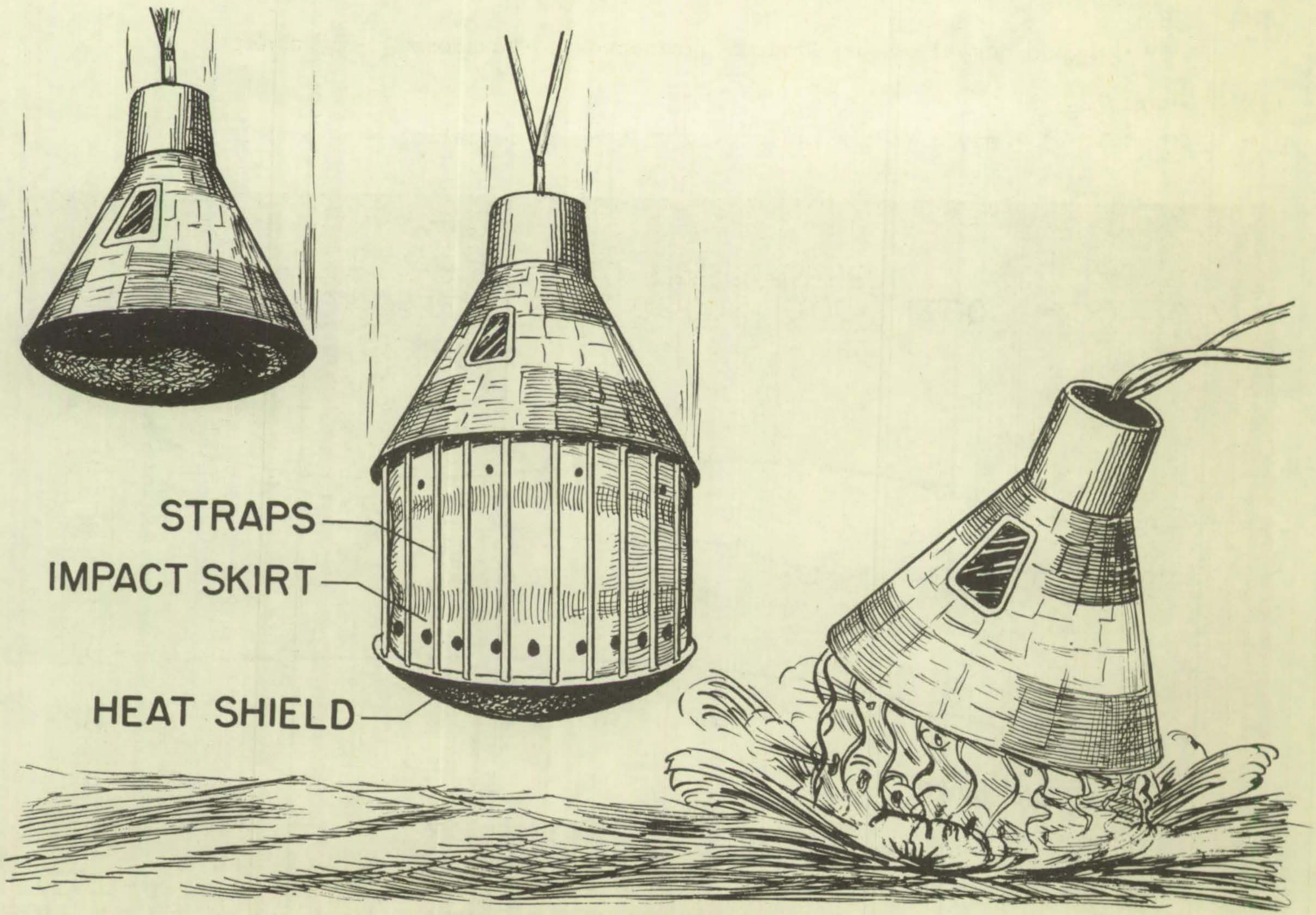

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Figure 27.- Illustration of landing bag.

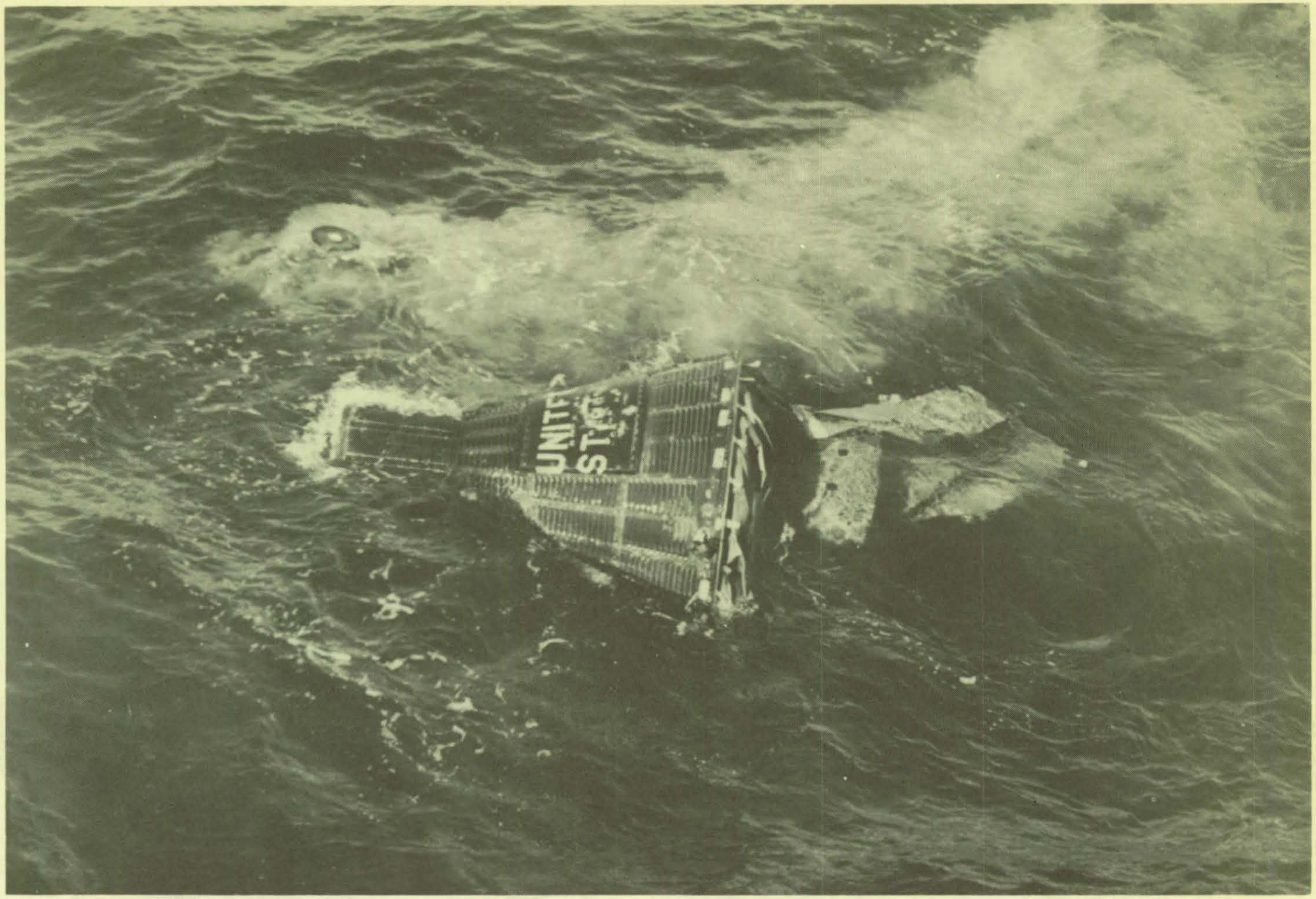

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Figure 28.- Photograph of spacecraft shortly before pickup on MR-2.

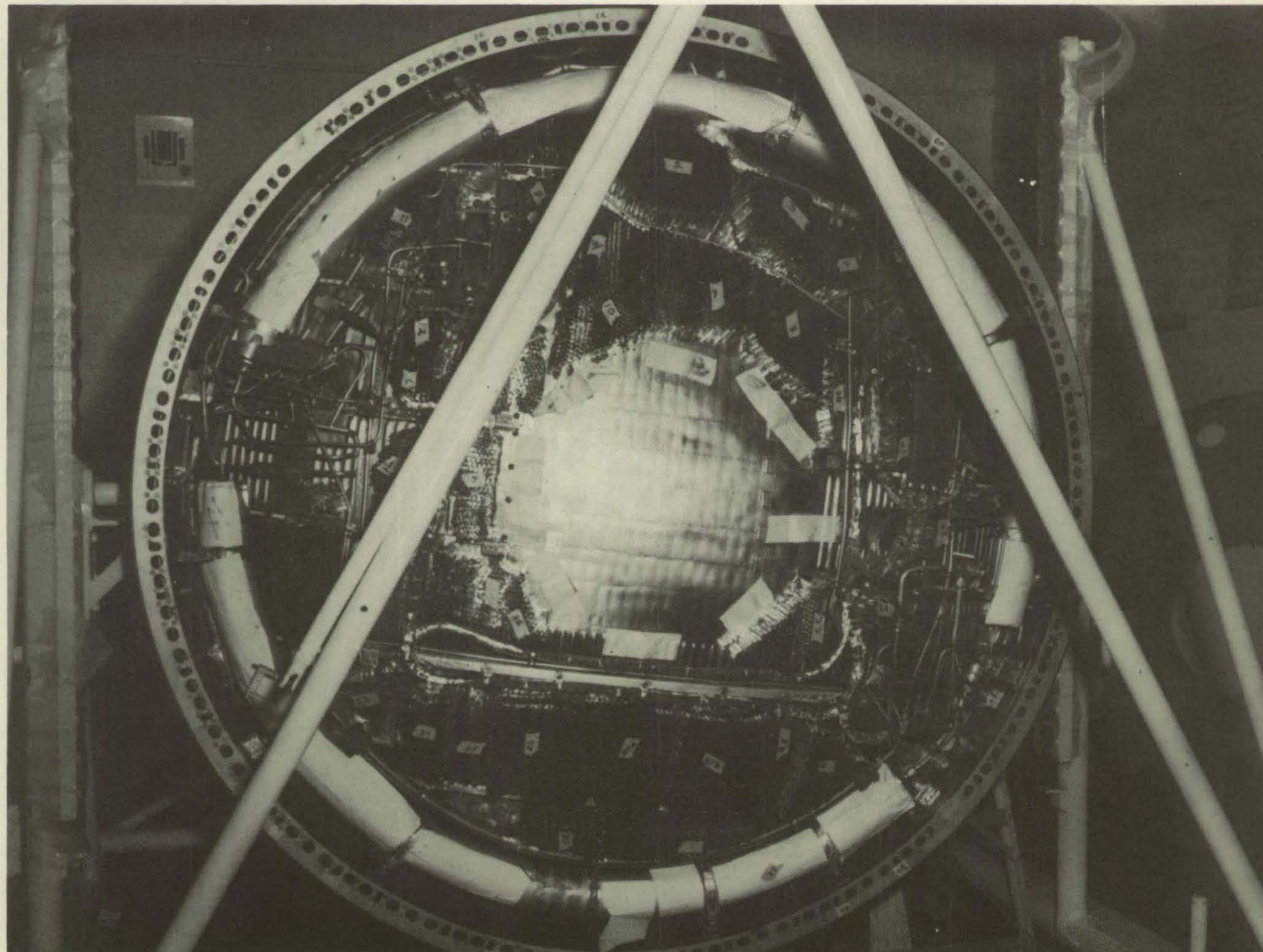

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Figure 29.- Protection of tower pressure bulkhead.

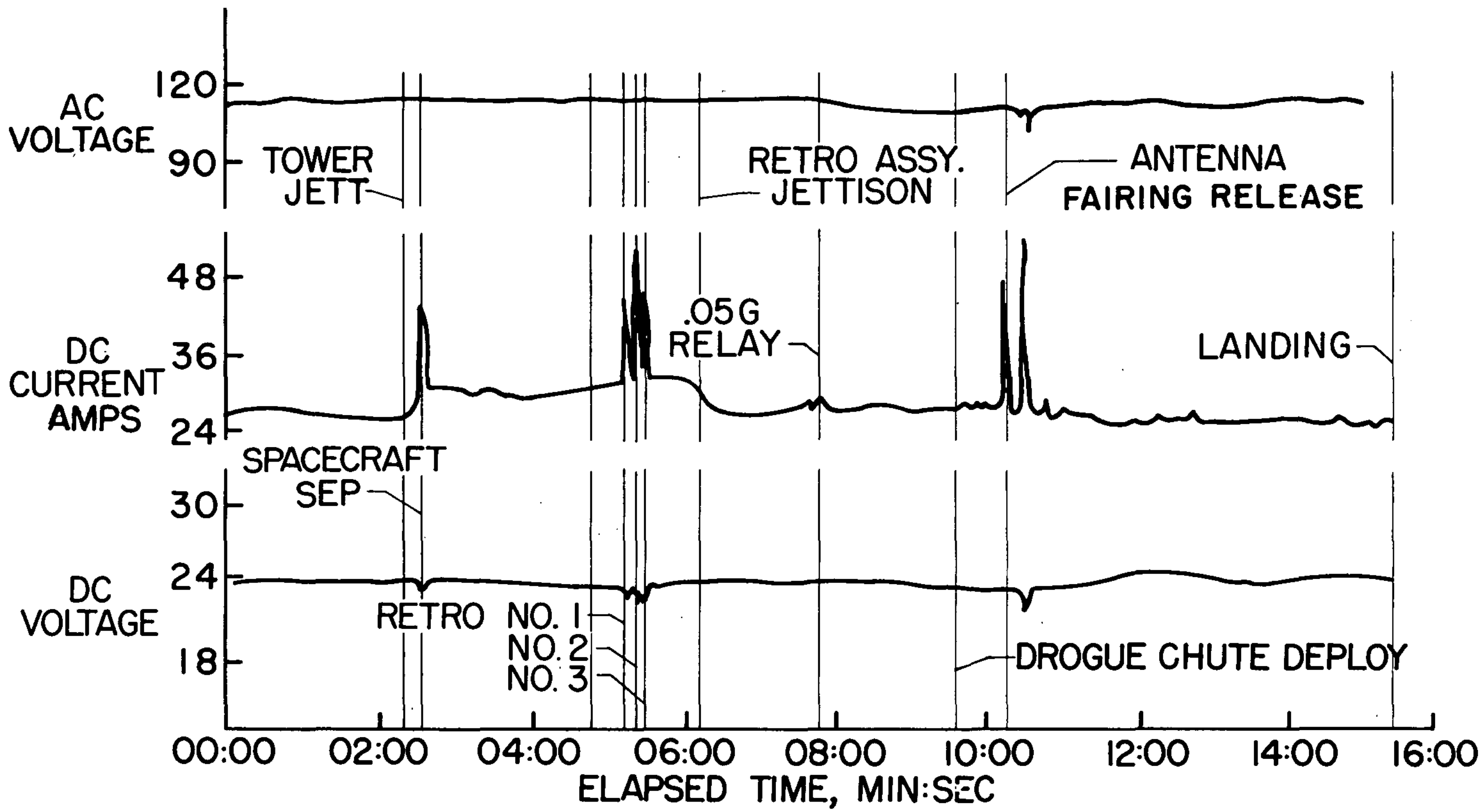

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Figure 30.- Time histories of d-c current, d-c and a-c voltage for MR-4.

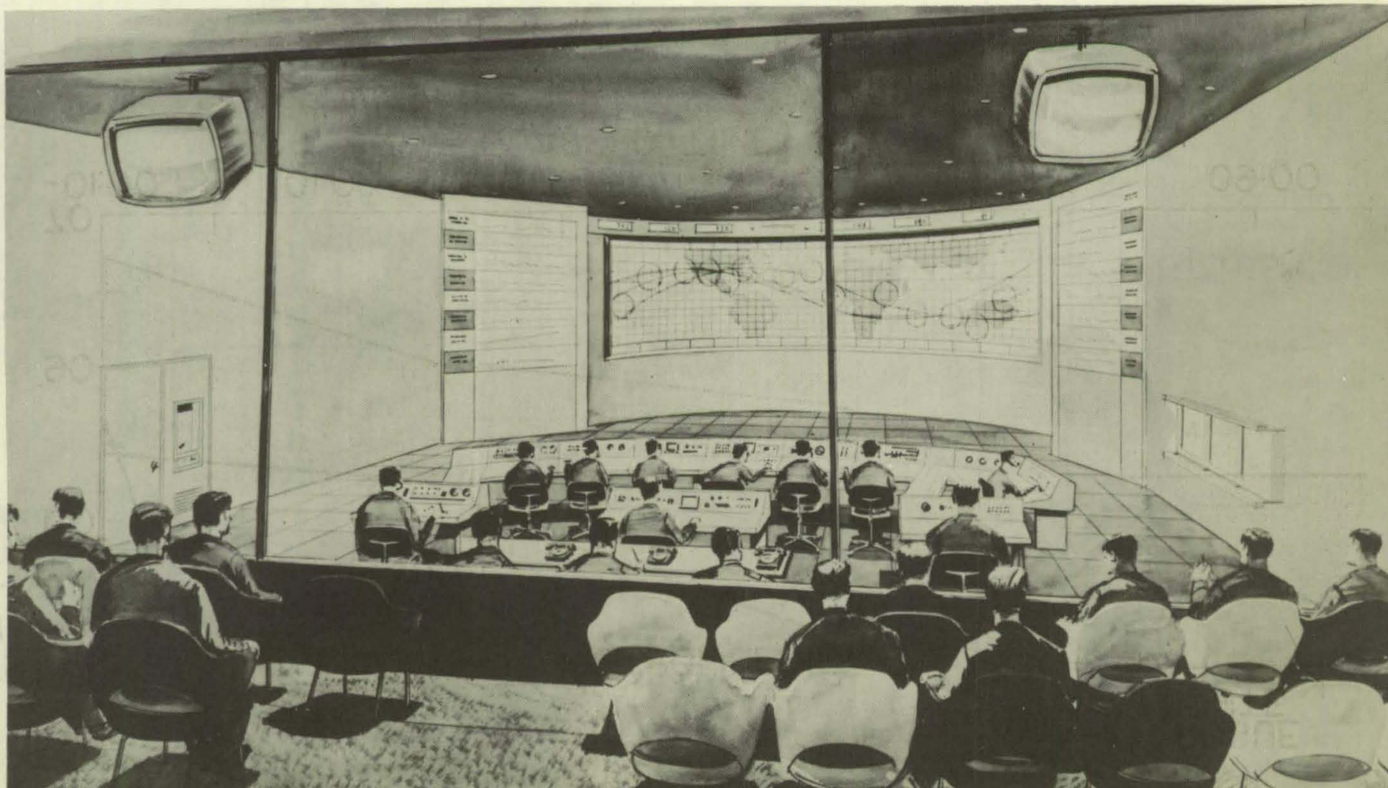

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Figure 31.- Illustration of Mercury control center arrangement.

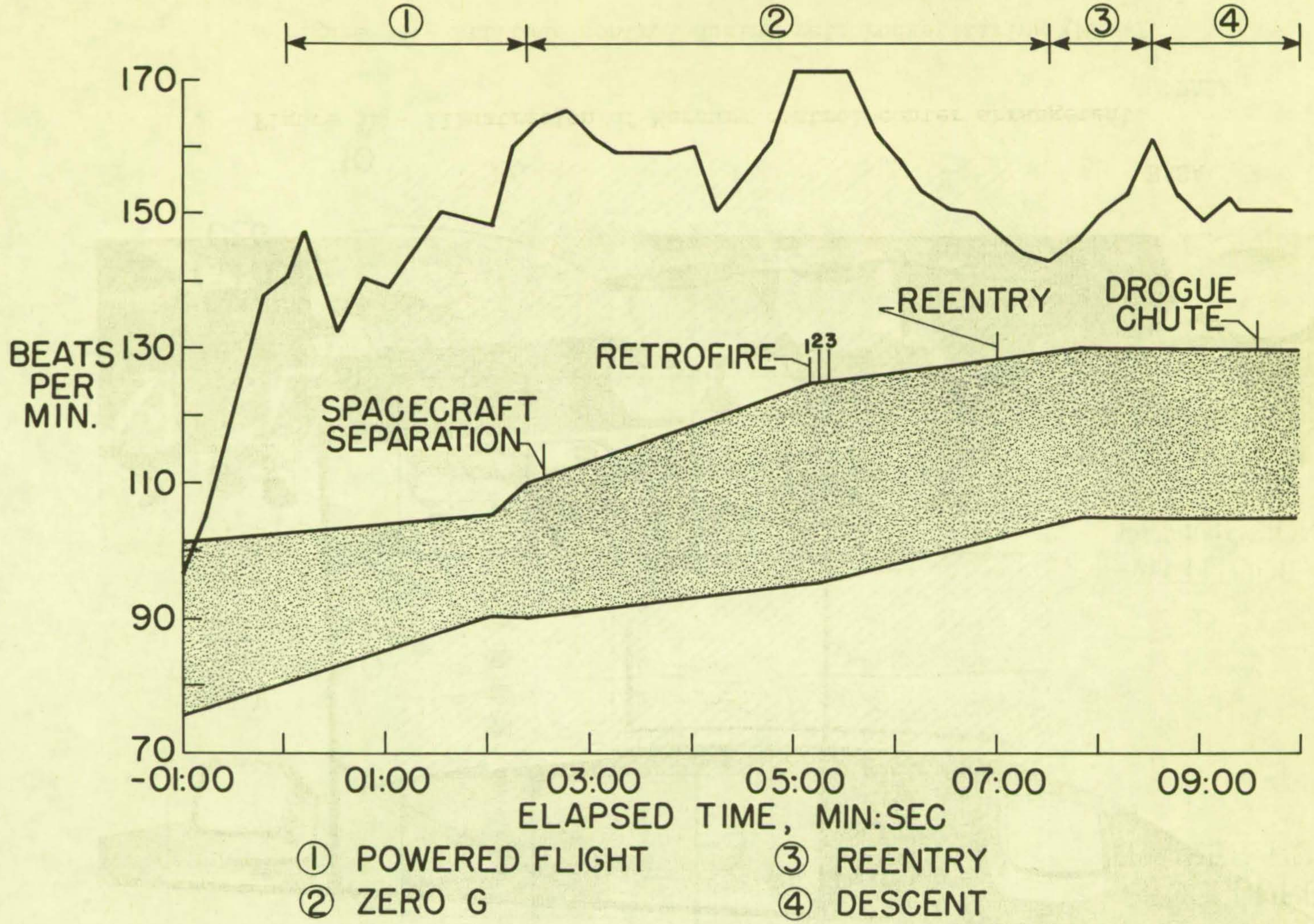

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Figure 32.- Pulse rate during MR-4 flight.

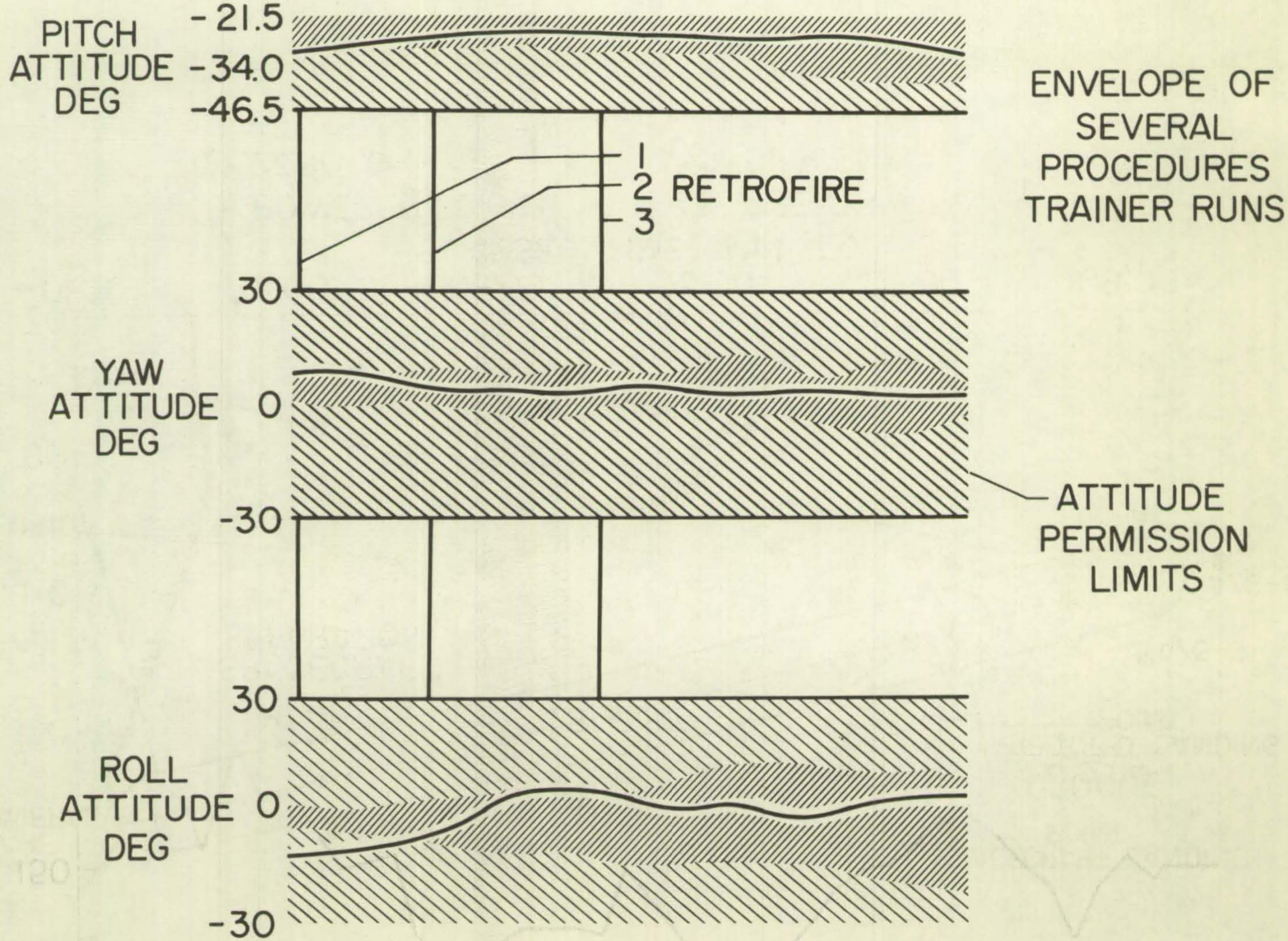

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Figure 33.- Attitude control during retrorocket firing (MR-4).

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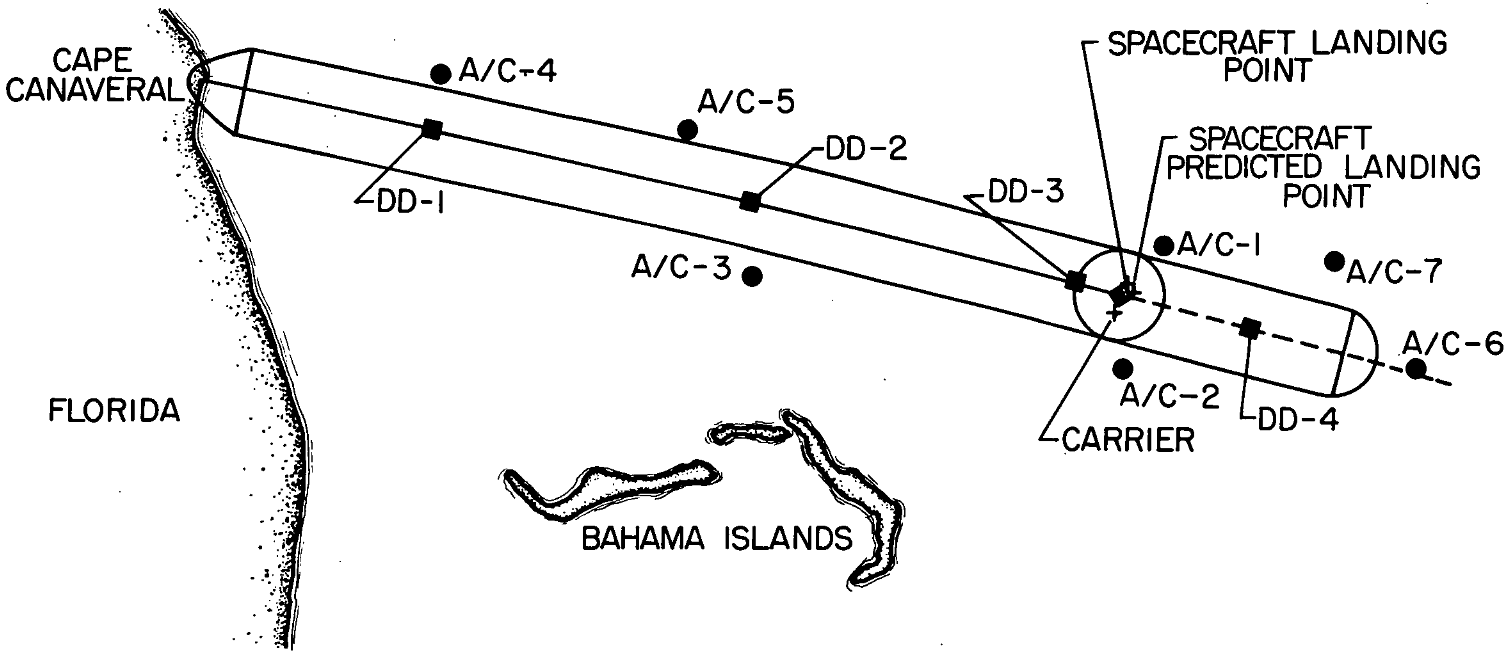

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Figure 34.- Chart of recovery operations.