NASA SP-45

MERCURY PROJECT SUMMARY

INCLUDING RESULTS OF THE

FOURTH MANNED ORBITAL FLIGHT

MAY 15 AND 16, 1963

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Manned Spacecraft Center

PROJECT MERCURY

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NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
PROJECT MERCURY

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ERRATA—NASA REPORT SP-45

Page 129—For the first five lines in left-hand column, substitute the following:

The United Kingdom also assisted in the selection of communication sites in Africa and in the South Pacific and continued to provide support in the operation and maintenance of certain communication facilities.

The Republic of Nigeria provided land near the city of Kano, assisted in the construction of the station and ground communication facilities, and provided continued support during the operational phase.

The Republic of Zanzibar provided land and assisted in the establishment of the station and ground communication facilities.

The Government of Spain provided land on Grand Canary Island and established the Instituto Nacional de Técnica Aeronáutica (INTA) as the Spanish agency to participate in the implementation and operation of this facility.

The Government of Mexico provided land and participated in the implementation of the station near Guaymas, Mexico. In a joint effort, the Mexico-United States Commission for Space Tracking Observation was formed to provide coordination for the construction and operation of this station.

In establishing stations as a joint effort with the various participating countries, every effort was made to make maximum possible use of local resources and people, to permit free access to the sites, and to establish a basis for continued cooperation throughout the program.

Pages 369–381— The following names were inadvertently omitted from Appendix E.

Aikenhead, Bruce A.
Armstrong, Neil
Baker, Charles
Baker, Thomas F.
Bathurst, Raymond
Bavely, James C.
Bayer, Philip J.
Berry, Lt. Col. S. L.
Brackett, Ernest W.
Breneman, G. Jean
Brockett, H. R.
Buckley, Edmond C.
Chiabotta, R. L.
Clark, Lt. Col. Raymond L.
Conger, Dean
Connor, Lt. Col. Joseph
Cox, Hiden T.
Decherd, Mary C.
Dembling, Paul G.
Dick, Louise
Donlan, Charles J.
Draim, Lt. Cmdr. John E.
Dunkleman, Dr. Lawrence
Evans, Peggy R.
Ferrando, James A.
Ferrando, Rita P.
Frutkin, Arnold W.
Gaever, A. Les
Gamble, Dr. Allen O.
Gesell, Ralph T.
Giannini, William F.
Gibbs, Col. Asa B.
Gill, Dr. Jocelyn R.
Glahn, Earl W.
Glennan, Dr. T. Keith
Goett, Dr. Harry J.
Hand, Ben R.
Haney, Paul
Hare, Linda J.
Harlan, Charles S.
Hartley, Robert M.
Hayes, Capt. Richard
Heaton, Lt. Col. Donald J.
Hemperly, John O.
Henry, Maj. Richard C.
Holmes, D. B.
Holmes, Jay
Horner, Richard E.
Hunter, Willson H.
Hyatt, Abraham
Jenkins, Thomas E.
Johnson, Clinton T.
Johnson, Harold G.
Johnson, Jennie M.
Keany, J.
Kehlet, Alan B.
Kier, Cmdr. Kenneth
Krieger, Robert L.
Kuettner, Dr. Joachim P.
Land, Vinton T.
Leech, Ted B.
Love, James T.
McCaskill, Patsy L.
McGee, Bernard J.
McTigue, John
Neal, James L.
Ostrander, Maj. Gen. Donald R.
Overton, John D.
Petersen, Cdr. Forrest N.
Porter, Thomas J.
Powers, Col. John A.
Rabb, L.
Reed, Carol C.
Rice, Charles N.
Ricker, Harry H., Jr.
Roadman, Brig. Gen. Charles
Salmassy, Omar K.
Sanders, Newell D.
Schmidt, Richard A.
Seamans, Dr. Robert C.
Silverstein, Abe
Soulé, Hartley A.
Stack, John
Stelter, Laverne R.
Stockwell, Ephriam
Thompson, Carolyn B.
Thompson, Floyd L.
Truszynski, G. M.
Turner, Lt. Col. W. R.
von Braun, Wernher
Walker, Joseph
Wallace, Robert F.
White, Dr. Stanley C.
Williams, J. J.
Wilson, Charles
Wolhart, Walter O.
Wood, Clotaire
Wyatt, D. D.
Young, Col. Robert P.
Zimmerman, C. H.

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FOREWORD

This document presents a summary of the planning, preparation, experiences, and results of Project Mercury and includes the results of the fourth United States manned orbital flight conducted on May 15 and 16, 1963, are also included. The papers are grouped into four main technical areas: The space-vehicle development, mission support development, flight operations, and mission results. The performance discussions contained in the various papers for the concluding Mercury mission form a continuation of the information previously published for the three manned orbital flights and the two manned suborbital flights. Although this document, to a limited degree, summarizes the results of the previous manned flights, the formal postflight reports published for these earlier missions should be consulted for greater detail.

The material presented in this document has been prepared in a short period of time. It reflects the close cooperation and intense efforts of the authors, the staff editors, and the printers, all of whom are to be commended for their dedicated efforts.

KENNETH S. KLEINKNECHT,
Manager, Mercury Project.

W. M. BLAND, JR.,
Deputy Manager, Mercury Project.

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1. PROJECT REVIEW

By WALTER C. WILLIAMS, *Deputy Director for Mission Requirements and Flight Operations, NASA Manned Spacecraft Center;* KENNETH S. KLEINKNECHT, *Manager, Mercury Project, NASA Manned Spacecraft Center;* WILLIAM M. BLAND, JR., *Deputy Manager, Mercury Project, NASA Manned Spacecraft Center; and* JAMES E. BOST, *Chief, Engineering Operations Office, Mercury Project Office, NASA Manned Spacecraft Center*

Summary

The United States' first manned space flight project was successfully accomplished in a 4⅔ year period of dynamic activity which saw more than 2,000,000 people from many major government agencies and much of the aerospace industry combine their skills, initiative, and experience into a national effort. In this period, six manned space flights were accomplished as part of a 25-flight program. These manned space flights were accomplished with complete pilot safety and without change to the basic Mercury concepts. It was shown that man can function ably as a pilot-engineer-experimenter without undesirable reactions or deteriorations of normal body functions for periods up to 34 hours of weightless flight.

Directing this large and fast moving project required the development of a management structure and operating mode that satisfied the requirement to mold the many different entities into a workable structure. The management methods and techniques so developed are discussed. Other facets of the Mercury experience such as techniques and philosophies developed to insure well-trained flight and ground crews and correctly prepared space vehicles are discussed. Also, those technical areas of general application to aerospace activities that presented obstacles to the accomplishment of the project are briefly discussed. Emphasis is placed on the need for improved detail design guidelines and philosophy, complete and appropriate hardware qualification programs, more rigorous standards, accurate and detailed test procedures, and more responsive configuration control techniques.

Introduction

The actual beginning of the effort that resulted in manned space flight cannot be pinpointed although it is known that the thought has been in the mind of man throughout recorded history. It was only in the last decade, however, that technology had developed to the point where man could actually transform his ideas into hardware to achieve space flight. Specific studies and tests conducted by government and industry culminating in 1958 indicated the feasibility of manned space flight. Implementation was initiated to establish a national manned space-flight project, later named Project Mercury, on October 7, 1958.

The life of Project Mercury was about 4⅔ years, from the time of its official go-ahead to the completion of the 34-hour orbital mission of Astronaut Cooper. During this period, much has been learned about man's capabilities in the space environment and his capabilities in earthbound activities which enabled the successful accomplishment of the objectives of the Mercury Project in this relatively short period. It is the purpose of this paper to review the more significant facets of the project beginning with the objectives of the project and the guidelines which were established to govern the activity. As in any form of human endeavor, there are certain signs which serve as the outward indication of activity and progress. For the Mercury Project, these signs were the major full-scale flight tests. These tests will be reviewed with particular emphasis on schedule, the individual mission objectives, and the results from each mission. Then, the organization with which management directed the activities of Project Mercury will be explained, particularly with respect to those internal interfaces between major segments of NASA and those external interfaces with contractors and other governmental departments. The resources expended during the project will be explained with discussions on manpower and cost. In addition, the major results of the project will be discussed as will those areas which presented severe obstacles to technical progress.

This paper is primarily a review; greater detail in many of the areas discussed can be obtained by reference to other papers in this document and to the documents listed in the bibliography.

Objectives and Guidelines

The objectives of the Mercury Project, as stated at the time of project go-ahead, were as follows:

(1) Place a manned spacecraft in orbital flight around the earth.

(2) Investigate man's performance capabilities and his ability to function in the environment of space.

(3) Recover the man and the spacecraft safely.

After the objectives were established for the project, a number of guidelines were established to insure that the most expedient and safest approach for attainment of the objectives was followed. The basic guidelines that were established are as follows:

(1) Existing technology and off-the-shelf equipment should be used wherever practical.

(2) The simplest and most reliable approach to system design would be followed.

(3) An existing launch vehicle would be employed to place the spacecraft into orbit.

(4) A progressive and logical test program would be conducted.

More detailed requirements for the spacecraft were established as follows:

(1) The spacecraft must be fitted with a reliable launch-escape system to separate the spacecraft and its crew from the launch vehicle in case of impending failure.

(2) The pilot must be given the capability of manually controlling spacecraft attitude.

(3) The spacecraft must carry a retrorocket system capable of reliably providing the necessary impulse to bring the spacecraft out of orbit.

(4) A zero-lift body utilizing drag braking would be used for reentry.

(5) The spacecraft design must satisfy the requirements for a water landing.

It is obvious by a casual look at the spacecraft (fig. 1–1) that requirements (1), (3), and (4) were followed as evidenced by the escape tower, the retrorocket system that can be seen on the blunt end of the spacecraft, and the simple blunt-body shape without wings. Items (2) and (5) have been made apparent by the manner in which the astronaut has manually controlled the attitude of the spacecraft during orbital maneuvers, retrofire, and reentry, and by the recovery of the spacecraft and astronauts after each flight by recovery forces which included aircraft carriers and destroyers.

Basically, the equipment used in the spacecraft was derived from off-the-shelf equipment or through the direct application of existing technology, although some notable exceptions were made in order to improve reliability and flight safety. These exceptions include:

(1) An automatic blood-pressure measuring system for use in flight.

(2) Instruments for sensing the partial pressures of oxygen and carbon dioxide in the oxygen atmosphere of the cabin and suit, respectively.

Some may argue with the detailed way in which the second basic guideline of simplicity was carried out; however, this guideline was carried out to the extent possible within the volume, weight, and redundancy requirements imposed upon the overall system. The effect of the weight and volume constraints, of course, resulted in smaller and lighter equipment that could not always be packaged in an optimum way for simplicity.

Redundancy probably increased the complexity of the systems more than any other requirement. Because the spacecraft had to be qualified by space flight first without a man onboard and then because the reactions of man and his capabilities in the space environment were unknown, provisions for a completely automatic operation of the critical spacecraft functions were provided. To insure reliable operation, these automatic systems were backed up by redundant automatic systems.

The third guideline was satisfied by an adaptation of an existing missile, the Atlas. The modifications to this launch vehicle for the use in the Mercury Project included the addition of a means to sense automatically impending catastrophic failure of the launch vehicle and provisions to accommodate a new structure that would form the transition between the upper section of the launch vehicle and the spacecraft. Also, the pilot-safety program was initiated to insure the selection of quality components.

Application of the fourth guideline is illustrated by the major flight schedule which is discussed in the next section.

Major Flight Schedules

Planned Flight Test Schedule

The Mercury flight schedule that was planned early in 1959 is shown in figure 1–2. These are the major flight tests and include all those scheduled flight tests that involved rocket-propelled full-scale spacecraft, including boilerplate and production types. The planned flight test program shows 27 major launchings. There are three primary types of tests included in these, one type being the research-and-development tests, another being primarily flight-qualification of the production spacecraft, and the third being the manned orbital flight tests. In addition, the tests with the Mercury-Redstone launch vehicle provided some early ballistic flights for pilot training. Involved in the planned flight-test program were four basic types of launch vehicles, the Little Joe, the Mercury-Redstone, the Mercury-Jupiter, and the Mercury-Atlas.

Four Little Joe flights and two of the Atlas powered flights, termed Big Joe, were planned to be in the research and development category to check the validity of the basic Mercury concepts.

The qualification program was planned to use each of the four different launch vehicles. The operational concept of the qualification program provided for a progressive build-up of flight-test system complexity and flight-test conditions. It was planned that the operation of all

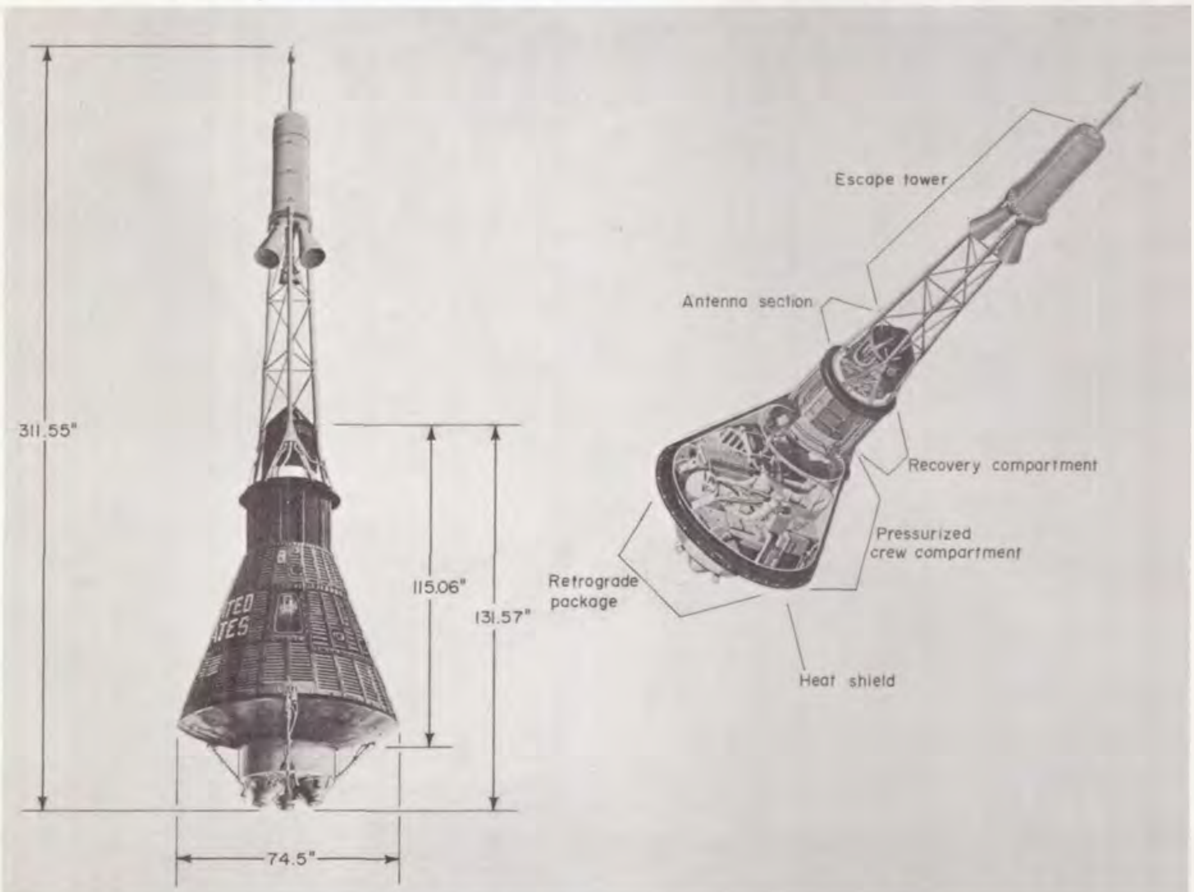


FIGURE 1–1.—General view of spacecraft.

hardware items would be proven in those environments to which they would be subject in both normal and emergency conditions associated with attainment of the planned mission conditions. One qualification flight test was planned with the use of the Little Joe launch vehicle. This test was planned to qualify the operation of the production spacecraft in a spacecraft-abort situation at the combination of dynamic pressure, Mach number, altitude, and flight-path angle that represented the most severe condition anticipated for the use of this system during an orbital launch. There were eight flight tests planned with the use of the Redstone launch vehicle. The first two were intended to be unmanned tests used to qualify the production spacecraft and to qualify the production-spacecraft launch-vehicle combination. The remaining six Mercury-Redstone flights were to be used to train and qualify Mercury astronauts for later orbital flights. Two flight tests were planned in which the Jupiter launch vehicle was to be used. The first one of these was to be made to qualify the production spacecraft for those flight conditions which produced the greatest load factor during reentry. The second Jupiter powered flight was scheduled as a backup to the first. The qualification program for the production spacecraft also included plans for three flight tests using the Atlas launch vehicle and the remainder of the flights were expected to be used for manned orbital flight if the flight qualification achieved at the time so warranted.

This flight-test plan was developed and proposed in early 1959 as a test plan that represented a completely trouble-free preparation and flight-test program. According to this schedule, the first manned orbital flight could have occurred as early as April of 1960. This flight-test schedule represents planning that was done before experience was gained in the production of spacecraft flight hardware and, particularly important, before any experience had been gained in the preparation of space flight equipment for manned flight.

The planned flight test schedule (fig. 1–2) presents some missions that are shaded. This shading indicates that these particular missions were eliminated during the course of the program because the requirement either was not necessary or was satisfied by some other means. In addition, it should be noted that the objectives of some of the other missions were altered to fit the situation as the project advanced.

Actual Flight Test Schedules

The 25 major flight tests accomplished during the Mercury Project are shown in figure 1–3, in the order of their occurrence. Those flight-test missions which are marked with solid circles in-

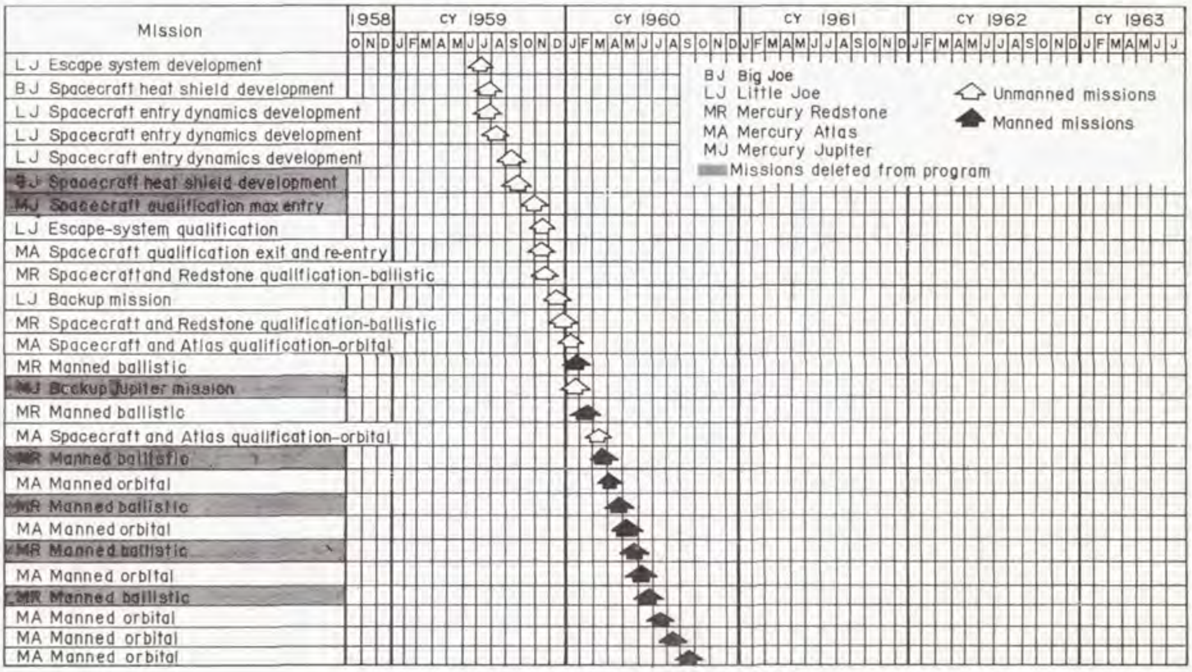


FIGURE 1–2.—Planned flight schedule as of January 1959.

dicate the missions that were added to this schedule as a result of lessons learned during some of the preceding flight tests or because of extensions to the basic mission objectives as in the case of the last two missions, MA–8 and MA–9.

Little Joe 1.—The flight test program was initiated with the Little Joe 1 research-and-development mission that was scheduled for July of 1959. The actual launch attempt came in the following month, on August 21, at the NASA launch site, Wallops Station, Va. A nearly catastrophic failure occurred at a time late in the launch countdown as the vehicle battery-power supply was being charged. At this time, the escape-rocket sequence was unintentionally initiated and the spacecraft was separated from the launch vehicle and propelled into the air as in a pad-abort sequence. The escape sequence was accomplished correctly, though initiated by a fault. The tower was jettisoned properly, the drogue parachute was deployed as it should have been, but the main parachute deployment circuitry was not activated because of a lack of sufficient electrical power. The spacecraft was destroyed on impact with the water. The cause of the failure was determined by detailed analyses to be a "back-door" circuit which permitted the launch-escape system to be activated when a given potential had been supplied to the battery by ground charging equipment. The launch vehicle, though fully loaded with six solid-propellant rocket motors, was left undamaged on the launcher.

Big Joe 1.—Spacecraft checkout for the launch of Big Joe 1 was accomplished at the Cape Canaveral launch site starting in June of 1959. The primary purpose of the flight was to investigate the performance of the ablation heat shield during reentry, as well as to investigate spacecraft reentry dynamics with an instrumented boilerplate spacecraft. Other items that were planned for investigation on this flight were afterbody heating for both the exit and reentry phases of flight, drogue and main parachute deployment, dynamics of the spacecraft system with an automatic control system in operation, flight loads, and water-landing loads. Recovery aids, such as SOFAR bombs, radio beacons, flashing light, and dye markers, had been incorporated. This spacecraft was not equipped with an escape system. The mission was accomplished on September 9, 1959. Because of the failure of the Atlas booster engines to separate, the planned trajectory was not followed exactly, but the conditions which were achieved provided a satisfactory fulfillment of the test objectives. The landing point of the spacecraft was about 1,300 nautical miles from the lift-off point, which was about 500

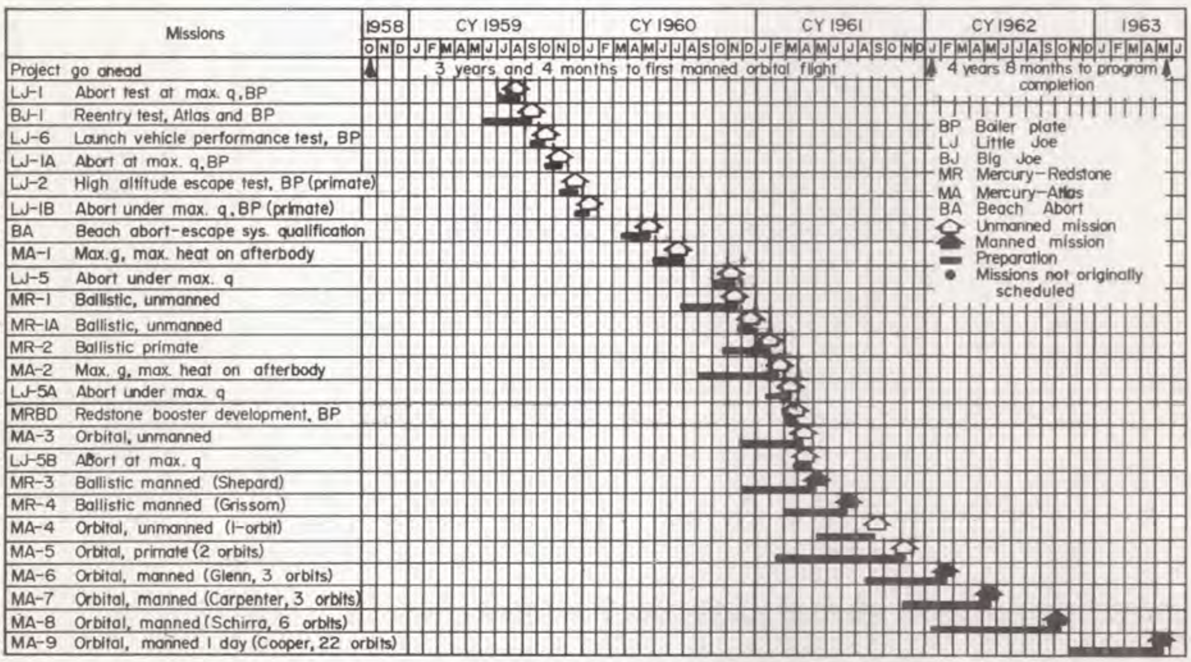


FIGURE 1–3.—Actual flight schedule.

nautical miles short of the intended landing point. Even so, the recovery team retrieved the spacecraft about 7 hours after landing.

Data from instrumentation and results of inspection of the spacecraft showed that the heat-protection method planned for the production spacecraft was satisfactory for a normal reentry from the planned orbit. On the basis of these results, the backup Big Joe mission was cancelled.

Little Joe 6.—The Little Joe 6 mission was successfully accomplished on October 4, 1959, from the Wallops Station launch site and demonstrated a qualification of the launch vehicle by successfully flying with staged propulsion on a trajectory which gave structural and aerodynamic loads in excess of those expected to be encountered on the other planned Little Joe missions. In addition, a method devised for correcting the launcher settings for wind effects, the performance of the booster command thrust termination system, and the launch operation were checked out satisfactorily. Two minor modifications were made to the Little Joe vehicle as a result of this flight to protect the second-stage rocket motor and the launch vehicle base from heat radiated from the thrusting motors.

Little Joe 1A.—Little Joe 1A was launched on November 4, 1959, from the Wallops Station launch site, as a repeat of the Little Joe 1 mission. The inflight abort was made, but the first-order test objective was not accomplished because of the slow ignition of the escape rocket motor. This slow ignition delayed spacecraft-launch-vehicle separation until the vehicle had passed through the desired test region. All second-order test objectives were met during the flight and the spacecraft was successfully recovered and returned to the launch site. All other Mercury hardware used in this test, principally the major parts of the escape and landing systems, performed satisfactorily.

Little Joe 2.—The Little Joe 2 mission, which was intended to validate the proper operation of the spacecraft for a high altitude abort, was accomplished on December 4, 1959, from the Wallops Station launch site. The abort sequence was initiated at an altitude of almost 100,000 feet and approximated a possible set of abort conditions that could be encountered during a Mercury-Atlas exit flight to orbit. In addition to the first-order objectives, the spacecraft reentry dynamics behavior without a control system was found to be satisfactory. The spacecraft dynamic stability on descent through the atmosphere was found to be as expected. Additional information was obtained on the operation of the Mercury parachute, the Mercury spacecraft flotation characteristics, and the operational requirements of spacecraft recovery by surface vessels. A monkey was a passenger on this mission; both the monkey and the spacecraft were recovered in satisfactory condition at the end of the mission.

Little Joe 1B.—The Little Joe 1B mission was successfully accomplished on January 21, 1960, from the Wallops Station launch site. This mission had been added to the flight schedule because of the failures of Little Joe 1 and Little Joe 1A to meet the test objectives. On this mission, all test objectives were successfully met, with the accomplishment of an abort at the conditions described for Little Joe 1A. This spacecraft also had a monkey as a passenger. Both the monkey and the spacecraft were recovered satisfactorily at the end of the mission.

Beach Abort 1.—Mission Beach Abort 1 (BA–1) was accomplished on May 9, 1960, from the Wallops Station launch site and marked the first time that a production spacecraft underwent a major qualification flight test. Production spacecraft 1 was a reasonably complete spacecraft and contained many systems that later spacecraft would be equipped with. It was launched on an abort sequence from a launcher on the ground. The escape-rocket motor provided the impulse as it would on an escape from a launch vehicle while still on the pad. The test was successful and the feasibility of an abort from a pad was adequately demonstrated. Though the mission was successful, certain modifications to spacecraft equipment were found to be desirable after the performance of these systems was analyzed. Although separation of the escape tower was accomplished, it was not considered satisfactory because of the small separation distance provided. This resulted in the redesign of the escape-system jettison rocket-motor nozzles. The single nozzle was replaced by a tri-nozzle assembly to prevent rocket-motor performance loss by impingement of the exhaust plumes on the escape-tower structure. This modification proved to be satisfactory and was retained for the remainder of the Mercury program. Another anomaly was the poor performance of the spacecraft telemetry transmitters. Investigation showed that the cause of this poor performance was a reversal of the cabling of the transmitter systems; thus, for the first time in the program, inadvertent cross connection of connectors had been deleted.

Mercury-Atlas 1.—The Mercury-Atlas 1 (MA–1) vehicle was launched from the Cape Canaveral test site on July 29, 1960. The primary purpose of the MA–1 flight was to test the structural integrity of a production Mercury spacecraft and its heat-protection elements during reentry from an exit abort condition that would provide the maximum heating rate on the afterbody of the spacecraft. The spacecraft involved was production item 4 and was equipped with only those systems which were necessary for the mission. An escape system was not provided for this spacecraft. The mission failed about 60 seconds after lift-off. The spacecraft and launch vehicle impacted in the water east of the launch complex. Because of this failure, an intensive investigation into the probable causes was undertaken. As a result of this investigation modifications were made to the interface area between the launch vehicle and the spacecraft to increase the structural stiffness. This inflight failure and subsequent intensive investigation resulted in a considerable delay in the launch schedule and the next Mercury-Atlas launch was not accomplished until almost 7 months later.

Little Joe 5.—The Little Joe 5 vehicle was launched on November 8, 1960, from the Wallops Station launch site. The test was intended to qualify a production spacecraft. It was a complete specification spacecraft at that time with the following exceptions: the landing-bag system was not incorporated; the attitude stabilization and control system was not fully operational, but was installed and used water to simulate the control system fuel; and certain components of the communications system not essential to the mission were omitted. The mission failed during flight when the escape-rocket motor was ignited before the spacecraft was released from the launch vehicle. The spacecraft remained attached to the launch vehicle until impact and was destroyed. The exact cause of the failure could not be determined because of the condition of the spacecraft components when recovered from the ocean floor and because of the lack of detailed flight measurements. The results of the analyses attributed the failure to components of the sequential system, but the cause could not be isolated. The sequential systems of spacecraft 2 and 6 were modified to preclude the possibility of a single erroneous signal igniting the escape-rocket motor.

Mercury-Redstone 1 and 1A.—The Mercury-Redstone 1 (MR–1), which was to provide qualification of a nearly complete production spacecraft number 2, in flight with a Mercury-Redstone launch vehicle, was attempted on November 21, 1960, at the Cape Canaveral launch site. The mission was not successful. At lift-off, the launch-vehicle engine was shut down and the launch vehicle settled back on the launcher after vertical motion of only a few inches. The spacecraft also received the shutdown signal and its systems reacted accordingly. The escape-rocket system was jettisoned and the entire spacecraft landing system operated as it had been designed. Analyses of the cause of malfunction showed the problem to have been caused by failure of two ground umbilicals to separate from the launch vehicle in the proper sequence. In the wrong sequence, one umbilical provided an electrical path from launch-vehicle power through blockhouse ground and the launch-vehicle engine cut-off relay coil to launch-vehicle ground that initiated the cut-off signal. Except for loss of expendable items on the spacecraft, such as the escape system and the parachutes and the peroxide, the spacecraft was in flight condition. The launch vehicle was slightly damaged in the aft section by recontact with the launcher The spacecraft and launch vehicle were demated. The launch vehicle was replaced by another Mercury-Redstone launch vehicle, and the spacecraft was again prepared for its mission. Modifications included a long ground strap that was placed between the launch vehicle and the launcher to maintain electrical ground until umbilicals had been separated. The refurbished spacecraft and new Mercury-Redstone launch vehicle were launched successfully as mission MR–1A on December 19, 1960. At this time, all test objectives were met. All major spacecraft systems performed well throughout the flight. The launch-vehicle performance was normal except for a higher than nominal cut-off velocity. The only effects of this anomaly were to increase the range, maximum altitude, and maximum acceleration during reentry. The spacecraft was picked up by a helicopter 15 minutes after landing and was delivered back to the launch site on the morning after the launch.

Mercury–Redstone 2.—The MR–2 mission was accomplished on January 31, 1961, from the Cape Canaveral test site with a chimpanzee as a passenger. Production spacecraft 5 was used. The mission was successful and the majority of the test objectives were met. Analyses of launch-vehicle data obtained during the flight revealed that launch-vehicle propellant depletion occurred before the velocity cut-off system was armed and before the thrust chamber abort switch was disarmed. This combination of events resulted in an abort signal being transmitted to the spacecraft from the launch vehicle. The spacecraft reacted correctly to the abort signal and an abort sequence was properly made. The greater than normal launch-vehicle velocity combined with the velocity increment obtained unexpectedly from the escape-rocket motor produced a flight path that resulted in a landing point about 110 nautical miles farther downrange than the planned landing point. This extra range, of course, was the prime factor in the 2 hours and 56 minutes that it took to locate and recover the spacecraft. The chimpanzee was recovered in good condition, even though the flight had been more severe than planned. By the time the spacecraft was recovered, it had nearly filled with water. Some small holes had been punctured in the lower pressure bulkhead at landing. Also, the heat-shield retaining system was fatigued by the action of the water and resulted in loss of the heat shield. Another anomaly that occurred during the flight was the opening of the spacecraft cabin inflow valve during ascent, which prevented the environmental control system from maintaining pressure at the design level. Because the pressure dropped below the design level, the emergency environmental system was exercised, and it performed satisfactorily. From the experiences of this flight, a number of modifications were made to the spacecraft systems to avoid recurrence of the malfunctioning items. These modifications included the following:

(1) An additional fiber glass bulkhead was installed between the heat shield and the large pressure bulkhead to protect the bulkhead during landing, and items in the large pressure bulkhead area that could be driven "daggerlike" through the larger pressure bulkhead during the landing were removed or reoriented.

(2) The heat-shield retention system was improved with the addition of a number of cables and cable-retention devices. The modified heat-shield retention system was proved to be capable of retaining the heat shield to the spacecraft in rough seas for periods of up to 10 hours.

(3) Tolerances of the inflow valve detent system were changed to assure positive retention during periods of vibration.

Mercury–Atlas 2.—The Mercury–Atlas 2 vehicle was launched from the Cape Canaveral test site on February 21, 1961, to accomplish the objectives of the MA–1 mission. The space vehicle for this flight consisted of the sixth production spacecraft and Atlas launch vehicle No. 67–D. Several structural changes made in the spacecraft launch-vehicle interface area as a result of the failure of the preceding Mercury–Atlas missions were as follows:

(1) The adapter was stiffened.

(2) The clearance between the spacecraft retropackage and the launch-vehicle lox tank dome was increased.

(3) An 8-inch-wide stainless-steel band was fitted circumferentially around the upper end of the launch-vehicle lox tank.

(4) The lox-valve support structure was changed so that the valve was not attached to the adapter.

(5) Special instrumentation was installed in the spacecraft launch-vehicle interface area to measure loads, vibrations, and pressures.

The major test objective of the MA–2 mission was to demonstrate the integrity of the spacecraft structure, ablation shield, and afterbody shingles for the most severe reentry from the standpoint of load factor and afterbody temperature. The flight closely matched the desired trajectory, and the desired temperature and loading measurements were obtained. The spacecraft landed in the planned landing area and was recovered and placed aboard a recovery ship approximately 55 minutes after it was launched. A preliminary evaluation of measured data and a detailed inspection of the recovered spacecraft indicated that all test objectives were satisfied and that the spacecraft structure and heat-protection elements were in excellent condition.

Little Joe 5A.—The Little Joe 5A mission was accomplished on March 18, 1961, from the Wallops Station launch site. This was an added mission, as a result of the failure of the Little Joe 5. For the Little Joe 5A mission, production spacecraft 14 and the sixth Little Joe launch vehicle to be flown were used. The spacecraft was a basic Mercury configuration with only those systems installed that were required for the mission. As during the Little Joe 5 mission early ignition of the escape-rocket motor occurred. The mission was unsuccessful. However, unlike the Little Joe 5 mission, a backup spacecraft separation system was initiated by ground command and successfully separated the spacecraft from the launch vehicle and released the tower. Because of the severe flight conditions existing at the time of parachute arming, both main and reserve parachutes were deployed simultaneously. They filled and enabled the spacecraft to make a safe landing. All other active systems operated properly except that the cabin pressure-relief valve failed to maintain the spacecraft cabin pressure because of a piece of safety wire found lodged in the seat. The spacecraft was recovered and returned to the launch area in good condition. Analysis of data from the spacecraft proved that the early ignition of the escape rocket motor was caused by structural deformation in the spacecraft-adapter interface area. This early ignition permitted separation sensing switches to falsely sense movement and give the signal for the remainder of the sequence. The corrections applied were to reduce air loading in the area by better fairing of the clamp-ring cover, by increasing the stiffness of the switch mounting and reference structures, and rerouting the electrical signals from these switches through a permissive network.

Mercury-Redstone-Booster Development.—The Mercury-Redstone-Booster Development (MR-BD) mission was made on March 24, 1961, from the Cape Canaveral launch site, with a Mercury-Redstone launch vehicle and the refurbished and ballasted Little Joe 1A research-and-development spacecraft. This flight was made as the result of the analyses of the performance of the launch vehicles on the Mercury-Redstone 1A and Mercury-Redstone 2 flights, which showed that there were some launch-vehicle problems that required correction and requalification. Most of these problems had to do with the overspeed performance that was attained during those missions. The flight was successful and analyses of the launch-vehicle data indicated that the launch-vehicle corrections were entirely satisfactory. No recovery of the spacecraft was attempted since it was used only as a payload of the proper size, shape, and weight, and no provisions were made to separate it from the launch vehicle during the mission.

Mercury-Atlas 3.—The Mercury-Atlas 3 (MA-3) mission was accomplished on April 25, 1961, from the Cape Canaveral test site. The planned flight, which was intended to orbit an unmanned production spacecraft once around the earth, was terminated about 40 seconds after lift-off by range-safety action when the launch vehicle failed to roll and pitch over into the flight azimuth. The spacecraft was aborted successfully as the result of the command signal and was quickly recovered. The spacecraft came through the abort maneuver with only minor damages. The performance of all spacecraft systems was generally satisfactory throughout the short flight. The spacecraft used on this mission was the eighth production unit. The launch vehicle, Atlas 100-D, had increased skin thickness in the forward end of the lox tank and had the abort sensing and implementation system installed for closed-loop operation. Analysis of records indicated that there was an electrical fault in the launch vehicle autopilot. Subsequent action resulted in closer examination of electrical components and connections.

Little Joe 5B.—The Little Joe 5B vehicle was launched on April 28, 1961, from the Wallops Station launch site. The vehicle was composed of Mercury production spacecraft 14A and the seventh Little Joe launch vehicle to be flown. The spacecraft, which had previously been used for the Little Joe 5A mission, had been refurbished with only those systems installed that were required for the mission. There was no landing bag and certain other nonessential systems were missing. It was the first spacecraft to be flight-tested with modified spacecraft-adapter clamp-ring limit-switch mountings and fairings. Also, the sequential system was modified to prevent the limit switches on the spacecraft-launch-vehicle clamp ring or the spacecraft-escape-tower clamp ring from closing any circuits which would ignite the escape rocket until the band separation bolts were fired. These changes in and around the spacecraft-launch-vehicle interface and in the sequential system were made as the result of the problems encountered in missions Little Joe 5 and Little Joe 5A. Because of a severe change in flight path as the result of the delayed ignition of one of the two main launch-vehicle rocket motors, the test was made at substantially more severe flight conditions than planned. The abort was planned to be initiated at a dynamic pressure of 990 lb/sq ft; instead the dynamic pressure had attained a value of about 1,920 lb/sq ft when the abort was initiated. However, the spacecraft escape system worked as planned and this test successfully demonstrated the structural integrity of the Mercury spacecraft. The spacecraft landed in the ocean after about 5 minutes of flight and was recovered and returned to the launch site in less than 30 minutes after launch. Analyses of the flight data and inspection of the spacecraft after the mission showed the spacecraft to be in good condition. An anomaly that showed up was the failure of two of the small spacecraft umbilicals to eject. Evidence indicated that these umbilicals failed to eject because of interference with the clamp-ring fairing after its release. This condition was corrected by changing the manner in which the fairing was supported on subsequent spacecraft. All test objectives were considered to have been met.

Mercury-Redstone 3.—The Mercury-Redstone 3 (MR–3) mission, the first manned space flight by the United States, was successfully accomplished on May 5, 1961, from the Cape Canaveral launch site. Astronaut Alan B. Shepard was the pilot. The space vehicle was composed of production spacecraft 7 and a Mercury-Redstone launch vehicle, which was essentially identical to the one used for the MR–BD launch-vehicle qualification mission. Analyses of the results of the mission showed that Astronaut Shepard satisfactorily performed his assigned tasks during all phases of the flight. Likewise, launch vehicle and spacecraft systems performed as planned. The spacecraft achieved an altitude of about 101 nautical miles and was in weightless flight for slightly over 5 minutes. Postflight examination of Astronaut Shepard and inspection of the spacecraft showed both to be in excellent condition. A helicopter pickup was made of the spacecraft after the pilot had made his egress from the side hatch of the spacecraft and had been hoisted aboard the helicopter. The pilot and the spacecraft were landed aboard an aircraft carrier 11 minutes after spacecraft landing, and the spacecraft was brought back to the launching site the morning after the flight.

Mercury-Redstone 4.—The Mercury-Redstone 4 (MR–4) flight was successfully made on July 21, 1961, from the Cape Canaveral launch site. Astronaut Virgil I. Grissom was the pilot. The space vehicle was made up of the 11th production spacecraft and a Mercury-Redstone launch vehicle essentially identical to the one used for MR–3 mission. The spacecraft on this mission was somewhat different from spacecraft 7, in that, for the first time, a manned spacecraft had a large top window, a side hatch to be opened by an explosive charge, and a modified instrument panel. The spacecraft achieved a maximum altitude of about 103 nautical miles, with a period of weightlessness of about 5 minutes. The flight was successful. After landing, premature and unexplained actuation of the spacecraft explosive side hatch resulted in an emergency situation in which the spacecraft was lost but the pilot was rescued from the surface of the water. Analyses of the data from the flight and debriefing by the astronaut indicated that, in general, the spacecraft systems performed as planned, except for the action of the spacecraft hatch. An intensive investigation of the hatch actuation resulted in a change in operational procedures. No fault was found in the explosive device.

Mercury-Atlas 4.—The Mercury-Atlas 4 (MA–4) vehicle was launched on September 13, 1961, from the Cape Canaveral launch site; it was a repeat of the MA–3 test and became the first Mercury spacecraft to be successfully inserted into orbit, returned, and recovered. Further objectives of this flight were to evaluate the

Mercury network and recovery operations concerned with orbital flight. The space vehicle for this flight was made up of Mercury–Atlas launch vehicle 88–D, with the same modifications as the launch vehicle used on the MA–3 mission, and the spacecraft which was used on the MA–3 mission. The spacecraft had been refurbished and designated 8A for this mission. This was a very complete spacecraft which included a man-simulator onboard to provide a load on the environment control system during orbital flight. Other differences between this spacecraft and spacecraft flown on subsequent missions were:

(1) The landing bag was not installed

(2) The spacecraft had small viewing windows rather than the large overhead window used on later spacecraft

(3) The spacecraft entrance hatch did not have the explosive-opening feature

(4) The instrument panel had a slightly different arrangement.

The launch vehicle provided the desired orbital path with a perigee of 85.9 nautical miles and an apogee of 123.3 nautical miles. The planned retromaneuver over the coast of California resulted in a landing in the Atlantic Ocean approximately 160 nautical miles east of Bermuda in the primary landing area. The spacecraft was recovered in excellent condition 1 hour and 22 minutes after landing. The mission achieved the desired objectives, even though certain anomalies showed up in systems behavior during the mission. None of the anomalies had serious consequence. The anomalies and action taken are as follows:

(1) A spacecraft inverter failed during the powered phases of flight. The cause was determined to be a vibration-sensitive component and found to be preventable by more precise and exacting acceptance tests.

(2) Some anomalies in the spacecraft scanner signals were detected during the mission. Steps were taken to modify the system to make it less sensitive to the effects of cold cloud layers.

(3) A leak developed in the spacecraft oxygen-supply system during the exit phase of the flight. The leak was small, and sufficient oxygen was available for the mission. Postflight analyses determined that the leak was caused by failure in a pressure reducer. The fault was corrected for subsequent missions.

(4) Some thrusters in the spacecraft automatic attitude control system had either reduced output or no output during the latter part of the orbit. Postflight analyses indicated that possibly the trouble was contamination of the metering orifices in some thruster assemblies.

Mercury–Atlas 5.—The Mercury–Atlas 5 (MA–5) mission was successfully made on November 29, 1961, from the Cape Canaveral launch site. A chimpanzee was the passenger on this flight. The mission was planned for three orbital passes and was to be the last qualification flight of the Mercury spacecraft and launch vehicle prior to a manned mission. The orbit was about as planned with perigee at 86.5 nautical miles and apogee at 128.0 nautical miles. Further objectives of this flight were to evaluate the Mercury network and recovery operations. In general, the spacecraft, launch-vehicle, and network systems functioned well during the mission until midway through the second pass when abnormal performance of the spacecraft attitude control system was detected and verified. This malfunction precluded the probably successful completion of the third pass because of the high rate of control fuel consumption. Accordingly, a retrofire command was transmitted to the spacecraft which resulted in it landing in the selected area at the end of the second pass. Recovery was completed 1 hour and 15 minutes after landing. The chimpanzee performed his assigned tasks without experiencing any deleterious effects during the mission and was recovered in excellent condition.

The primary anomaly during the mission was the control-system trouble which gave rise to increased fuel consumption by the attitude control system and which precipitated the abort of the mission at the end of the second orbital pass. The trouble was found to be a stopped-up metering orifice in one of the low-roll thrusters. Corrective action applied to subsequent missions included closer examinations for contamination in this system.

The spacecraft used for this mission was production spacecraft 9; and since it was the last qualification vehicle prior to the first manned orbital flight, it was intentionally made as nearly like the spacecraft for the manned mission as possible. This spacecraft included the large viewing window over the astronaut's head position, the landing bag, a positive lock on the emergency-oxygen rate handle, an explosive-release type hatch, new provisions for cooling the inverters, and rate gyros modified to insure satisfactory operation in the vacuum condition. The launch vehicle, Atlas 93–D, was much like those launch vehicles used on the previous two Mercury–Atlas missions; however, some additional modifications were included on this vehicle. These modifications included a new lightweight telemetry system and a redundant path for the sustainer engine cut-off signal.

Mercury–Atlas 6.—Mercury–Atlas 6 (MA–6), the first manned orbital space flight made from the United States, was successfully made on February 20, 1962, from the Cape Canaveral test site. Astronaut John H. Glenn, Jr., was the pilot. The flight was planned for three orbital passes to evaluate the performance of the manned spacecraft systems and to evaluate the effects of space flight on the astronaut and to obtain the astronaut's evaluation of the operational suitability of his spacecraft and supporting systems. All mission objectives for this flight were accomplished. The astronaut's performance during all phases of the mission was excellent, and no deleterious effects of weightlessness were noted. In general, the spacecraft, launch vehicle, and network system functioned well during the mission. The main anomaly in spacecraft operation was the loss of thrust of two of the 1-pound thrusters which required the astronaut to control the spacecraft for a large part of the mission manually. The orbit was approximately as planned, with perigee at 86.9 nautical miles and apogee at 140.9 nautical miles. During the second and third passes, a false indication from a sensor indicated that the spacecraft heat shield might be unlocked. This indication caused considerable concern and real-time analyses resulted in the recommendation that the expended retropackage be retained on the spacecraft during reentry at the end of the third pass to hold the heat shield in place in the event it was unlatched. The presence of the retropackage during reentry had no detrimental effect on the motions of the spacecraft. Network operation, including telemetry reception, radar tracking, communications, command control, and computing, were excellent and permitted effective flight control during the mission. The spacecraft for this mission was production unit number 13 which was essentially the same as spacecraft 9 used in the MA–5 mission except for those differences required to accommodate the pilot, such as the couch, a personal equipment container, filters for the window, and some minor instrumentation and equipment modifications. The launch vehicle was Atlas 109–D. It differed from the MA–5 launch vehicle in only one major respect. For this launch vehicle, the insulation and its retaining bulkhead between the lox and fuel tank dome was removed when it was discovered that fuel had leaked into this insulation prior to launch. The spacecraft landed in the planned recovery area, close to one of the recovery ships. The spacecraft, with the astronaut inside, was recovered approximately 17 minutes after landing. The astronaut was in excellent shape.

Action to prevent recurrence of the anomalies encountered during the MA–6 mission included relocation of metering orifices and a change in screen material in the attitude control system thruster assemblies. Improved specifications, tighter quality control, and more conservative switch rigging and wiring procedures were applied to the sensors that indicated heat-shield release.

Mercury–Atlas 7.—The Mercury–Atlas 7 (MA–7) vehicle was launched on May 24, 1962, from the Cape Canaveral launch site. Astronaut M. Scott Carpenter was the pilot for this mission. The mission was planned for three orbital passes and was a continuation of the program to acquire additional operational experience and information for manned orbital space flight. All objectives of the mission were achieved. The spacecraft used for this flight was production unit number 18 which was very similar to the spacecraft 13 used on the MA–6 flight. Some of the more significant features and modifications applied to this spacecraft include: the SOFAR bomb and radar chaff were deleted, the earth-path and oxygen partial pressure indicators were deleted, the instrument observer camera was removed, provisions for a number of experiments and evaluation were added, a more complete temperature survey system was added, the astronaut's suit circuit constant-bleed orifice was deleted, the landing-bag limit (heat-shield release) switches were rewired to prevent erroneous telemetry signals should one switch malfunction.

The launch vehicle, the Atlas 107–D, was similar to the previous Atlas launch vehicle except for a few minor changes, the major one of which was that for this mission, the fuel tank insulation bulkhead was retained. Launch-vehicle performance was satisfactory. A perigee of 86.8 nautical miles and an apogee of 145 nautical miles were the orbital parameters. During most of the flight, the spacecraft-system operation was satisfactory until, late in the third pass, the pilot noted that the spacecraft true attitude and indicated attitude in pitch were in disagreement. Because this control system problem was detected just before retrofire, no corrective action was possible and the astronaut was forced to provide manual attitude control, using the window and horizon as the attitude reference, for the retrofire maneuver. Retrofire occurred about 3 seconds late, and the optimum spacecraft attitudes were not maintained during retrofire. As a result, the spacecraft landed several hundred miles downrange of the planned landing point. Because of this, recovery of the astronaut was not accomplished until about 3 hours after landing. The spacecraft was retrieved later by a destroyer after about 6 hours in the water. Exact cause of the control system malfunction was not determined because the scanner circuitry suspected of causing the anomaly was lost when the antenna section was jettisoned during the landing phase. Changes in checkout procedures used in launch preparations were incorporated to prevent recurrence of this type of problem.

Mercury–Atlas 8.—The Mercury–Atlas 8 (MA–8) vehicle was launched from the Cape Canaveral launch site on October 3, 1962; Astronaut Walter M. Schirra, Jr., was the pilot. The MA–8 mission was planned for six orbital passes in order to acquire additional operational experience and human and systems performance information for extended manned orbital space flight. The objectives of the mission were successfully accomplished. The orbital parameters were as follows: perigee, 86.9 nautical miles; and apogee, 152.8 nautical miles. The space vehicle for this mission consisted of production spacecraft 16 and Atlas launch vehicle 113–D. The spacecraft was basically the same as spacecraft 18 utilized on the previous mission; however, a number of changes were made in the configuration to increase reliability, to save weight, to provide for experiments, and to conduct systems evaluations. The launch vehicle also had some changes as compared with the previous Mercury–Atlas launch vehicle. These changes include the following: the fuel tank insulation bulkhead was removed at the factory to be similar to the launch vehicle for the MA–6 mission, the two booster engine thrust chambers had baffled ejectors installed for improved combustion characteristics, and no holddown delay was programed between engine start and beginning of release sequence.

The pilot performed numerous experiments, observations, and systems evaluations during his mission. For the first time, extended periods of drifting flight were accomplished. Pilot adherence to the flight plan was excellent. Basic spacecraft systems, launch-vehicle systems, and ground-network systems performed well with only a few minor anomalies. The landing was made in the Pacific Ocean within sight of the primary recovery ship, and the spacecraft and pilot were recovered in about 40 minutes.

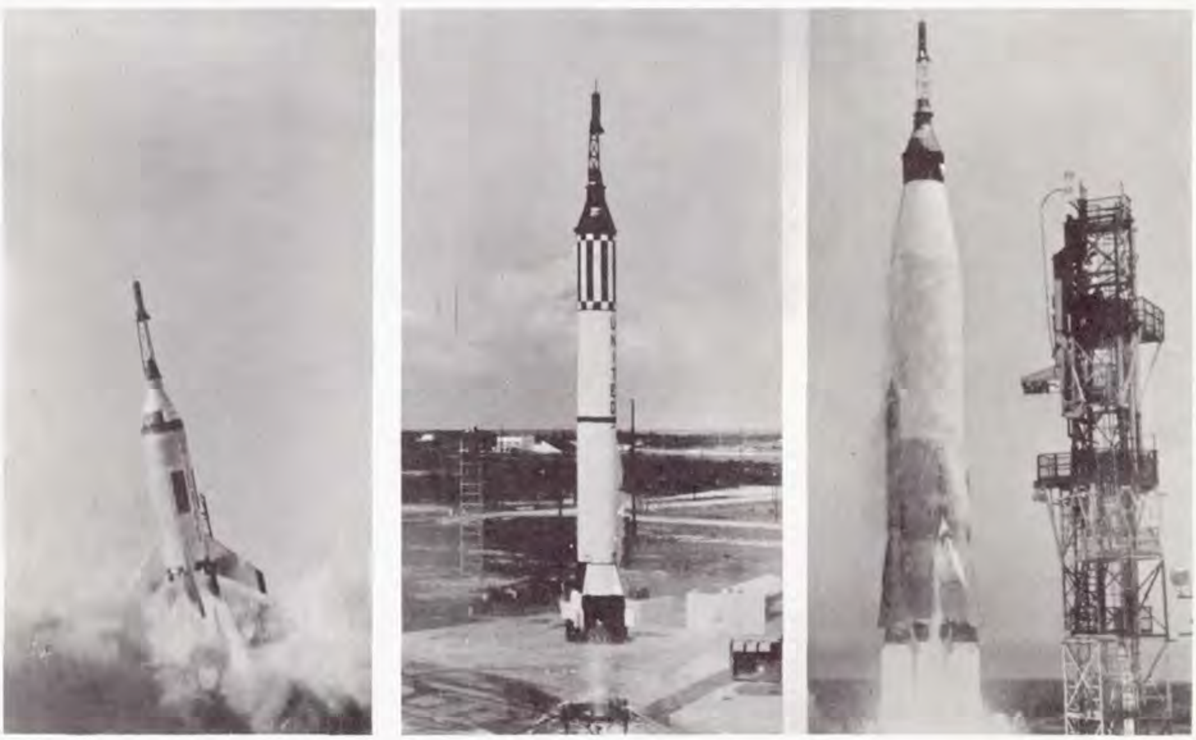
Mercury–Atlas 9.—The Mercury–Atlas 9 (MA–9) mission utilizing production spacecraft 20 and Atlas launch vehicle 130–D, was successfully accomplished on May 15 and 16, 1963, with Astronaut L. Gordon Cooper as the pilot. It was launched from the Cape Canaveral test site for a planned 22 orbital-pass mission. Launch-vehicle performance was excellent and a near perfect orbit was attained. The orbital parameters were as follows: perigee, 87.2 nautical miles; apogee, 144.2 nautical miles. For the first 18 orbital passes, the spacecraft systems performed as expected, and the pilot was able to adhere to the flight plan and perform his activities as planned. Up to that time, anomalies were limited to small nuisance-type problems. Beginning with the 19th orbital pass, the spacecraft systems problems began with actuation of the 0.05g warning light. Investigation of the occurrence of this warning light indicated that the automatic control system had become latched into the mode required for the reentry phase. Later, the alternating-current power supply for the control system failed to operate. These failures were analyzed by the pilot and the ground crew in real time and it was determined that the pilot would have to make a manual retrofire and reentry. He performed these meneuvers with close precision and landed a short distance from the prime recovery ship in the Pacific. The pilot and the spacecraft were recovered and hoisted aboard the carrier only 40 minutes after landing. More detailed results of this mission are contained in other papers in this document.

Lift-off photographs of the three types of Mercury space vehicles are shown in figure 1–4.

PERFORMANCE

An examination of the history of the major flight tests, presented in figure 1–3, will show that the basic objectives of the Mercury Project were achieved $3\frac{1}{3}$ years after official project approval, with the completion of Astronaut John Glenn's successful orbital flight on February 20, 1962. Subsequently, Astronaut Carpenter completed a similar mission. Then, Astronauts Schirra and Cooper completed orbital missions of increased duration to provide additional information about man's performance capabilities and functional characteristics in the space environment. In addition, increasing numbers of special experiments, observations, and evaluations performed during these missions by the pilots as their capabilities were utilized have provided our scientific and technical communities with much new information. It is emphasized that goals beyond those originally established were achieved in a period of $4\frac{2}{3}$ years after the beginning of the project with complete pilot safety and without change to the basic concepts that were used to establish the feasibility of the Mercury Project.

In early 1959, immediately after project go-ahead, the first manned orbital flight was scheduled to occur as early as April 1960, or 22 months before the event actually took place (see fig. 1–5). This difference was caused by an accumulation of events which included delays in production spacecraft deliveries, difficulties experienced in the preparations for flight, and by the effects of the problem areas that were detected during the development and early qualification flight tests. The primary problem areas included those which were associated with the spacecraft–launch-vehicle struc-



Little Joe Redstone Atlas

FIGURE 1–4.—Lift-off photograph of the three types of Mercury space vehicles.

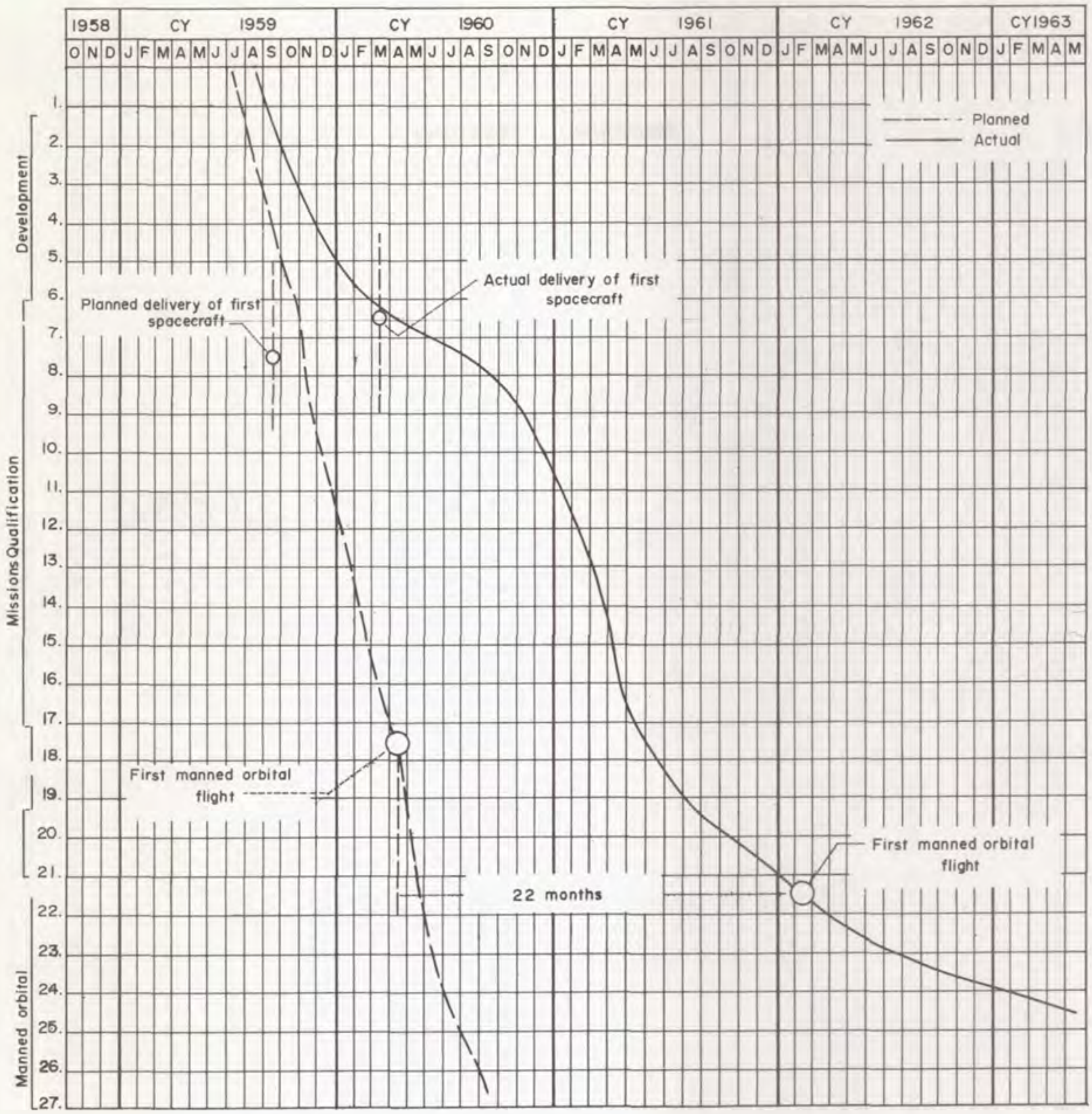


FIGURE 1–5.—Comparison of planned and actual flight schedules.

tural interface on the MA–1 mission, spacecraft sequential-system sensors on Little Joe missions 5 and 5A, launch-vehicle umbilical-release sequence on the MR–1 mission, launch-vehicle propulsion system on MR–2, and launch-vehicle control system on MA–3.

The applicability of these statements can be illustrated by reference line representations of the planned and actual schedules that are compared in figure 1–5. This comparison shows that the flight-test program was intiated about 1 month late. Missions through the development phase and those missions accomplished through most of the qualification phase were accomplished at about the planned rates. The major deviations occurred in 1960 when production spacecraft deliveries were later and when launch preparation took longer than planned. The planned schedule allowed for about a 4-week prelaunch preparation period at the launch site. Actual preparation time averaged about six times the estimated amount. Some of the additional required preparation time was compensated for by concurrent preparation of several spacecraft. Also, some significant problems were encountered during the early qualification missions which caused delays in the schedule by requiring additional missions to accomplish the objectives. These delays were accumulative and were not reduced during the life of the project. The delays that occurred later in the project resulted from deliberate efforts to insure that the preparation for the manned flights was complete and accurate and, still later, from changes made to increase the spacecraft capabilities.

Figure 1–3 shows that 25 flight tests were made in the 45-month period between the first mission and the end of the project, for an average of about one flight test in each 2-month period. This is a very rapid pace when the development and qualification nature of the program is considered. Even so, the average rate was low when compared with the rate that was maintained during the last part of 1960 and the early part of 1961 when five spacecraft were in preparation at once and the launchings occurred more frequently than once a month. It should also be noted that, during the period of high launch rate, preparations were accomplished at two widely separated sites, Cape Canaveral, Fla., and Wallops Station, Va.

While the flight missions were the significant outward signs of the project activity that resulted from the total effort, it was the behind-the-scenes activities that made the missions possible. The contents of figure 1–6 show the concurrent activity that existed in a number of the more significant areas of Project Mercury in order to reduce the time required to accomplish the objectives. The specific requirements in many areas were dependent upon the development being accomplished in the other areas. Thus, there was a continual iteration process carried on which resulted in a gradual refinement of requirements and completion of the work.

Management

Modes of Operation

Development of the management structure and operating mode to direct this complex and rapidly moving project began concurrently with the approval of the plans for a program of research and development leading to manned space flight which were presented to Dr. T. Keith Glennan, the first Administrator of the National Aeronautics and Space Administration (NASA) on October 7, 1958. The plans approved by Dr. Glennan on that date had been formulated by a joint National Advisory Committee for Aeronautics-Advanced Research Project Agency (NACA–ARPA) Committee, chaired by Dr. Robert R. Gilruth, at that time Assistant Director of Langley Research Center. The committee had been established during the summer of 1958 to outline a manned satellite program. With the approval of these plans by the Administrator of NASA, formerly the NACA, Dr. Gilruth was authorized to proceed with the accomplishment of the Manned Space Flight Project.

The Space Task Group (STG), later to become the Manned Spacecraft Center (MSC) was informally organized after this assignment to initiate action for the project accomplishment. The initial staff was comprised of 35 personnel from the Langley Research Center and 3 from the Lewis Research Center.

On November 5, 1958, the STG located at the Langley Research Center was formally established and reported directly to NASA Headquarters in Washington, D.C. At the same time, Dr. Gilruth was appointed head of the STG and project manager of the manned satellite program. By the end of November 1958 the manned satellite program was officially named Project Mercury.

The overall management of the program was the responsibility of NASA Headquarters, with project management the responsibility of the STG. It was recognized from the beginning that this had to be a joint effort of all concerned, and as such, the best knowledge and experience as related to all phases of the program and the cooperation of all personnel was required if success was to be achieved. It was also recognized that it was an extremely complex program that would probably involve more elements of government and industry than any development program before undertaken. Because of this complexity and involvement of so many elements, management was faced with an extremely challenging task of establishing an overall operating plan that would best fit the program and permit accomplishment of all objectives at the earliest possible date. To achieve

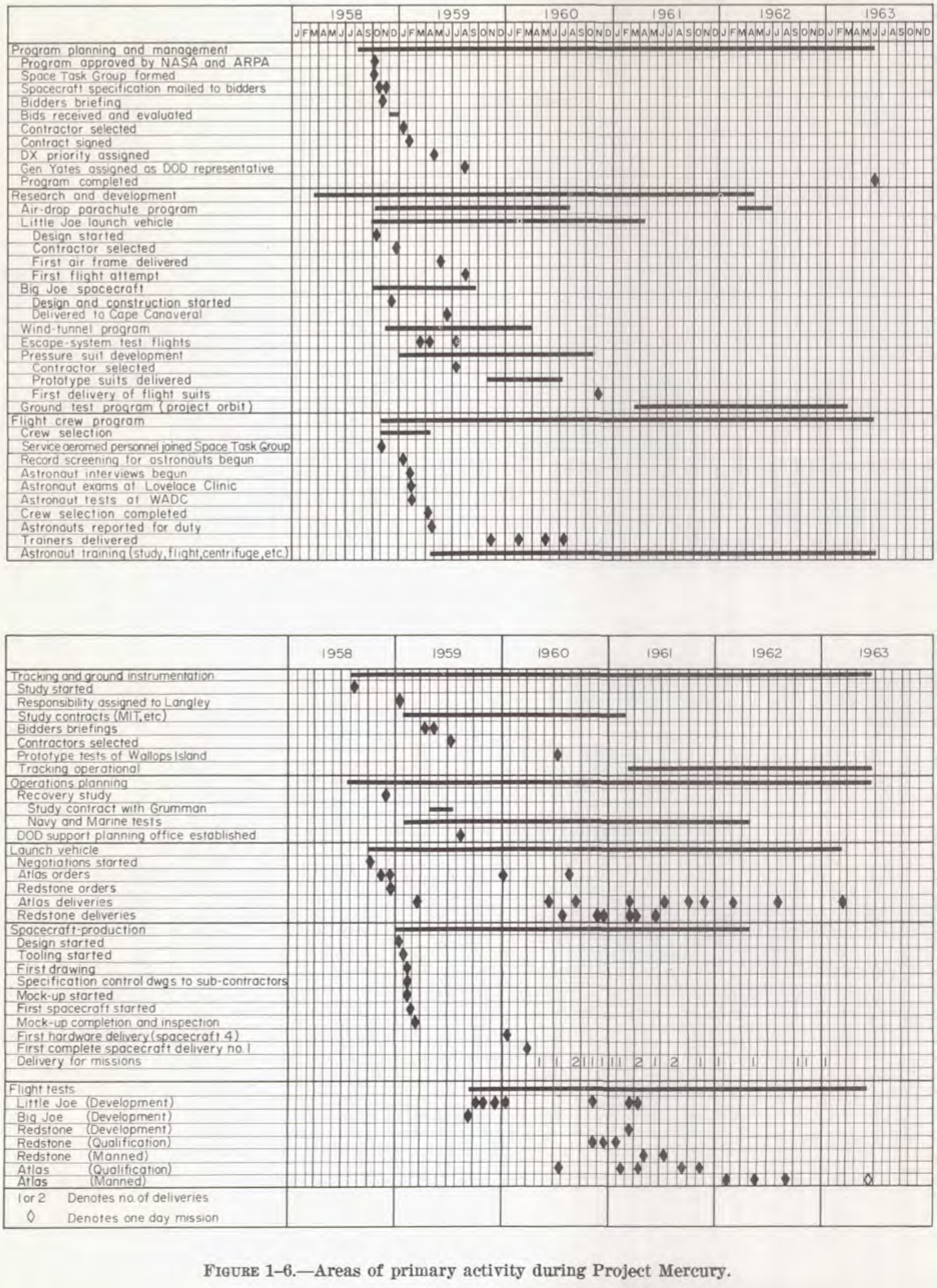


FIGURE 1-6.—Areas of primary activity during Project Mercury.

this task a general working arrangement was established as shown in figure 1–7. This figure illustrates in a very simplified format, the general plan used.

The arrangement was basically comprised of three working levels. The first level established the overall goals and objectives as well as the basic ground rules and the means for their accomplishment. The next level was responsible for establishing technical requirements and exercising detailed management. The detailed management was performed at this level and provided the approval and authorizing interface with all elements supporting the project. The bond of mutual purpose established here provided the direction and force necessary to carry the project forward. This same bond was evident in the groups or teams, in the third level of effort, set up to carry out the detailed implementation and, where necessary, further define the requirements. This level consisted of teams comprised of personnel from all necessary elements with responsibility for the assigned task and most knowledgeable in the area for which the group was responsible. These third level teams were established as required to investigate and define detailed technical requirements and insofar as possible to make the arrangements to implement their accomplishment. The team continued to function until all details of a particular technical requirement were worked out to the satisfaction of those concerned. As the tasks assigned to a particular team were completed, that team was phased out. New teams were established to meet new requirements which evolved and requirements of various phases as the project progressed.

An example of this working arrangement with a general explanation of how it worked is shown in figure 1–8. This example shows the arrangement used to procure and develop the Atlas launch vehicle for manned flight. To accomplish this, procurement agreements and overall policy were established between the U.S.

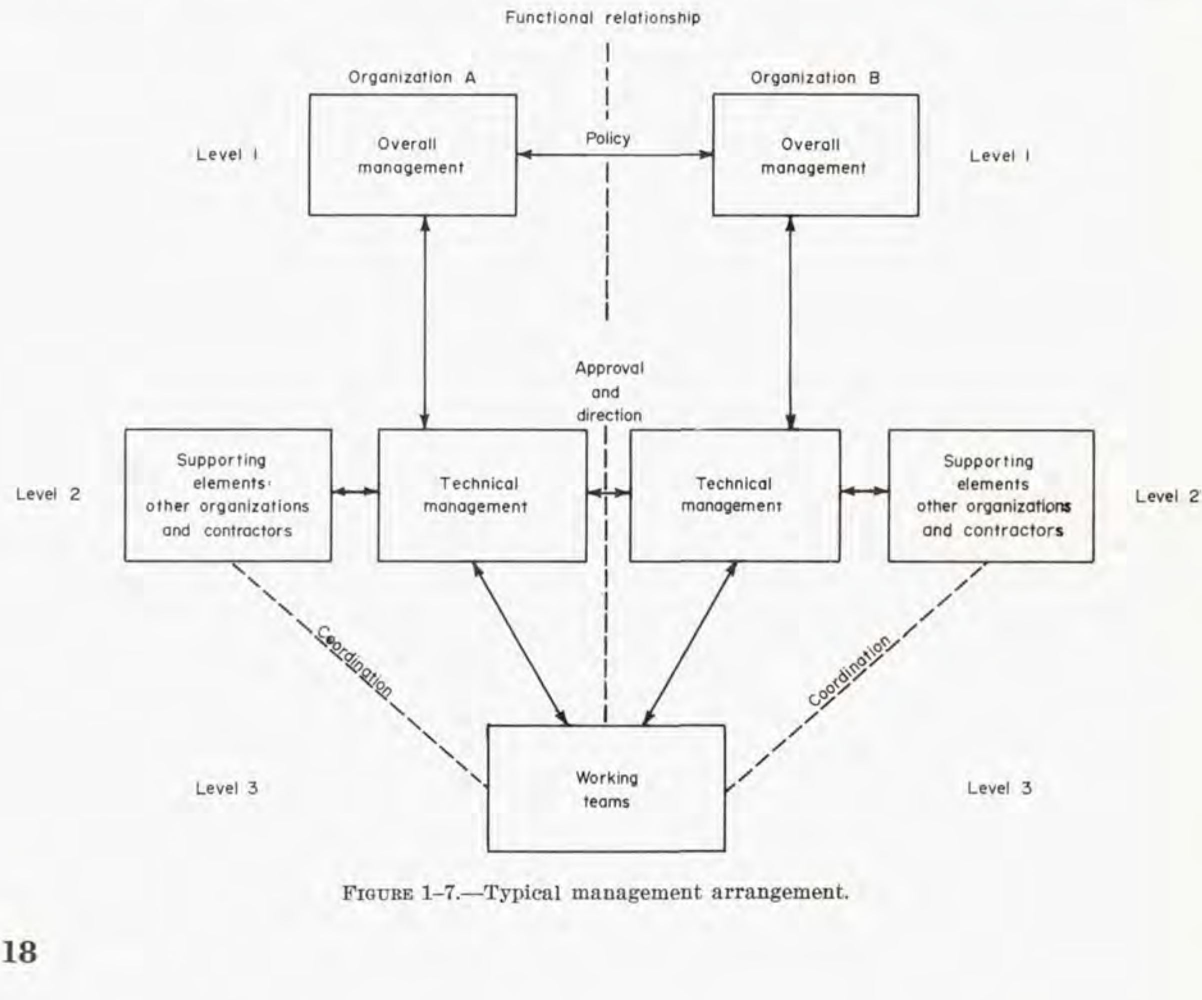


FIGURE 1–7.—Typical management arrangement.

Air Force Ballistic Missile Division of the Department of Defense and the NASA Headquarters. Working within the framework of these agreements the Atlas Weapons Systems Command of the U.S. Air Force and the NASA STG formulated the basic technical requirements necessary to adapt the Atlas for use in the program. Working teams consisting of specialists from the STG and the Atlas Weapons Systems Command were established to define the detail requirements and initiate the necessary action for their implementation. This implementation could be direct for cases in which the team had the authority or the recommendation for implementation could be forwarded to the necessary level of authority. In any case, the next higher level could alter the decisions of the lower level if developments required. This arrangement also provided a "closed-loop" management structure, thus assuring positive means of communication and proper technical directions. Frequently, specialists from the contractors and other supporting elements were included in the teams to assemble the best available talent to solve the problem. Quite often, tasks involving considerable effort were assigned directly to individual team members by the chairman of the group for implementation.

The same general arrangement was employed between NASA elements in accomplishing major tasks, such as establishing the Worldwide Tracking Network, as illustrated in figure 1–9. In addition to the many overall arrangements that had to be made in establishing the Worldwide Tracking Network, such as agreements with foreign governments, working through the State Department, regarding the location and operation of ground stations in their territory, the task of providing the hardware and facilities that made up the ground stations represented a major task that was primarily the responsibility of the STG and the Langley Research Center. This example covers the means by which the basic technical requirements and hardware needs of the ground stations were accomplished through the combined efforts of the STG and Langley. The Langley Research Center was responsible for the procurement and establishment of the network, with the basic flight monitoring and control requirements being the responsibility of the STG. The overall agreements regarding the implementation of this effort were established at the Director-Project Manager level with the basic technical requirements being defined at the level of the cognizant divisions. After the basic requirements were presented to the Langley Re-

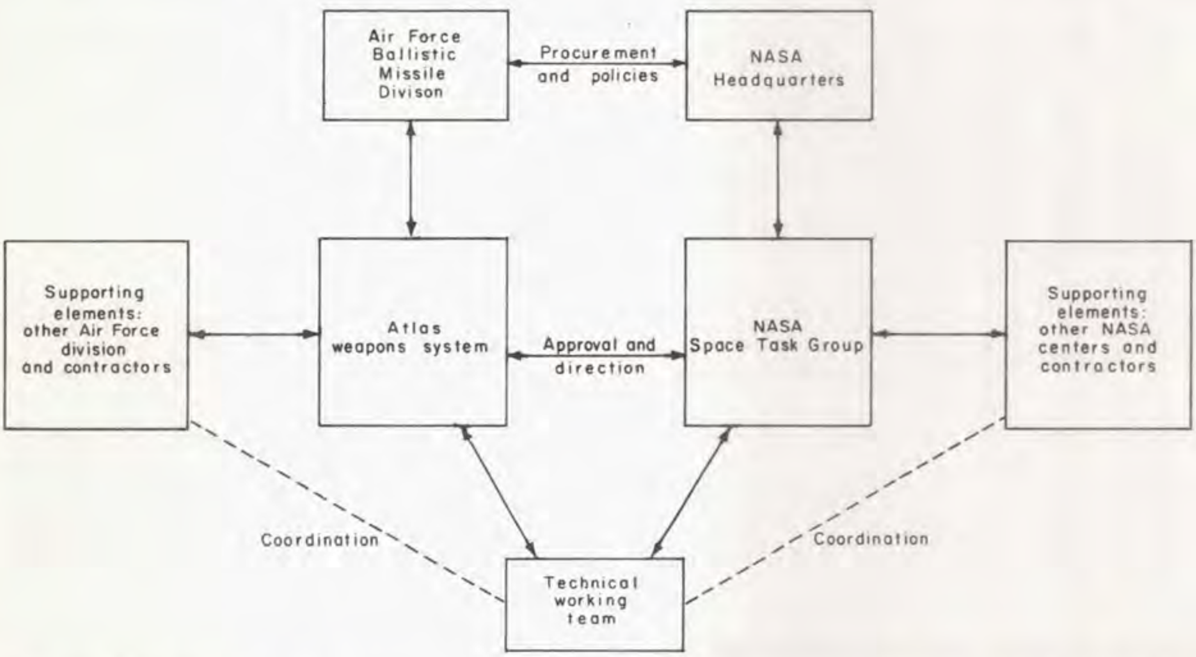


FIGURE 1–8.—Management arrangement used to procure, develop, and prepare the Atlas launch vehicle for manned flight.

search Center, teams were established to discuss and resolve the detail technical requirements of the network. For example, a team was assigned the task of establishing the communications and tracking requirements and resolving the type of equipment to be used on the spacecraft and the detail design characteristics of this equipment. They then had to determine if suitable receiving equipment for the ground stations was available or if it had to be developed. This involved coordinating overall requirements given to both the Langley Research Center's ground station contractors and the STG's spacecraft contractor to determine if the desired requirement could be achieved and if not, to determine an acceptable means of achieving the desired results. This points out only one detail area that this kind of group had to resolve; other areas such as location of the ground stations, frequencies of transmission, bandwidths, spacecraft antenna radiation patterns, and so on presented the same type of problems that had to be resolved. These efforts evolved into the Mercury Worldwide Tracking Network, the operation of which was the responsibility of the Goddard Space Flight Center (GSFC). Similar arrangements existed between the many elements necessary to develop the network and implement its operation.

To illustrate further this type working arrangement the identifications on figure 1–7 could be changed to represent those of the STG and the spacecraft contractor, McDonnell Aircraft Corporation (MAC). In this instance it was recognized by both parties that normal contractual procedures alone were insufficient to achieve the desired results within the scheduled time frame. Direct communication regarding technical requirements between the specialists of STG and MAC had to be the rule rather than the exception. Management agreements on the upper levels provided the framework whereby this could be accomplished and provided the management decisions for project direction. Frequently, the teams determined a course of action and proceeded without further delay, with verification documentation following through regular channels. The "closed-loop" built into the working arrangement provided the assurance that contractual and program requirements were met in all cases. Regular management reviews of hardware status and task achievement kept management abreast of the problem areas and afforded the opportunity for timely direction of effort to many specific problem areas. This mode of operation enhanced the rapidity with which a design change could be implemented or a course of action altered. This contributed to the timely conclusion of a project.

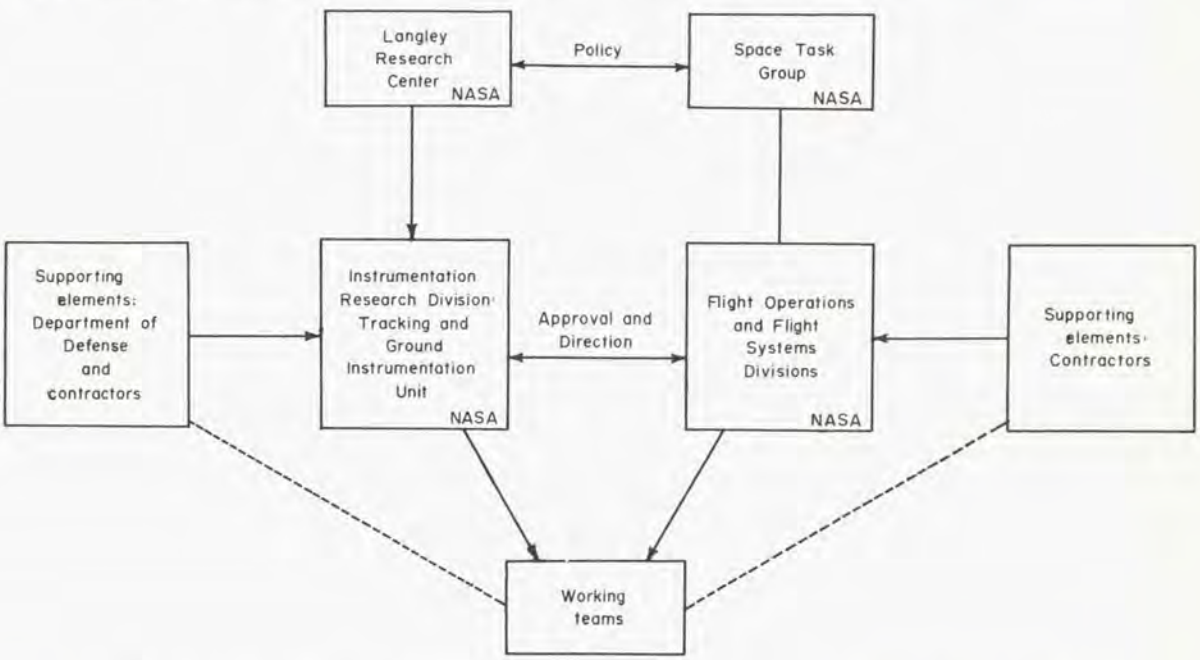


FIGURE 1–9.—Management arrangement used to establish the ground tracking organization.

The foregoing discussion is primarily concerned with the management techniques that existed with the external organizations, but the same type of procedure was commonly used within the organizational structure of the STG. As firm definition of the program emerged and final spacecraft design details were formalized, it became necessary to centralize the coordinating effort within the STG. To accomplish this, centralized review meetings were conducted on a regular basis to correlate all elements of the effort and ascertain that unified approaches and directions were maintained. These meetings were attended by cognizant personnel from within the STG and by personnel from other activities when required. The primary function of these meetings was to obtain the best inputs available for the technical management of the project and to control the engineering and design and thereby the configuration of the spacecraft. Information channeled into these meetings was dispersed directly to the responsible individuals within the STG, with assignments being made directly to the cognizant organization when action was required. Technical direction required as a result of action initiated at the coordination meetings, after thorough review as to need, cost, and effect on schedule, was issued to the applicable contractors. Meetings of this type provided fast response and accurate direction throughout the duration of the project. As the staff and project responsibilities increased, the support administrative functions performed by the Langley Research Center, such as Personnel, Procurement and Supply, and Budget and Finance Offices, were incorporated into the STG management organization.

The formation of the Mercury Field Operations Organization at Cape Canaveral marked the entry of Project Mercury into the operational phase of the program. In conjunction with this an Operations Director was appointed with complete responsibility and authority for flight preparation and mission operations. The Operations Director also served as the single point of contact for Department of Defense (DOD) activities supporting Project Mercury.

Although the general management modes of operation previously discussed were applied throughout the duration of the project, a different type functional organization was established for the specific purpose of conducting a space-flight mission. The organization covering the flight operations phase of the project was a line organization with elements from the government and contractor organizations involved in the operation reporting directly to the Operations Director. Figure 1–10 illustrates the manner in which these elements merged to form this functional line organization.

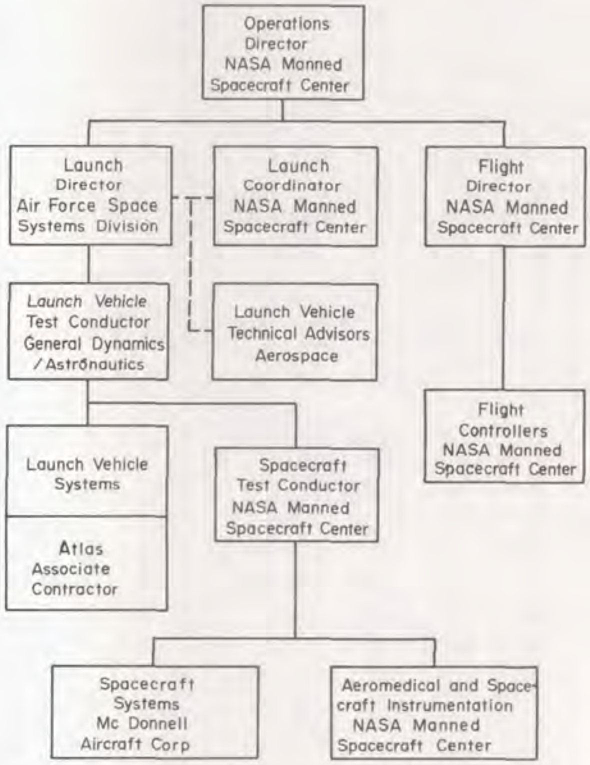


FIGURE 1–10.—Integrated functional organization for launch operations.

An organizational chart of this nature fails to show the unified effort, the cooperation, and the team work that was evident in every Mercury flight. All elements of government and industry supporting the project pulled together toward a common goal, with each individual striving to do his best. Without this spirit of cooperation and team work, the degree of success experienced in Project Mercury would not have been possible.

The success of Project Mercury demonstrated not only the reliability of the equipment but also the effectiveness of the management organization and the working arrangements with the various supporting elements throughout government and industry. Efforts to assure that Project Mercury would meet its objectives evolved in the high level agreements that resulted in clear lines of authority and responsibility for technical direction.

With the increasing national effort in the field of space exploration, additional manned space projects were assigned to the STG. Because of the increased emphasis and scope of the manned spaceflight effort, the MSC was established in November 1961 from the nucleus provided by the STG. Soon after the MSC was established, the Mercury Project Office was created and assigned the responsibility and authority for detailed management and technical direction of the project, working with the support of other MSC units in areas in which they had cognizance or had specific specialties needed to achieve project objectives. The MSC organization existing at the end of the project is shown in figure 1-11. The Mercury Project Office provided the project management to the conclusion of the project and used the same general management method established early in the program.

Tools

A reporting system was required by management to control the fast-moving project so that effective and timely decisions could be made. Various methods used by management to accomplish this included reports, schedules, cost control, and later, program evaluation and review technique (PERT) in addition to the technical reviews previously mentioned.

Many types of technical reports were prepared for management in order to keep it abreast of progress and problems. These reports were concise and factual status reports issued daily, weekly, monthly, and quarterly to highlight progress or lack of progress without conjecture. Obviously, close to the launch date, the daily reports became the most important. Another valuable report was the one prepared after the completion of each mission. These were prepared expeditiously to present analyses of the performance of all the systems involved in the mission, from the lowest elements through operational recovery techniques. The results of these analyses were used immediately after a mission to form the basis for corrective action that often influenced the hardware on the very next mission. These results were issued in formal report formats that contained detailed descriptions of the mission and equipment, performance analyses, result of investigations of anomalies, and much of the data. The reporting effort became greater as the complexity and duration of the missions increased, and larger reports and longer preparation times resulted. However, in most cases, the reports were printed for distribution within 30 days after the mission. The report of the MA-9 mission, for example, contained more than 1,000 pages of information.

Innumerable documents were generated covering all aspects of the program during the life of Project Mercury so that management as well as the individual elements could have overall knowledge of project details and progress. These documents were prepared by all elements participating in the program and included such general types as drawings, familiarization manuals, specifications, operational procedures, test procedures, qualification status, test results, mission results, reports on knowledge gained and status reports of all kinds. It is estimated that at least 30 formal documents, excluding drawings, engineering change orders, and so forth, were issued during the course of the project. A partial listing of the types of documentation used during the program is included in appendix A.

Overall schedule control was accomplished by the use of a Master Working Schedule which indicated major milestones, such as spacecraft deliveries and checkout periods, launch-vehicle deliveries and checkout times, launch-complex cleanup and conversion, and tracking network status. Detailed bar-chart schedules were maintained in areas of direct concern, such as individual spacecraft at the manufacturer's plant, launch preparation of the spacecraft and launch vehicle at the launch site, astronaut training, and the major test programs.

To control cost, management constantly monitored commitments, obligations, and expenditures through the normal accounting techniques. During the later phases of the program, the project office maintained cost control charts on which approved programed funds were shown, as well as obligations for a given time period. From these charts, management could tell at a glance the amount of remaining unobligated funds for any given area.

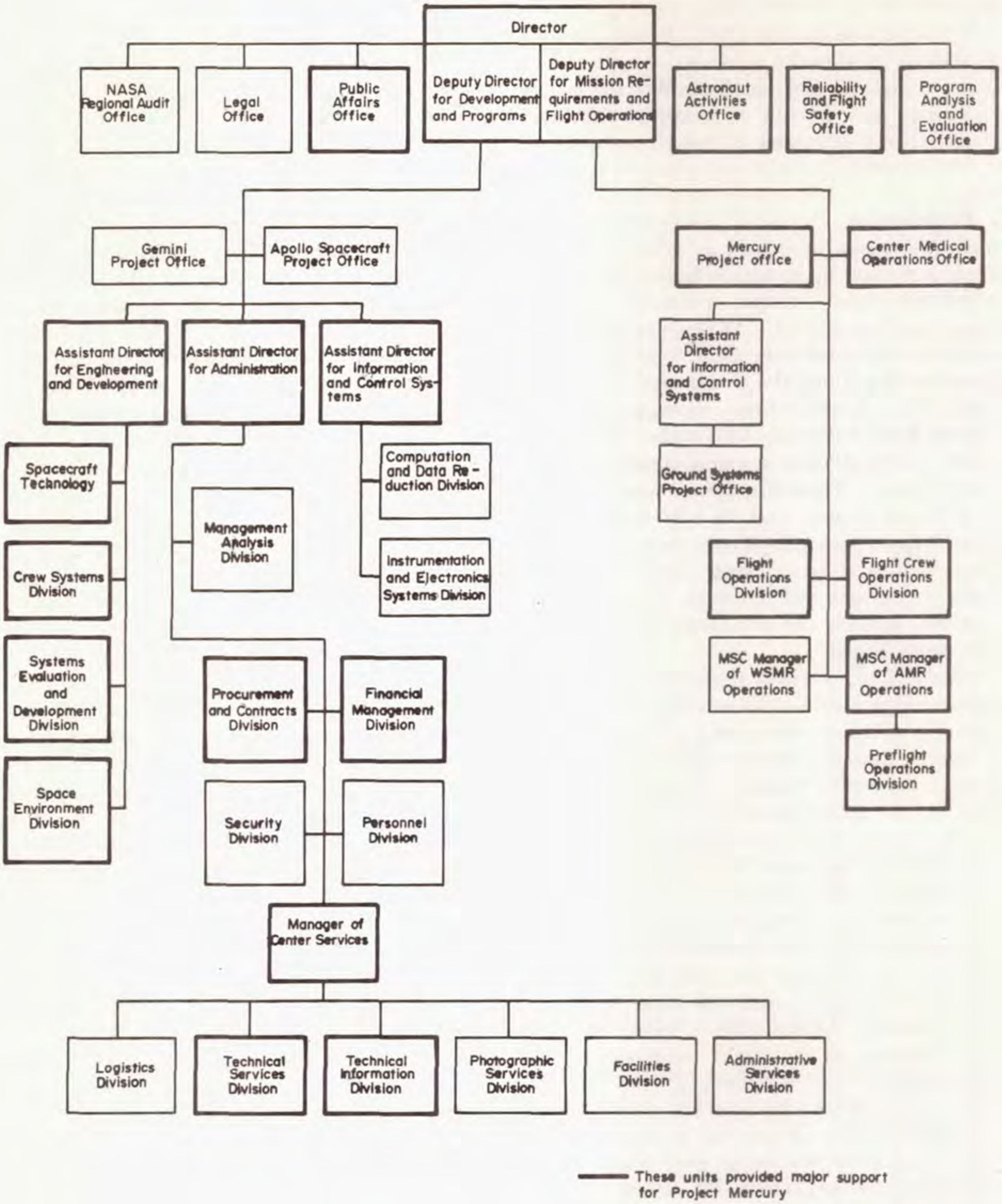


FIGURE 1–11.—Organization existing at end of Project Mercury.

In the last year and a half, the Manned Spacecraft Center applied the PERT system to cover all areas of the project. The PERT network information was analyzed and updated biweekly and provided useful information on a timely basis to make it possible to employ the use of redundant action paths or to apply additional effort when it appeared as though problems in a single, critical path would result in long delays.

Engineering, technical, configuration, and mission reviews were held as often as once a week to present up-to-date information on proposed technical changes, potential problem areas, and test results. At these meetings, the necessary decisions were made to keep the program moving along the chosen path at the desired rate. At other times, development engineering inspections were held at the contractors' plants as significant systems approached delivery status. These inspections were attended by top management and the best, most experienced supervisors, pilots, engineers, specialists, inspectors, and technicians. As a result of these inspections and thorough validating discussions, requests for mandatory corrective action were issued.

Flight safety reviews attended by top management probably constituted the most significant management tools used in Project Mercury to insure that the proper attention had been given to necessary details. These reviews were held in the days immediately before launch. In the process of ascertaining that the material required for presentation at the meetings would be acceptable, the technical work in progress was reviewed in great detail with particular emphasis being placed on results of tests, modifications, and changes that had been incorporated and the action that was taken to correct discrepancies. At the reviews, then, the questions relating to the flight readiness of the spacecraft, the launch vehicle, the crew, the network, the range, and the recovery effort could be answered in the affirmative, except in those cases where actual anomalies were discovered in the test results, data, or records during the presentation. Of course, these anomalies were then completely corrected or resolved, because no Mercury launchings were ever made in the face of known troubles or unresolved doubts of any magnitude that could affect mission success or mission safety.

Resources

Many milestones occurred during the 57 months of the project as shown in figure 1–3. Mercury history reflects 25 major flight tests in a 45-month period. It should be noted that launch preparations and flights were accomplished from two widely separated sites: Cape Canaveral, Fla., and Wallops Station, Wallops Island, Va. Twenty-three launch vehicles were utilized—seven Little Joe, six Mercury–Redstone, and ten Mercury–Atlas. Two flight tests, the off-the-pad abort and the first Little Joe flight test, did not utilize launch vehicles. Fifteen production spacecraft were utilized for the flights, some of which were used for more than one flight mission or test unit. One spacecraft was used entirely for a ground test unit.

The broad range of effort which occurred, often concurrently, during the life of the project required the services of large numbers of people, as illustrated in table 1–I. At the height of this effort there were 11 major contractors, 75 major subcontractors, and 7,200 vendors working to produce the equipment needed for Project Mercury. Also included in this endeavor were the task forces from the DOD supplying ships, planes, medical assistance, manpower, and so on in support of flight and recovery operations. During the development and qualification phase of the project, effort was expended from Langley Research Center, Lewis Research Center, George C. Marshall Space Flight Center, Goddard Space Flight Center, Ames Research Center, Wallops Station, and DOD involving hundreds of people. Colleges and universities also investigated many different and significant facets of Project Mercury. At the height of the program, there were some 650 people working directly on Project Mercury in the MSC and over 700 more in other parts of the NASA. In all, it is estimated that there were more than 2,000,000 persons located throughout the United States who directly or indirectly provided support for the Mercury Program. The general locations of the major contractors, universities, NASA centers and other government agencies are illustrated in figure 1–12.

Table 1-I.—Peak Manpower Support

Source	Approximate peak numbers	
NASA:		1,360
Direct	650	
Research and development	710	
Industry:		2,000,000
Contractors (11)	33,000	
Major subcontractors (75)	150,000	
Vendors (7,200)	1,817,000	
Department of Defense		18,000
Educational groups		168
Others		1,000
Total		2,020,528

FIGURE 1-12.—Distribution of organizations in the United States that supported the project.

Lists of government agencies, prime contractors, and major subcontractors and vendors are presented in appendixes B, C, and D, respectively. A list of NASA personnel who contributed to the Mercury Project effort is presented in appendix E.

The total cost of the Mercury Program as published in the Congressional Committee Record in January 1960 was estimated to be $344,500,000. The basic objectives were fulfilled with the successful completion of the MA-6 flight and additional space experience was obtained from the MA-7, MA-8, and MA-9 missions. The latest accounting shows a total project cost of $384,131,000; however, final auditing has not been completed. These cost figures include the cost of the Mercury tracking network which will be used for manned space programs for years to come, and the cost of the operational and recovery support sup-

Table 1-II.—Cost Breakdown

Breakdown	Percent of total		Cost in millions of dollars	
Spacecraft:		37.6		144.6
Design	8.6		33.2	
Production	5.6		21.7	
Test and flight preparation	4.2		15.9	
Subcontract	16.2		62.2	
Qualification	3.0		11.6	
	37.6		144.6	
Network		32.4		124.6
Launch vehicles		23.7		90.9
Operations		4.3		16.4
Supporting development		2.0		7.6
Total		100.0		384.1

plied for each mission. A cost breakdown is presented in table 1-II, indicating how the funds were used. It is shown that the largest part of the funds went into the development of the spacecraft and the Worldwide Tracking Network. This is not surprising since these items required complete development. About 24 percent was expended for various launch vehicles. The remainder of the funds was spent for operational expenses and for supporting research and development. A breakdown of the spacecraft costs shows that approximately equal percentages were spent on design and on production. Almost one-half of the total spacecraft cost was spent on subcontracts by the spacecraft contractor.

The peak rate of expenditures in the program, as illustrated in figure 1-13, occurred dur-

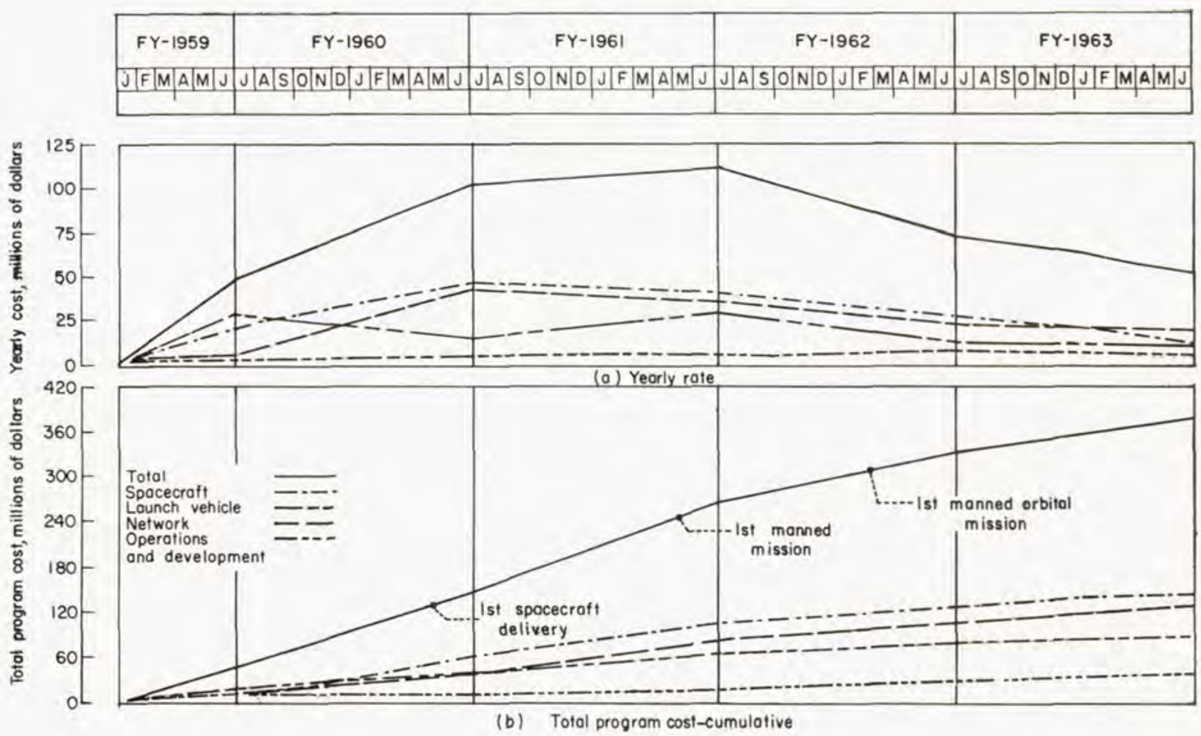


FIGURE 1-13.—Rate of expenditures and accumulated cost.

ing the fiscal year of 1961 and can be attributed to several factors. During this period, more than half of the total production spacecraft were delivered and more major flight missions were accomplished than in any other comparable time period. Launch activities were supported both at Wallops Station, Va., and at Cape Canaveral, Fla. Funds were being spent on the Worldwide Tracking Network for the coming orbital missions. The Redstone phase of flight program was nearing completion and the Atlas phase was approaching a peak. Also, much astronaut training was accomplished and the first manned ballistic flight was completed during this period.

Technical Experience

The major results obtained and the significant philosophies and techniques developed during the course of the project are grouped for discussion in the following areas: physiological and psychological responses of man in the space environment, flight and ground crew preparational procedures, and techniques and philosophy for launch preparation.

Responses of Man

The manned Mercury flights produced considerable information on human response and general physiological condition. Some of the most significant results may be summarized as follows:

(1) Results of repeated preflight and postflight physical examinations have detected no permanent changes related to the space-flight experience, although Astronauts Schirra and Cooper temporarily showed indications of orthostatic hypotension after their missions.

(2) There have been no alarming deviations from the normal, and the astronauts have proved to be exceedingly capable of making vital decisions affecting flight safety, taking prompt accurate action to correct systems deficiencies, accomplishing spacecraft control, and completing all expected pilot functions.

(3) The weightless state for the time periods of up to 34 hours has shown no cause for concern. Food and water have been consumed and the astronaut has slept. No abnormal body sensations and functions have been reported by the astronauts. The health of all of the astronauts has been good and remains so.

Not only has it been found that man can function normally in space, at least up to a maximum of 34 hours, but it has been found that he can be depended upon to operate the spacecraft and its systems whenever it is desired that he do so. On the MA–6 and MA–7 missions, the astronauts overcame severe automatic control system difficulties by manually controlling their spacecraft for retrofire and reentry. Also, on the MA–9 mission, the performance of the astronaut demonstrated that man is a valuable spacecraft system because of his judgment, his ability to interpret facts, and his ability to take corrective action in the event of malfunctions which would have otherwise resulted in a failure of the mission.

The astronauts also proved that they were qualified experimenters. As a result, the weight allocated in each succeeding manned orbital space flight increased from 11 pounds on MA–6 to 62 pounds on MA–9 for equipment not related to mission requirements. In each of these missions, the astronauts have demonstrated their ability to perform special experiments and to be a scientific observer of items of opportunity.

It can be concluded that the astronauts have proved to be qualified, necessary space systems, with flexible, wide-band-observation abilities, and have demonstrated that they could analyze situations, make decisions, and take action to back up spacecraft systems when provisions were made to give them the capability.

Crew Preparation

Studies, simulators, and training equipment for preparing flight crews and simultaneous participation of flight and ground crews in simulated missions were important to the success of the mission. This training is discussed in detail in later papers of this document. Before the final round of training and simulation began, it was found necessary to formulate and freeze a well-defined, detailed flight plan. This must be done far enough in advance of the mission to give the pilot sufficient time to train to the particular plan with the ground network teams who will support him during the mission. It has also been found to be important to avoid filling every available moment of the flight with a planned crew or ground-station activity. Time must be available to the flight crew to manage the spacecraft systems and to investigate anomalies or malfunctions in the system and to observe and measure the unexpected. Time must be provided to allow the pilot to consider thoughtfully his reactions to the space environment and its effects upon him. He must have time to eat and drink and to obtain sufficient rest. Training in simulator devices has proved to be a valuable tool for preparing a man for space flight. Well in advance of his flight, the pilot must have detailed training in the basic systems and procedures for the mission. In addition to preparing the pilot for normal and emergency flight duties, the training must also prepare him to conduct successfully the special experiments assigned to his mission. For certain of these tasks, the pilot becomes a laboratory experimenter and must be suitably trained. So far, many different training modes have been used to good advantage. These modes include lectures by specialists, discussions with the associated scientists, familiarization sessions with the specialized flight equipment before the flight, and parallel study in the field of the experiment. During the project, the special training given the astronauts produced trained experimenters for each mission.

Launch Preparation

In the process of hardware checkout during launch preparations, it has been found essential to have detailed written test and validation procedures, procedures that are validated and followed to the most minute detail during the preliminary systems checkout and, again, during later and final systems and integrated systems checkouts. It is necessary for the procedures to be so written that even small anomalies become readily apparent to those persons involved in the checkout. These persons must be so trained and indoctrinated that they are always watchful for anomalies which would be direct or indirect indications that the hardware may be approaching failure. Checkouts are not completed at the end of the detailed procedures, for it has been found that the data accumulated during a checkout procedure may reveal, upon detailed analyses, further symptoms that all is not well within a system. Finally, the Mercury personnel have developed and adhered to a philosophy that is believed to be a basic reason for Mercury's operational success. This philosophy is that Mercury launchings will not take place in the face of known troubles or in the face of unresolved doubts of any magnitude that could possibly affect mission success or flight safety. It is believed that adherence to this philosophy is of utmost importance to success of any manned space flight program.

Areas for Improvement

A list of those general technical areas that appeared to be either the source of, or a major contributing factor to the problems that repeatedly cost the project time and money would include design requirements, qualification practices, definition of standards, tests and validation procedures, and configuration management. The conditions and effects described in these areas are not unique to this project, but represent those that generally exist in the aerospace field. Therefore, improvements in these areas would be beneficial in reducing the number of discrepancies that may potentially cause schedule delays and rising costs. Discussion of these areas will reveal that in most trouble areas careful and continuing attention to detail and quality assurance program were not as effective in the aerospace industry as necesary. It is believed that the need for improvements has become clear and that the changes for the space flight era are beginning to be made.

Design Requirements

Requirements and philosophies applied during the detail design phase have a profound and lasting effect on the overall performance of a project; therefore, some of the more significant shortcomings observed in the design phase are emphasized. Adequate design margins must be established and they must be adequate. An example where inadequate margins were detrimental is the weight-sensitive landing system. Experience with aircraft and spacecraft designs shows that weight continues to increase with time. In Mercury, this increase was significant; and although the rate tended to decrease with time, it was present throughout the duration of the project. The orbital weight of the spacecraft increased at an average rate about 5 pounds (0.2 percent) per week during 1959 and 1960; thereafter the increase averaged less than 2 pounds per week, even after a strong weight-control program had been initiated. The overall weight increase caused an extensive requalification of the landing system because the original design did not have sufficient growth margin. During the initial design phase careful consideration should be given to the use of redundancy. There are different forms of redundancy and the correct form must be chosen for the particular application to prevent degrading the overall reliability of the system. Because of the hazards of space flight and the lack of provisions for repairing or replacing equipment in flight, it was imperative in Mercury spacecraft that all critical functions have redundant modes. The redundancy was made less automatic, as man demonstrated the capability of applying the redundant function or providing the redundancy himself.

In the design of a spacecraft, consideration must be given to accessibility of components and assemblies. More than 3,000 equipment removals were made during the launch preparations on an early spacecraft; at least 1,000 removals were performed during preparations of the other production spacecraft. The majority of these removals occurred to permit access to a failed part. It is important that the design be such that a minimum number of other components have to be disturbed when it is necessary to replace or revalidate a component.

Since man first began making things, particularly with machines that could produce identical copies, he has found himself in the position where interchangeability is a combination of a blessing and a trap. Time and time again airplanes, automobiles, and other types of systems have had troubles and faults, because things that could be connected wrong have been connected wrong, regardless of printed instructions, colors, or common sense. Therefore, it is imperative that electrical connectors, mechanical components, and pneumatic and liquid connectors be so designed that they cannot physically be assembled in the wrong orientation or in the improper order. Experience shows clearly that this requirement cannot be overemphasized. Mismated or misconnected parts continued throughout the project to ruin components, give false indications of trouble, and result in improper functions that can cause test failure during the life of the project.

In the design of equipment for specific applications, consideration must be made for the shelf-life periods, including a margin for delays and extensions to the schedule. Occasionally in Mercury, these periods were not adequate and some equipment had to be replaced because the lifetime limit had been exceeded while still in storage.

Still another and often overlooked consideration is compatibility of materials. This may be related to the materials themselves, to the environment, or, in the case of manned vehicles, to the sensitivity of the man. In any event, care must be taken to see that only those materials properly approved for use in the vehicle are actually used. Time and money were expended in Mercury to rectify cases where improper materials were found in the systems because someone had failed to follow the approved materials list.

Qualification Practices

Complete and appropriate qualification of components, assemblies, subsystems, and systems is essential for reliable performance of space equipment. In the design of the Mercury spacecraft, allowances were made for the unknown environment of the planned manned space-flight missions, by conservatism in design, by redundancy of equipment in systems, and, most important, by component qualification testing through ranges of environmental conditions that were believed to exceed the real conditions. The exact conditions that the components and equipment would be subjected to during Mercury space flights, of course, was unknown prior to the time of the flights. Therefore, care was taken in selecting the qualification conditions because underqualification could result in inflight failures, and drastic overqualification could cause unnecessary delays and high costs in the program. The selected qualification conditions proved to represent the actual environment conditions very well. Some modifications to the specifications were made as the project progressed to make allowances for specific environments, such as local heating in equipment areas and system-induced electrical "glitches." Complete coverage of conditions is important, but not sufficient if the qualification is not also appropriate. During the MA–9 mission, equipment faults occurred late in the mission which resulted in the failure of the automatic control system and required Astronaut Cooper to make his retromaneuver and reentry manually. These faults, which occurred in the electrical circuitry interfaces of the automatic control system, were caused by the accumulation of moisture. The components that suffered these faults had passed the Mercury humidity and moisture qualification tests; however, detail investigation revealed that one inappropriate step had occurred. The qualification procedures were set up so that the equipment was functionally validated before the test; however, during exposure to humid air and moisture, it was not functionally operated because it was not convenient to do so in the test facility. While it was being prepared for the posttest validation, it was given an opportunity to do some drying. The obvious fault was that the equipment was not required to operate during the entire course of the test. Of course, the weightless condition could not be simulated in these or any other ground tests and it is quite likely that this omission also played a role in this flight failure.

To be complete, qualification test requirements must be selected to cover all possible normal and contingent conditions and to allow for the integrated efforts that show up when a complete system is operated.

One way the qualification of a complete system has been accomplished in the project is through the use of full-scale, simulated environment tests. A spacecraft was completely outfitted with flight equipment and instrumented and tested under environmental conditions to reproduce as closely as possible the normal and abnormal, but possible, flight conditions. From these tests, it was possible to determine the effects of modifications and to demonstrate the performance of the integrated system. Almost 1,000 hours of this type of testing was accomplished, compared with less than 60 hours of actual space flight during the entire project.

Definition of Standards

It has become very apparent that certain standards that have been used for years in the aircraft industry must be revised and tightened to make them satisfactory for application to aerospace equipment. Among these are shop practices; for example, those practices used in preparing electrical wiring must be reevaluated to assure that each step is accomplished in a manner that meets high-quality standards. Insulation stripping, soldering, crimping or welding, and cleaning processes must be accomplished without degrading the materials and in such a way that the quality of the work can be verified. Requirements must be made more rigorous and must be thoroughly understood by the people performing the operations, by their supervisors, and by the inspectors to insure continuing high quality work.

Some space equipment is designed to close tolerances which make it very sensitive to contamination in any form; therefore, it is imperative that steps be taken to assure that proper and consistent cleanliness standards are set up throughout the manufacturing, assembly, validation, and checkout phases. A number of these cleanliness standards exist at the present time. However, what is considered clean by one standard may be dirty when compared with "clean" by a similar appearing standard. Steps are now being taken in the industry to formulate logical and consistent standards and it is necessary to implement and to enforce these standards as soon as possible to prevent recurrence of the continual difficulty caused in this project by contamination that ruined metering orifices, check valves, pressure regulators, relief valves, reducers, compressors, and other mechanical equipment, as well as electrical and electronic equipment.

Test and Validation Procedures

Checkout, test, and verification procedures must be compatible with one another and with procedures serving the same function on similar equipment at different test sites. Numerous cases of anomalies, or suspected malfunctions, and failed equipment have been traced to improper or incompatible test procedures and test mediums or equipment. Also, it was found that careful attention to test techniques is essential; otherwise equipment can be damaged because connections are made improperly or dirt can be introduced into the equipment by the test equipment. It has been found that test techniques must be tightened, verified, analyzed, and written in detail to lessen the chance for inadvertent steps to ruin the operation or give false assurance.

Configuration Control

During the course of the project, considerable effort was expended by NASA and its contractors in maintaining an accurate definition of system configuration so that configuration management could be properly maintained. Much of this was manual effort that could not respond as rapidly to changes and interrogations as desired. At least 12 major documents, some of which were updated continually, some periodically, and some for each mission, were used to present the necessary information which was summarized for the desired definition. Component identification, which is essential to component traceability, also was often a tedious, time-consuming, and inaccurate process. To provide for adequate configuration control, it is important that vital information of systems, subsystems, and components be gathered at a central point. Then, provisions must be made to view this information from appropriate levels and directions so that accurate and responsive configuration management can be accomplished. Eventual incorporation of such a system on a national scale would provide a retrievable file to insure maximum use of technical experience and to lessen the chance of repeated errors.

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2. PROJECT SUPPORT FROM THE NASA

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Summary

This paper outlines the contributions that were made to the Mercury Project by NASA organizations other than the Manned Spacecraft Center. These contributions began several years before the Mercury Project had official status through the basic research of the National Advisory Committee for Aeronautics which showed such a project to be feasible. The assistance provided by these organizations contributed directly to the timely development of the Mercury spacecraft and its systems, two of the three launch vehicles used in the Mercury program, and the Mercury Tracking Network.

Introduction

The efforts that were recently ended with the successful completion of the Mercury program did not begin with the initiation of the Mercury Project in late 1958 but, in reality, began several years before that date. The research conducted in the wind tunnels and other facilities of the National Advisory Committee for Aeronautics (NACA) in a decade preceding the Mercury Project established the concepts that eventually led to the Mercury Project. None of these original concepts needed to be changed during the Mercury program.

It is well known that the NACA provided its personnel and its facilities as a nucleus for the new agency when the NASA was established in October 1958. Almost immediately, a small group of scientists and engineers was organized at the Langley Research Center in Virginia to formulate plans for the Mercury Project. Many of this group were personnel of the Langley and Lewis Research Centers who had contributed to the original concepts of a man-in-space project in the preceding years. This organization became the Space Task Group (STG) and quickly began growing in size and capability. While the Space Task Group, and later the Manned Spacecraft Center (MSC), provided the direction and management of the Mercury Project, many thousands of scientists, engineers, technicians, and administrators throughout the NASA organization provided vital support for the Mercury Project. Without this support, Mercury could not have accomplished its goals within the time and costs that were realized.

It is appropriate to recognize that Langley Research Center is mentioned most frequently throughout this paper. The close association between Mercury and Langley is attributed to the fact that many of the original Space Task Group were personnel from the Langley Research Center and to the equally important fact that the STG and the MSC were physically located within the Langley Research Center for over 3½ years.

In addition to the formal technical support discussed in the following sections, administrative support was provided in the fields such as procurement, personnel, and security, by Langley in the initial phase of STG. The Launch Operations Center provided similar administrative support to the Mercury Field Office at Cape Canaveral.

Spacecraft Development

After a contract was awarded for the Mercury spacecraft, some 16 months passed before the contractor delivered the first production spacecraft. In order that full-scale tests could be conducted in the meanwhile, a large number of research and development spacecraft were constructed by NASA. These test articles were largely made of steel plate and, hence, have been called "boilerplates."

The boilerplates, which were made cheaply and quickly, resembled the Mercury spacecraft only in external configuration, in weight, and in center-of-gravity location. They were used primarily to obtain data on the performance of Mercury rocket motors and parachutes, and to obtain aerodynamic and thermal data needed for the design of the Mercury spacecraft.

In September, 1959, one of these boilerplates was flown through a ballistic flight by using the first Mercury-Atlas launch vehicle. This test, called Big Joe, was flown to gather thermodynamic data during reentry. This boilerplate was constructed in phases by both the Langley and the Lewis Research Centers. The Langley Research Center also provided the parachute landing system for the boilerplate and the Lewis Research Center designed and furnished the instrumentation and telemetry system. This successful flight test, in which the Langley and Lewis Centers played so large a part, provided valuable design data for the Mercury spacecraft.

The Langley Research Center also designed and constructed a series of boilerplates which were used in the Little Joe series of flights flown at Wallops Station, Va., in 1959 and 1960. The Little Joe tests were flown to prove the concepts of the launch escape system for inflight aborts at critical conditions and to evaluate the performance of this system.

Similar boilerplates were used in the Mercury program in drop tests for parachute-system qualification and as astronaut egress trainers until a Mercury spacecraft became available for this purpose. Much of the environmental qualification of equipment carried on all these boilerplates was conducted at Langley.

The many wind tunnels of the Langley, Lewis, and Ames Research Centers were used to perform tests early in the Mercury program to define the configuration of the Mercury spacecraft. Some 28 different wind-tunnel facilities conducted 103 separate investigations and accumulated over 5,300 hours of tunnel time by the end of 1960. These tests measured static and dynamic stability, pressure distributions, and heat-transfer data through subsonic, transonic, and supersonic speed regimes. Certain tests were made for vibration and flutter characteristics, and others to determine the correct size of the drogue parachute for stabilization. The Mercury escape and reentry configurations were tested alone and in combination with all of the launch vehicles in the Mercury program. Additional tests were made at Langley on alternate escape configurations, on the structural characteristic of the Mercury shingles, and on Mercury heat-shield materials. Langley also assisted in the data reduction and analysis of tests run outside of NASA, such as the buffet study made in a wind-tunnel at the Air Force Arnold Engineering Development Center.

Tests were conducted at Wallops Station, Va., early in the program to evaluate the escape system planned for the Mercury spacecraft. These tests used both boilerplate and production spacecraft with the production escape and landing systems. The first such tests were "off-the-pad" aborts. These tests were followed by inflight aborts from the Little Joe launch vehicle. Wallops supported these tests with radar tracking, optical tracking, photography, telemetry reception, data playback, and radio command functions. This support was in addition to providing normal launch and range-clearance support and shop and office facilities.

During the development of the propulsion systems for the Mercury spacecraft, special tests were conducted in a high-altitude wind tunnel at the Lewis Research Center to evaluate the performance of the escape rocket and retrorocket motors. The popgun effect of firing the posigrade rocket motors into the Mercury-Atlas adapter cavity between the spacecraft and the launch vehicle was measured. In addition, the effect of the escape rocket exhaust on the Mercury spacecraft window was evaluated.

Lewis also conducted developmental tests on the hydrogen peroxide reaction control system and on the manual proportional control system in the altitude chamber.

The Langley Research Center conducted a series of tests on the solenoid valves for the reaction control system thrusters. These tests were conducted in altitude chambers to determine the effect of vacuum on the valve. The results of the tests established that a vacuum did not affect the operation of a valve even when it was not operated for 24 hours. A method of evaluating the movement of the solenoid valve's seat by measuring the electric current flow (signature) was developed for these tests. This method of measuring the valve's signature was later used for selecting valves that were acceptable for flight.

The development of the spacecraft landing system required an extensive series of tests which began at Langley Research Center in 1958. In the early development of the main parachute, drops were made at West Point and Wallops Island, Va., and at Pope Air Force Base, N.C. Langley supported these tests with personnel, aircraft, test vehicles, instrumentation, and tracking equipment. Later tests were made at the NASA Flight Research Center at Edwards Air Force Base, Calif., to develop the Mercury drogue parachute. For these tests, the Flight Research Center provided personnel, test vehicles, and all other facilities needed to accomplish the program. The development of the landing-impact skirt required the assistance of NASA facilities at Langley Research Center and Wallops Station.

In the development of the Mercury heat protection system, the Langley Research Center made numerous structural tests at elevated temperatures on samples of the ablation heat shield, the René 41 conical shingles, and the beryllium recovery-section shingles.

When a formal program was established by Manned Spacecraft Center to conduct special inflight experiments on Mercury flights which were not directly related to the mission objectives, other NASA organizations proposed and furnished many of the experiments that were performed. On all the manned orbital flights, the Goddard Space Flight Center and the NASA Headquarters Office of Space Sciences sponsored experiments related to astronomy and earth and space science in general. These organizations also provided assistance in the evaluation of all proposed experiments. Goddard provided special filters and other optional equipment used in making some of these space-science observations.

The flashing-beacon experiment flown on the MA–9 flight was designed, constructed, and qualified by the Langley Research Center. Langley also provided the balloon-drag experiments flown on MA–7 and MA–9. The Lewis Research Center proposed and furnished the zero-gravity experiment carried on the MA–7 spacecraft. On the MA–8 flight, a number of ablation materials were bonded to the recovery-section shingles to evaluate them for heat-protection on future spacecraft. Langley not only furnished two of these materials, but conducted many tests on samples of the coated shingles to assure a good bond and no degradation of the safety aspects of the MA–8 mission.

Launch-Vehicle Development

The NASA centers were involved in the procurement and operation of two of the three launch vehicles used in the Mercury program—the Little Joe and the Redstone. The Little Joe was conceived early in 1958 by the same group at Langley that formulated the man-in-space program. This launch vehicle performed much of the qualification of the Mercury spacecraft at approximately one-sixth the cost of an Atlas. Shortly after the official start of Project Mercury, the Space Task Group requested Langley to accept the responsibility for the procurement of six flight vehicles and one test article. Accepting this responsibility, Langley performed the basic design of the vehicle, wrote the specification, evaluated contractors' proposals, and awarded and monitored the contract for detail design, construction, and testing. After delivery of the Little Joe vehicles, Langley provided personnel for the assembly, checkout, and launch of these vehicles at Wallops Station, Va. A command destruct system was also designed and provided by Langley for the first four Little Joe vehicles. In addition, Langley designed and constructed the spacecraft-launch-vehicle adapters for all Little Joe flights.

The Marshall Space Flight Center was instrumental in implementing the Mercury-Redstone program. Marshall's task was the provision of a launch vehicle for manned flight that had previously been used only for unmanned payloads of considerably lighter weight. Technical groups were formed to conduct studies and perform reliability and structural tests. As a result of these studies, a number of modifications were made in the Redstone launch vehicle to make it acceptable for manned flight. Major modifications, made largely at Marshall, were made in some subsystems, and an Abort Sensing and Implementation System (ASIS) was designed for and integrated into the launch vehicle. Other work done at Marshall included compatibility testing of the spacecraft-launch-vehicle combination and static firing of each launch vehicle prior to delivery to Cape Canaveral. The resulting launch-vehicle reliability was a milestone in the Mercury program that contributed to the reduced requirement for only five Redstone flights instead of the eight originally programed.

Prelaunch checkout and launch operations for the Mercury-Redstone missions were conducted by the NASA Launch Operations Center at Cape Canaveral which was formerly the Launch Operations Division of the Marshall Space Flight Center. The Launch Operations Center now provides much support to the Manned Spacecraft Center at Cape Canaveral in many technical and administrative areas and in the provision of facilities.

Mercury Network Development

Of considerable importance in the successful accomplishment of the Mercury missions was, of course, the worldwide Mercury Tracking and Communications Network. The responsibility for the development of this network was given to the Langley Research Center. A group formed at Langley in early 1959 wrote the specifications for the network and awarded a contract for its design and construction in July 1959. After the contract award, this Langley group continuously monitored and contributed to the design and development of the network facilities. The nerve center of the Mercury network is the automatic, high-speed computing equipment located at and operated by the Goddard Space Flight Center. Langley's responsibility for the network ended with the acceptance of the facilities by the government. Thereafter, the maintenance and operation of the Mercury network became the total responsibility of the Goddard Space Flight Center.

I

SPACE-VEHICLE DEVELOPMENT

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3. SPACECRAFT SYSTEMS DEVELOPMENT AND PERFORMANCE

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Summary

Project Mercury began in 1958 with some basic systems research and a number of feasibility studies to determine if a spacecraft could be built which would sustain man in orbital space and return him safely to earth. Although it was recognized that some system development would be required, many of the spacecraft systems could be synthesized from existing hardware. A top priority was placed on the spacecraft production from the contract award in 1959, and 3 years later Astronaut John H. Glenn, Jr., completed three orbital passes about the earth. In this time span, design, development, and qualification of the spacecraft and its systems were accomplished nearly concurrently. The ground and flight-test programs, which included hundreds of wind-tunnel tests and parachute drops from aircraft, provided an opportunity to develop flight systems and acquire operational experience as the program progressed. Though a continuing attention to engineering detail by technical specialists and management personnel throughout the project, the spacecraft and its systems were qualified for suborbital flight in approximately 2 years from the spacecraft contract award date. Many lessons have been learned which were not only applied to Mercury systems development, but which have been applied in more advanced space projects. Interesting conclusions regarding system performance can be derived by reviewing all of the flight results. The spacecraft control system was a source of considerable trouble during the project. However, when inflight failures of this type occurred, it was the backup capability of the pilot which made possible the successful completion of the mission. In fact, the pilot's ability to control accurately the spacecraft attitude was instrumental in three of the four manned orbital flights in completing the mission successfully when a malfunction was present in the automatic system. One of these control-system malfunctions, an electrical anomaly during Astronaut Cooper's mission and the only one of major significance in the spacecraft throughout the entire 34-hour flight, was successfully circumvented by the pilot's manual control during the critical retrofire and reentry maneuvers.

Introduction

The initial goal of Project Mercury was to place a man into orbit successfully and return him safely to earth, and this objective was fulfilled in February 1962 by the flight of Astronaut John H. Glenn, Jr. This objective was confirmed 3 months later by the flight of Astronaut M. Scott Carpenter. The final two missions in Mercury constituted a continuation of a program to acquire new knowledge and operational experience in manned orbital space flight. The ninth Mercury-Atlas mission (MA–9) was planned for up to 22 orbital passes and was the concluding flight in the United States' first manned space program. The primary objectives of the MA–9 mission were to evaluate the effects on the astronaut of approximately 1 day in orbital flight, to verify that man can function as a primary operating system of the spacecraft; and to evaluate the combined performance of the astronaut and the spacecraft, which was specifically modified for the 1-day mission.

The MA–9 spacecraft, *Faith 7*, used by Astronaut Cooper in successfully performing the fourth United States manned orbital mission was basically similar to those used for previous orbital flights. The major exceptions were system modifications prompted by the extended nature of the mission, and these changes will be discussed in later paragraphs. It is important to note, however, that since the original design of the Mercury spacecraft all major system concepts have remained essentially unaltered. Although some design and early development were conducted prior to the official award of the prime contract, the Mercury spacecraft was developed, qualified, and met its original objective of manned orbital flight 3 years after the spacecraft contract award in 1959. In this brief span of time, many lessons have been learned and much experience has been gained in the design, development, and operation of manned orbital flight systems. In this paper, the intent is to describe brie ly the original design philosophy, discuss the system development and qualification experiences, and present a summary of the experiences relating to systems performance.

Design Philosophy

In the initial design of the Mercury spacecraft, two guidelines were firmly established: (1) to use existing technology and off-the-shelf equipment wherever practical and (2) to follow the simplest and most reliable approach to system design. These guidelines were administered to provide for the most expedient realization of program objectives. The original Mercury concept also included a number of mandatory design requirements which were imposed on the spacecraft contractor:

(1) The spacecraft must be fitted with a reliable launch-escape system which would rapidly separate the spacecraft with its crew from the launch vehicle in case of an imminent disaster.

(2) The mode of reentry into the earth's atmosphere would be by drag braking only.

(3) The spacecraft must carry a retrorocket system capable of providing the necessary impulse to bring the vehicle out of orbit.

(4) The spacecraft design should place prime emphasis on the water-landing approach.

(5) The pilot must be given the capability of manually controlling spacecraft attitude.

In many design areas, there existed no previous experience in reliable system operation which could be applied to the Mercury concept, and new development programs had to be initiated. In addition, there was no information pertaining to man's capability to operate under space environmental conditions, particularly weightlessness; therefore, all of the spacecraft systems which relate to crew recovery from orbit had to be designed for automatic operation and many had to include redundancy. It has since been learned that man is not only a contributory element but a necessary part of the spacecraft. It is important to note that because of the pilot's demonstrated ability to function as a primary operating system of the spacecraft, some of the redundant elements were not required and were deleted.

The spacecraft systems (fig. 3–1) include the heat protection, mechanical and pyrotechnic spacecraft control, communications, instrumentation, life support, and electrical and sequential systems. The mechanical and pyrotechnic system group comprises the separation devices, the rocket motors, the landing system, and the internal spacecraft structure. These systems have been described in previous literature (refs. 1 to 10); therefore, detailed descriptions are not included in this paper.

The design requirements stated earlier involved certain implications for these systems. The launch-escape system was found to be most practical if it incorporated a solid rocket motor to propel the spacecraft rapidly away from the launch vehicle during an abort in the atmosphere. This type of system needed to provide a high level of thrust for a brief time period should be easily handled in the field and should require a minimum of servicing. The tower arrangement could be readily assembled to the spacecraft and jettisoned during powered flight once it no longer was required for abort.

An important design feature of the Mercury spacecraft was the favorable manner in which the astronaut was exposed to flight accelerations. For all major g-loads, which occur during powered flight, launch-escape motor thrusting, posigrade motor thrusting, retrograde motor thrusting, reentry, parachute deployment and touchdown, the pilot experienced acceleration in the most favorable manner, one that forces him into the couch (fig. 3–2).

The mode of reentry was specified to be drag braking only because of simplicity. This concept implied that the configuration should be a blunt body with high drag properties having a slender afterbody, primary because of heating considerations. Thus the bell shaped Mercury configuration was evolved, and the heat-protection system was devised to accommodate this shape. Originally, a beryllium thermal shield employing the heat-sink principle was specified. The specification was later changed to provide a more efficient ablation-type heat shield, which was used on all Mercury–Atlas orbital missions. Because the heat flux was expected to be considerably less on the afterbody than at the heat shield, a combination of insulation and thin shingles constructed of an alloy to withstand high temperature was calculated to be sufficient in maintaining the temperature of the pressure vessel at a safe level. The exterior finish of the spacecraft body was intentionally made a dull black because of its high emissivity and, therefore, favorable thermal radiation properties.

Again, because of their reliability and ease of handling and servicing, solid propellants were chosen for the retrorocket system. For even greater reliability, however, a system of three solid rocket motors, any two of which would effect a safe reentry, was chosen. These three rocket motors, together with three additional rockets to effect spacecraft-launch-vehicle separation, were assembled in a jettisonable package to permit a clean reentry configuration.

For the period during and after touchdown, the spacecraft had to meet two basic requirements. These requirements were: (a) the structure had not only to retain its integrity such that it would be habitable after landing and (b) the touchdown decelerations had to be reduced to an acceptable level. Touchdown deceleration was primarily limited by the human tolerance to acceleration; and, because of the blunt shape of the spacecraft, touchdown decelerations of as high as 50g could have resulted even for a water landing. Therefore, a landing-shock attenuation system was designed which consisted of a fiberglass fabric bag with holes in it and was attached between the spacecraft structure and the ablation shield. Prior to landing, the ablation shield would be deployed and the shield weight would extend the bag, which would fill with air and provide a cushion against the landing shock. The landing bag arrangement adequately attenuated the landing deceleration loads to approximately 15g.

In addition to the automatic and rate control modes of the attitude control system, two manual control modes, one electrical and the other mechanical, were provided the astronaut. This control-mode arrangement had the feature that,

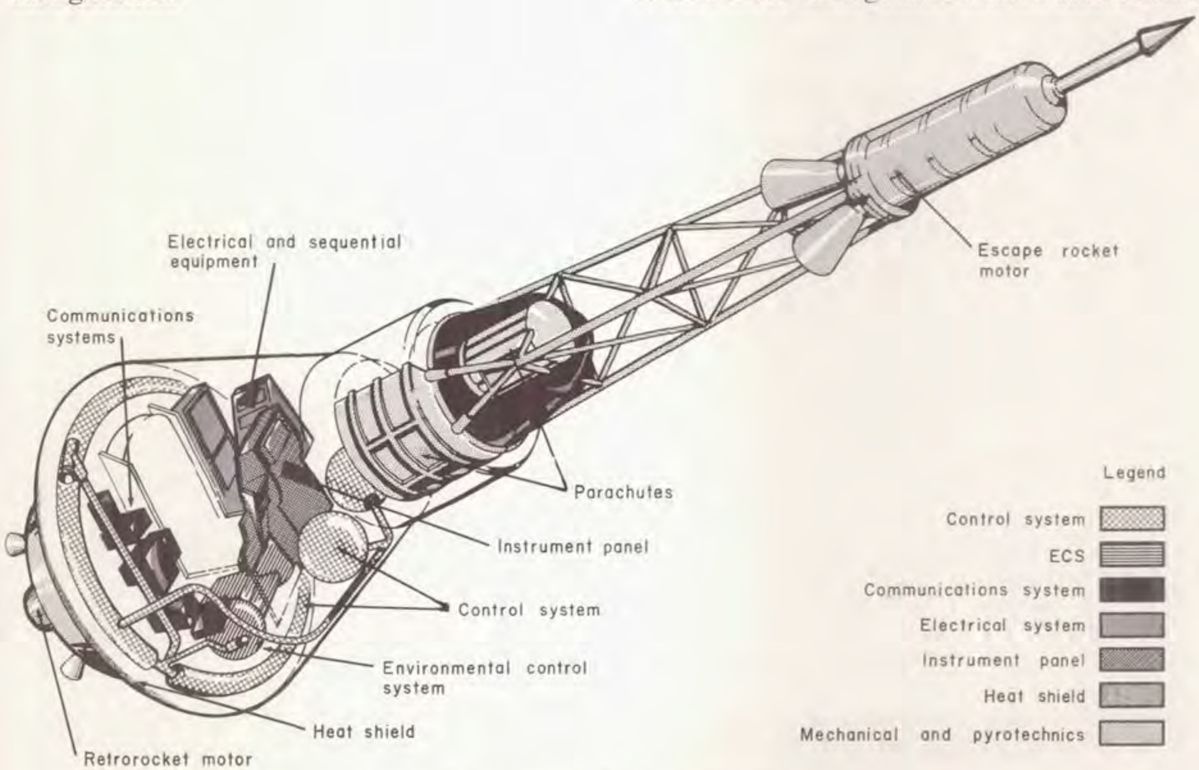

FIGURE 3-1.—Spacecraft interior arrangement.

in the event of a spacecraft power failure, the direct-linkage mechanical mode would still be available for control. The two manual control modes were each supplied control-system fuel from separate tanks for additional reliability. Although the thrust units were designed to provide an impulse sufficient for the majority of spacecraft maneuvers, these redundant manual control modes could be used simultaneously, if desired, in critical situations, such as retrofire and reentry, where rapid response to undesirable attitude rates might become necessary.

A monopropellant reaction control system using hydrogen peroxide as the fuel was chosen for the spacecraft control system to provide the simplest system design and installation. Furthermore, similar systems had already been developed for use on other space vehicles. A flexible bladder under pressure provided a positive means of fuel expulsion.

Many challenging design problems were encountered in the remaining spacecraft systems because of the new operating environment. As a result of the need to provide flight-control support on the ground, the requirement for multiple redundancy and high reliability in the communications system was evident. Although part of the instrumentation system was not required for flight safety and mission success, certain parameters, such as those which indicate the psysiological well-being of the crew and the proper operation of critical spacecraft systems, were necessary for effective flight control and monitoring. The remainder of the instrumentation data was acquired to complement the flight-control parameters for use in postflight

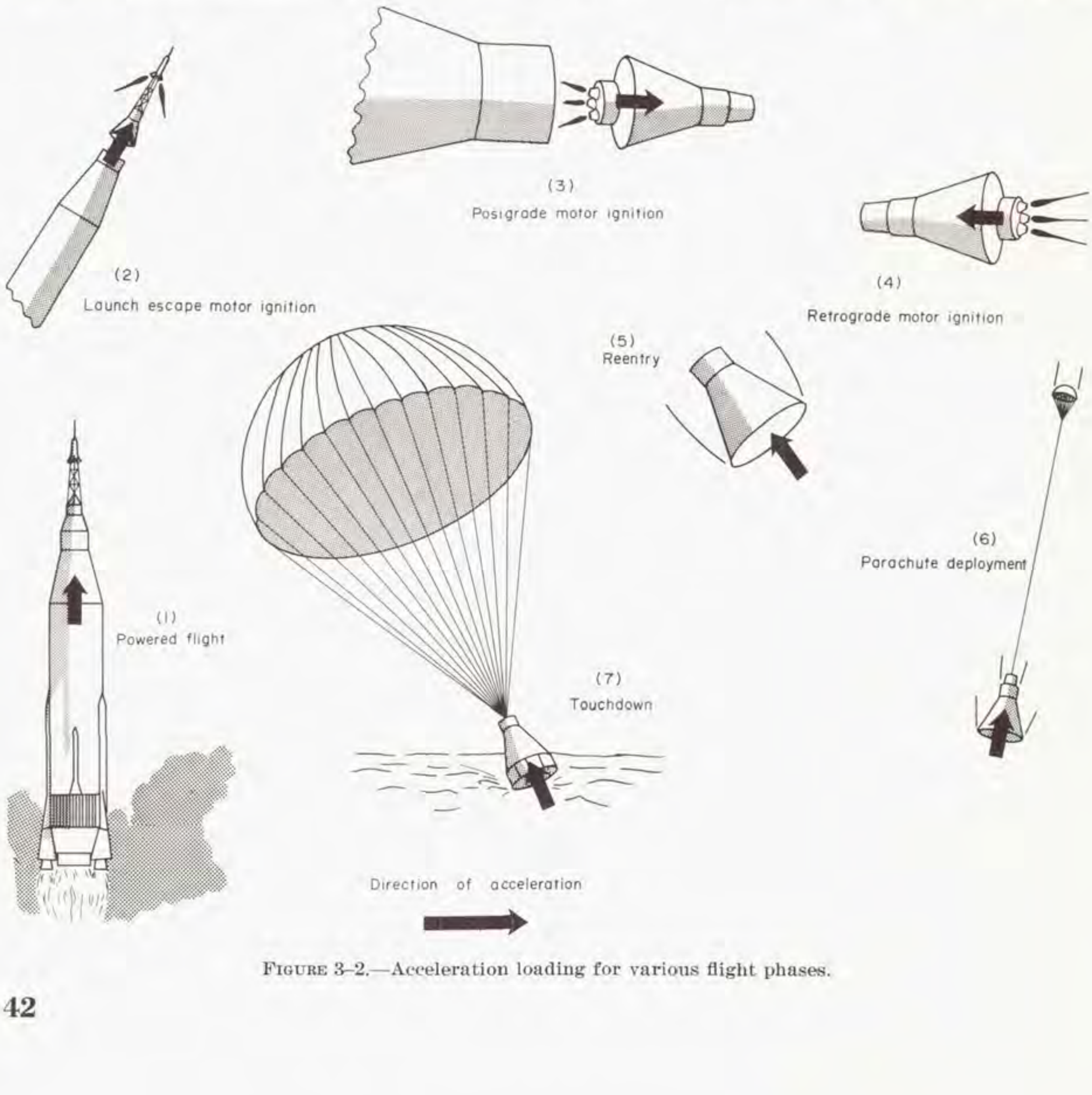

FIGURE 3-2.—Acceleration loading for various flight phases.

analyses of system performance. New design areas were opened up in the fields of gas partial pressure measurement and of bioinstrumentation, such as long term attachment of human sensor leads. The life-support-system design considerations involved a development task, since it was concerned with the sustenance of the astronaut and his protection from the hard vacuum of space, as well as from the widely varying temperature conditions associated with an orbital-flight profile. This system also was required to provide for the management of the cooling and drinking water in the spacecraft, the food to be consumed by the pilot, and his normal liquid wastes, again in the weightless environment. Although pressure suits and cooling equipment had been used in high-performance aircraft, only part of this experience could be directly applied to the design of the Mercury environmental control system because of weightless flight and more demanding performance requirements. In the electrical and sequential design area, the application of previous design work and use of off-the-shelf components was made. But the very nature of the mission and the requirement for reliability, automation, and system redundancy imposed a degree of complexity somewhat greater than any previous manned flight system. This increased electronic complexity, in turn, made it more difficult to insure interface compatability, eliminate stray voltages (back-door circuits), and minimize system sensitivity to current transients.

As an example of the consequences of stray voltages, the Little Joe–1 mission, the first launch attempt using a full-scale Mercury spacecraft, is cited. This test, conducted at Wallops Island, Va., was in the final moments of countdown when, during a spacecraft battery charging operation, a stray voltage initiated the launch escape sequence. The spacecraft was separated by the escape motor from the launch vehicle, and the drogue parachute was properly deployed. Because the battery had been only partially charged, sufficient current was not available to deploy the main parachute, and the spacecraft was destroyed upon landing. This back-door circuit was subsequently located and eliminated.

Because of work conducted immediately prior to and in the early period following contract award, the system-design phase of the project proceeded at a rapid pace. Wind-tunnel research, studies by prospective subcontractors and vendors, the joint participation of key NASA and other government installations, and early design studies by the eventual prime contractor all helped to facilitate the design effort and make possible the early availability of test hardware.

Based on the total Mercury experience, one of the underlying principles during the initial design period should be an emphasis placed on "designing for operation." For example, one of the lessons learned was that the instrumentation system should be designed with mission flexibility as a guide, such that, in the later phases of the program, new instrumentation requirements can be handled with a minimum of complication. In still another area, it was learned that component accessibility can be extremely important where schedule demands become critical. Certain time-critical systems and short-life components must be easily accessible in order to minimize the degree of disturbance to other systems and the time required to replace these types of units. Because of the weight and volume constraints, this concept could not faithfully be applied in the design evolution of the Mercury spacecraft, and significant penalties have been experienced whenever items needed to be removed under a tight schedule. It was learned in Mercury that all systems requiring manual operation by the astronaut must be designed with the limitations of the cabin volume (see fig. 3–3), suit mobility, and weightlessness in mind.

Development and Qualification

As in any development program, one of the original ground rules at the outset of Project Mercury was to conduct a logical and progressive test program. This concept was closely maintained from the beginning of the project through the flight of Astronaut Cooper last May. Success in certain phases of this test progression has made possible the elimination of certain backup or follow-on flights. Since the time that Mercury was initially conceived, literally thousands of individual tests have been conducted in which test articles were used in all forms from components to full-scale spacecraft and under all combinations of real and simulated operating conditions. For example, during the 1-year period from November 1959, about 10 months after the prime contract was awarded, to November 1960, some 270 hours were spent in testing the environmental control system in the altitude chamber, with a man wearing a pressure suit in the chamber to load the circuit more realistically. Early in 1961, further tests were conducted, often using astronauts, in the centrifuge to qualify the environmental system under acceleration loads.

For convenience, the spacecraft-system testing can be grouped into ground tests and flight tests of special test articles. The ground tests, in turn, can be categorized into areas of research, design, development, qualification, acceptance, and checkout. The discussion of development flight tests, which will be restricted to those using other than production spacecraft, consists of research studies, development tests, and qualification programs. The performance of the production spacecraft will be discussed in a later section of this paper. It is interesting to note that because of the rapid pace dictated by the high priority of the program, many of the individual test programs were conducted concurrently. This technique involved some risk, since, had a major problem developed, the expense in both time and money could have been considerable. The following paragraphs relate the more salient lessons learned during the formal Mercury development and qualification test program.

Ground Testing

The research tests included those which attempted to verify design theories or sought new methods for accomplishing a given design task, whether it was a structural assembly, a heat-protection system, or improved methods of instrumenting the spacecraft and its crew. Hundreds of tests of this type, particularly those conducted in the wind tunnel, were car-

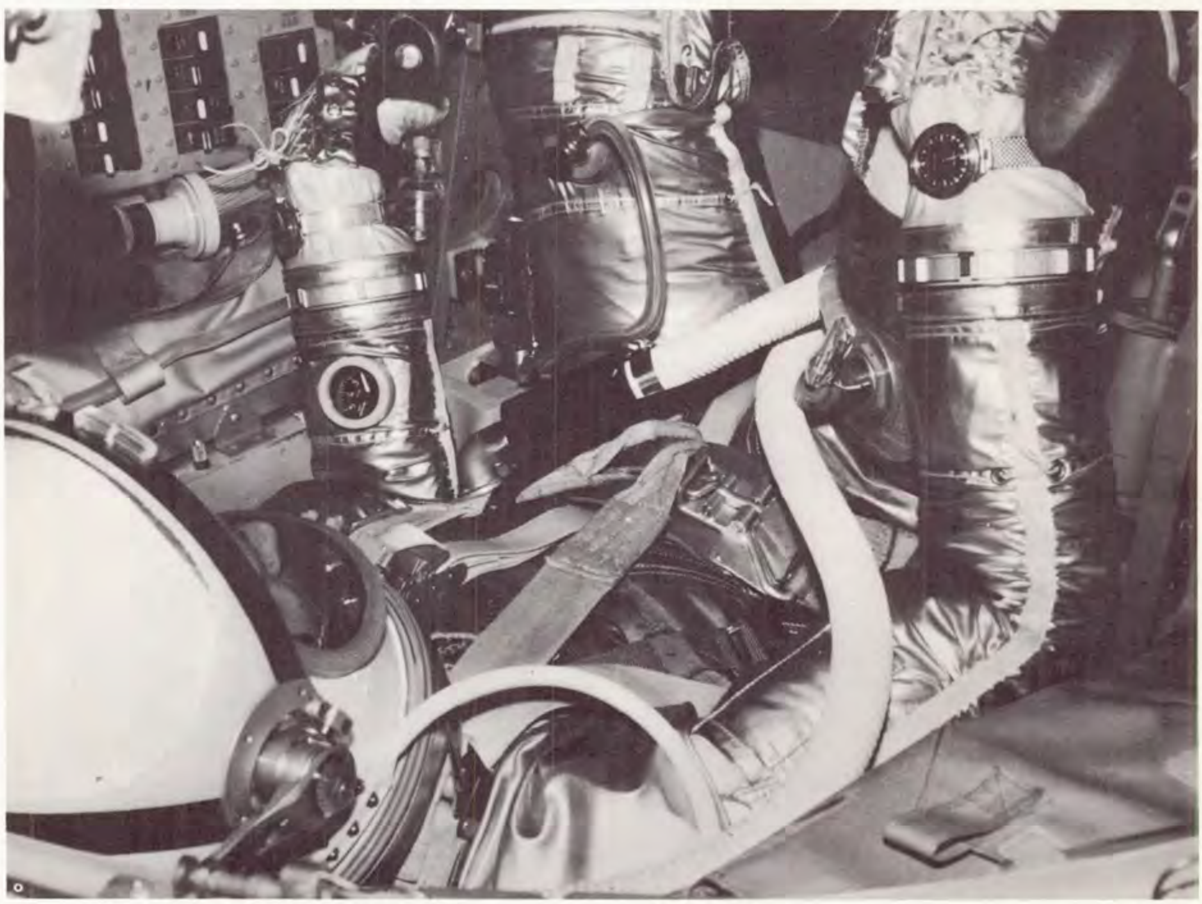

FIGURE 3-3.—Photograph of spacecraft interior.

ried out in the early phases of the Mercury effort at many of the NASA centers and at the contractor's plant. These tests will always be required when a new flight spectrum in a relatively unknown operational environment is penetrated, as it was in Mercury. It was tests of this kind which established the basic Mercury configuration, a shape which has already been projected into more advanced manned space programs.

The design testing, exemplified by the breadboard layouts in the case of electrical and sequential circuitry, was conducted jointly by the NASA and the contractor. This effort made possible the proof testing concurrent with initial design studies. Many thousands of tests were conducted, such as those in the design of the spacecraft-control-system thrust chambers, once the initial concept had been established.

When the basic design concept had evolved to a working hardware item, development testing served to expose this concept in the laboratory to the many combinations of operational and environmental conditions expected in space. Development testing was naturally hampered by the fact that weightlessness, a prime example, could not be adequately simulated on the ground; and this very deficiency resulted in an ineffective design for the water separation device of the environmental control system. The development of Mercury systems was a continuing program through the final mission and was aimed at mission flexibility, even after the spacecraft had been basically qualified for manned orbital operation. It was during the development testing that facets of the design which pertain to all aspects of its use were most evident, including the design-for-operation standards. It is in this testing area that engineering mock-ups have proved to be extremely valuable. In the case of the landing system, drop tests of boilerplate spacecraft were made to develop the landing-system deployment sequence and operation. Tests were made in the altitude chamber to verify that systems could operate for their required life cycle under realistic conditions. In essence, the development-test phase provided a means of validating the design concept and proving its intended reliability features.

Qualification testing conducted on the ground can further impose realistic operational conditions on a test article in various combinations for the specific purpose of verifying its reliable operation for inclusion as a final flight article. That is, there can and should be more than one type of qualification program for a given component, subsystem, or system, but these programs should become progressively more demanding on the capability of the hardware. In this testing area, adherence to prescribed test criteria must be rigorously enforced. The various combinations of qualification tests can be grouped into environmental tests, load tests, and performance tests with each of these groups having a specific purpose. Sometimes, the test conditions are not realistic enough or are not sufficiently demanding to reveal system weaknesses. During Mercury, for some of the subsystems, it was not until the actual unmanned flights that a system could be fully qualified for manned operation. For example, the launch-escape tower was subjected to all expected environmental conditions, an exhaustive series of load tests, and the operational situations associated with the launch-escape-system performance tests. Yet in the actual qualification flight program the heating loads on the truss structure of the tower were found to be more critical than had been calculated. Ground qualification is relatively inexpensive compared with full-scale flight qualification, and any system discrepancies which can be revealed in this phase will yield rewards in terms of time and expenditures later on. For example, during an early qualification test, it was found that the original igniters in the retrorocket motors would sometimes fail and blow out through the rocket nozzle before the main propellant grain had been ignited. New igniters, actually miniature solid rockets, were substituted for the original igniters. Had this system characteristic been overlooked through the manned orbital flights, the consequences could have been catastrophic. For flight-acceptance tests on units scheduled to be installed in flight vehicles, however, it was found that care should be taken not to over-test the article to the point at which its useful lifetime is approached or exceeded. During qualification testing, one must be assured that the unit being tested is not a "handmade" article and that, later on, a similar production version will not fail because it does not have the same ability to withstand the testing environment. Of course, a critical requirement for the qualification program is that the test conditions imposed on the hardware exceed those expected to be present in the design environment in order to provide a safe margin for manufacturing deviations and unanticipated design weaknesses. It was found in Mercury that no single qualification criterion necessarily applies to all systems, and local operating conditions must be evaluated specifically for each system to insure that they are adequately accounted for in the qualification test environment.

It was learned in Mercury that, whenever a significant design change is to be incorporated into the spacecraft, a new hardware qualification program should be initiated to requalify major systems. Approximately 1,000 hours of test time were accumulated on a full-scale spacecraft in a program called "Project Orbit" which was conducted in a vacuum-thermal facility to insure that, during the orbital flight program, systems would maintain their previously demonstrated performance. As an example, when the spacecraft thruster assemblies were modified as discussed in this paper, the modified assemblies were tested in a vacuum chamber as part of the Project Orbit testing. These tests, using hydrogen peroxide, were made to determine if exposure to combined temperatures and low pressures for the expected duration of the mission would have adverse effects on the operation of the thruster assemblies. It was found to be most effective if actual operating conditions and procedures, including preflight checkout tests, could be realistically simulated in order to expose hardware to a complete operating cycle. Since system qualification and operating reliability are so closely related, the reader is referred to the paper entitled "Reliability and Flight Safety" for additional details.

Finally, the acceptance and checkout tests which are conducted by using actual flight hardware involve the same recommendations previously mentioned, those of avoiding overtesting, realistic operational test conditions, and thoroughness. It was learned in Mercury that, if tests of this type are conducted at multiple stations across the country by separate groups, the test procedures must be consistent if the test results are to be comparable. It is essential to repeat a system checkout if the system has been disturbed for any reason, such as the removal of another system where a definite interface exists. The acceptance and checkout aspect of ground testing is more thoroughly discussed in the paper entitled "Spacecraft Preflight Preparation."

Flight Testing

This brief discussion of the development flight phase of Mercury will be limited to those flights where specially configured test vehicle (boilerplate spacecraft) were employed. Because the experiences gained by flights of production spacecraft are of more operational significance, they will be presented in the next section, Systems Performance. The flight-test program began with a number of tests in which spacecraft models were flown by using small multistage rockets. These tests provided preliminary data on the aerodynamic properties of the chosen external configuration. Almost concurrently with these flights, tests of the parachute systems were staged in which boilerplate spacecraft were dropped from cargo aircraft. These "drop tests" were initiated as an important step in the early design and development of the landing system. Specifically, the drogue parachute was developed by utilizing a weighted pod, which was dropped from an aircraft at high altitude. Other early flight tests included off-the-pad, or beach, aborts to develop the launch-escape system. In 1959, a reentry flight was conducted in which a specially designed and instrumented spacecraft and an Atlas launch vehicle were used to provide aerodynamic-heating data in the real flight spectrum. This flight, termed "Big Joe," was the first test in Mercury in which the Atlas was used. It was as a result of the data derived during this flight that the shingles initially on the spacecraft cylindrical section were replaced with somewhat thicker shingles made of beryllium to provide for more effective heat protection. The final series of early flight tests used the solid-propellant Little Joe vehicle (shown in fig. 3–4) to test the launch-escape system concept at critical inflight abort condition. Although most of the early flight tests were of a developmental nature, their missions served to qualify critical flight systems for later, more demanding flight tests. The intermediate series of aircraft drop tests, for instance, was completed to qualify the parachute and landing-shock attenuation systems. During this test phase in Mercury, valuable system improvements were incorporated at a minimum of cost and time.

FIGURE 3-4.—Mercury Little-Joe launch-vehicle configuration.

Weight Growth

A critical problem which was present throughout the Mercury program was that of weight growth. This problem, which seems to be characteristic of any development program where high performance and reliability are required, almost defies the steps taken to control weight. Figure 3-5 depicts the weight chronology of the spacecraft's orbital configuration. The maximum growth in weight was approximately 10 pounds per week in the very early phases of the program, but this figure was reduced to less than 2 pounds per week, or approximately ½ percent, at the final stage of the program. The launch weight of Astronaut Cooper's spacecraft, *Faith 7*, was some 700 pounds greater than the original design weight, despite repeated design reviews and other continuing weight controls. The lesson here is that proper planning must account for the inevitable weight growth in the design and development of high-performance spacecraft, since the consequences of not planning for it are either a degradation of the performance goals or exceeding the capability of the launch vehicle with its attendant delays.

Attention to Detail

One of the most significant lessons learned from the Mercury program was the need for a careful and continuing attention to quality and engineering detail in all phases of the program. The spacecraft is made up of many individual systems and components to form a complex entity, and only through a close monitoring of the design and development of each piece of hardware and its relationship to all other associated components is it possible to recognize and correct problems rapidly before a costly failure occurs. Many performance discrepancies could not be anticipated because of the lack of experience or the inability to simulate adequately realistic conditions in the early test program. Later tests, however, were established to reveal these anomalies with a minimum of cost and delay. Although somewhat limited by the lack of experience, attention to detail during the design phase resulted in the incorporation of sys-

FIGURE 3-5.—Weight chronology for Mercury specification spacecraft.

tem redundancy, where a direct relationship to mission success existed.

As a prime example of the attention given to the incorporation of redundancy in the detailed design of critical spacecraft components, the actuation system of the launch-escape-tower clamp ring was backed up in nearly every component because of the serious consequences that would have resulted from a failure of the escape tower to jettison. In this system, the clamp ring is assembled at three points on its periphery, with each point being held by a dual explosive unit. Five of these six pyrotechnic units were ignited by an electrical squib, whereas the sixth was actuated by a percussion cap. Each of the electrical units incorporated a dual bridgewire. The automatic sequence was designed to send electrical signals from one power source to six of the bridgewires, with another but independent electrical supply for the remaining four bridgewires. Should the automatic relay fail, the astronaut was provided with a manual pull-ring which would energize the same jettison relay and also operate a gas generator to initiate the percussion cap, such that, in the event of failure in both the circuit to the sequencing relay and the two separate electrical power buses, the percussion cap would ignite. Actuation of any one of the six pyrotechnic explosive bolts was sufficient to effect proper separation of the escape tower from the spacecraft. The pyrotechnic circuit for the spacecraft-launch-vehicle adapter clamp ring was operated in a nearly identical manner.

During the development phase, an adherence to test specifications was maintained through a continued scrutiny of detailed performance results as they became available. Throughout the manned flights, attention to detail was necessary for an early recognition of possible problem areas, provided a means of responding to suggested action items, and precluded the occurrence of some system failures which ordinarily would have caused launch postponements and possibly a catastrophe.

Systems Performance

During the design of the Mercury spacecraft, one of the most important considerations was that, should individual components or even entire systems fail, some means would exist either to complete the mission safely or to conduct a successful mission abort so that crew safety would be maintained. A summary of the flight-program objectives and results for the full-scale spacecraft is given in table 3–I. Of primary significance in the table is the fact that during the manned flight phase, all major systems operated satisfactorily, although on three of these missions, the astronaut was required, because of improper operation of the automatic control system, to conduct the retrofire maneuver manually. There were system malfunctions and performance discrepancies in each of these flights, but they were of such a nature that either a backup system or astronaut could circumvent the anomaly or that the failure of a component, such as an instrumentation sensor, was not critical to mission success. The system experience during the flight program was characterized by a number of isolated component anomalies, rather than a critical failure of such magnitude that a catastrophe resulted. This system development, accounting for system malfunctions and performance discrepancies, the action taken to correct them, and the steps required to increase system capability for the extended flight of Astronaut Cooper, is discussed in the following paragraphs. Since system anomalies are discussed specifically as they pertain to the continuing development of the major spacecraft systems, references 5, 6, 8, and 10 should be consulted for a more detailed performance discussion. Although random failures and system deficiencies are mentioned briefly herein, the greater emphasis is placed on system performance as it relates to design experience and the lessons which can be derived from actual operation of the systems in the space environment. Throughout the flight program, with the exception of the MA–9 mission, no changes were required specifically to accommodate a longer flight duration. The modifications made to the *Faith 7* (MA–9) spacecraft including those incorporated to make possible the extended flight period are summarized in table 3–II. Each major spacecraft system will be discussed separately, as in previous reports on the individual manned flights (refs. 5, 8, and 10).

Heat Protection System

The heat protection system performed satisfactorily throughout the entire program and essentially as designed.

Some cracking and slight delamination of the ablation heat shield following reentry have been experienced on certain flights, but this occurrence has been of no real consequence. It was established that this minor delamination did not occur during the reentry heating period and probably resulted from the shock sustained at landing. Since the flotation attitude depends somewhat on the heat-shield weight, a slight modification was made to the *Faith 7* spacecraft to provide for retention of any small portions which might possibly have broken away after touchdown. It has always been desirable to achieve the most upright position in the water to facilitate astronaut egress.

Temperature measurements were made at various depths in the ablation shields for the orbital flights, and the maximum values experienced during reentry are summarized in figure 3–6 for each flight. The measurements showed good agreement with predicted values and were satisfactory.

Mechanical and Pyrotechnic Systems

The mechanical and pyrotechnic systems consist of the separation devices, the landing system, the rocket motors, and the internal spacecraft structure. Each of the systems in this group is discussed separately.

There have been only minor problems with the separation devices. The primary separation planes (shown in fig. 3–7) are those between the launch-escape tower and the spacecraft cylindrical section, between the spacecraft and the launch vehicle, at the heat shield, and at the spacecraft hatch. In three of the earlier unmanned qualification flights, some difficulty was experienced in separating the spacecraft-adapter umbilicals, but postflight examinations showed that the pyrotechnic charges ignited satisfactorily. Further investigation revealed, however, that aerodynamic loads during clamp-ring separation had caused the clamp-ring segments to damage the umbilicals. A minor redesign of the clamp-ring cover which protects these separation devices eliminated the problem. In the Mercury-Redstone 4 (MR–4) mission, the explosively actuated side hatch, incorporated for the first time for this flight, was prematurely released. The astronaut egressed rapidly through the open hatch, and the spacecraft subsequently took on sea water and sank before recovery could be effected. A postflight investigation involving a thorough analysis and exhaustive testing was conducted, but the cause of the malfunction has never been established. However, the landing and recovery procedures were altered for succeeding missions to minimize the possibility of this malfunction recurring. The only other performance anomaly with regard to separation devices occurred in the recent flight of Astronaut Cooper. Here,

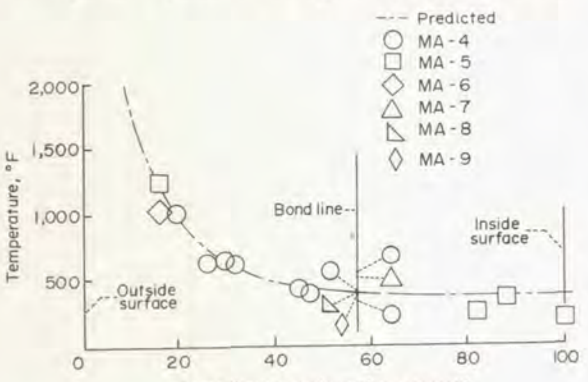

FIGURE 3–6.—Ablation shield maximum temperatures.

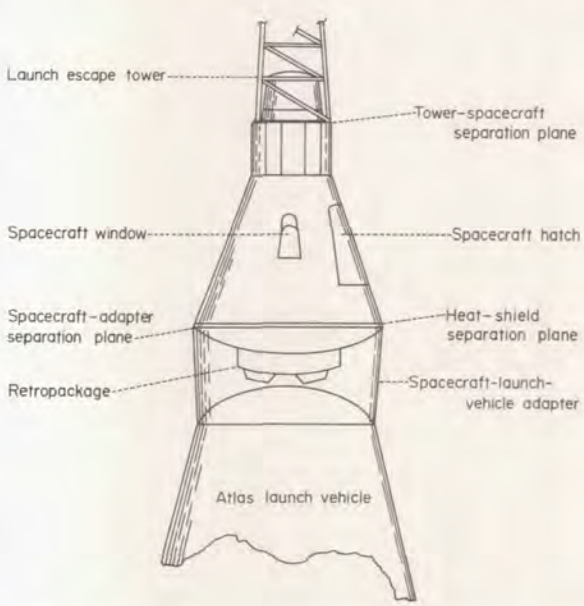

FIGURE 3–7.—Major spacecraft separation planes.

Table 3-I.—Mercury Flight Program Summary

Mission [a]	Spacecraft [b]	Launch date	Flight duration [c], hr:min:sec	Occupant	Basic test objectives [d]	Summary of results [e]
LJ-1	BP	Aug. 21, 1959	00:00:20		Max. dynamic pressure abort; evaluate launch escape and recovery systems.	Object. not met; inadvertent abort initiated during countdown.
Big Joe	BP	Sept. 9, 1959	00:13:00		Ballistic flight; evaluate heat-protection concept, aerodynamic shape, and recovery system.	Successful.
LJ-6	BP	Oct. 4, 1959	00:05:10		Ballistic flight; qualify launch-vehicle structure; evaluate command system.	Successful.
LJ-1A	BP	Nov. 4, 1959	00:08:11		Max. dynamic pressure abort; same as LJ-1.	Primary object. not met; escape motor ignition was late during reduced pressure region.
LJ-2	BP	Dec. 4, 1959	00:11:06	Rhesus monkey	High-altitude abort; evaluate launch, abort, and reentry dynamics on S/C; recovery.	Successful.
LJ-1B	BP	Jan. 21, 1960	00:08:35	Rhesus monkey	Max. dynamic pressure abort; same as LJ-1A; evaluate launch and abort.	Successful.
Beach abort	S/C 1	May 9, 1960	00:01:16		Off-the-pad abort; qualify structure and launch escape system for simulated pad abort.	Successful; expended rocket motor and tower not separated as quickly as expected.
MA-1	S/C 4	July 29, 1960	00:03:18		Ballistic flight; S/C-launch-vehicle compatibility; thermal loads in critical abort.	Object. not met; mission failed at about 60 sec after lift-off; S/C not recovered.
LJ-5	S/C 3	Nov. 8, 1960	00:02:22		Max. dynamic pressure abort; qualify launch escape system and structure.	Object. not met; S/C did not separate from launch vehicle.
MR-1	S/C 2	Nov. 21, 1960	00:00:00	Simulated man	Suborbital flight; qualify S/C-launch-vehicle compatibility, posigrades, ASCS.	Test object. not met; launch vehicle shutdown at lift-off; S/C landing system correctly deployed.
MR-1A	S/C 2	Dec. 19, 1960	00:15:45	Simulated man	Suborbital flight; same as MR-1	Successful; cutoff overspeed caused overshoot.
MR-2	S/C 5	Feb. 21, 1960	00:16:39	Chimpanzee	Suborbital flight; qualify ECS, landing bag.	Successful; launch vehicle failed to shutdown until fuel depletion, S/C overshot by 130 miles.
MA-2	S/C 6	Feb. 21, 1961	00:17:56		Ballistic flight; same as MA-1	Successful.
LJ-5A	S/C 14	Mar. 18, 1961	00:23:48		Max. dynamic pressure abort; same as LJ-5.	Object. not met; escape rocket ignited early; S/C recovered intact.

MR-BD	BP	Mar. 24, 1961	00:08:23		Suborbital flight; evaluate modifications to correct MR-1 and MR-2 malfunctions.	Successful.
MA-3	S/C 8	Apr. 25, 1961	00:07:19	Simulated man	One-pass orbital flight; evaluate all S/C systems, network, recovery forces.	Object. not met; launch vehicle failed to follow roll program; S/C escape system operated.
LJ-5B	S/C 14A	Apr. 28, 1961	00:05:25		Max. dynamic pressure abort; same as LJ-5 and LJ-5A.	Successful.
MR-3	S/C 7	May 5, 1961	00:15:22	Alan B. Shepard	Suborbital flight; familiarize man with space flight; evaluate response and S/C control.	Successful; first American astronaut in space.
MR-4	S/C 11	July 21, 1961	00:15:37	Virgil I. Grissom.	Suborbital flight; same as MR-3	Successful; premature hatch release caused S/C to take on water and sink; astronaut recovered.
MA-4	S/C 8A	Sept. 13, 1961	01:49:20	Simulated man	One-pass orbital flight; same as MA-3.	Successful; open circuit in control system caused S/C to land 75 miles uprange; S/C recovered.
MA-5	S/C 9	Nov. 29, 1961	03:20:59	Chimpanzee	Three-pass orbital flight; qualify all systems, network, for orbital flight recovery.	Successful; control system malfunction terminated flight after two passes.
MA-6	S/C 13	Feb. 20, 1962	04:55:23	John H. Glenn, Jr.	Three-pass orbital flight; evaluate effects on and performance of astronaut in space; astronaut's evaluation of S/C and support.	Successful; first American to orbit earth; control system malfunction required manual retrofire and reentry; erroneous T/M signal, retropack retained through reentry; S/C landed 40 miles uprange.
MA-7	S/C 18	May 24, 1962	04:56:05	M. Scott Carpenter.	Three-pass orbital flight; same as MA-6; evaluate S/C modifications and network.	Successful; horizon scanner circuit malfunction required manual retrofire; yaw error caused S/C to land 250 miles downrange, recovery in 3 hr.
MA-8	S/C 16	Oct. 3, 1962	09:13:11	Walter M. Schirra, Jr.	Six-pass orbital flight; same as MA-6 and MA-7 except for extended duration.	Successful; partially blocked ECS coolant valve delayed stabilizing suit temperature until 2nd pass; S/C landed 4½ miles from primary recovery ship.
MA-9	S/C 20	May 15, 1963	34:19:49	L. Gordon Cooper, Jr.	Twenty-two pass orbital flight; evaluate effects on man of up to 1 day in space; verify man as primary S/C system.	Successful; short circuit late in flight disabled ASCS, inverters, prompted manual retrofire and reentry; S/C landed 4½ miles from ship.

[a] LJ—Little Joe launch vehicle mission; MA—Mercury-Atlas (launch vehicle) mission; MR—Mercury-Redstone (launch vehicle) mission; BD—Booster development.

[b] BP—Boilerplate spacecraft; S/C—spacecraft; S/C 10, 12, 15, 17, 19 not used in flight program.

[c] Duration measured from lift-off to landing.

[d] ASCS—automatic stabilization and control systems; ECS—environmental control system.

[e] Object.—objectives of flight; prop.—propellant; T/M—telemetry.

Table 3-II.—Summary of Modifications to MA-9 Spacecraft

System	Modification	Justification
Spacecraft control system.	1. Removed rate control system (RSCS) 2. Added 15-pound-capacity fuel tank 3. Installed modified 1- and 6-pound thrust chambers 4. Installed interconnect valve	1. Not necessary; reduced weight by 12 lb 2. Additional control capability [a] 3. Improved reliability and operating characteristics 4. Improved control-fuel management
Communications systems.	1. Removed backup UHF voice transmitter 2. Installed slow-scan television unit	1. Primary unit reliable, reduced weight by 3 lb 2. Inflight evaluation of TV for ground monitoring of astronaut and instruments
Instrumentation system.	1. Deleted backup telemetry transmitter 2. Changed recorder speed from 1⅞ ips to 15/16 ips and programed 3. Deleted periscope 4. Deleted low-level commutator	1. Primary unit reliable, reduced weight by 2 lb 2. Greater flight coverage necessary without changing recorder or reel size 3. Reduce weight by 76 lb; unnecessary for attitude reference 4. Served its purpose on previous flights
Life support systems	1. Added 4 lb of breathing oxygen 2. Installed parallel suit-coolant control valve 3. Added inline condensate trap 4. Added urine and condensate transfer systems with manual operation 5. Added 9 lb of cooling water 6. Added 4.5 lb of drinking water 7. Added 0.8 lb of CO^2 adsorber	1. Necessary for extended mission 2. Added reliability in case of partial valve blockage as experienced in MA-8 3. Existing condensate system believed ineffective 4. Increase urine and condensate storage capability because of extended mission 5. Increase cooling capability because of mission 6. Necessary for increased mission duration 7. Necessary for increased mission duration
Electrical and sequential systems.	1. Replaced two 1,500 watt-hour batteries with two 3,000 watt-hour units 2. Replaced two of three inverters	1. Necessary for extended flight duration 2. Improved thermal and operating properties

[a]Tank intentionally serviced to only 10 lb. of fuel.

four of the five umbilicals, two between the spacecraft and the adapter and three between the spacecraft and the retropackage (fig. 3–8) failed to separate in a normal manner. Later analysis revealed that each of the malfunctioned disconnects (see fig. 3–9), which normally contained a dual charge came from a special test lot which did not contain the main charge of explosive powder. Somehow, this lot had been improperly marked as intended for flight hardware. The umbilical which separated normally contained the intended amount of explosive and came from a properly identified lot. The four umbilicals which failed to separate pyrotechnically were released through actuation of a backup mechanical device. This experience points up the necessity for close control of flight articles and a means for establishing that the hardware intended for flight satisfies prescribed specifications.

The landing system, which includes the main, reserve, and drogue-stabilization parachutes and the landing-shock attenuation system (landing bag), has never failed in flight during the production-spacecraft flight program. In the second Mercury-Redstone mission, the heat shield was lost after landing because the metal retaining straps and landing-bag material to which the shield was attached failed as a result of wave action and strengthening of existing straps for later spacecraft eliminated this problem. The only other anomalies in the operation of the landing system were concerned with the altitude of parachute deployment, and these anomalies are discussed in the Electrical and Sequential Systems section. The successful performance of the landing system, particularly the parachutes, can be attributed to a thorough test program involving some 80 air drops of full-scale spacecraft.

FIGURE 3-8.—Spacecraft photograph displaying retro-rocket umbilicals.

The rocket motors include the launch-escape motor, the retrorockets, the posigrade rockets, and the launch-escape-tower jettison motor. All of the rocket motors used solid propellants, and their nominal thrust values are indicated in table 3-III. Each of these rocket systems has operated satisfactorily throughout the Mercury flight program. It was found early in the program that the launch-escape tower did not separate rapidly enough from the spacecraft after an off-the-pad abort test because of thrust impingement on the tower; therefore, the tower-jettison rocket-nozzle configuration was subsequently changed from a one- to a three-nozzle arrangement. Because of reliable launch-vehicle operation, the launch-escape system was never needed for an atmospheric abort during the manned flight program, and the large escape motor successfully ignited each time when the system was normally jettisoned. An abort, however, occurred during the unmanned MA-3 mission, and the system operated satisfactorily.

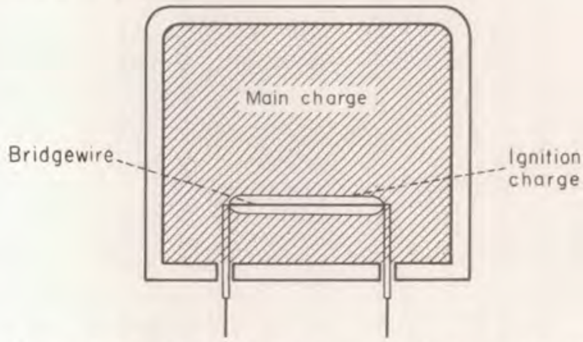

FIGURE 3-9.—Schematic diagram of explosive umbilical disconnects.

Table 3-III.—Nominal Rocket Motor Characteristics

Rocket motor	Number of motors	Nominal thrust each, lb	Approximate burning time each, sec
Escape	1	52, 000	1
Tower jettison	1	800	1. 5
Posigrade	3	400	1
Retrograde	3	1, 000	10

The internal spacecraft structure has been compromised only once during a mission critical situation, a record which is essentially proved by the fact that water, following an ocean landing, had never entered the spacecraft in appreciable amounts, except in one instance, because of a structural failure. In the MR-2 mission following landing recontact of the heat shield with the large pressure bulkhead caused puncturing that resulted in a sizable leakage rate.

The spacecraft was recovered, however, within a safe period. During postflight inspections of all manned spacecraft, some evidence of recontact by the heat shield upon landing has been present, but this damage to the large pressure bulkhead has been slight. The integrity of the spacecraft's load-carrying structure was especially proven during the Little Joe flight program. In one of these flights, the late ignition of one of the Little Joe rocket motors caused the trajectory to be considerably flattened, and as a result the spacecraft was exposed to loading conditions approximately twice those expected for a normal flight.

Spacecraft Control System

The spacecraft control system provides for attitude control and rate stabilization of the spacecraft during the orbital and reentry phases. In addition to the system electronics, the spacecraft control system is composed of two independent reaction control systems (RCS), one of which supplied fuel for the automatic stabilization and control system (ASCS) and fly-by-wire (FBW) modes and the other which, until MA–9, supplied the manual proportional (MP) and the rate stabilization and control system (RSCS) modes. The RSCS unit was installed in the MR–4 and subsequent flights as a backup to one of the secondary modes of the ASCS, that of auxiliary damping. This unit was removed as unnecessary for the MA–9 flight, with major deciding factors being its high fuel-consumption characteristics and weight. The FBW and MP modes were available for direct manual control by the astronaut, initially as backups to the ASCS and in the final two orbital flights as modes of equal priority. Although the control system has operated adequately in all of the manned flights, largely because of the ability of the pilot to exercise precise attitude control manually, this system has exhibited failures of one type or another in nearly every flight. The one exception was the six-pass mission of Astronaut Schirra, in which the system operated correctly.

The single most prevalent malfunction in the control system during the early manned flight program was the intermittent failure of the small 1-pound thrust-chamber assemblies (thrusters). In addition, during a manned suborbital flight (MR–3) a 6-pound thruster also failed to produce thrust when required. During the MA–5 flight, the mission duration was terminated early because of a failure in the thrust chamber assembly. During the flight of Astronaut Glenn, intermittent failures of the 1-pound pitch and yaw thrusters would have caused a similar early termination of the mission had the pilot not been present to exercise his manual control option. Immediately following the first inflight thruster failures, a complete analysis was begun to determine the exact cause of the system discrepancy. In the postflight inspections for the MR–3, MA–5, and MA–6 spacecraft, small particles were discovered at critical points in the thrust chamber assembly, and for the MA–5 mission a large metal deposit which partially blocked the thruster orifice was found. Although thruster malfunctions were experienced during the MA–4 flight, the postflight inspection did not reveal any thruster valve contamination. The exact mechanism for transporting these particles, some of which were found to be broken pieces from the stainless-steel dutch-weave screens which distributed the flow, to upstream points is still unknown. Three steps were taken for the MA–7 mission to correct this anomaly, one being the replacement of the dutch-weave screens with a combination of a stainless-steel fuel distribution plate and platinum screens, another being the reduction of the bore and size of the heat barrier, and the third being the relocation of the fuel-metering orifice to the upstream side of the solenoid valve (ref. 8). While these changes constituted the MA–7 modification, a more refined design change was being developed and qualified in the Project Orbit altitude chamber tests. This configuration, compared in figure 3–10 with previous 1-pound thruster configurations, involved both the 1- and 6-pound thrusters and was installed in the MA–9 spacecraft. No thruster failures of this type occurred on either the MA–7, MA–8, or MA–9 flights after the modifications had been successively incorporated.

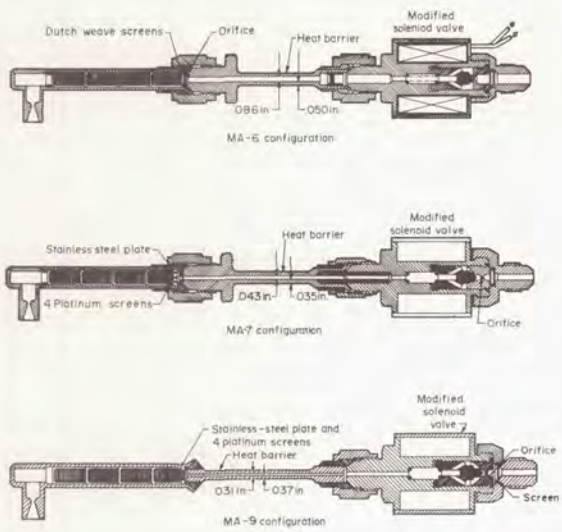

FIGURE 3-10.—Comparison of 1-pound thrust-chamber configurations.

The horizon scanners, which were used to provide an external reference for the attitude gyros, were a source of difficulty in the earlier orbital flights. In the MR-4 flight after tower jettisoning, the scanner was observed to be generating unexpected ignore signals, the cause of which was later traced to the impingement and heating effects caused by the ignition of the launch-escape rocket. A modification to the horizon-scanner cover eliminated this problem.

In the MA-4 flight, both scanners exhibited output variations which could not be correlated with attitude changes, and this anomaly was subsequently found to have been partially caused by "cold-cloud effects"; in addition, a shorted capacitor in the scanner circuit contributed to the attitude discrepancy. Since the scanner unit had been designed without accurately taking into account the effect of high-altitude cloud formations in the view field, a temporary modification of altering the bias levels was made for the MA-5 flight, but this change did not completely eliminate the problem. Further system refinement involving signal clipping for the earth portion of the view resulted in a successful modification for the first manned orbital flight. Since that time, only isolated occurrences of "cold-cloud effects" have been observed. During the MA-7 flight, a horizon-scanner circuit failure (see ref. 8) of another type occurred, but because the antenna canister was normally jettisoned prior to landing, it was impossible to conduct a postflight inspection of the hardware and determine the cause of the failure. This malfunction, which occurred in the pitch scanner, is believed to have been random in nature within the scanner circuitry.

The only remaining control system problem of any consequence during the full-scale flight program was the existence of an open circuit in the pitch-rate gyro input to the amplifier-calibrator (Amp-Cal), or autopilot, during the MA-4 mission. The Amp-Cal is the electronic unit which generates automatic control system logic for the various ASCS operating modes. The partial loss of gyro information to the autopilot caused the spacecraft attitude to be in error at retrofire, which in turn resulted in the MA-4 spacecraft's landing some 75 nautical miles up range of the intended point. This malfunction was either not detected during preflight tests or it occurred during the flight.

Although the control system performed satisfactorily during Astronaut Cooper's mission, an electrical short circuit, which occurred at two of the power-carrying plugs into the autopilot and resulted in the loss of the automatic control mode during the final few orbital passes. However, because this malfunction occurred at this specific interface and is primarily of an electrical nature, it is discussed in a later paragraph under Electrical and Sequential Systems. Because of the loss of the automatic control mode during the retrofire and reentry flight maneuvers, the astronaut conducted these maneuvers by using both manual modes available to him.

The only other major modifications to the control system for the 1-day mission of Astronaut Cooper were the addition of a 15-pound-capacity fuel tank, which is shown in figure 3-11, and the incorporation of the interconnect valve between the two RCS systems for better fuel utilization, in an emergency, and for more effective fuel jettisoning.

Communications Systems

The original design configuration of the communications systems proved to have been the most conservative of all of the major systems. These systems—the voice transceivers, the radar beacons, the location aids, and the command receivers—operated satisfactorily throughout the flight program. Because of the excellent performance of these systems, some of their backup units were deleted, including one of the two command receivers and decoders and the high-frequency (HF) recovery transceiver for the MA–8 and MA–9 flights and the ultra-high frequency (UHF) backup voice transceiver for the MA–9 flight. One of the two UHF telemetry transmitters, which were part of the instrumentation system, was also deleted as unnecessary for the MA–9 mission. A slow-scan television system, shown in figure 3–12, was included for evaluation aboard the *Faith 7* spacecraft, but the quality and usefulness of its transmissions were not satisfactory.

In the initial two manned orbital flights, it was noted that signals were not being received from the HF recovery transmitter, but because of the circumstances at the time of recovery and the uncertainty of HF reception in the landing area, it could not be established that an anomaly existed. However, when this discrepancy still existed on the MA–8 mission, attention was directed to the ineffectiveness of the HF recovery beacon. Careful analysis revealed that when the HF "whip" antenna was pyrotechnically deployed upon landing, the spacecraft was usually not completely erect in the water. The combination of the electrically conducting products of combustion from the explosive charge used to extend this antenna and the fact that it was extended under water are believed to be the cause of this communications anomaly. The antenna was subsequently deployed by using pressurized nitrogen gas, which is nonconductive, and it was programed such that deployment would not occur until the antenna was clear of the water. Reception from this beacon was satisfactory during the MA–9 mission.

For the MA–8 flight, a pair of more sensitive microphones was installed in the pilot's helmet, and the increased sensitivity apparently caused the background noise from the launch vehicle to trigger the voice-operated relay in the air-ground circuit. For the MA–9 mission, these microphones were modified to reduce background noise sensitivity such that this triggering action ceased.

FIGURE 3–11.—Auxiliary reaction control system fuel tank.

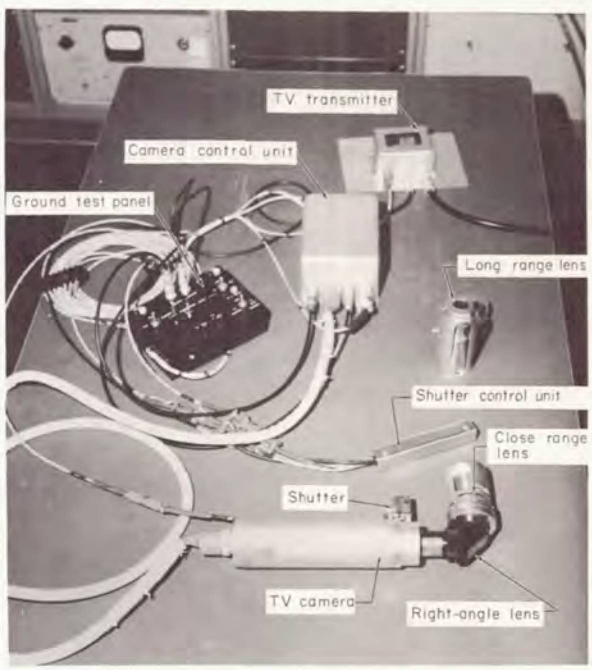

FIGURE 3–12.—Television system evaluated during MA–9.

Reports of reception of HF voice communications during the first three manned orbital flights were somewhat inconsistent with regard to quality, but the periods allowed for a complete inflight test of the HF voice equipment were also very brief. At any rate, because of reports that reception of HF voice signals during the first two manned orbital flights was unsatisfactory, a special HF antenna was installed on the retropackage for the MA–8 flight (see ref. 10). There were reports of excellent reception of signals from this antenna during the flight at ranges exceeding 2,000 nautical miles, while other reports stated that even when the spacecraft was nearly overhead, the reception was poor to unreadable. This inconsistency is not clearly understood, but the effects of spacecraft attitude at the time of transmission, the atmospheric propagation characteristics at the time of contact, and the status of operational ground equipment remain as unknown variables. A more closely controlled test of this special dipole antenna was conducted during the MA–9 flight, and it was fully successful. Although HF voice transmissions were heard during MA–8, the results of MA–9 were more consistent and indicated reliable operation. It might be mentioned that both the pilots and ground-control personnel preferred the UHF voice equipment to the HF system, particularly since none of the missions were such that nearly continuous communications were required. The UHF communications, of course, are limited to essentially line-of-sight ranges, but have signal-to-noise characteristics superior to those of HF in flight. However, the MA–9 astronaut found HF communications quite useful during the long periods in which he could not make UHF contact with a network station.

Although the command system has never been exercised for a commanded abort, its performance has been entirely satisfactory during other inflight exercises, such as the reception of signals for instrumentation calibration in all orbital flights and for an emergency voice communications test and a commanded wake-up tone in the MA–9 mission. For the unmanned orbital flights, MA–4 and MA–5, the command system was successfully used to control the operation of the spacecraft and bring it safely back from orbit.

Instrumentation System

The instrumentation system monitored over 100 performance variables and events throughout the spacecraft, and the operation of this system was satisfactory throughout the entire Mercury program. The system was designed with enough flexibility to incorporate required instrumentation changes as the program progressed. In the manned orbital flight phase, it was desired to have a more complete temperature survey at discrete spacecraft points, primarily on the spacecraft afterbody; and a low-level commutator circuit was installed. This unit was deleted from the MA–9 spacecraft as having served its purpose and to save weight. The confidence in the telemetry transmitters through the third manned orbital flight led to a decision to eliminate one of the two redundant units from the *Faith 7* spacecraft to save weight. The onboard recording capacity for the MA–9 flight was extended by changing the tape speed from 1⅞ inches per second (ips) to $^{15}/_{16}$ ips and reprograming the operation periods such that only essential information was recorded during the expected 34-hour period.

Probably the most widely known system malfunction in the entire Mercury program is that associated with the failure of a limit switch which sensed heat-shield release. During the MA–6 mission, ground-control personnel received a telemetry signal which indicated that the heat shield had been prematurely unlatched from the spacecraft. Although it was believed that this signal was improper and involved an instrumentation failure, a decision was made to reenter with the retropackage attached to insure that the heat shield would not part from the spacecraft during the critical reentry heating period. A postflight examination of the instrumentation revealed that a limit switch had a bent and loose shaft (shown in fig. 3–13) and that manipulation of the sensor without appreciably displacing the sensing shaft would generate an erroneous signal. This experience prompted a change in the installation technique and a directive for tighter quality-control standards to insure that prescribed manufacturing tolerances would be maintained. This type of malfunction did not recur in subsequent flights.

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FIGURE 3-13.—MA-6 limit switch used to sense heat-shield release.

Early in the flight program, beginning with the Little Joe 5 mission, the mechanical spacecraft clock was found to be sensitive to accelerations in excess of 5g. An electronic digital clock was substituted for this unit and operated satisfactorily.

During the MA-7 mission, the blood-pressure measuring system (BPMS) yielded data which were of only marginal value. The system was thoroughly checked out following the flight, and no major system malfunction was found. It was shown, however, that proper techniques, including establishing a proper amplifier gain setting, correlation with clinically measured values, and the fitting of the pressure cuff to the individual flight astronaut, were not well understood. A thorough review of the entire system, its operating characteristics, and the preflight calibration procedures was conducted in the months after the MA-7 flight, and the data quality for the MA-8 and MA-9 missions was correspondingly improved and resulted in usable values. A discussion of this anomaly from a medical standpoint is presented in the Aeromedical Preparations paper.

During the MA-9 mission, the programer, which automatically controls the operation and sequence of events of certain spacecraft systems, exhibited two anomalies, one inherent and the other resulting from a structural failure. The inherent anomaly, evident to varying degrees in previous flights, involved a sensitive control circuit containing transistors which actuated power relays to operate the programer. This circuit was sensitive to certain input voltage transients which occasionally caused undesired programer operation. Prior to the MA-9 flight, a loading resistor had been added to reduce the inherent sensitivity, and an on-off switch had been incorporated so that the pilot could shut the system down if improper operation occurred. On two occasions, the unit was inadvertently triggered and continued to call for instrumentation calibrations, one of its programed functions. On both occasions, the astronaut turned the system off, and no serious consequences resulted, but the need to improve system design for future programs in this area, particularly for transistorized circuits, is exemplified.

The other programer anomaly, although in a separate section of the system, involved the shearing of a pin used to maintain alinement of a gear in the programer drive mechanism. Figure 3–14 depicts the misalined gear, which resulted in an inflight binding of the programer and the preclusion of a significant portion of recorded data during the midpoint of the MA–9 flight until the astronaut switched from programed to continuous operation.

During the MA–9 flight, the respiration rate sensor failed to yield reliable data during and after the fifth orbital pass, but other sources of this information were found to be adequate.

FIGURE 3–14.—Misalined gear in MA–9 programer.

A postflight investigation of the system disclosed a broken solder joint at the attachment point of the sensor lead.

Life-Support Systems

The life-support systems primarily provide for control of the cabin and suit atmospheres, management of metabolic-waste products, and the supply of food and liquid for the astronaut. The major changes to the MA–9 life-support systems, including the environmental control system (ECS) (fig. 3–15), from those of previous missions were accomplished primarily in support of the increased mission time, and the most significant modifications were as follows:

(1) Addition of about 4 pounds of primary breathing oxygen (O_2), stored under pressure, for a nominal total of 12 pounds in the system.

(2) Increase in the carbon-dioxide (CO_2) adsorber, lithium hydroxide (LiOH), quantity from 4.6 to 5.4 pounds. The amount of activated charcoal, as the odor absorber, was decreased from 1.0 to 0.2 pound, which was sufficient.

(3) Increase in the stored coolant-system water from 39 pounds to 48 pounds.

(4) Increase in the capability of the urine collection and storage system.

(5) Addition of an improved condensate collection and storage system, including a new wick-type condensate trap (shown in fig. 3–16) to extract free water from the suit circuit of the ECS.

(6) Increase of the stored drinking water by 4.5 pounds for a total of 10 pounds of potable water.

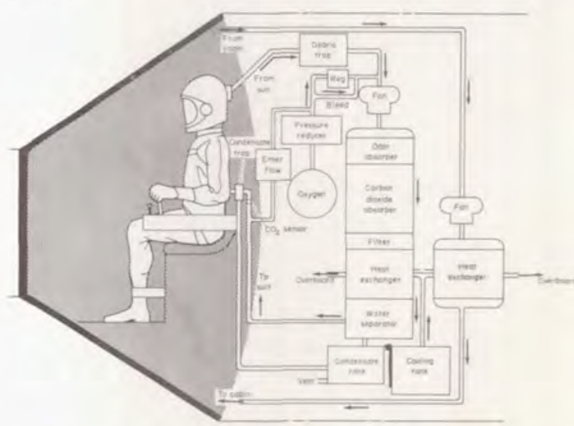
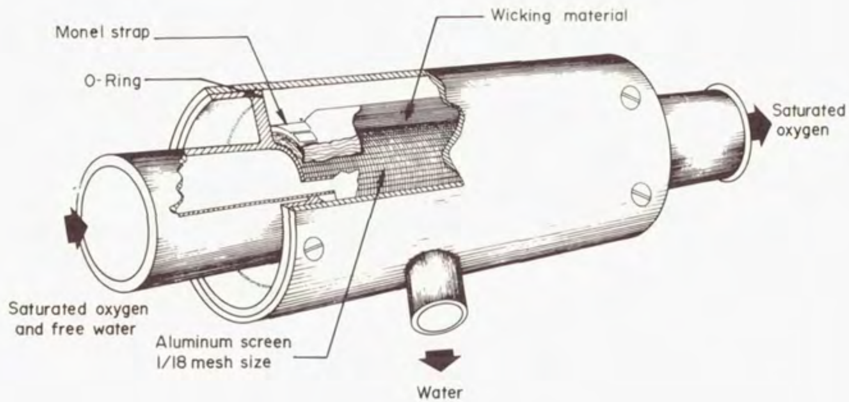


FIGURE 3–15.—Environmental control system schematic diagram.



(a) Condensate trap details

(b) Condensate trap

(c) Condensate trap installation

FIGURE 3–16.—MA–9 inline condensate trap.

A parallel coolant control valve (CCV) shown in the upper right corner of figure 3–17 was added in the suit cooling-water circuit for redundancy with the primary valve (top-left on the control plate) in the event of a serious valve blockage by contamination, which was experienced in the MA–8 mission.

The operation of the life-support equipment during the MA–8 mission was normal, except that the suit-circuit CCV was partially blocked by solidified lubricant and delayed the astronaut's stabilization of the cooling system at a comfortable level. Preflight procedures were changed for the MA–9 mission so that the CCV's were cleaned and properly lubricated prior to flight, but after the manned systems tests. The cooling water was also passed through a 0.15 micron filter before being transferred into the spacecraft. Blocking of the CCV during the MA–9 flight was not experienced. However, the astronaut was required to make a large number of minor changes to the suit CCV setting in an attempt to maintain the heat-exchanger dome temperature, which was the cooling system control parameter, within the desired range. No system deficiencies or hardware malfunctions were found during the postflight inspection or testing. It is a characteristic of

FIGURE 3–17.—Redundant coolant control valve for MA–9.

the system that changes in metabolic and external suit-circuit heat loads as a result of changes in the astronaut's level of activity, open visor operation, solar heat on the spacecraft, and internal spacecraft equipment heating will be experienced and will be reflected in the coolant requirements for the suit heat exchanger. These heat-load changes are not radical under normal conditions and the corresponding coolant flow changes would be small compared with the capacity of the CCV. It is quite possible that the sensitivity of this small-orifice valve, together with the astronaut's normally varying metabolic heat loads, could have resulted in the need for frequent coolant-flow adjustment.

An inline condensate trap, shown in figure 3–16, was designed to remove excess water from the suit-inlet hose and was installed near the entrance point on the suit. The condensate trap was activated periodically according to the flight plan by the astronaut's opening a hose clamp on the water outlet line from the trap. Condensate water was observed by the astronaut to have been flowing through this line, indicating that free water had probably passed around the sponge.

During the 21st orbital pass, the carbon dioxide (CO_2) level at the LiOH canister outlet began to show an increase on the CO_2 meter. Postflight chemical analysis of the canister showed definite channeling of the flow through the canister. Channeling is the localized or restricted passage of gas through the canister, rather than a uniform flow for maximum CO_2 adsorption. This channeling, which could reduce the effective canister lifetime, has never been experienced during ground testing or during any previous Mercury flight. Based on the amount of unused LiOH at the end of the flight, approximately 27 hours of normal usage remained. However, the actual operating capability of the canister could not be established because of the channeling effects. The exact reason for its occurring on MA–9 could not be established.

The cabin coolant water and fan were turned off according to the flight plan during much of the MA–9 mission in order to evaluate the effectiveness of the cabin cooling circuit. During this time, the electrical load varied according to mission requirements, and the cabin temperature was observed to cycle between 85° F and 95° F, as indicated in figure 3-18. Reduction in the electrical load during this no-cooling period resulted in corresponding reduction in cabin temperature. It is concluded that cabin cooling was not required during periods in which the Mercury spacecraft electrical system was powered down.

Problems were encountered during MA-9 with the condensate transfer system. The needle of the hand-operated pump, used to transfer liquid from the condensate tank to another container, became clogged with metal shavings from the pump shaft and the condensate could not be transferred. Normally, free water removed by the condensate trap and sponge separator flowed directly to the condensate tank, from which it was then intended to be pumped to storage bags. The condensate tank contained a porous plus to relieve the gas pumped from the sponge into the tank by the action of the sponge separator. Since it was known that this plug could pass water when the tank became nearly filled, the astronaut elected to discontinue operation of the condensate trap when the transfer pump became clogged. This action was taken to stop further flow from the trap to the tank and thereby help to preclude water from being released into the cabin.

No malfunction of the life-support system which compromised the mission or presented a marginal condition to the man occurred during any of the manned Mercury missions. Although minor malfunctions of equipment occurred on these flights, some of which were alleviated by the astronaut, none of these were repeated on successive flights. The suit cooling system has exhibited a history of undesirable operation, characterized by elevated suit inlet temperatures, wet undergarments, and a general lack of astronaut comfort. However, metabolic heat loads were removed sufficiently to keep body temperatures well below a physiologically marginal value. The causes of these cooling system problems for the suit circuit were twofold:

(1) Selection of an improper cooling system control parameter during the initial design period.

(2) Ineffectiveness of the suit-cooling-circuit water separator because of the unpredicted behavior of free liquid in a weightless condition.

Ground testing showed that the steam exhaust duct temperature used in MA-6 and MA-7 missions was not an adequate control parameter for controlling the operation of the heat exchanger. A probe, which sensed the steam temperature at the heat-exchanger dome (see fig. 3-19) between the two coolant evaporating passes, provided a more rapidly responding indication of the heat-exchanger operation. This control temperature parameter was used during the MA-8 and MA-9 flights with satisfactory results. The suit-inlet temperature range of 60° F to 70° F during most of these two flights was more comfortable than the 75° F to 80° F range experienced during MA-6 and MA-7. See figure 3-20 for a summary of suit-inlet temperatures experienced during the four manned orbital flights.

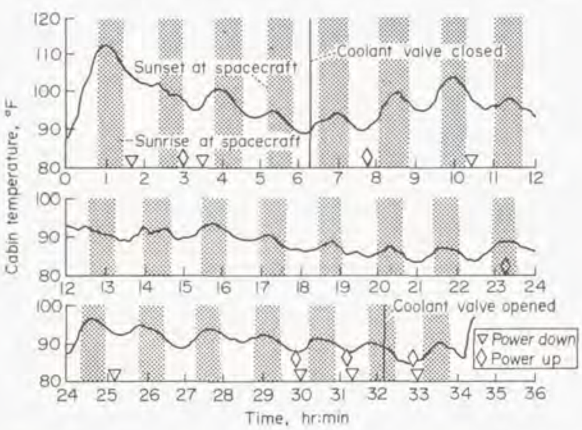


FIGURE 3-18.—Time history of MA-9 spacecraft cabin temperature.

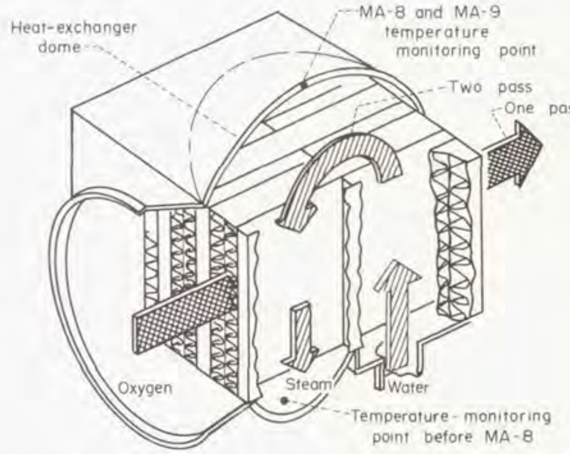


FIGURE 3-19.—Temperature monitoring points on heat exchangers.

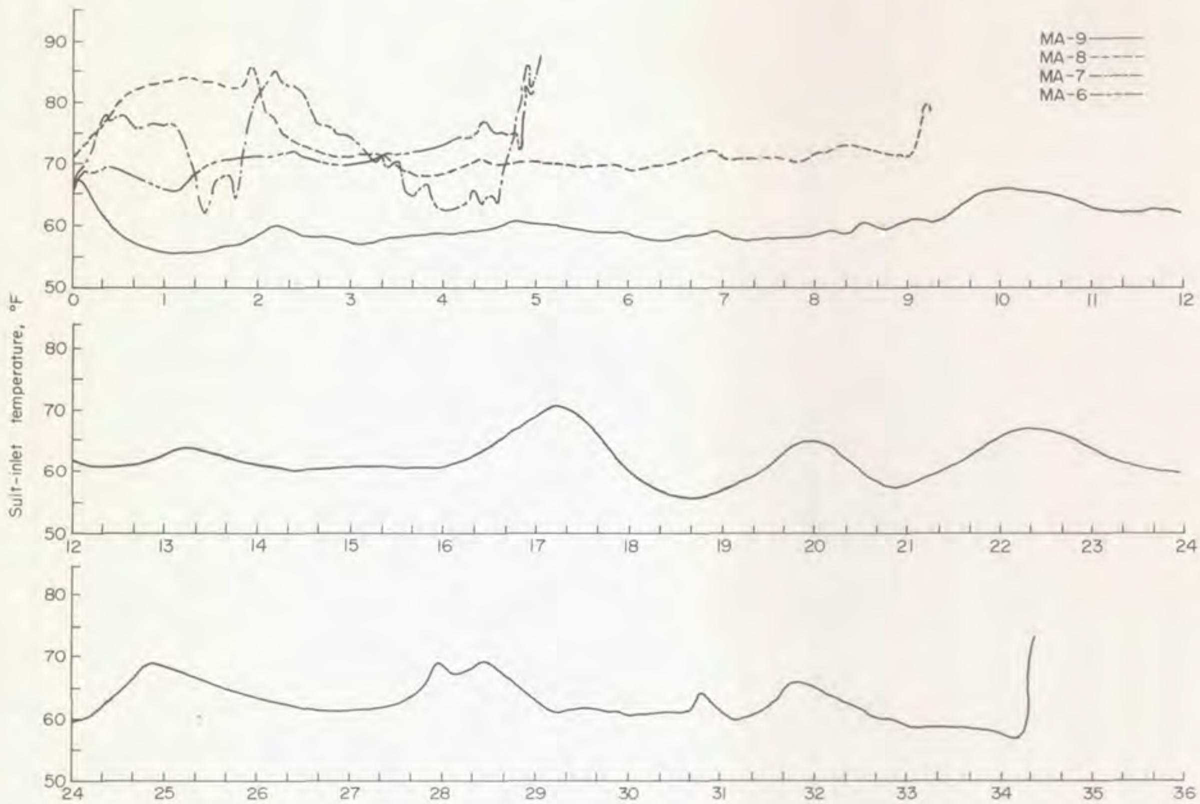


FIGURE 3-20.—Time history for suit-inlet temperature for manned orbital flights.

Other ground tests showed that water in the suit circuit, when condensed from the gas stream in the heat exchanger, was not carried by the gas flow to the sponge separator. This water is believed to have been held under weightlessness to the metal surfaces by surface tension and flowed from the cooling surfaces to the duct walls, thereby probably passing around the sponge in the separator. The condensate trap, which was installed in the MA-9 ECS, verified the need for a trap which will remove free condensate water traveling along the duct walls. Missions of even longer durations will require the extraction of all free condensate to keep the astronaut's body dry and thereby to obtain maximum comfort and hygiene.

Electrical and Sequential Systems

Except for some early development problems in the sequential system, this system group has performed satisfactorily throughout the Mercury program. Although there were no serious sequential problems throughout the manned flight program, there was an early deployment of the main parachute during the MR-4 mission and of the drogue parachute during MA-6. The reasons for these premature deployments have never been fully understood, since no system malfunction could be found during exhaustive postflight testing. During the later manned orbital missions, a modification to the sensing circuits for these sequential functions guarded against premature automatic deployment. The contractor was instructed to conduct a single-point failure analysis, which involved a detailed study of the electrical and sequential circuitry to establish all possible failure modes, and this analysis was conducted for all spacecraft systems before the MA-7 flight. The results of this study were evaluated for failure conditions that would singularly jeopardize flight safety, and appropriate modifications were incorporated into the MA-7 and subsequent spacecraft to improve reliability. The greater portion of these changes involved the electrical and sequential systems because of their unique relationship to critical mission functions. These changes dictated paralleling of redundant sensing elements in some cases in which the actuation of either element could initiate the proper function. In other cases where it was important that an event signal not be sent early, some elements were changed to a series function, as was done for the parachute-deployment circuitry.

The primary change to the electrical system for the MA–9 mission was the replacement of two 1,500-watt-hour batteries with two 3,000-watt-hour batteries. This change brought the power supply up to one 1,500-watt-hour and five 3,000-watt-hour batteries.

During the early phases of the flight program, difficulty was experienced in maintaining the temperatures of the electrical inverters below the maximum recommended operating level. A cooling system was subsequently installed for the two main inverters, but contamination problems and the limited effectiveness of this cooling system did not alleviate the elevated temperature situation appreciably. However, continued operation of these inverters from mission to mission, in conjunction with ground test results, without experiencing a temperature-associated failure, provided sufficient confidence that these units would operate satisfactorily. Finally, for the MA–9 mission, modified inverters with improved thermal characteristics were installed in place of two of the old style units (main 250 v-amp and 150 v-amp) and the open-cycle evaporative cooling system was deleted. The three spacecraft inverters functioned satisfactorily until late in the MA–9 flight when an electrical short circuit prevented their operating properly.

In the MA–9 flight, the failure which caused the greatest concern was first recognized at the early illumination of the 0.05g sequence light, which indicated that the automatic stabilization and control system (ASCS) had possibly switched to its reentry mode of operation, which would have included the initiation of rate damping and a steady spacecraft roll rate. Subsequent checks by the astronaut revealed, in fact, that this control mode had been enabled. A requirement for a manual retrofire maneuver was therefore imposed on the astronaut, but it was still the plan to use the autopilot during reentry. However, soon after this occurrence, the main inverter ceased to supply a-c power, and, in the switchover to the standby unit, this redundant element did not start properly. (Refer to fig. 3–21 for details involving the ASCS and power supplies.) Without a-c power for the control system, even the reentry control configuration was disabled; therefore, the astronaut was required to conduct this maneuver with manual control. This task was further complicated by a corresponding loss of gyro attitude indications because of the a-c power failure. A postflight inspection and analysis

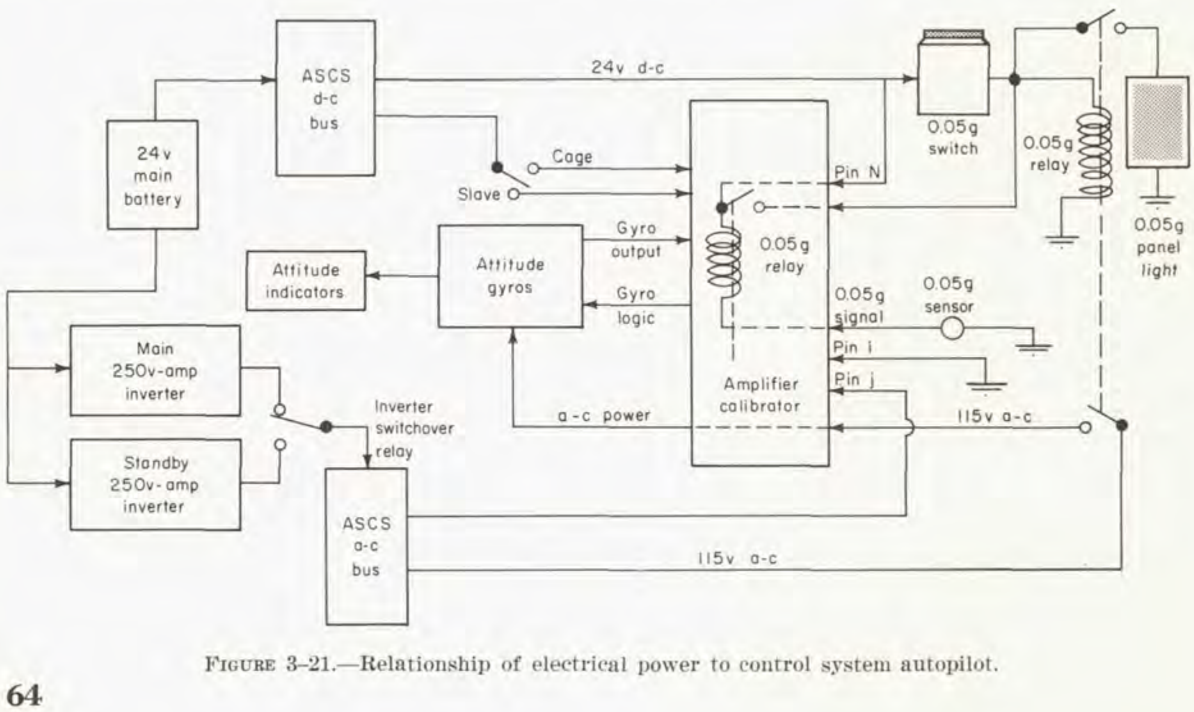
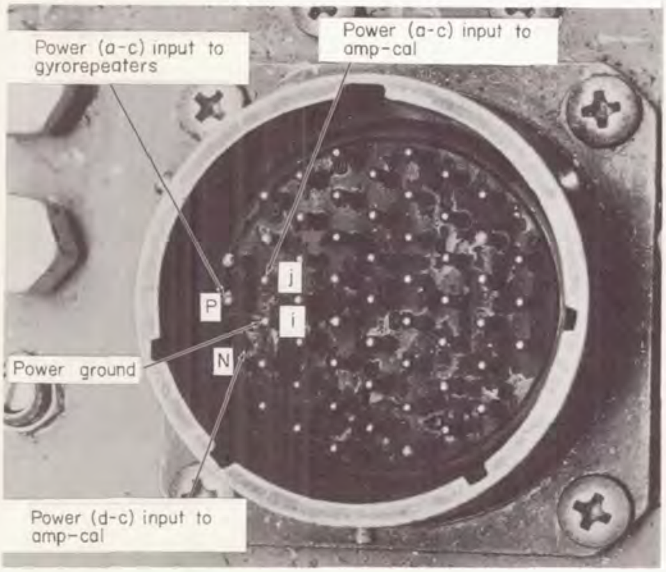


FIGURE 3–21.—Relationship of electrical power to control system autopilot.

of the trouble areas disclosed that a short circuit had occurred, both on the power plug (shown in fig. 3–22) to the ASCS amplifier-calibrator and to another connector (see fig. 3–23), also part of the ASCS power circuit. Both inverters under question were tested thoroughly after the flight and found to operate within specification, indicating that they did not contribute to the malfunction. Strong evidence exists that free water in the spacecraft cabin had been present near the multipin power-plug connection and eventually provided a current path in the insulation between the d-c power and grounding pins shown in right-hand photograph in figure 3–22. Pin N, labeled in the figure, was found to have been completely burned off. Figure 3–23 clearly indicates the significant corrosion revealed on the second connector during the post-flight disassembly and inspection.

Postflight tests duplicated the above hypothesis; that is, a short to ground could be effected upon application of condensate water. Resistance measurements taken across certain pins of the second plug immediately following the flight indicated electrical paths that could have caused the 0.05g indication. A likely source of the liquid which might have caused the electrical short circuit was the porous vent of the condensate tank in the environmental control system. This tank is located in the proximity of the autopilot power plugs, and normal cycling of the sponge squeezer during the flight could have forced condensate through the vent. Another possible source of water which could have produced the short circuit is the local condensation of cabin humidity, which may have been present because of a leak in the drinking-water valve or because of water vapor exhaled by the pilot when his helmet faceplate was open. Or the water droplets which leaked from the valve may have somehow been deposited, in part, directly on the power plug. This experience points up the need to minimize or eliminate the presence of free liquid or high humidity in a spacecraft cabin where electrical systems are functioning and to insulate and seal bare electrical connectors more effectively.

FIGURE 3–23.—Postflight photograph of MA–9 connector-socket rear face.



(a)—Front view showing burnt pin.

(b)—Rear view showing X-rayed current paths in insulation.

FIGURE 3–22.—Postflight photograph of MA–9 auto-pilot power plug.

Concluding Remarks

The Mercury spacecraft systems design and development phases were conducted concurrently and although this philosophy involved a known risk, it made possible the early realization of the project objectives. During this time, many valuable lessons were learned and exploited in the development and operation of manned space-flight systems.

In the system design, maximum use was made of existing technology and off-the-shelf equipment, and systems concepts were kept simple. However, some important advances in the technology also had to be initiated. It was found that the spacecraft and its systems must be designed for operational conditions. Examples of the design-for-operation standard relating to the preflight activities are system accessibility and the simplification of system interfaces. It is also important in the early system design to allow for an inevitable growth in weight.

During development and qualification testing, the test criteria cannot be compromised in most instances, since an overlooked system inefficiency will inevitably show up later where a redesign is more costly. However, it was also found in Mercury that no single qualification criterion necessarily applies to all systems, and local operational conditions must be individually evaluated for each system. Whenever system components are significantly modified, as was done for the *Faith 7* spacecraft to make possible the 34-hour flight capability, a new ground test program for hardware requalification should be administered to insure maintenance of previous reliability and operational standards.

In the area of hardware operation and performance evaluation, the Mercury flight program has been a most valuable experience. The most important lesson learned from operation of the spacecraft control system is that the pilot is a reliable backup to automatic system modes. In fact, the pilot's ability to control accurately the spacecraft attitude was instrumental in three of the four manned orbital flights in completing the mission successfully when a malfunction was present in the automatic system. Another valuable lesson in both the control system and cooling system designs was the avoidance of components which are especially sensitive to contamination. The small valves used to meter reaction control fuel and environmental control system cooling water should have been designed to employ larger flow areas to reduce susceptibility to particle blockage. Other than guarding against stray voltages and sensitivity to transients, the major lesson derived from the performance of the electrical and sequential systems was the need to seal and insulate effectively all electrical connectors from possible sources of free liquid and humidity in the spacecraft cabin. In the life support system, it was also found that the cooling systems must be designed with adequate margins and that food, water, and waste management devices require particular attention because of plumbing complexity and the effects of weightlessness.

Throughout the Mercury development and flight programs, quality control and rigid manufacturing standards were found to be absolutely mandatory if incidental flight failures and discrepancies were to be avoided. Throughout the project, a careful and continuing attention was given to engineering detail in order to make possible the early recognition of system weaknesses and their implications in the operation of flight hardware and to provide meaningful and effective courses of action. This attention to detail was an important reason for the success of the Mercury flight program, particularly the manned suborbital and orbital missions.

Acknowledgement.—The authors wish to gratefully acknowledge the analytical and documentary efforts of the many NASA engineers and technicians who applied their knowledge and foresight unselfishly during the postflight evaluations of the various spacecraft systems for each Mercury mission and without whose contributions this paper would not have been possible.

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4. MERCURY-REDSTONE LAUNCH-VEHICLE DEVELOPMENT AND PERFORMANCE

By JOACHIM P. KUETTNER, Ph. D., *Chief, Saturn-Apollo Systems Integration Office, NASA George C. Marshall Space Flight Center;* and EMIL BERTRAM, *Chief, Special Projects Office, NASA Launch Operations Center*

Summary

The Mercury-Redstone launch vehicle was used for the first United States ballistic manned space flights. As a prelude to the orbital flight program, the Mercury-Redstone missions provided an opportunity to evaluate the performance of the Mercury spacecraft, the reactions of the astronauts to brief periods of space flight, and the launch and recovery operations. The first steps toward man-rating a tactical missile were made in a series of design changes and modifications based on ground and flight testing. This paper describes development of the first U.S. manned launch vehicle, including the abort system, the reliability programs necessary for pilot safety, and the performance of the Mercury-Redstone space vehicle.

Introduction

The Mercury-Redstone launch vehicle was the United States' first manned launch vehicle. However, it is only the first of a series of launch vehicles which will exhibit an increasing capability in manned space payloads.

By early 1959, several decisions were made in regard to the performance required of a launch vehicle needed for the first phase of the manned flight program. The vehicle had to have both the reliability and performance to place a manned, 2-ton payload safely into a suborbital trajectory in which at least 5 minutes of weightlessness would be experienced and an apogee of at least 100 nautical miles would be attained. In addition, the vehicle had to be available in time to support the desired flight schedule. These requirements narrowed the choice to launch vehicles which had already been developed for a military mission.

At this time, two surplus Jupiter C missiles were available from the Army Ballistic Missile Agency (ABMA). The Jupiter C was an advanced version of the Redstone, a tactical military missile with a record of over 50 successful flights to verify its reliability. The original Redstone could not meet the mission requirements; however, the Jupiter C had elongated propellant tanks, a lighter structure, and the required performance for Mercury. The Jupiter C launch vehicle had been used for conducting reentry studies and placing the first U.S. satellite, *Explorer I*, into orbit.

Therefore, the Redstone vehicle, in its Jupiter C modification, satisfied the basic Mercury suborbital requirements of availability and performance.

However, the Jupiter C did not incorporate all the necessary safety features; and further adaptation was necessary for use as a manned launch vehicle. This development, which is sometimes referred to as "man rating," had as its three major guidelines safety during launch, satisfactory operation from a human-factors standpoint, and adequate performance margins.

The actual adaptation took place in three phases: basic modifications, modifications after ground tests, and modifications after flight tests. Although there were specific hardware changes during the development, the basic man-rating program and design concepts did not require major alteration.

Basic Vehicle Modification

As noted, some basic modification was necessary to adapt the Jupiter C to the Mercury mission requirements. The required modifications and additions made the new Mercury-Redstone launch vehicle physically distinguishable from both the Redstone and Jupiter C missiles. Figure 4–1 illustrates the differences between these configurations. It should be noted that each successive version of the original Redstone was progressively longer.

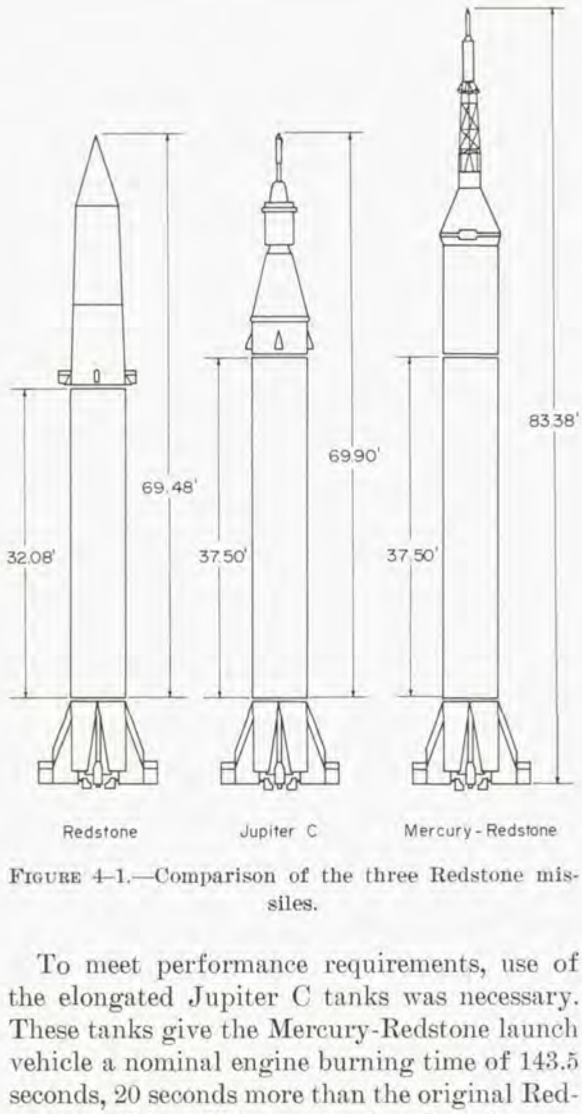

FIGURE 4–1.—Comparison of the three Redstone missiles.

To meet performance requirements, use of the elongated Jupiter C tanks was necessary. These tanks give the Mercury-Redstone launch vehicle a nominal engine burning time of 143.5 seconds, 20 seconds more than the original Redstone vehicle. This greater burning time required the addition of a seventh high-pressure nitrogen tank to pressurize the larger fuel tank and an auxiliary hydrogen peroxide (H_2O_2) tank to power the engine turbopump.

To decrease the complexity for the basic Mercury-Redstone, three changes were made:

(1) The Redstone stabilized platform (ST–80) were replaced by the LEV–3 autopilot for vehicle guidance. The LEV–3 system, although less complex, was more reliable and met the guidance requirements of the Mercury-Redstone mission.

(2) The aft unit, containing the pressurized instrument compartment, and adapter were permanently attached to the center tank assembly. In the tactical version, these units separated with the payload to provide terminal guidance.

(3) A short spacecraft adapter, including the spacecraft-launch-vehicle separation plane, was supplied by the spacecraft contractor. This arrangement simplified the interface coordination.

To prevent major changes midway in the program, the engine was immediately changed from the A–6 to the A–7 model. The A–6 engine was scheduled to be phased out, and a shortage of hardware was expected to occur during the Mercury-Redstone program. This early changeover avoided a foreseeable problem area but required an accelerated test program.

For the Mercury-Redstone launch vehicle, alcohol was chosen as the fuel. Although the Jupiter C had used unsymmetrical diethyltriamine (UDETA) for greater performance, its toxicity was higher than that of alcohol and was considered to be undesirable for manned flights. However, the selection of alcohol led to a problem with the important jet control vanes because of the extended burning time which caused greater erosion of these vanes. Hence, a program was initiated to select jet vanes of the highest quality for use in Mercury.

The prevalves were deleted from the Mercury-Redstone launch vehicle in order to increase mission success. These valves had been used in the tactical missiles between the propellant tanks and the main propellant valves to prevent possible fuel spillage in the event of a main valve failure. However, failure of the prevalves to remain open in flight would have resulted in a mission abort.

To provide for maximum crew safety, an automatic inflight abort-sensing system was added to the launch vehicle and an emergency egress operation was established for the launch complex. These factors were primary considerations in man-rating the Redstone and are discussed in greater detail later.

The Mercury-Redstone was aerodynamically less stable than the standard Redstone. Because of the unique payload characteristics and the elongated tanks, the Mercury-Redstone was expected to become unstable in the supersonic region approximately 88 seconds after lift-off. (See fig. 4–2.) To compensate for this instability to some degree, 687 pounds of ballast were added forward of the instrument compartment.

Changes were also necessary because of the decreased lateral bending frequencies. The configuration and payload changes reduced the Mercury-Redstone bending frequencies to one-fourth those experienced by the standard Redstone. (See fig. 4–3.) As a result, resonance problems appeared during both ground and flight testing. The second bending mode had to be filtered out of the control system to prevent feedback.

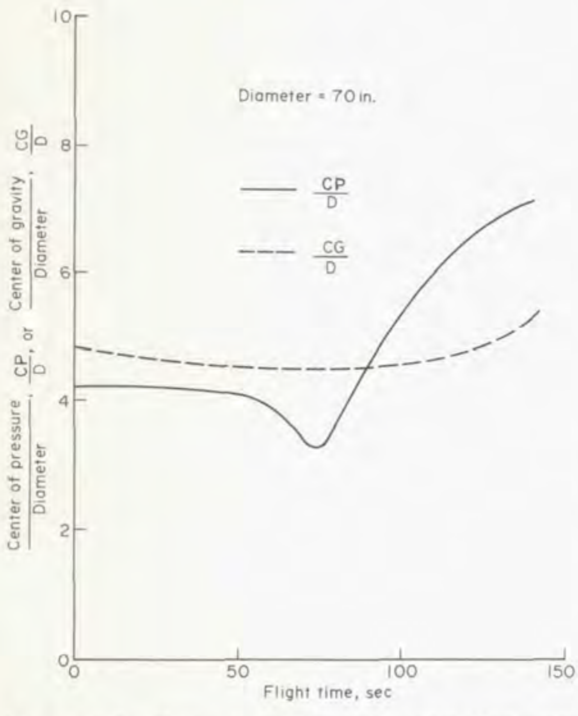

FIGURE 4–2.—Center-of-gravity and center-of-pressure location of Mercury-Redstone during time of flight.

In all, a total of 800 changes were made before the Mercury-Redstone project was completed. The major modifications just described, as well as many minor changes beyond the scope of this paper, resulted in a reliable man-rated vehicle.

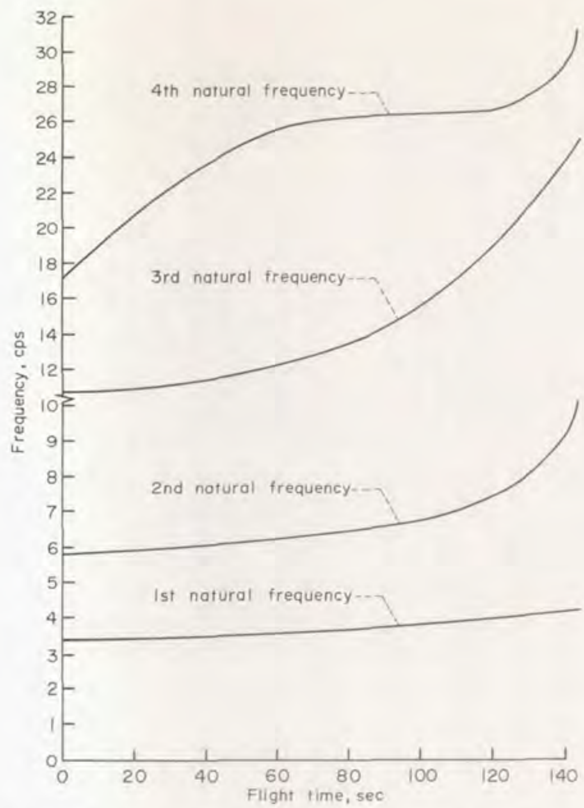

FIGURE 4–3.—Mercury-Redstone lateral bending modes.

Abort System Description

Even though the vehicle was expected to perform properly, a launch-escape system was required for maximum crew safety as long as a catastrophic launch-vehicle failure remained a possibility. Therefore, an automatic inflight system was developed which supplied an abort signal to the spacecraft in the event of an impending catastrophic failure of the launch vehicle. This signal caused engine cut-off, escape-rocket ignition, and spacecraft separation. This cut-off mode was in addition to those sent when the mission conditions were achieved and in the event an emergency command destruct signal had to be sent. Because the vehicle was to be manned, the destruct signal had a built in 3-second delay to allow time for adequate spacecraft separation. The abort system, shown in figure 4–4, sensed and was activated by: unacceptable deviations in the programed attitude of the launch vehicle, excessive turning rates, loss of thrust or loss of electrical power.

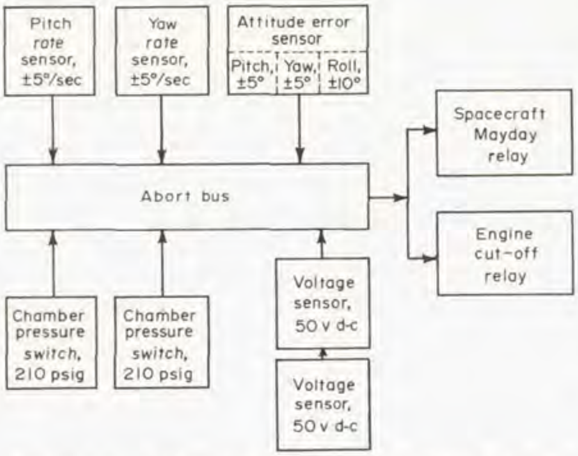

FIGURE 4-4.—Block diagram of Mercury-Redstone automatic abort sensing system.

The criteria for the abort system were based on an evaluation of over 60 Redstone and Jupiter C flights and a failure-mode analysis. The number of parameters was kept at a minimum, since an overly complicated system could result in little improvement, if any, in overall flight safety. A selection of those parameters which would reflect the operation of only vital systems was therefore required. Hence the abort system sensed primarily output or downstream parameters, each of which were then representative of many different types of failures.

For example, a sudden change in the attitude of the vehicle indicated trouble in the control system, regardless of the source of this trouble. It could be the result of a failure in the control computer or some mechanical system or the limits of controllability having been exceeded. By establishing critical values for pitch, yaw, and roll angle, a variety of problems, including the unstable "flip-over" with a subsequent explosion, could be predicted in time for a safe abort. As other examples, loss of thrust, rough combustion, and an impending explosion could be sensed from variations in the combustion chamber pressure. Finally, a loss in electrical power or of the electrical interface between the spacecraft and launch vehicle could be effectively sensed.

As shown in figure 4-4, the abort system circuitry was designed to include adequate redundancy. The combustion chamber pressure (P_c) switches were wired in parallel to assure an abort capability even if one sensor failed. Since the predominant failure mode of electrical voltage sensors is opposite that for a pressure switch, the relays controlled by the voltage sensors were connected in series. Although a single sensor monitored pitch, yaw, and roll attitudes, as well as pitch and yaw attitude rates, redundancy was implicit for these attitude and rate measurements because of their interdependency.

To supply the necessary timing functions to the abort system, relay interlocks were used to prevent arming of the abort system prior to lift-off and to disarm the system at normal shutdown. The P_c switches were armed after engine start and disabled prior to normal shutdown. Here, additional relays also provided circuit redundancy and lock-in of the abort signal.

Time is a critical factor in the abort procedures, and the method of abort initiation is completely dependent on it. Because some launch vehicle failures could very rapidly result in a catastrophe, the abort was designed to be automatically initiated. Since some failures would not cause an immediate catastrophe, manual backup was incorporated. The astronaut, blockhouse, mission control center, and range safety could initiate an abort during specifically assigned flight periods, some of which overlapped.

Nominal Mission Profiles

The Mercury-Redstone launch vehicle, whose nominal mission profile is shown in figure 4-5, accelerated the Mercury spacecraft into a suborbital flight at a nominal speed of approximately 6,460 feet per second. At launch-vehicle–spacecraft separation the flight-path angle was 41.80°, the altitude, 200,000 feet, and the Mach number, 6.30. The maximum acceleration at cut-off was 6.3g.

In figure 4-5, several important launch vehicle sequencing points are indicated. A circuit permitting automatic engine cut-off prior to abort was activated 30 seconds after lift-off. Prior to this time, this circuit was disabled because cut-off in the first 30 seconds would have resulted in an impact of the launch vehicle on land which was undesirable; therefore, only the range safety officer could initiate an engine shutdown. To prevent an early jettisoning of the escape tower the normal shutdown circuitry was not armed until 129.5 seconds. At 131 seconds the velocity cut-off accelerometer was armed. This arming occurred 12 seconds before nominal expected engine cut-off time to allow for higher-than-expected launch-vehicle performance for a non-optimum mixture ratio, which could result in premature propellant depletion. The chamber pressure sensors to the automatic abort system were deactivated at 135 seconds, thus preventing an abort signal at the time of cut-off. Both cut-off activation and pressure switch deactivation were originally scheduled to occur at 137.5 seconds, but as a result of the early shutdown of MR–2, the times indicated in the figure were selected for all subsequent flights.

At engine shutdown, nominally at 143 seconds, the abort system was deactivated and the escape tower jettisoned. Spacecraft separation occurred 9.5 seconds after shutdown to allow for thrust tail-off.

Reliability, Testing, and Quality Assurance

As mentioned earlier, the basic launch vehicle had a history of 69 flights prior to the first manned flight upon which to base failure-mode and reliability prediction. Two such predictions were made. The first prediction used the record of all Redstone, Jupiter C, and Mercury–Redstone development and qualification flights. The second prediction used an artificial Redstone configuration composed of individual components flown at different times on previous flights.

To find the weak spots in the total vehicle, large subsystems were submitted to a special reliability test program. All major missile sections and the systems contained in each were vibrated under temperature and humidity conditions simulating the actual environments of transportation, prelaunch, and flight. Bending and compression loads were applied up to 150

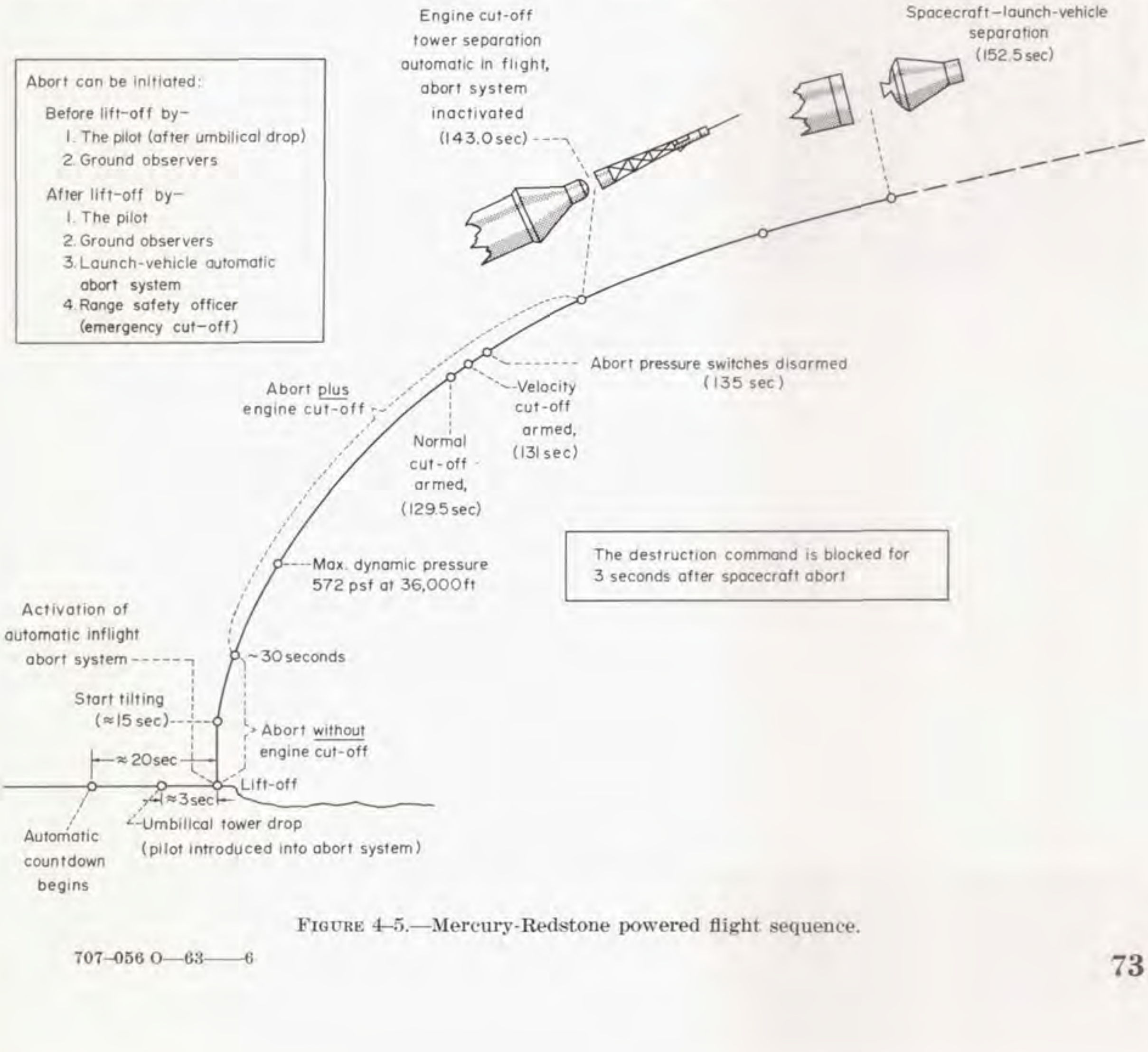

FIGURE 4–5.—Mercury-Redstone powered flight sequence.

percent of maximum flight loads, thereby establishing positive margins of safety. When trouble spots were found, individual component testing was followed up with additional systems tests.

Figure 4–6 shows the vehicle contractor's combined environmental test facility. This facility applied flight vibrations and rigid body motions up to 4g at 2,000 cps simultaneously with temperatures up to 115° F. This testing proved the importance of investigating the interaction of all component masses.

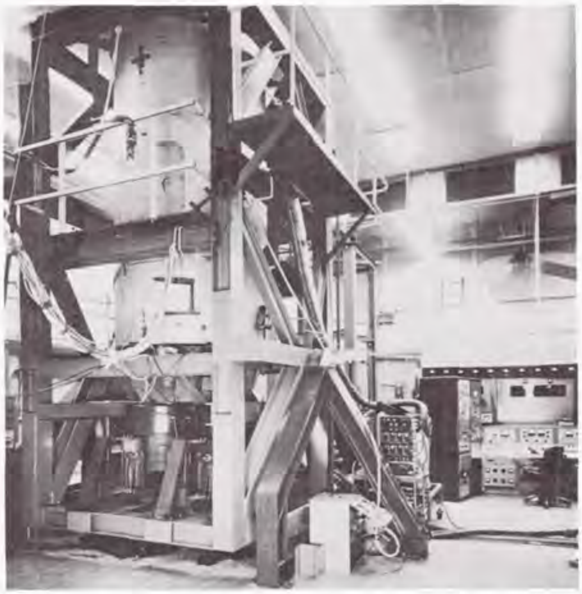

FIGURE 4–6.—The contractor's combined vehicle motion and vibration test stand.

In addition, structural flight simulation, spacecraft–launch-vehicle interface compatibility, clamp-ring operation, and static firing tests were made. Figure 4–7 shows the mating of the spacecraft and launch vehicle prior to a noise and vibration test conducted at the NASA Marshall Space Flight Center (MSFC).

Quality assurance procedures were relatively more refined than for the tactical vehicle because of the stress placed on crew safety. An awareness program required that every Mercury system assembly carry a special Mercury stamp indicating that it had passed special inspections and that all personnel involved in its manufacture and assembly were aware of the quality expected. Particular attention was paid the areas involving soldering techniques, welding repairs, and preparation of instructions.

FIGURE 4–7.—Static firing, noise and vibration test stand.

Changes Resulting From Ground Tests

During the vibration test program, several components failed or were damaged. These components included an engine piping elbow, an H_2O_2 bottle bracket, the abort-rate switch-mounting bracket, wires in the roll-rate switch, and an antenna mounting stud. Similar problems occurred in other components. The success of the modifications proved the value of total system testing.

Since the A–7 engine was new, extensive test firings were made. During these firings, an instability was discovered at 500 cps and eliminated through a modification to the fuel injector. Investigation as to the source of another low-frequency oscillation eventually led to the discovery that the static test tower was at fault. Modification of the static test tower subsequently removed it as a trouble source.

Checkout and Launch Operations

Prior to shipment to the launch site at Cape Canaveral, the Mercury-Redstone abort system was checked by introducing simulated malfunctions and evaluating the abort system responses.

The first three launch vehicles were also carefully tested for compatibility with the spacecraft at MSFC.

At Cape Canaveral, the Mercury-Redstone countdown was conducted in two parts with a rest period in between to reduce fatigue of the launch crew. Lox loading was scheduled for completion at 180 minutes prior to lift-off to minimize the possibility of an additional 12-hour delay for lox tank purging and drying during the recycle time in the event of a launch cancellation after lox loading. The astronaut was to be inserted into the spacecraft after lox loading at approximately 120 minutes prior to lift-off. A period of 4 hours was considered to be a tolerable time between astronaut insertion and lift-off to accommodate possible holds in the countdown.

Emergency Egress and Pad Abort

Special astronaut safety precautions were required after insertion since the launch vehicle was already fueled; therefore, launch pad emergency egress procedures were developed. A study (see fig. 4–8) to determine the best mode to retrieve an incapacitated astronaut indicated the blockhouse-controlled service structure would provide the most expeditious escape. If, however, he were able to exit without help,

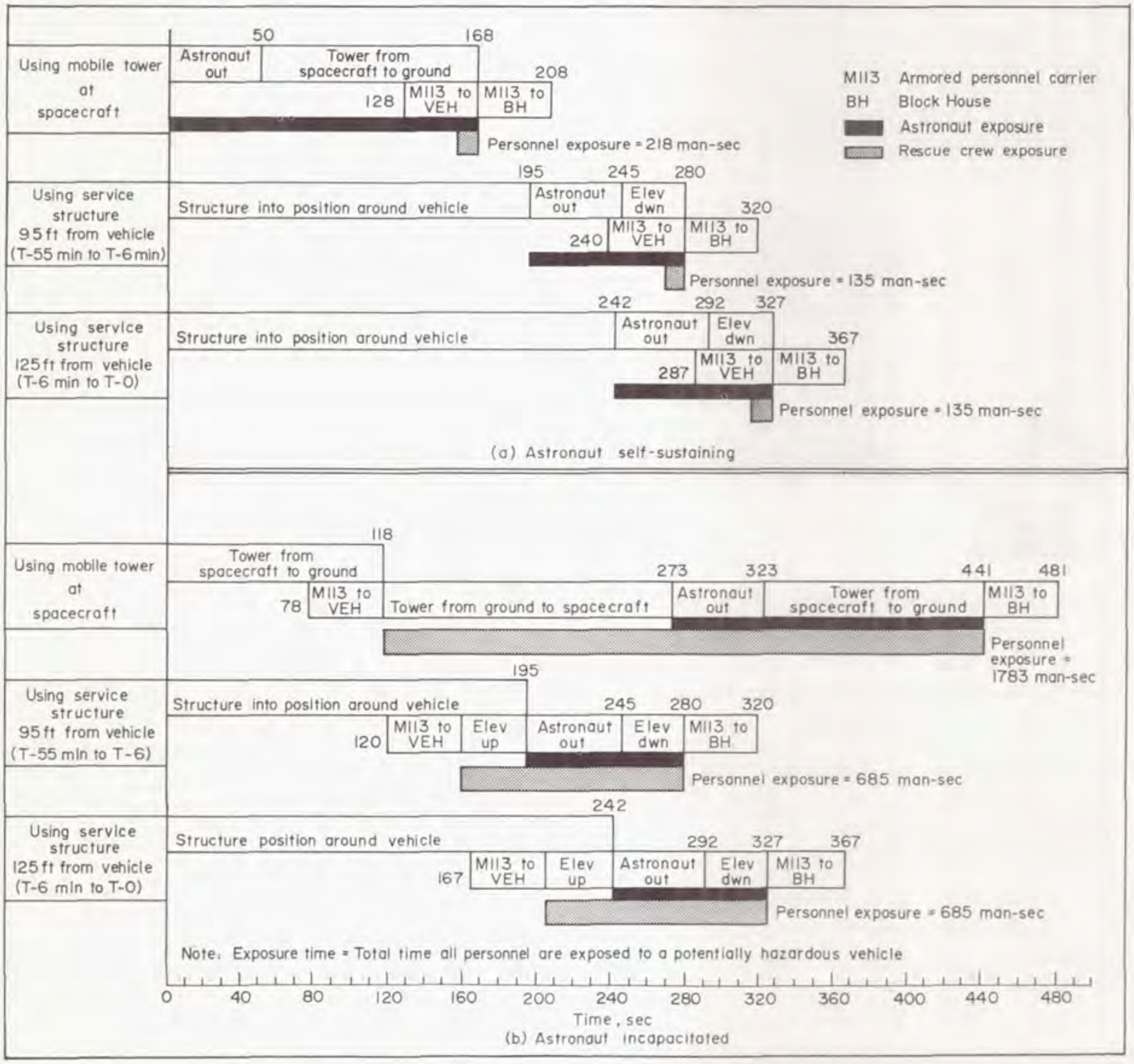

FIGURE 4–8.—Time study of astronaut emergency egress.

he could use the pad escape tower, or "Cherry Picker," shown in figure 4–9. The cab of this specialized escape equipment, which was permanent but extendable, was stationed near the spacecraft hatch until just prior to lift-off. Utilization of this escape device was combined with the use of fire trucks, an armored personnel carrier (M–113), and rescue teams for exit from the pad area. In case of a pad abort, recovery procedures and vehicles, including army helicopters and amphibious craft, were organized and prepared to assist.

FIGURE 4–9.—MR–3 with "Cherry Picker" and remote controlled service structure.

System Modifications Resulting From Flight Operations

Problem areas revealed during the qualification flight-test program (MR–1, MR–2, MR–BD) lead to the following modifications:

(1) The MR–1 launch attempt proved the need for ground-negative until all other electrical connections were separated. Thus, a ground strap was added. This strap is shown in figure 4–10.

(2) A scale-factor error resulting from an excessive pivot torque on the LEV–3 longitudinal integrating accelerometer caused the MR–1A launch vehicle to experience a cut-off velocity exceeding the nominal value by about 260 feet per second. Use of softer wire and the relocation of the electrical leads eliminated the problem.

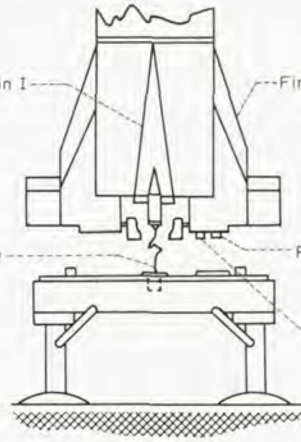

FIGURE 4–10.—Mercury-Redstone ground strap.

(3) As a backup to the integrating accelerometer fix, a time-based cut-off signal was established at 143 sec for the MR–2 and MR–BD (booster development) missions. These later flights proved that the accelerometer functioned properly, and use of the cut-off timer was discontinued.

(4) The thrust controller on MR–2 failed wide open causing lox depletion 0.5 second before deactivation of the abort P_c switches and before integrating accelerometer arming, which could have prevented this trouble. To prevent a similar occurrence on the remaining flights, velocity cut-off arming and P_c abort switch disarm were separated in time. Velocity cut-off arming was advanced to 131 sec to take care of earlier-than-predicted cut-off velocity, while P_c disarming was set at 135 sec, keeping the combustion chamber pressure abort capability as long as possible, but removing this capability early enough to take care of a high propellant consumption rate.

(5) Flights MR–1A, MR–2, and MR–BD experienced momentary roll rates approximately twice that of the earlier Redstone vehicle ($\sim$ 8°/sec as against $\sim$ 4°/sec—abort limits were 12°/sec). Since the missile was not

subject to damage at this rate, the roll-rate abort sensor was deleted after MR–BD to increase mission success. The roll attitude angle abort limit of 10° was retained.

(6) An interaction of the second bending mode with the yaw and pitch axis control required the addition of a network filter to reduce control loop gain between 6 and 10 cps. The interaction was noted on flights MR–1A and MR–2 and is illustrated in figure 4–11.

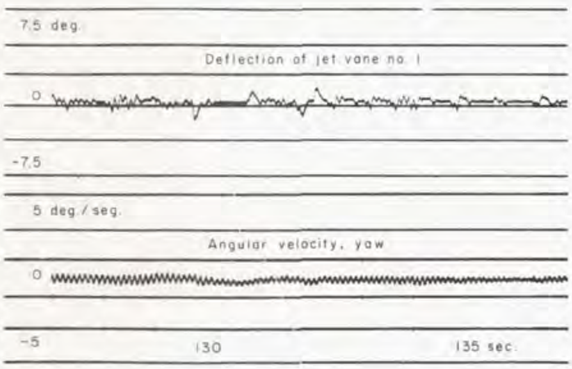

FIGURE 4–11.—Second bending mode oscillations in yaw toward end of MR–1A flight.

(7) During MR–1A, MR–2, and MR–BD, undesirable vibrations in the adapter and instrument compartment were evident. On MR–3 these were dampened with 340 pounds of lead-impregnated plastic compound added to the bulkhead and walls of the section. The weight of this compound was substituted for an equal amount of ballast weight. Fourteen longitudinal stiffeners were also added to the internal skin surface. These improvements are depicted in figure 4–12. Since Astronaut Shepard still noted considerable vibrations during powered flight in MR–3, an additional 102 pounds of the dampening compound, X306, were added to the instrument compartment of MR–4. The summation of these changes resulted in the Mercury-Redstone shown in figure 4–13.

Flight Results

Three qualification flights were conducted for the Mercury-Redstone flight series. MR–1 was launched on November 21, 1960. After rising a few inches, it settled vertically back on the launcher. It proved the need for careful examination of electrical circuitry and led to the addition of a strap for proper electrical grounding.

The sequence of events which led to MR–1's difficulties started during the lift-off when the power and control connectors did not disconnect simultaneously. Because of mechanical adjustments, the power plug disconnected 29 milliseconds prior to the control plug. This permitted part of a 3-amp current, which would have normally returned to ground through the power plug, to pass through the "normal cut-off" relay and its ground diode. The cut-off terminated thrust and jettisoned the escape tower.

The spacecraft did not separate from the launch vehicle because the g-load sensing requirements in the spacecraft were not met. "Normal cut-off" started a 10-second timer which, upon its expiration, was supposed to signal separation if the spacecraft acceleration was less than 0.25g. (This sequencing was designed to minimize the occurrence of a spacecraft launch-vehicle recontact. However, MR–1 had settled on the pad before the timer expired and the g-switch sensing 1g blocked the separation signal.)

The barostats properly sensed that the altitude was less than 10,000 ft and therefore actuated the drogue, main, and reserve parachutes in the proper sequence. The reserve parachute was released because no load was sensed on the main parachute load sensors. To prevent this failure from recurring, engine pressure was monitored and, if normal at 129.5 seconds, the normal booster cut-off signal path to the spacecraft was armed.

Following the MR–1 attempt, the spacecraft was refurbished and mated to a new launch vehicle, scheduled to be launched as MR–1A. The MR–1A space vehicle successfully accomplished the MR–1 mission objectives on December 19, 1960. The launch was slightly compromised by a scale-factor error in the longitudinal integrating accelerometer which caused cut-off velocity to be 260 feet per second higher than normal. This higher velocity caused the spacecraft to experience somewhat higher reentry deceleration. During the flight, all measured abort parameters remained below the limits and the abort system functioned as expected.

MR–2, launched January 31, 1961, carried a chimpanzee named "Ham." On this flight, the

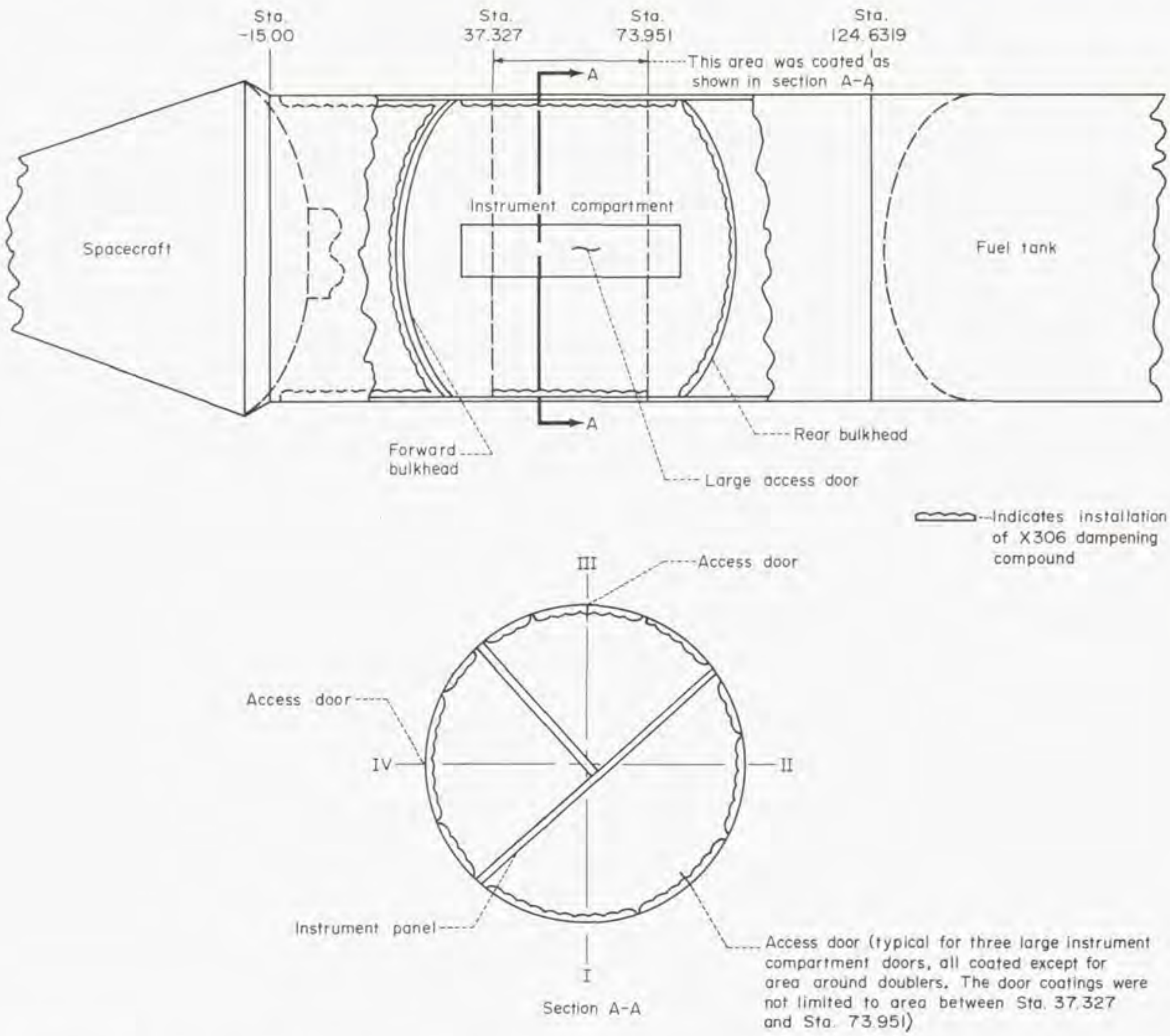

FIGURE 4-12.—Installation of dampening compound in instrument compartment and adapter section for Mercury-Redstone 4 (MR-4).

thrust controller ran above nominal resulting in propellant depletion 0.5 second before abort pressure sensor deactivation. The abort system was able to sense this early shutdown and aborted the spacecraft. The above normal cut-off velocity, combined with the thrust of the escape motor caused the spacecraft to land well beyond the intended recovery area. The simple timing changes explained previously were made to take care of higher propulsion system tolerances.

MR-BD was launched on March 24, 1961, to evaluate a filter network added in the launch vehicle control circuit and modifications incorporated to eliminate the overspeed condition experienced on MR-1A and MR-2. The filter network was intended to dampen the effect of the second bending mode frequency (6 to 10 cps) on the pitch and yaw loop. The flight went exactly as expected and proved the effectiveness of this change.

MR-3 was the first manned flight. With Astronaut Alan Shepard as the pilot, the spacecraft lifted off at 9:34 a.m. e.s.t. on May 5, 1961. All objectives assigned to the launch vehicle were successfully accomplished and no system malfunction occurred. During powered flight,

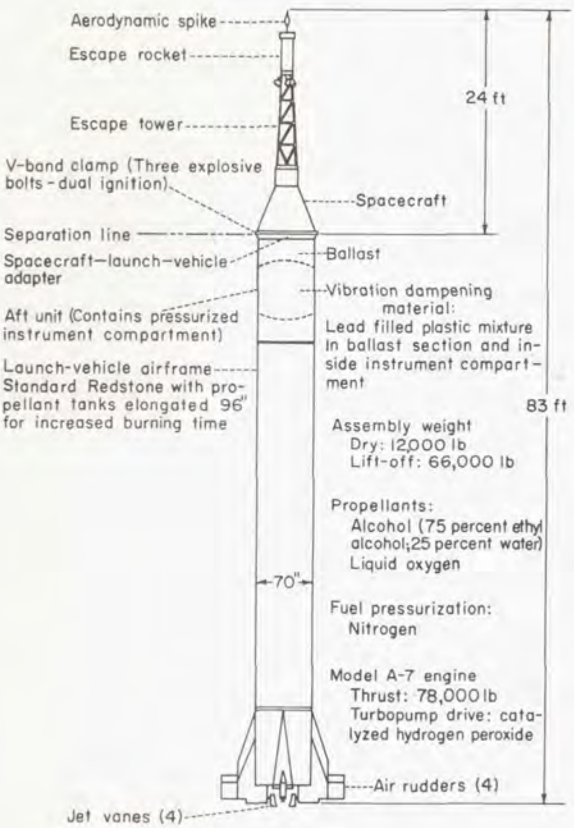

FIGURE 4-13.—Mercury-Redstone configuration.

the astronaut reported buffeting. However, telemetry data indicated lower vibrations than on earlier flights. To reduce these vibrations, additional dampening material was added to the instrument compartment prior to the remaining flight.

Concluding the Mercury-Redstone program was MR-4 carrying Astronaut Virgil I. Grissom in the second manned suborbital space flight. Again, all launch-vehicle systems worked properly and all objectives were achieved. Improved vibration reports indicated that the additional dampening material added to the instrument compartment proved effective.

The Mercury-Redstone flight program was concluded on a positive note with the successful MR-4 mission on July 21, 1961. The first manned flight into space had been accomplished by MR-3 in just over 2½ years from the project's initiation. The initial objectives of providing space flight familiarization and training for astronauts had been accomplished. The spacecraft was exposed briefly to space flight conditions. Of equal importance was the invaluable training of the ground crew in the preparation, launching, and the recovery of a manned spacecraft.

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5. MERCURY-ATLAS LAUNCH-VEHICLE DEVELOPMENT AND PERFORMANCE

By Lt. Colonel C. L. Gandy, Jr., *Space Systems Division, U.S. Air Force;* and Major I. B. Hanson, *Space Systems Division, U.S. Air Force*

Summary

In this paper the overall Atlas launch-vehicle program in support of Project Mercury is discussed. The paper includes the areas of both management and operations. Implications to be drawn from the presentation are that sound planning by experienced Air Force personnel early in the program; strong top-level management support; great attention to engineering, manufacturing, and operational detail; and strong individual motivation have been responsible for the success of this portion of Project Mercury. The procedures used in the launch-vehicle program were not conceived or promulgated by any one individual overnight. Rather, they grew from the experience of many and were further shaped by the program itself as it progressed.

Introduction

This paper presents the management aspects of the launch-vehicle system in redirecting a ballistic-missile weapon system into a launch-vehicle system for manned space research. Early agreements between the U.S. Air Force and the National Aeronautics and Space Administration (NASA) established the program responsibilities and identified the management interfaces. Specific guidelines were laid down by the Air Force Chief of Staff to provide effective support to NASA within the military framework of what was then known as the Air Force Ballistic Missile Division. Definitive policies were established to insure maximum launch-vehicle safety for the pilots. The initial overall Mercury systems engineering as it affected the launch vehicle was performed by U.S. Air Force/NASA technical panels and then gradually shifted to the Air Force and its technical contractor, Space Technology Laboratories, and more recently the Aerospace Corporation, for more specific systems engineering.

The basic Atlas "D" system as it existed at the beginning of the program is described to provide a basis for the explanation of the launch-vehicle modifications that were required to support the mission. A brief description is given of the problems that were associated with the individual launch-vehicle flights and the results of the postflight evaluations. A more detailed postflight evaluation is given of the MA-9 flight.

Program Management

During the mid-1950's, the U.S. Air Force conducted a number of studies dealing with manned space flight. Many plans had been formulated and several of the programs had reached a detailed development plan state when, in August 1958, the President directed the assignment of the man-in-space effort to the National Aeronautics and Space Administration. On October 7, 1958, the Space Task Group was organized at Langley Field, Virginia, to manage the then established and later named, Project Mercury.

During the period from October 1958 until April 1959, a series of meetings took place between NASA and the Air Force Ballistic Missile Division to define the AFBMD support required by the NASA-Space Task Group. The problems considered included: definition of the scope of NASA's effort, definition of launch-vehicle requirements, definition of procurement procedures, launch schedules, and launch facilities. It is interesting to note that at the time of the first NASA visit to AFBMD on October 23, 1958, the proposed program envisioned over 25 flights using the Redstone, Thor or Jupiter, and Atlas launch vehicles. Spacecraft orbital weight was to be approximately 2,100 pounds for a 120 nautical-mile orbit. Additional meetings culminated in the issuance to AFBMD of NASA Order HS–24 on November 23, 1958, which specifically requested that the Air Force supply one "C" series Atlas to support Project Mercury. The order specified that this was the initial request of a proposed program which would require approximately 13 boosters of the Atlas and Thor class. On December 8, 1958, AFBMD received NASA Order HS–36 which requested nine "D" series Atlas boosters. Subsequent amendments to HS–36 deleted HS–24, changing the total requirements to 10 Atlas "D" vehicles, later to 14 "D's," eliminating the Thors. Further discussions between the two agencies resulted in the agreement that the Air Force would have full responsibility for the development, procurement, production and launch of the Atlas vehicles for Project Mercury (see fig. 5–1). The final meeting of this series was held between General Schriever, then Commander AFBMD, and Dr. Glennan, Administrator of NASA, on April 7, 1959, in Washington. The basic memorandum of understanding between NASA and the USAF grew from this conference.

A program office was established within the AFBMD to manage the launch vehicle effort, and the services of the Space Technology Laboratories (STL) were requested within the framework of the Atlas weapons system program to support Mercury. Specific guidelines were laid down by the Commander of AFBMD in order that maximum responsiveness to NASA requirements could be assured.

The early systems engineering was accomplished within the framework of technical panels established by NASA. Participants in the panel work were drawn from various NASA organizations, McDonnell, AFBMD, STL and the Atlas manufacturer, General Dynamics/Astronautics. Once the initial problem areas had been defined, technical panels were subdivided into working groups with specific technical areas assigned to assure that thorough treatment was given to all engineering problems. Through the medium of the technical panels, basic trajectory conditions were developed. The launch-escape system concept was born and specific requirements were developed. Reliability goals were established, and systems restraints were imposed. In order to implement, in detail, the general systems approach developed through the technical panels, the Air Force called upon STL to perform these tasks. It was necessary to institute a special systems engineering and technical direction effort for the Mercury/Atlas program, and the STL Mercury Project Office was established in the Fall of 1959 under the direction of Mr. B. A. Hohmann. In the summer of 1960, when the Aerospace Corporation was organized, the task was transferred to this new organization. The majority of the STL Mercury office personnel transferred to Aerospace continued to perform their original jobs. The basic responsibilities of the systems engineering and technical direction group were to develop the technical requirements, monitor the systems and launch-vehicle development, provide trajectory calculations and guidance equations, analyze both ground and flight-test results, assure production acceptability of the launch vehicle, assist in administering the pilot safety program, and provide systems integration of the Atlas associate contractor's systems.

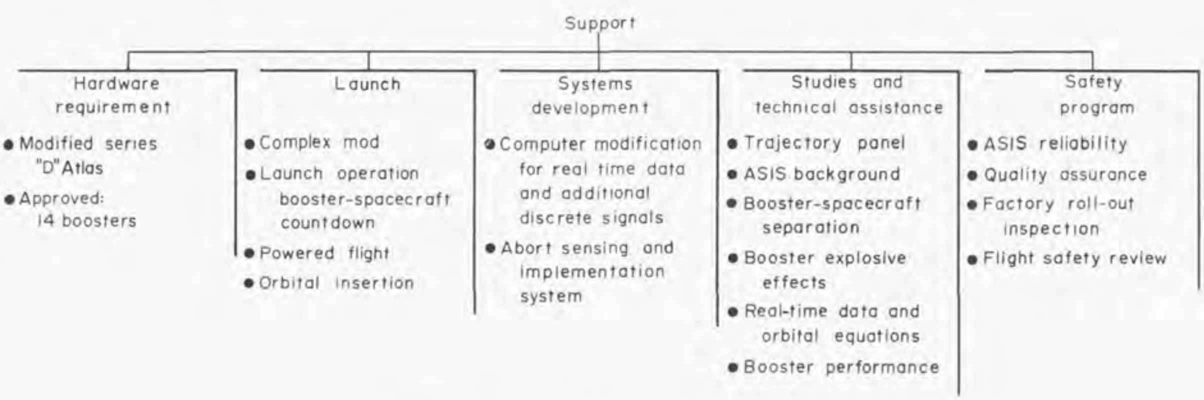

FIGURE 5–1.—Space Systems Division support.

The Space Systems Division and the Aerospace Corporation program offices together were the focal point for detailed management of the launch vehicle program. Program requirements reached this level along a formal path (see fig. 5–2) established from Headquarters NASA to Headquarters USAF, to the Air Force Systems Command (AFSC), to Space Systems Division (SSD), to the Deputy for Launch Vehicles (SSV) to the program offices. A shorter and less formal but equally binding path existed from Manned Spacecraft Center directly to the program offices. Direction received along either path was translated by the program office personnel into action items and routed to the proper agency for accomplishment. Contractual direction and configuration management were controlled by the SSD Program Office originally through the Atlas Weapons System Program Office and later through the SSD Standard Launch Vehicle III (SLV III) Office. Subsystem offices within SSD were responsive to the Mercury launch vehicle program office in the areas of guidance and propulsion systems. Technical direction was handled informally by direct contact between the Aerospace program office and the contractors and formally through the SSD program office.

The Atlas associate-contractor team consisted of General Dynamics/Astronautics (GD/A) who furnished the Atlas airframe and basic vehicle, Rocketdyne Division of North American Aviation (R/D) who furnished the propulsion system, General Electric (GE) who provided both the airborne and ground portions of the guidance system, and Burroughs Corporation who provided the A–1 Computer for inflight guidance in conjunction with the GE system. GD/A performed the launches at the Atlantic Missile Range (AMR) under the supervision of the 6555th Aerospace Test Wing, and the other contractors provided appropriate launch services. Other valuable members of the Atlas team were the Air Force's Western and Eastern Contract Management Regions whose personnel insured the contractors' compliance with contract provisions and performed quality control and technical inspection functions.

Early in the Mercury program, Major General O. J. Ritland, as Commander of BMD recognized that a safety program should be instituted to protect the Mercury pilot. Accordingly, he directed that studies be conducted to determine what efforts were required to insure

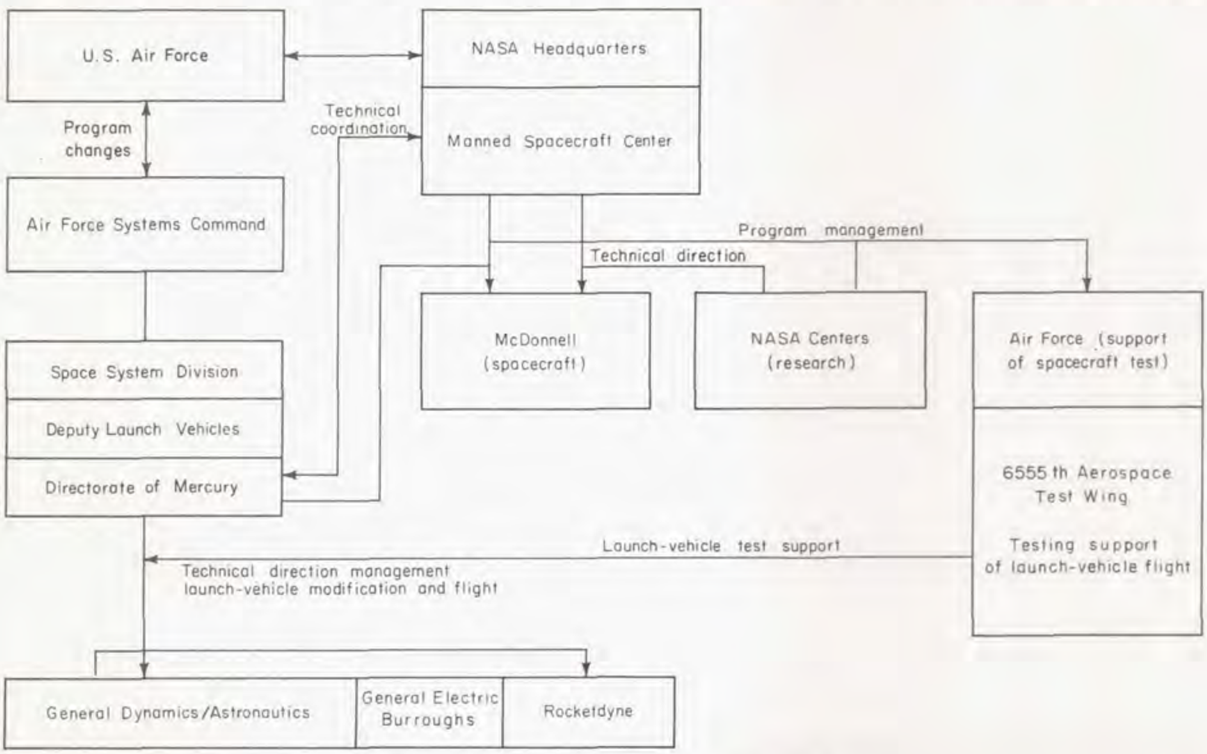

FIGURE 5–2.—Management responsibilities.

safe powered flight and to assure the program management that the launch vehicle was indeed ready for manned flight. This study resulted in the Pilot Safety Program for Mercury-Atlas launch vehicles (see fig. 5-3), a program which has dominated the management of the launch-vehicle portion of Project Mercury.

The basic objectives of the program have been to assure design reliability and adequate pilot safety. Recognizing that the Atlas had been designed as a weapons system and had not been required to meet the reliability expected of a manned system, program personnel established these objectives. The first was to be met through quality of production and end-product excellence. The quality of production would be assured through education and motivation of all personnel associated with manufacture of the hardware, through special component selection and marking procedures, and through special handling techniques. End-product excellence could be assured by requiring that no shortages would be tolerated at the time of launch-vehicle acceptance, and that the vehicle must be complete and up to date with no provisions for field modifications. This assurance would be gained by means of a detailed and highly critical factory roll-out inspection. The inspection would be conducted by experienced and well qualified personnel from both the Aerospace and SSD program offices. NASA observation was invited.

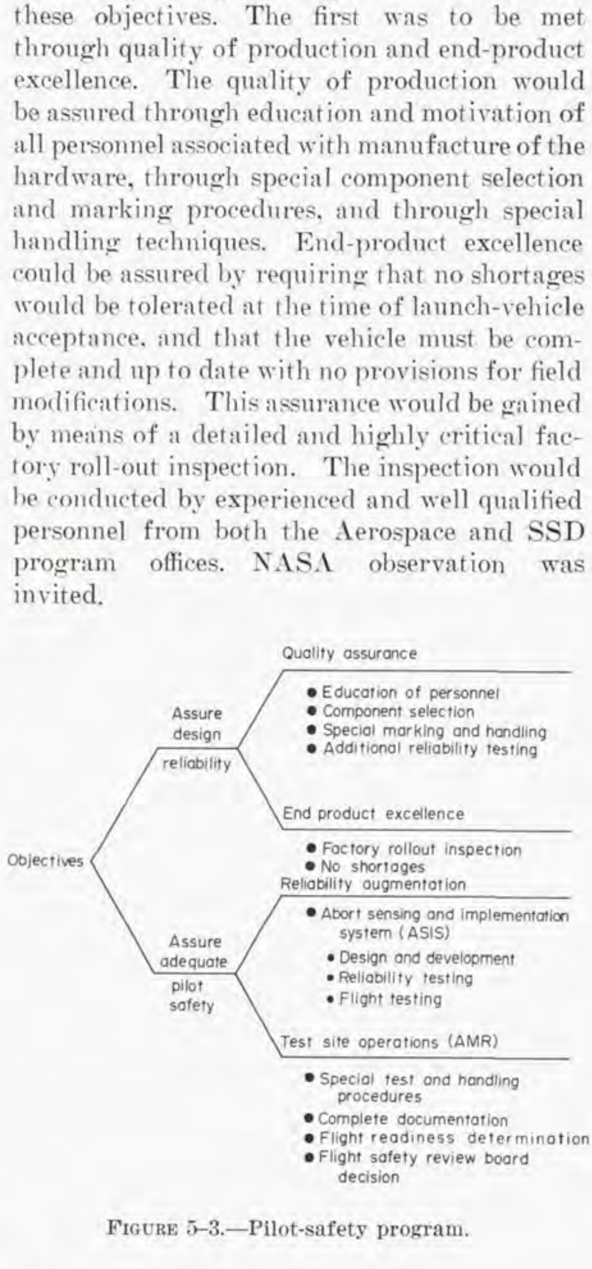

FIGURE 5-3.—Pilot-safety program.

The second objective of assuring adequate safety would be met by providing reliability augmentation and by special test-site operations. The abort sensing and implementation system (ASIS) was designed to bridge the gap between the existing reliability of the launch-vehicle and the near perfection required of a manned system. The ASIS was an automatic system designed to sense an impending catastrophic failure and initiate spacecraft escape prior to the failure. The ASIS itself had to be an extremely reliable system. This reliability was obtained first through a design based upon redundant sensors and circuitry. Then rigid design reviews, stringent ground testing, and finally flight testing were conducted for the system.

The special test-site operations started with unique Mercury handling procedures for the launch vehicle and a requirement that complete documentation be maintained on all prelaunch operations. The documentation, in turn, led to assurance that the vehicle was indeed flight ready upon completion of the required prelaunch testing. The flight readiness was certified by the Mercury–Atlas Flight Safety Review Board. This board was established as a high-level Air Force and Aerospace board chaired for all manned flights by the Commander, SSD.

Basic Atlas Description

At the time of the original NASA order for Mercury–Atlas launch vehicles in the fall of 1958, the U.S. Air Force development flight test program was principally concerned with the Atlas "C" model. The "D" model (see fig. 5-4) which was scheduled to begin testing in 1959, was considered the operational system and was therefore selected as the most suitable for use as the Mercury launch vehicle. The following paragraphs give a general description of the basic Atlas "D" vehicle from which the launch vehicle for the Mercury spacecraft was developed.

The Atlas launch vehicle comprises of two main sections, the body or sustainer section and the aft or booster-engine section. The booster-engine section is connected to the sustainer thrust ring by a mechanical system which permits separation. The Atlas is considered a 1½-stage missile in that only the boost engines and associated hardware are jettisoned at the completion of the first stage of firing.

The sustainer section is made up of a thin wall, fully monocoque structure pressure vessel and derives its rigidity from internal pressurization. The sustainer body is a welded structure of corrosion-resistant stainless-steel sheets varying in thickness from 0.048 inch to 0.015 inch. The tank is approximately 50 feet in length. The forward end consists of a thin dome on which the liquid oxygen boil-off valve is mounted. The base of the dome is joined to the first skin of a conical section whose upper diameter is approximately 70 inches. The conical section joins a cylindrical section 10 feet in diameter. The lower end of the tank is conical, tapering to a point. A hemispherical diaphragm called the intermediate bulkhead divides the tank into a forward section for liquid oxygen and an aft section for RP–1 fuel. A thrust ring joins the conical aft section to the cylindrical portion of the tank. Annular baffles in the tanks serve to dampen propellant sloshing. The sustainer engine with its associated equipment and subsystems is gimbal-mounted to the sustainer thrust cone which is the aft end of the fuel tank. Vernier engine thrust chambers are gimbal-mounted on opposite sides of the structure at the extreme aft end of the cylindrical portion of the tank. Equipment pods containing electronic and electrical units are attached to the tank skin 90° around the tank from the verniers.

The aft section or booster-engine section consists of two booster engines, structure, and associated equipment. It is attached to the thrust ring at the aft end of the tank section by a mechanism which releases it for separation. The motion of this section is controlled during separation by jettison tracks. A radiation shield protects the aft section from the heat radiated from the engine exhaust.

The propulsion system consists of a Rocketdyne MA–2 rocket-engine group made up of two main assemblies: the booster section (see fig. 5–5) consisting of two booster engines having 154,000 pounds of thrust each and the sustainer-vernier group (see fig. 5–6) consisting of

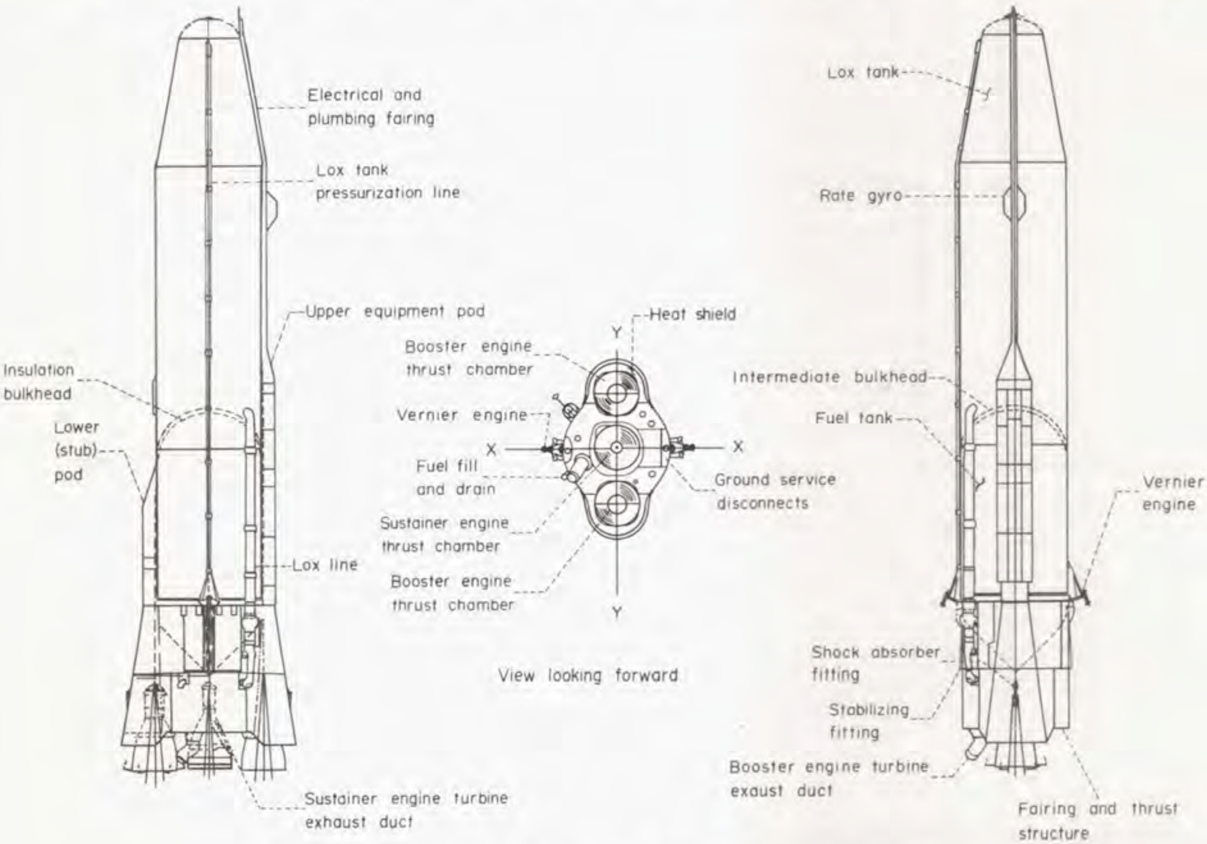

FIGURE 5–4.—Three-view drawing of basic Atlas configuration.

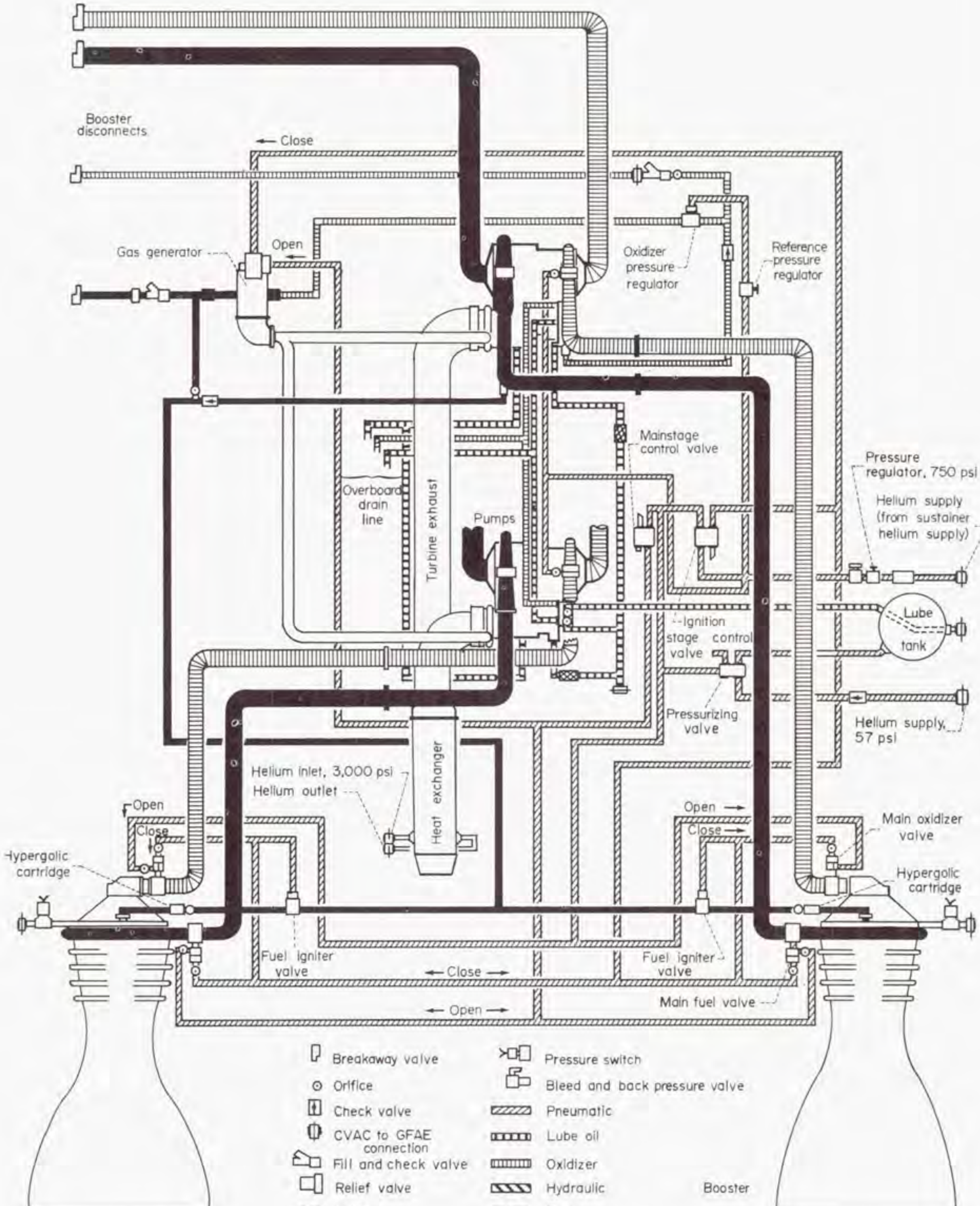

FIGURE 5-5.—Propulsion system for booster engines.

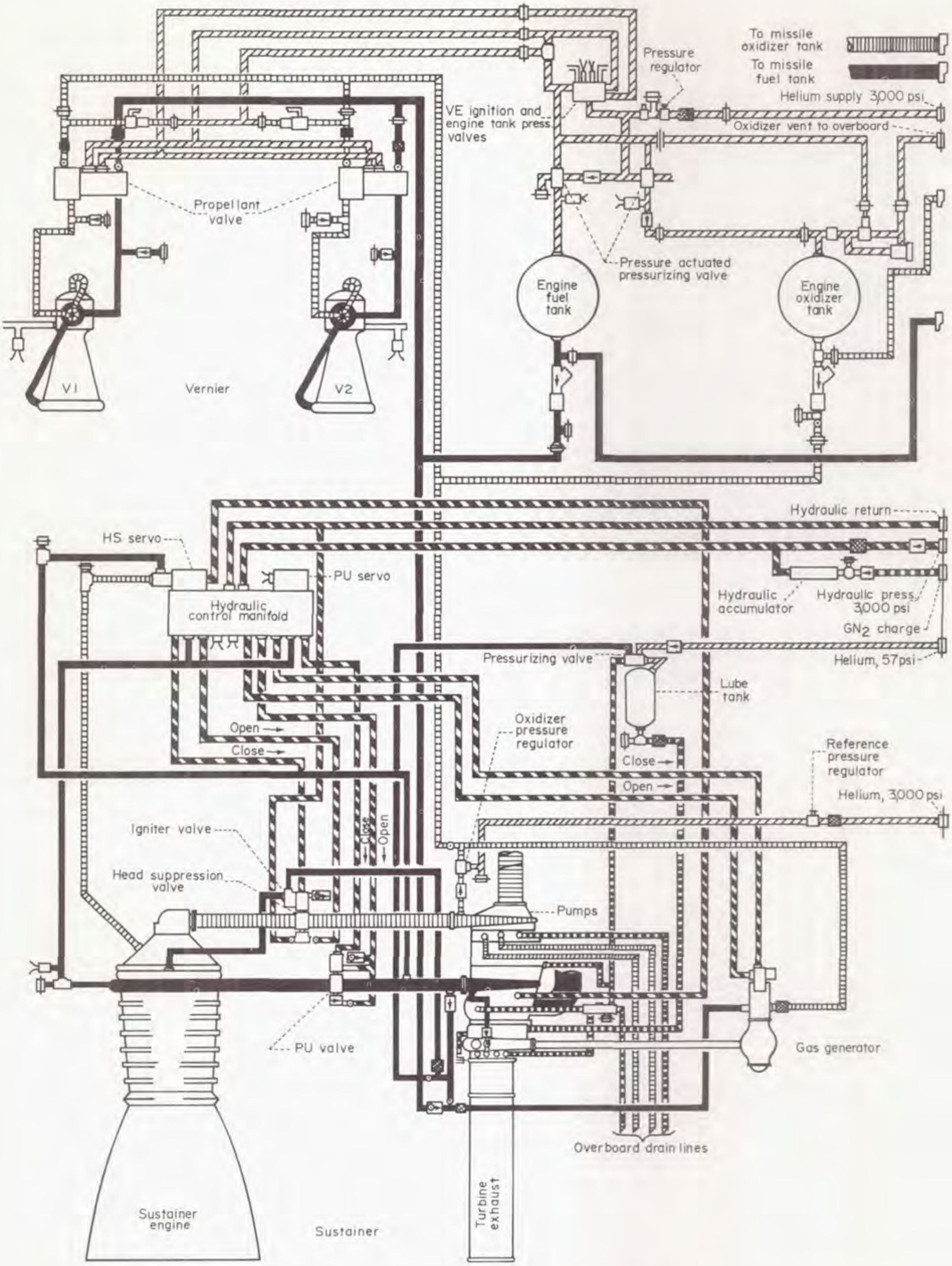

FIGURE 5-6.—Propulsion system for sustainer engines.

one sustainer engine having 57,000 pounds of thrust and two vernier engines having 1,000 pounds of thrust each. All are single-start, fixed-thrust rocket engines utilizing liquid oxygen and a liquid hydrocarbon fuel (RP–1) as propellants.

The booster engine is composed of two identical thrust chambers and a power package. Two dual turbopumps in the power package deliver the propellants under high pressure to the thrust chamber. The turbopumps are driven by high-speed turbines, energized by high-velocity gas supplied by a single gas generator. The power package also includes the hydraulic pump used for lubrication of the turbopump gears. The booster gas generator consists of a spherical combustion chamber and an exhaust manifold. After start, liquid oxygen and fuel are supplied to the combustion chamber under pressures developed by the turbopump. The combustion gases are routed to the turbopump turbine wheels by the exhaust manifold after which the gases pass through the heat exchanger to heat and expand helium for vehicle-system pressurization and then are vented overboard. High-pressure propellants exiting from the turbopumps are routed through valves which control the flow of propellants to the fuel manifold and oxidizer dome. The two thrust chambers are bell shaped and made up of tubes running lengthwise from the top of the chamber to the bottom of the skirt. Fuel is routed through these tubes to cool the chamber walls. A pyrotechnic igniter initiates combustion of the fuel-oxidizer mixture. Thrust loads are transmitted to the missile through gimbal mounts on each chamber allowing the chambers to be swiveled a maximum of 5° in pitch and yaw about the vehicle centerline.

The sustainer engine is gimbal mounted to the thrust cone of the fuel tank. The assembly is similar to that of the booster engines. The sustainer engine dual turbopump supplies propellants to the vernier engine in addition to the sustainer engine. The sustainer engine fuel-lox mixture is continuously controlled during flight by the Propellant Utilization Subsystem (PU) in order to maintain optimum mass ratio of the propellants and thus reduce unusable residuals to a minimum. The sustainer engine gimballing is controlled in pitch and yaw within an arc of ±3°. The sustainer engine is used for steering only after the booster engines have been shut down. The sustainer is operated throughout the flight and is at full thrust at lift-off.

The vernier engines are installed on the aft airframe in two separate units. Propellants for starting the vernier engines are provided by pressurized start tanks and are supplied by the sustainer turbopump for the remainder of the flight. The thrust chamber is double walled and also contains fuel for cooling of the thrust chamber walls. The vernier engines provide roll control throughout flight; pitch and yaw control during staging; and pitch, roll, and yaw during the vernier solo phase during flights in which this phase of operation is utilized. Mercury-Atlas vehicles do not have a vernier solo period. The chamber can be moved through an arc of approximately 140° in pitch and 50° in yaw.

The automatic start sequence of the rocket engines is accomplished by initiating propellant flows into the thrust chambers, the firing of igniters, and the burning through of igniter detector links. These must be accomplished in the proper sequence and total time, or automatic shutdown of the engine will occur.

A propellant utilization system shown in figure 5–7 is used to effect emptying of the propellant tanks as nearly simultaneously as possible. This subsystem continuously senses the mass of the propellants remaining in the tanks and computes the error resulting from a comparison of the mass ratio of the remaining propellants with a nominal mixture ratio. This error signal then adjusts the rate of fuel flow by repositioning the sustainer-engine fuel-control valve to allow the burning of more or less fuel in order that the required mass ratio can be maintained. This assembly is made up of two manometers, each enclosing a mandrel coated with a dielectric material, and a computer-comparator. The unit senses the propellant masses by functioning as a variable capacitor by area contact with a column of mercury balanced against the liquid-propellant head in each tank. The mandrels are shaped in such a way that the capacitance is analogous to the mass of propellant remaining in each tank.

The airborne pneumatic system provides the structural rigidity for the main propellant tanks and also provides the necessary head to

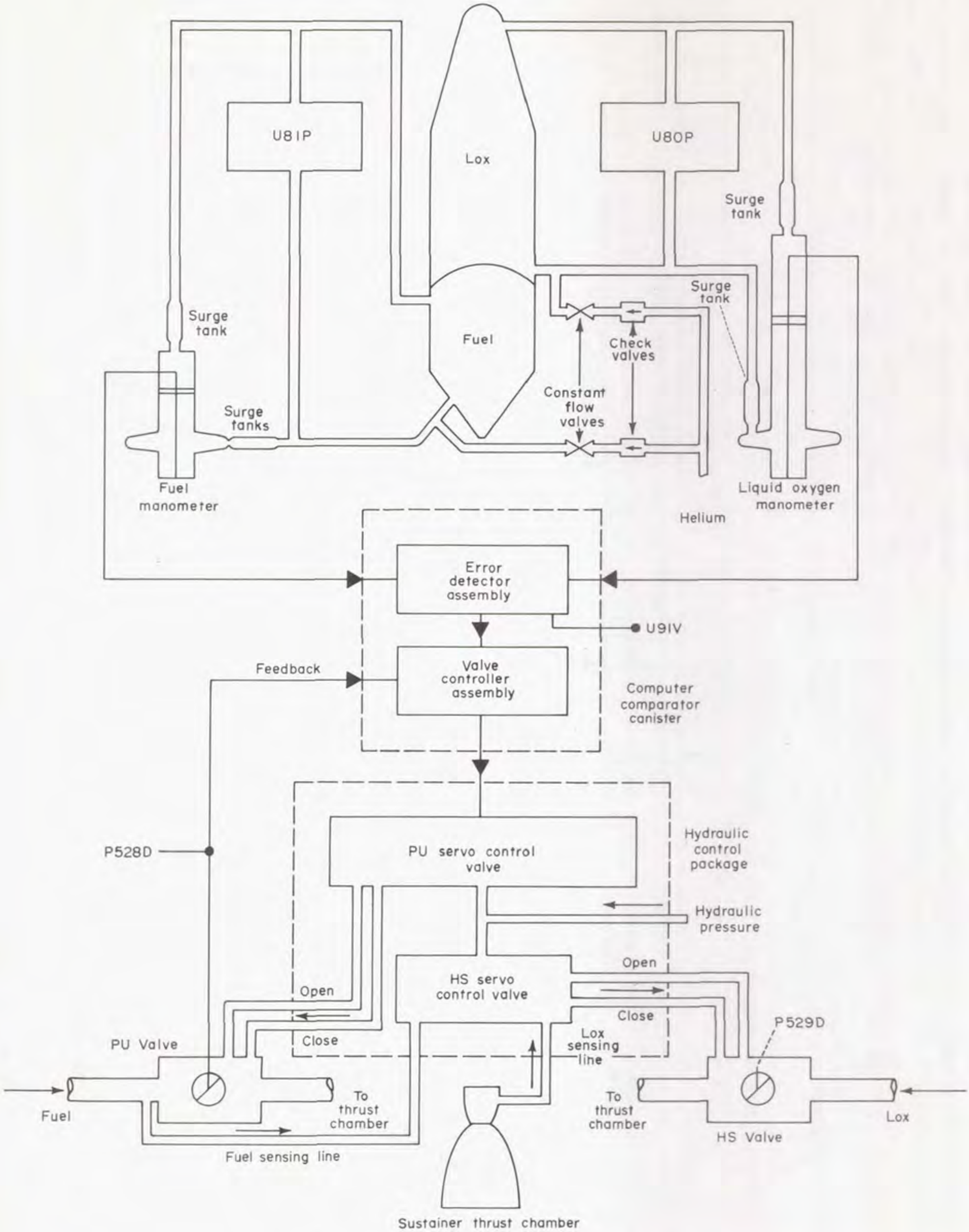

FIGURE 5-7.—Propellant utilization system.

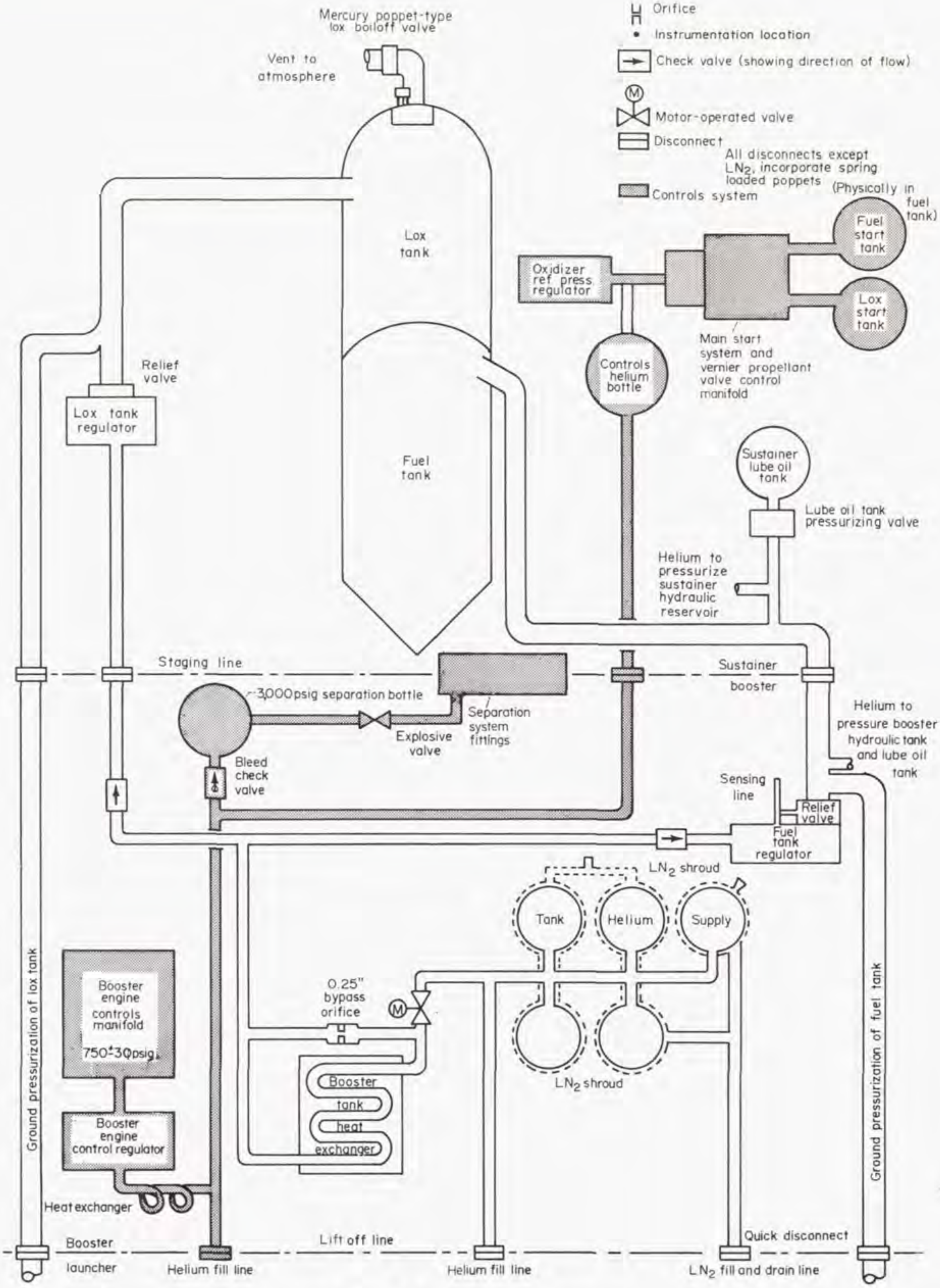

FIGURE 5–8.—Pneumatic system.

prevent the turbopumps from cavitating at low acceleration levels. This pneumatic system, presented schematically in figure 5–8, is used throughout the missile for control, reservoirs, lubricant tanks and the pressurization of the vernier engine propellant tanks. The pneumatic system also provides the actuation force for the first stage separation latches. The pressurization medium is helium, and liquid nitrogen is used to refrigerate the vehicle borne helium supply during the prelaunch phase of the countdown. Five spherical titanium storage vessels are used for the primary supply and are jettisioned with the booster section at staging. The control helium bottle is retained with the sustainer section and provides control pressure for the sustainer section. Tank pressurization is maintained by helium throughout booster-engine operation only. After first stage separation, no helium is required since oxidizer vaporization will keep the pressure in the oxidizer tank above the allowable minimum limits, and main fuel-tank pressure decay will not reduce this pressure beyond the minimum of allowable limits throughout the remainder of the flight. A liquid-oxygen tank boil-off valve is used to maintain proper cryogenic conditions of lox during tanking and holds.

The electrical subsystem (see fig. 5–9) is composed of a 28 v d-c main missile battery and a 115 v d-c three-phase 400 cps inverter. Battery power is provided to the inverter, propulsion subsystem, flight control subsystem, propellant utilization system and abort sensing and implementation system (ASIS). A power changeover switch is used to transfer both a-c and d-c

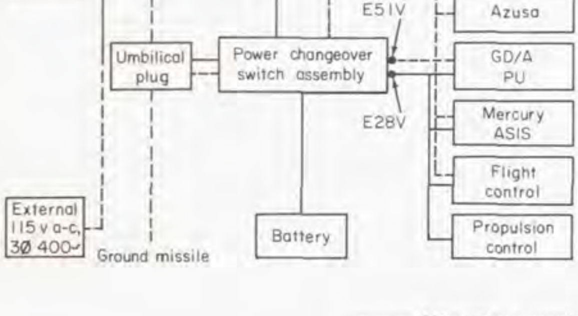

FIGURE 5–9.—Electrical system.

power from external to internal. The position of this switch is manually selected in the launch control blockhouse. The main battery is a remotely activated unit consisting of 20 silver zinc cells connected in series and housed in a sealed canister. The inverter is a rotary-type inverter using a magnetic amplifier voltage and frequency regulator and associated noise filters. The inverter is three phase-WYE connected.

The flight control subsystem consists of a flight programer, an autopilot, and 10 gimbaled thrust-chamber actuator assemblies. The subsystem stabilizes and steers the vehicle along the desired flight path by controlling the direction of the engine thrust vectors. Steering commands are generated on the onboard flight programer during the boost phase. Shortly after first-stage separation, the airborne portion of the guidance subsystem is enabled to provide steering commands to the autopilot for the remainder of the sustainer phase. The autopilot (see fig. 5–10) consists of a gyro package, a servo amplifier package, a programer, an excitation transformer, and engine-position feed-back transducers. On the standard Atlas "D", the main gyro package is located at station 991 and contains three rate gyros, three displacement gyros, and associated electronic equipment. The programer is a transistorized electrical timing device which controls the various flight sequential functions such as roll and pitch programs, staging filter changes, guidance enable, and so forth throughout the entire flight. The programer has two major sequences, the first of which is initiated at 2-inch motion of the missile and the second at receipt of the staging command from the ground-based portion of the guidance subsystem. The servo-amplifier package provides the integrating circuits and includes the necessary filters to insure proper flight attitudes and rates.

The guidance subsystem (see fig. 5–11) consists of the ground-based General Electric Mod III–A X-band radar system, the Burroughs A–1 computer system, and the airborne General Electric Mod III–A guidance group. The Mod III system consists of a position-tracking radar subsystem which determines the position vector of the missile with respect to the guidance station, plus a rate subsystem, which by Doppler techniques measures the missile velocity. In addition, the tracking radar serves as a data

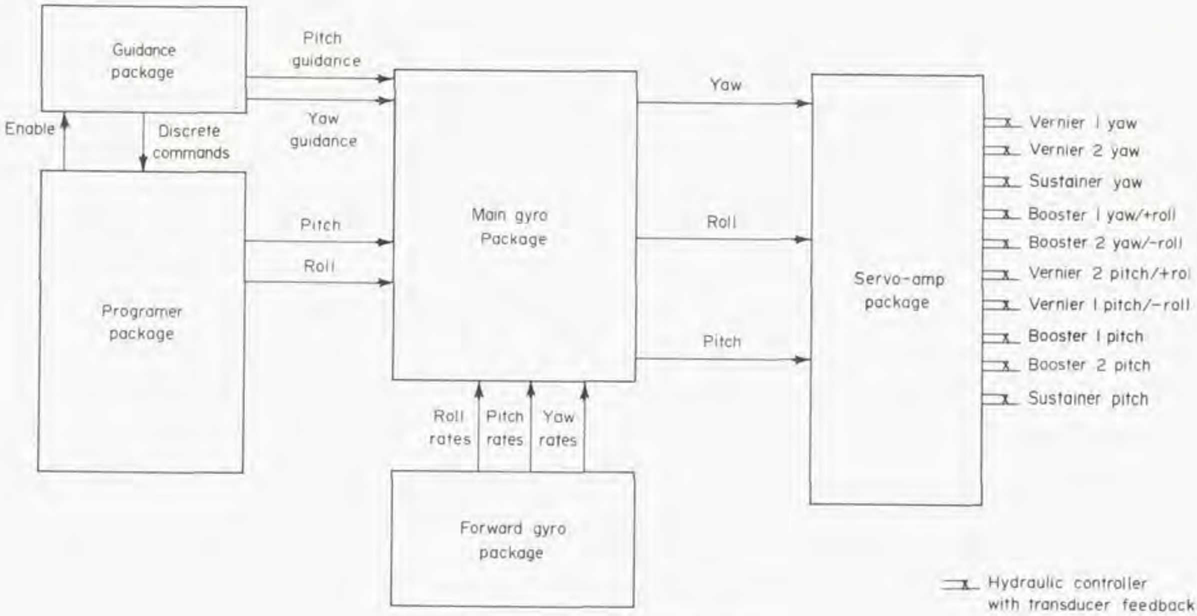

FIGURE 5-10.—Flight control system.

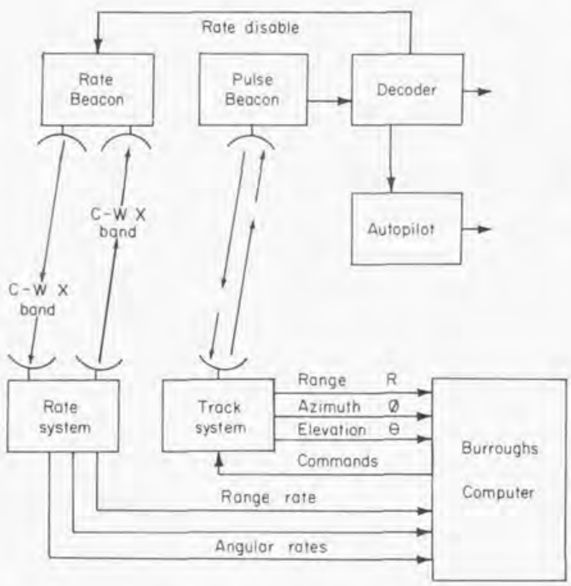

FIGURE 5-11.—Guidance system, MOD III.

link to provide operational commands to the missile-borne equipment. Position and rate data from the radar are transmitted to the Burroughs A-1 computer for processing in accordance with the guidance equations. The computer generates corrective commands which are then fed back into the radar to be transmitted as steering signals to the launch vehicle.

Although weapon-system Atlas vehicles do not require telemetry transmission, research and development vehicles have such a requirement. Two telemetry subsystems were used on Mercury flights. The standard subsystem was used on flights through MA-4 (Atlas 88D). Subsequent flights utilized a lightweight telemetry subsystem (see fig. 5-12) which will be described in the next section.

Two additional systems are installed for the use of range safety personnel. The first is the range safety command system which receives, decodes, and activates the arming, engine shutdown, and destruct functions. The other system is the Azusa radio tracking system which monitors launch vehicle space position and velocity. The Azusa system data are sent to the Atlantic Missile Range IBM 7090 computer which continuously predicts the instantaneous impact point (IIP) of the launch vehicle.

Atlas Modifications For Mercury

The Atlas "D" vehicle had been chosen for the task of launching Mercury on the basis of its being the most reliable launch vehicle available with the requisite performance during the time period of the program. It was not possible to start at that point to design a "man-

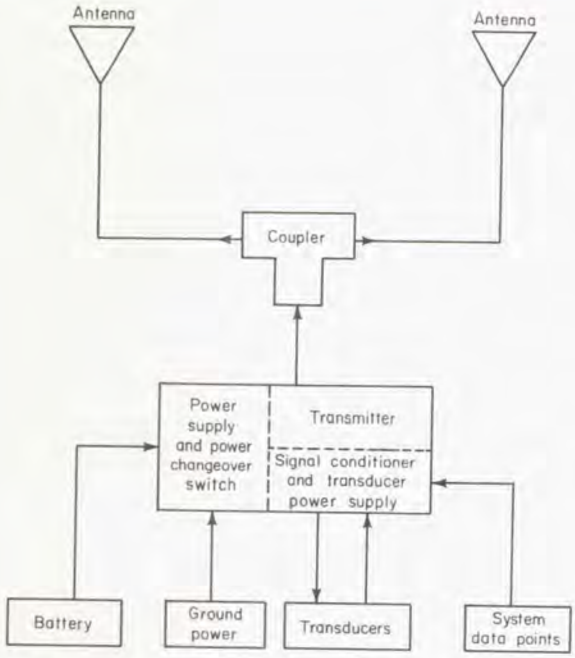

FIGURE 5-12.—Lightweight telemetry system.

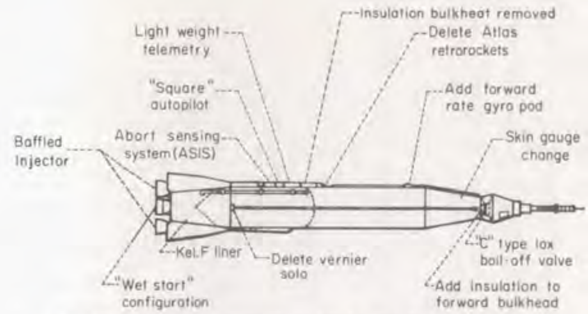

FIGURE 5-13.—Launch-vehicle modifications for Mercury.

rated" vehicle to perform the Mercury flights without several years' delay to the program. Therefore, to capitalize on the reliability inherent in the basic design of the vehicle which had been demonstrated in Atlas development flight tests, a ground rule of the booster program was to make a minimum number of changes to the launch vehicle. Only those changes necessary to adapt the vehicle to the requirements of the Mercury mission or those required to improve the safety of the vehicle for manned flight would be authorized. As with any development program, flight-test experience established the need for incorporation of additional modifications with the major purpose being the enhancement of reliability and pilot safety. It should be recognized, however, that an extremely conservative approach was taken with regard to such changes. Modifications required extensive ground testing, and no critical modification to be used in a manned flight was incorporated until it had been successfully flown on at least one other Atlas. The following paragraphs describe the major system modifications incorporated in Mercury-Atlas launch vehicles. These changes are shown schematically in figure 5–13.

In the first category of changes required by the Mercury mission, one of the most important of the changes was the addition of a new autopilot rate gyro package in a position considerably ahead of that used on the standard Atlas "D". This addition was dictated by the longer Mercury payload and its effect on the flexible Atlas tank during flight. The modification provided optimum attitude rate sensing with resulting minimum engine deflections for more efficient performance of the launch vehicle. The standard rate gyro installation was retained for abort system sensing.

Additional changes in this category include the deletion of the vernier solo phase of operation and relocation of the retrorockets from the launch vehicle to the spacecraft for use as posigrade rocket motors. In the vernier solo mode of operation the vernier engines remain in operation after sustainer engine cut-off, which allows very delicate adjustments to vehicle velocity. Deletion of this mode permitted a reduction in weight and mission complexity with a resultant improvement in performance and reliability. Relocation of the retrorockets was feasible since the Mercury spacecraft was lighter and the posigrade rockets would thus be more efficient in separating the spacecraft from the launch vehicle. The standard Atlas used these retrorockets to "back off" the launch vehicle from the payload. This relocation of the Atlas retrorockets to the spacecraft retropack required that the thin skin of the lox dome be protected from the rocket exhaust. This was accomplished by developing a fiberglass shield that attached to the mating ring and covered the entire dome. A wet-start technique was also incorporated in the engine starting sequence to minimize starting transients. Another change required for the Mercury mission affected the guidance system. Because the trajectory of the Mercury-Atlas flight differed greatly from that of the weapon system vehicles, new guidance antennas were required to insure maximum signal strength throughout powered flight. Extensive theoretical and model work was required to develop antennas which would have suitable radiation patterns.

By far the most important change made to the Atlas in support of Project Mercury was the development and installation of an entirely new system, the Abort Sensing and Implementation System (ASIS). This system was designed to bridge the gap between the admittedly less than perfect reliability of the basic Atlas weapon system design and that near-perfect reliability desirable for a manned flight system. From a very searching and thorough analysis of Atlas flight data, it was seen that certain missile parameters deviated from a norm sufficiently ahead of catastrophic failure to be used as warnings. It was decided to develop an extremely reliable automatic system to monitor these parameters and to signal the spacecraft escape system when a catastrophe was imminent.

The parameters that were considered the most significant for abort indications (see fig. 5-14)

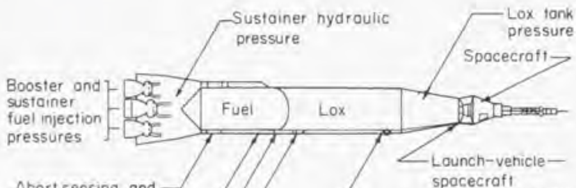

FIGURE 5-14.—Abort system sensors for Mercury-Atlas launch vehicle.

were the liquid oxygen tank pressure, the differential pressure across the intermediate bulkhead, the missile attitude rates about all three axes, rocket-engine injector manifold pressures, sustainer hydraulic pressure, and the launch-vehicle a-c power. Dual sensors for each of these parameters were incorporated into the Atlas system and operation outside a predetermined tolerance band then caused the ASIS to drop out the 28 volt power being supplied to the catastrophic failure detection relays. This drop-out of voltage provided an additional measure of safety in that if the abort sensing system failed in itself, the loss of power to the spacecraft would also cause an abort. This system was developed at GD/A under the direction of the Air Force and its systems engineering contractor and with the coordination of the NASA Manned Spacecraft Center group. This subsystem with its sensors was flown "piggy-back" on Atlas research and development vehicles prior to the first Mercury-Atlas flight at which time it was flown in the open-loop configuration. The first closed-loop flight of this system was the MA-3 mission. The flight very successfully demonstrated the capability of the ASIS when the launch vehicle was destroyed by the range safety officer. The ASIS satisfactorily signaled an abort to the spacecraft in sufficient time to permit adequate separation of the spacecraft from the Atlas explosion.

To provide additional safety measures with the automatic abort, commanded abort, and range safety command destruct, a 3-second delay was incorporated between the signal that commanded engine shutdown and the signal that ignited the destruct package on the launch vehicle. With this change, the launch vehicle could not be destroyed by command for a period of 3 seconds after the engines were shut down. This delay was incorporated to provide adequate separation of the spacecraft from the launch vehicle prior to a command destruct. To provide protection to the launch area, a lockout was incorporated from lift-off to 30 seconds that prevented an abort command from signaling engine shutdown. The spacecraft launch-escape motor had sufficient thrust to provide adequate separation from the Atlas during this period. Immediately after the failure of the MA-1 (Atlas 50D) mission, a special board was convened to investigate the cause of the failure. A number of separate phases of investigation were performed under the direction of the board. These included extensive analyses by Aerospace and GD/A of the thermal environment, discontinuity stresses, and aerodynamic loads. Wind-tunnel tests were performed to gain more knowledge of the aerodynamic conditions imposed on the total flight vehicle in the transonic and maximum dynamic-pressure regions. Analyses conducted by NASA Space Task Group personnel indicated the possibility of concentrated loads being introduced into the

Atlas through the forward structural ring which mated with the spacecraft adapter. None of the investigations or analyses were able to pinpoint the exact cause of the initial failure of the vehicle, but there was no question of the fact that the failure had occurred in the area of the forward lox tank and the spacecraft adapter.

Because of the failure of MA–1 in July 1960 and the successful flight from a structural standpoint of Big Joe I (10D) in September 1959, a coordinated decision was made by BMD and NASA to increase the thickness of the four forward skins of the Atlas lox tank on future Mercury-Atlas launch vehicles to approximately the same dimensions as those on 10D. At the same time it was agreed that the spacecraft adapter would be stiffened. In order to fly the MA–2 mission with Atlas 67D, a thin-skinned vehicle, without undue delay a temporary modification was made. A stainless steel reinforcing band was installed about the lower flange of the mating structure (Station 502 ring) and the first skin aft.

Early in the Mercury program, it was decided to incorporate the electronic "square" autopilot in place of the electromechanical "round" autopilot. The reason for selecting the relatively new electronic system over the proven round autopilot was to obtain improved reliability, improved maintainability due to modular plug in packaging, much increased flexibility to allow for most types of mission changes, and ease of manufacturing by eliminating much of the hidden, point-to-point wiring, and the mechanical setup of the programer. The improved reliability was a result of including such design features as electronic switching in place of mechanical switching, electronic integration in place of electromechanical integration, and improved circuit board design.

Initial flight testing in the Atlas program was accomplished by using an early type of telemetry system. The weight and power requirements to operate the early system were high, and oscillator stability degraded over a short operating time span. A transistorized, lightweight system was developed by GD/A to support the Centaur flight test programs and appeared to be well suited to the Mercury program (fig. 5–12). NASA requested the Air Force to incorporate the new lightweight system as soon as practicable. This system was first flown on launch vehicle 100D.

Normal cut-off of the sustainer and vernier engines is initiated by a discrete signal from the Burroughs computer to the ground guidance station. The ground guidance station then retransmits this signal to the airborne decoder which in turn signals engine shutdown. A partially redundant path for the sustainer-engine cut-off (SECO) discrete transmission was developed early in the program. This path enabled the Burroughs computer to forward the signal to the launch vehicle through the range safety command transmitter, to the airborne receiver and then to the engine relay control. This path was not wholly redundant because no duplication existed in the computer function for generating the SECO time; therefore, a single failure mode still remained. As a result, discussions with the AMR range personnel brought out the capability of the Azusa system to provide a completely redundant SECO discrete signal. The Azusa system in conjunction with the IP 7090 computer continuously computed the instantaneous launch-vehicle impact point (IIP) for Range Safety purposes. With certain modifications to the IP 7090 program it was possible to obtain the time at which orbital velocity was attained. This time was provided electrically by land line to the NASA Flight Director. The Flight Director used this signal as a backup in the event of a failure or malfunction of the Mod III guidance system. This backup SECO system was susceptible to guidance noise; therefore, it was discontinued after the MA–8 mission.

The SECO discrete transmitted to the launch vehicle through the range safety command system as described above, was originally tied to the output of the guidance decoder which obtained a SECO discrete through the guidance system. Both SECO signals used the same path from the guidance decoder and the range safety command receiver to the engine shutdown relays. Additional engineering was required to reroute the signal to provide a completely redundant path.

It is pointed out later in the paper that a problem was discovered with the guidance system at low antenna elevation angles. After a thorough study of the hardware involved, it was concluded that the excessive noise in received signals was cyclic in nature and was caused by an as yet undetermined atmospheric phenomenon. To reduce the effect of the noise in the over-all guidance loop, first the guidance equations were modified to provide additional smoothing, and second, the rate station base legs were increased from 2,000 to 6,000 feet. Although the latter modification did not reduce the actual noise being received, the deleterious effect of the noise on the received signals was reduced by approximately 3 to 1. The third and more complex phase of the study was the development of a mathematical model of the noise to permit a more detailed analysis of the trajectory equation changes that were necessary to minimize this effect. These changes were made to the guidance equations and used on the MA-9 mission.

A fuel tanking test that was being accomplished between the first and second launch attempts of the MA-6 mission brought out a problem that necessitated a major airframe change. The plastic foam material that is used for insulating the base of the liquid oxygen tank from the fuel tank is contained between two hemispherical bulkheads which separate the lox and fuel. A more detailed description of this problem is contained in a description of the MA-6 mission. The limited need for the insulation material coupled with the undesirable feature of removing the bulkhead in the field indicated the need for eliminating the insulation bulkhead from all future Mercury vehicles. A change in the production line stopped further installations of this material.

A major modification in the propulsion system was required to eliminate the possibility of combustion instability. Early in the Atlas program, it was found through flight test experience that combustion instability in the booster engines could cause catastrophic failure of the entire missile. The probability of the occurrence was low; however, the need for maximum safety in the manned space program dictated the need for corrective action. Initially, rough combustion monitors were incorporated and the Atlas was held down for an additional period of time, to allow sensing of the engine vibration characteristics. A rough combustion cut-off (RCC) system then would automatically shut down the engine if combustion instabilities occurred. Again, a thorough ground and flight test program was required before installation on Mercury–Atlas launch vehicles. Another modification provided redundancy in the electrical portion of the propulsion system to insure engine shutdown at SECO. Action was taken also to reroute electrical circuitry to insure proper valve sequencing during start in the high-pressure liquid oxygen plumbing.

Another major modification was made to the booster engine turbopumps. Flight and component testing experience show that incidents had occurred where the lox pump impeller had rubbed against the inlet adapter of the pump. This rubbing caused sufficient heat to ignite the lox and in some cases cause an explosion in the turbopump. Extensive analyses and tests could not pinpoint the exact cause for rubbing; however, the effect of the rubbing could be eliminated by lining the inlet adapter with a plastic material. Months of component and system testing and engineering review were required to provide positive assurance of the suitability of this modification.

Limited changes were made to the pneumatic system specifically for Mercury. Considerable effort was expended however on analyzing tank pressure oscillation that occurs during lift-off under certain payload conditions. The necessary precautions were taken until this problem was resolved. To resolve the entire problem a complex computer model was developed to represent the dynamic conditions existing in the pneumatic system and structure of the Mercury-Atlas vehicle. It was found at the conclusion of the study that earlier characteristics of the helium regulator which controls pressurization gas to the oxidizer tank tended to drive the system into a resonant condition. The new regulator that was used with Mercury did not have the unstable characteristics; therefore, flight restrictions were removed.

The propellant utilization (PU) system was modified to insure an outage of lox rather than fuel in the event abnormal flight characteristics caused the vehicle to expend the total propellant. Early studies had indicated that a safer engine shutdown would be possible in this propellant depletion shutdown case if the lox supply was the first to be consumed. The PU system normally monitors the propellant levels to maintain the proper ratio of onboard propellants. For the Mercury-Atlas the system was modified to drive the mixture ratio to the lox-rich condition at 10 seconds prior to SECO to reduce the ratio of lox to fuel. More recently, a revised method of calibration and a slightly modified mandrel have been developed to provide a more accurate method of maintaining proper propellant ratios.

A normal phenomenon associated with the Atlas vehicle is a roll oscillation that occurs with the missile as the vehicle becomes free of the launcher mechanism. Ordinarily this roll is of small magnitude, and quickly corrected as the autopilot is enabled. A review of flight test history showed that certain vehicles were displaced at roll rates which approached the abort threshold established for the ASIS in roll. Two parallel studies were accomplished to review this problem area. One study reevaluated the abort thresholds to determine if the roll rate limit could be increased. The other study attempted to determine the cause for the roll oscillation in order that a proper modification could be made. It was determined that limited opening of the threshold in roll could be accomplished. The study into the cause for the roll included developing a mathematical model of the launcher mechanism, analysis of control forces required to rotate the missile similar to that demonstrated in flight, base recirculation, engine alinement, and a review of engine acceptance data at Rocketdyne. It was readily apparent that the canted turbine exhaust duct contributed to the clockwise roll moment. This force could cause only half of the roll moment experienced by the missile. Acceptance data from the engine supplier showed that a group of 81 engines had an average roll moment in the same direction of approximately the same magnitude as that experienced in flight. Although the acceptance test-stand and flight-experience data on individual engines did not correlate, it was determined that offsetting the alinement of the booster engines could counteract this roll moment and minimize the roll tendency at lift-off. This change was flight tested and found to correct the roll moment satisfactorily; therefore, the change was incorporated for MA–9 in Atlas 130D.

Flight Test Summary

Big Joe

The first Mercury-Atlas launch was that of Big Joe 1, Atlas number 10D, on September 9, 1959. Atlas 10D was built originally as an R and D vehicle but had received the initial Mercury modifications. The payload was a boilerplate spacecraft. The purposes of the flight were to test the spacecraft's ablative heat shield, afterbody heating, reentry dynamics, attitude control and recovery capability.

Two flight readiness firings (FRF) were performed on Big Joe 1. The first, on September 1, 1959, ended immediately after T–0 because the ignition stage delay timer commanded shutdown of the rocket engines when neither sustainer nor main engine ignition followed normal vernier ignition. There was no booster or stand damage. The second FRF was successfully completed on September 3, 1959, with normal ignition, transition to main stage and shutdown by the engine timer after approximately 19 seconds of running time.

During the launch on September 9, 1959, engine ignition, thrust buildup and lift-off were normal, and launch vehicle performance was completely satisfactory throughout the booster phase. However, after booster engine cut-off (BECO) the booster section failed to jettison and remained attached to the vehicle for the duration of the flight. The sustainer continued to power the vehicle until propellant depletion some 14 seconds prior to normal cut-off. The malfunction resulted in the vehicle failing to achieve planned maximum velocity and in exceeding planned maximum altitude.

Although the injection conditions were considerably different from the preplanned values, the spacecraft reentry satisfied the NASA test objectives. By extrapolating the acquired data, NASA Space Task Group was able to derive the information which was required for spacecraft design. The spacecraft was recovered and returned to Cape Canaveral. Since the data from Big Joe 1 satisfied NASA requirements, a second Mercury launch, Big Joe 2 (Atlas 20D), which had been scheduled for the fall of 1959, was cancelled and the launch vehicle was transferred to another program.

MA–1

The first of the Mercury-Atlas series, MA–1, was launched at 8 : 13 a.m. e.s.t. on July 29, 1960, from AMR Launch Complex 14. The vehicle consisted of Atlas 50D and Mercury Spacecraft number 4, the first production spacecraft, and adapter. The spacecraft primary test objectives concerned structural integrity, afterbody heating and reentry dynamics from a temperature critical abort. Launch vehicle objectives concerned the capability to release the spacecraft at the desired insertion conditions and the evaluation of the open-loop operation of the Abort Sensing and Implementation System (ASIS). A single successful FRF was accomplished on July 21, 1960.

Lift-off and flight of the vehicle were nominal until 57.6 seconds after lift-off when a shock was registered by both the launch vehicle and spacecraft axial accelerometers. The vehicle at that time was at approximately an altitude of 30,000 feet and 11,000 feet down range. The sequence of sensing of the shock indicated that the disturbances occurred in the area of the adapter and the forward portion of the lox tank. All Atlas telemetry was lost at 59 seconds, which is believed to be the time of final missile destruction. Spacecraft telemetry however, continued until 202 seconds, which was the time of landing on the sea, approximately 5 miles downrange. The only launch vehicle primary test objective accomplished was successful evaluation of the open-loop performance of the ASIS which generated an abort signal at 57.6 seconds due to loss of normal a-c voltage.

The failure investigation and results are discussed in the section *Atlas Modifications for Mercury* in this paper.

MA–2

The MA–2 mission was flown by using the Atlas 67D and a production Mercury spacecraft. Test objectives for this flight were concerned with the ability of the spacecraft to withstand reentry under the temperature-critical abort conditions and with the capability of the Atlas to meet the proper injection conditions. This Atlas "D" modified for the Mercury mission, was unique in the program in that it incorporated a stainless steel reinforcing band installed around the vehicle between stations 502 and 510. A thin sheet of asbestos was installed between the reinforcing band and the tank skin. This modification was installed as a precaution against the type of failure which had occurred on the previous MA–1 flight. Atlas 67D had accomplished a successful Flight Readiness Firing on November 19, 1960.

Launch countdown was satisfactory. Although 70 minutes of hold and recycle time were required, none of this time was required for the launch vehicle systems. Lift-off occurred at 9 : 10 a.m. e.s.t. on February 21, 1961. Ignition and transition to main stage were normal, and lift-off was clean. The launch-vehicle flight was uneventful. All test objectives were fully met, and the spacecraft was successfully recovered. This launch was the first one which was preceded by a full Flight Safety Review Board in accordance with the Mercury-Atlas Booster Pilot Safety Program.

MA–3

Atlas 100D, the launch vehicle for the MA–3 mission, was launched from Complex 14 at AMR at 11 :15 a.m. e.s.t. on April 25, 1961. The mission was terminated by the range safety officer after approximately 43.3 seconds due to failure of the launch vehicle to follow its roll and pitch programs. Although the launch-vehicle was destroyed as a result of a malfunction, considerable benefit was derived from the flight test. First, the satisfactory closed-loop performance of the ASIS was demonstrated when the booster engines were shutdown and escape rocket ignition was initiated automatically by the ASIS. The escape was so successful that the spacecraft was recovered some 20 minutes after launch and reused on the next flight.

Second, because of the nature of the failure an intensive reexamination of the complete electrical circuitry and its design, manufacture and installation for both the launch complex and the Atlas was conducted. The malfunction which caused flight termination was isolated to the flight programer or associated circuitry. The programer either failed to start or started and then subsequently stopped without initiating the roll and pitch program. The programer was subsequently recovered, examined, and tested. The most probable cause of the flight failure was traced to contamination of one of the programer pins which under vibration could have caused the failure. The extensive review that was conducted to analyze the flight failure also revealed other deficiencies in the flight control systems. Changes were made to the system to eliminate these possible failure modes and to improve the over-all system reliability.

MA–4

On August 24, 1961, the Flight Safety Review Board for the MA–4 mission (Atlas 88D) performed a thorough review of all pertinent problem areas and all recent Atlas flight test problems. At the completion of the meeting, the Flight Safety Review Board approved the use of Launch Vehicle 88D for the MA–4 mission. The launch was delayed for a 1-week period, and during this period of time a transistor malfunction in one of the flight control canisters aroused considerable concern. An investigation into the factors associated with this failure necessitated an Air Force Program Office decision to delay the flight in order that flight control equipment could be reworked to eliminate this failure mode. The contractor responded to this decision with a concentrated effort to rework and test the equipment in time to support a mid-September launch. On September 12, 1961, the Flight Safety Review Board reconvened. The flight control canister rework was reviewed in detail and the Board concluded that 88D was suitable for launch. The 88D was scheduled for a 250-minute countdown starting at 2:50 a.m. e.s.t. on September 13, 1961. There were four holds and a recycle which resulted in a total count of 374 minutes. Propulsion system performance was normal throughout the start sequence, additional hold-down period and flight. Thrust chamber vibration levels were normal during the hold-down period and chamber pressures were nominal. Lift-off occurred at 9:04 a.m. e.s.t. The flight control systems satisfactorily generated the missile roll and pitchover programs and responded correctly to guidance discrete and steering commands. An oscillation in the pitch plane was evident from T+15 seconds to T+21 seconds. Missile bending was evidenced by an accelerometer located on the lox-dome, launch-vehicle flight control rate gyros, and by spacecraft rate gyros. A change to a launch-vehicle automatic hydraulic actuator had been incorporated on the MA–4 launch vehicle, and the flight control gains had been modified. A postflight modal analysis of the MA–4 data showed that marginal stability characteristics existed with these changes; therefore, additional filtering was deemed to be necessary for future Mercury flights. Propellant slosh amplitudes during the booster phase were low and considerably less than that observed on launch vehicle 67D. The spacecraft injection conditions on the flight of 88D were of the poorest quality of all Mercury-Atlas flights. Tolerance limits were not exceeded; however, a thorough study was required to determine the cause. An analysis of the flight data brought to light tracking phenomena associated with low incident angles. Under certain conditions the guidance system could be affected by varying atmospheric refraction towards the end of flight when the vehicle was approaching the horizon. Limited experience had been obtained at these low elevation angles with the Mod III guidance system. A continuing study was conducted by SSD, GE, Aerospace Corporation, and Space Technology Laboratories in conjunction with the AF Electronic System Division and its technical staff to determine the source and limitations of this phenomenon. Knowledge gained from this study was later used to rewrite the trajectory equations to reduce the effects of refraction anomalies. The postflight evaluation of the launch vehicle 88D mission indicated that all flight objectives were successfully achieved.

MA–5

On November 28, 1961, the Flight Safety Review Board met to consider all aspects of the MA–5 (93–D) mission. Included in the Board review were the autopilot changes that resulted from the previous flight and a thorough discussion of the activities and studies conducted in the evaluation of the guidance phenomena. Additional problems associated with other Atlas space and weapons flight test were reviewed. The Board committed the vehicle to launch.

A number of holds were required during the countdown on November 29, 1963. The data link between the GE ground guidance station and the Mercury Control Center dropped out temporarily, requiring a 4-minute hold, and a 3-minute hold was called at T−7 minutes to resolve a pulse beacon anomaly. Ignition and transition into mainstage were accomplished satisfactorily and within expected limits. There was no indication of the pitch oscillation observed on the launch of 88D. Following lift-off a slight oscillation was noted in the pitch channel during the roll program which is common to all launches. The usual flight oscillation due to slosh was observed from T+86 seconds to T+100 seconds. Staging transients were normal. Approximately 30 seconds before sustainer engine cut-off, a slight oscillation appeared in the pitch channel. This condition persisted for 15 seconds, but the magnitude of the oscillation was of no significance. All flight test objectives were met and the performance of the launch vehicle was within expected tolerance limits.

MA–6

The historic flight of Astronaut John Glenn was conducted on board Atlas launch vehicle 109D and Mercury Spacecraft number 13. This was the flight for which the Atlas Pilot Safety Program had been conceived and for which the launch vehicle team had been preparing so long. Major General O. J. Ritland, then Commander, SSD, convened the Fight Safety Review Board on January 26, 1962, to determine the suitability of Atlas 109D for support of the MA–6 mission. In addition to reviewing the readiness of 109D, the Board reassessed the critical problem areas in the development of the Atlas in support of the Mercury program. This reassessment included all major developments, flight-test incidents and corrective action, the results of additional reliability tests and analyses conducted specifically for Mercury, the performance and test status of the abort system, performance margins experienced on past flghts and the prediction for MA–6, the configuration differences between the previous Mercury vehicle and 109D, and the production and test history of 109D prior to its arrival at AMR. One minor, last-minute problem with a faulty pin connection in the staging umbilical necessitated a second session of the board on January 26, 1962. The condition was repaired, and a complete series of tests to validate all the pin connections in the connector was satisfactorily accomplished. After the second session the Board committed 109D for the launch of MA–6. Adverse weather in the launch area forced the cancellation of the first launch attempt on January 27, 1962. After a tanking test was conducted on January 30, fuel was detected in the insulation bulkhead located between the fuel and liquid oxygen tanks. The insulation bulkhead is located beneath the intermediate bulkhead that structurally separates the two tanks and is composed of a plastic foam material vented to the fuel tank and supported by a thin steel membrane. Test of the plastic material indicated that sufficient fuel could be retained in the insulation material to overload the membrane supporting the insulation bulkhead under flight accelerations. Inasmuch as it was not possible to assess the amount of saturation accurately, a decision was made to remove the insulation material and the supporting structure. The extent of the repair on Atlas 109D at AMR constituted a major but necessary rework of the vehicle in the field. Because of the extent of the repair a highly qualified group of personnel from Aerospace, 6555 ATW and GD/A were selected as a special committee to review all procedures associated with the task. This group also was responsible for validating of the complete task. The primary reason the task was authorized as a field modification was because it had been successfully performed in the field only weeks before on Atlas 121D, the Ranger 3 launch vehicle which flew successfully.

The combined Atlas-Mercury countdown was begun at 11:30 p.m. e.s.t. on February 19, 1962. A built-in hold of 90 minutes was scheduled to begin at T−120 minutes. At T−280 minutes, a telemetry check indicated the Azusa impact predictor was "no-go." The ground station was checked and found to be operating satisfactorily. The tower decks around the transponder were raised, but still the Azusa system could not achieve a satisfactory lock. A decision was made to change the transponder which was accomplished by T−273 minutes. The test was resumed and Azusa was declared "go" at T–213 minutes. No hold time was involved. At T−149 minutes, during the flight control system test, there was a sudden drop in the rate beacon automatic gain control (AGC). The first backup beacon was substituted for the original unit during the built-in hold. This hold was extended for 30 minutes and then extended another 15 minutes to complete installation and retesting. Ten additional minutes of hold were required for the spacecraft. At T−60 minutes a 30-minute hold was requested by Mercury Control Center which was then extended an additional 5 minutes. At T−45 minutes a 15-minute delay was instituted to catch up with the countdown procedures. Lox tanking began at 8:30 a.m. e.s.t. Lox pump problems caused a 25-minute delay in the count. A 2-minute hold at T−6.5 minutes was requested by Mercury Control. The count then proceeded normally to T−0. Lift-off of 109D and Astronaut Glenn occurred at 9:47 a.m. e.s.t. Propulsion system operation during ignition was satisfactory. The longitudinal oscillation normally expected at lift-off were nominal and damped out by approximately 25 seconds after lift-off. Performance of the guidance system was satisfactory. The missile was acquired by radar at the normal time, and tracking was maintained continuously throughout SECO. Steering began at 155 seconds with 60-percent pitchup and 23-percent yaw right commands of 10 and 5 seconds duration, respectively. These initial commands were acceptable for the planned trajectory. Thereafter pitch steering did not exceed 10 percent and yaw steering 5 percent until the end of the flight. Flight control system performance was satisfactory. All monitored programer pitch functions occurred at the proper time. Staging sequence was normal and no evidence of pitch oscillation buildup occurred during the flight. Insertion accuracies were good and well within the tolerance requirements established by NASA. Postflight evaluation of the mission indicated that all systems functioned satisfactorily, and no significant anomalies were apparent.

MA–7

Atlas 107D was shipped to AMR on March 7, 1962, to support the MA–7 flight of Astronaut Carpenter in spacecraft number 18. The vehicle was erected on March 14, 1962, and no serious problems were found during the prelaunch activity. A joint spacecraft and launch-vehicle flight-acceptance composite test (FACT) was conducted on May 4, 1962. The Flight Safety Review Board met on May 23 under the chairmanship of Lt. General Estes, then Commander of SSD, for the purpose of determining the readiness of 107D to support the second Mercury manned orbital launch. The combined Atlas-Mercury countdown began at T−390 minutes at 11:00 p.m. e.s.t. May 23, 1962. The count proceeded very smoothly and without delay until T−11 minutes when the NASA flight director called a 15-minute hold because of unfavorable ground visual conditions. An additional 15-minute hold for the same reason was requested. At 7:17 a.m. e.s.t. an additional 10-minute hold was requested to analyze airborne refractometer test data to determine its effect on the ground guidance system. At 6:28 a.m. e.s.t. an additional 5-minute hold was called to complete the analysis of the refractometer data. Countdown was resumed at 7:34 a.m. e.s.t. and proceeded normally to T−0.

The Atlas vernier-sustainer and booster ignition and transition to mainstage were normal. Lift-off transients were very small and the normal pitch oscillation seen during the roll program was of minimum magnitude. Guidance lock-on was normal. No yaw command was necessary at the time of guidance enable. A slight pitchup was commanded, after which no steering commands were required until just before SECO. Staging transients were very small. An anomaly occurred in the sustainer hydraulic system when at T+192 seconds telemetry data showed that the sustainer engine control hydraulic pressure had begun to drop. The number two ASIS pressure switch activated at T+265.1 seconds when system pressure dropped below the abort level. The number one ASIS switch, which is on a separate sensing line, did not activate and therefore no abort signal was generated. Other telemetry measurements did not show corresponding hydraulic pressure drop. Test simulations conducted after the flight duplicated flight test indications when the sense line was cold soaked at liquid oxygen temperatures. Action was taken to modify future Mercury vehicles by insulating the sense lines. Guidance accuracies for the flight were improved as a result of the extension of the ground based rate system base legs. This was the first Mercury flight to incorporate this modification.

MA–8

Atlas launch vehicle 113D scheduled to support the MA–8 mission on October 3, 1962, incorporated the baffled injector modification in the two booster engines. Sufficient ground and flight test experience had been conducted to provide adequate assurance of the additional flight safety possible with this modification. However, recent ground and flight test failures of the sustainer turbopump created a new atmosphere of concern in the engine area. Investigation of these failures did not reveal any specific cause. Therefore, additional testing was required to determine the susceptibility of 113D to a similar malfunction. An extensive analysis of these past failures did point out that two conditions were common to the failures. The first condition was that the failure occurred during the period of time the fuel control valve was moving into the control position during start. Secondly, the malfunction had always occurred during the initial test of the system in that configuration. For these reasons it was determined that conducting an FRF on 113D in its launch configuration should expose the turbopump to this failure mechanism. Accordingly, an FRF was conducted on September 8. Post FRF evaluation indicated that the propulsion system was flight ready.

Major General Ben I. Funk, Commander, SSD, conducted the Flight Safety Review for the MA–8 mission at 9:30 a.m. e.s.t. on October 2, 1962, to determine the flight readiness of Atlas 113D. NASA concurred with the board's recommendation that the vehicle was in suitable condition to support the MA–8 mission.

MA–8 (Atlas 113D) was launched at AMR Complex 14, 7:15 a.m. e.s.t. on October 3, 1962. The performance of the propulsion system was satisfactory. Telemetered values of all measurements were indicative of normal system operation. Because of the incorporation of the production baffled thrust chamber injectors on the booster engines the missile hold-down time was not extended, and the rough combustion cut-off system was installed open loop on the booster and the sustainer engine for instrumentation purposes only. Flight control data indicated the usual clockwise roll transient at lift-off; however, in this case the transient condition approached 80 percent of the abort threshold. Longitudinal oscillations and pitch oscillations during the initial portion of the flight were nominal and slosh amplitudes were within expected values. All monitored programer switch functions occurred at the proper times and staging sequence was normal. A low amplitude roll limit cycle was apparent from approximately 252 seconds to SECO. Performance of the guidance system was satisfactory with negligible steering commands required after responding to the initial inputs. Insertion conditions were very close to nominal.

MA–9

Atlas 130D was the sixth consecutive launch vehicle to place a Mercury spacecraft into earth orbit. It was the tenth and final launch vehicle used in the Mercury-Atlas program. 130D was accepted at the General Dynamics/Astronautics plant at San Diego, California, on March 15, 1962. Acceptance of this vehicle marked the attainment of a long standing goal of the SSD–Aerospace launch vehicle program offices: acceptance of a Mercury-Atlas launch vehicle without discrepancies or contractual deviations.

The Flight Safety Review Board convened on May 13, 1963, with Major General Ben I. Funk, Commander, SSD, as chairman, to review the status of Atlas 130D to support the MA–9 mission. The MA–8 launch-vehicle performance and the MA–9 launch-vehicle predicted performance were reviewed. All differences between the MA–8 and MA–9 vehicles were discussed, as well as the flight qualification of these changes. The history of manufacturing and testing of 130D at the manufacturer's plant and the prelaunch history at AMR were reviewed. Atlas flight-test experiences were updated to insure that no related problems existed and the board agreed that 130D was ready for flight. An initial launch attempt was made on May 14, 1963; however, the diesel engine used for retracting and stowing the gantry caused a delay in the count when it malfunctioned. Subsequently, the launch was postponed until the following day because of a malfunction in the radar at Bermuda.

The Atlas prelaunch operation, which began on time at midnight of May 14, 1963, was scheduled for a 390-minute countdown plus one planned hold of 90 minutes duration at T—140. There was one unscheduled hold of 4 minutes duration at T—11 minutes 30 seconds, to investigate a signal fluctuation in the Mod III ground guidance system. The anomaly was attributed to an outside source of radiation, and the countdown was resumed. The whole launch vehicle countdown had been exceptionally smooth, and no further delays were encountered. Ignition, transition to mainstage and lift-off were normal with no additional hold-down beyond the normal approximately 2 seconds between flight lock-in and release. Lift-off occurred at 8:04:13 a.m. e.s.t., on May 15, 1963. As the vehicle came off the launcher arms it rolled counterclockwise approximately 0.3° before this minor transient was corrected by autopilot control initiation at 40″ motion. The expected slight longitudinal oscillation associated with lift-off occurred during the first few seconds of missile motion and damped normally. At two seconds after lift-off the roll program was enabled and 130D rolled toward its climbout heading of 72°. The roll program was completed at 15 seconds, and the booster pitch program was enabled. Slight lofting took place during the early portion of the booster powered flight; however, the vehicle intercepted the planned trajectory at 125 seconds. Propellant sloshing became noticeable at 55 seconds, reaching a maximum amplitude at 98 seconds and decaying to a negligible value by 120 seconds. Propellant slosh during this period of time is normal, but the amplitudes on this flight were higher than on most previous Mercury launches. Postflight review of the 130D flight control gains indicated they were within tolerance but below nominal. Higher than normal propellant slosh amplitudes could be expected under these conditions. Booster engine cut-off (BECO) was accomplished at 132.5 seconds with booster section staging at 135.4 seconds. Space position at BECO was very close to planned. At BECO the sustainer engine was nulled in pitch and yaw to assure proper clearance of the booster section during the jettison phase. After booster jettison the sustainer was reactivated in pitch and yaw. The sustainer-stage pitch program was initiated at staging plus 5 seconds and was completed at 159 seconds after lift-off. Entrance into the guidance steering mode was relatively smooth with the initial steering response being slightly up and to the right. After the initial correction, only extremely small steering commands were transmitted. SECO occurred at 303.03 seconds, approximately 1 second earlier than planned. Burnout conditions of the launch vehicle were very close to those planned and were within a few feet per second high in velocity, 500 feet low in altitude, and 0.005° low in flight path angle.

A detailed analysis of flight test data has shown that the launch vehicle performance was very close to nominal. An over-all vehicle postflight trajectory simulation did indicate that the effective specific impulse of the total launch vehicle system was within, but on the high side, of the tolerance band.

The pneumatic system operated satisfactorily, and no anomalies were noted. The tank pressure oscillation which normally occurs at lift-off was of very low magnitude and of no significance to the flight. Adequate pressures were maintained in both lox and fuel tanks and well above the abort limits at all times.

The propellant utilization system exhibited very smooth characteristics throughout the flight and was holding at the nominal position during the period prior to sustainer engine cut-off, indicating that the propellant mass ratio was correct. The PU system on this flight utilized a slightly reshaped mandrel and improved calibration techniques compared to previous Mercury flights.

The sustainer and booster engine hydraulic systems behaved in a normal manner with only slight booster position response to auto-pilot system demands occurring during the propellant sloshing period.

The a-c power supply frequency and the main battery voltage were within specified limits through powered flight. The a-c voltage ran 0.4 to 0.7 volt above the nominal but within the tolerance band. Slight vehicle lofting occurred as a result of this minor shift in a-c voltage.

The flight control system functioned satisfactorily and properly stabilized the launch vehicle. All guidance discrete and steering command functions of the flight control system were properly carried out. GE and Azusa data indicated that the total magnitudes of the booster phase roll and pitch programs were extended slightly beyond nominal but were still well within allowable limits. The major contributor to these excesses was the higher than normal inverter voltage output during the launch to BECO phase of powered flight. It should be noted that the effect of higher than nominal engine performance during boost phase tended to counteract the effect of higher than nominal inverter voltage on the pitch program. As previously pointed out, the propellant slosh was greater than that on most previous flights but its effect on attitude rates was negligible. A low-amplitude roll limit cycle was evident from BECO to SECO. This motion had been noted on previous Mercury-Atlas flights and was not considered detrimental to the mission.

All instrumentation measurements functioned properly throughout the flight, and the telemetry quality was such that a very thorough analysis of all flight parameters was possible.

The range safety command system was not required until the auxiliary sustainer cut-off signal (ASCO) was transmitted 0.04 second after the BECO guidance discrete signal in accordance with the computer program logic.

Performance of the ASIS was satisfactory. Review of launch-vehicle data did not reveal the existence of any undetected abort condition. Switching functions to change abort logic and parameter levels were accomplished in the planned manner from launch throughout powered flight to SECO.

6. RELIABILITY AND FLIGHT SAFETY

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Summary

This paper summarizes the reliability and flight safety features of the Mercury Project. The difference between reliability and flight safety is briefly discussed. The basic concept that no single failure would cause an abort, and that no single failure during an abort would result in loss of the pilot, dictated the need for redundancy and manual over-ride capabilities in spacecraft critical systems.

An existing missile was modified to provide the launch vehicle, and its reliability was augmented by a program of special testing and by careful selection of components. In addition, an abort sensing system was developed for the launch vehicle to provide for sensing of impending catastrophic failure and activation of the spacecraft escape system.

A conservative design approach was used for the spacecraft, incorporating redundancy in all critical systems where possible, in order to provide reliability. Off-the-shelf proven components were used where possible to avoid development problems, and standard design practices were used for designing components where proven components were not available.

The success of the flight-test program proved the effectiveness of the ground test program in disclosing essentially all "early development" and human induced type failures.

Flight safety reviews for the launch vehicle and the spacecraft, and a mission review for all aspects of the mission, were conducted prior to each mission and proved to be effective.

Introduction

The Mercury approach to reliability and flight safety was a practical approach to the problem of achieving manned orbital operation with a reasonable degree of reliability and safety at the earliest possible time. It was an all-out effort to apply knowledge and experience accumulated in years of aircraft and missile flight to get the best chance of mission success and flight safety from parts and components that already existed, or would be brought to the flight stage in, roughly, 2 years. The success of manned space flight required an extensive effort involving dedication of many individuals and their unstinting use of time, there being no sophisticated shortcuts to the disclosure of the many problems and the solving of these problems to assure success of each flight. Consideration of cost, manpower, or schedule were never allowed to influence any decisions involving mission success or flight safety.

Throughout the program, there proved to be a need for stringent attention to details of design, fabrication, quality control, testing and training; emphasis was placed on streamlining the failure analysis and corrective action procedures, incorporating on-the-spot failure analysis at the launch site.

Reliability and flight safety, although closely related, are not exactly the same thing. The former refers to the probability that a given mission will proceed to completion without mishap. This probability combined with the reliability of the escape system provides the overall flight safety or probability of crew survival. It may be pointed out that flight safety can be achieved by building a high reliability vehicle with little or no provisions for escape, as in the case of a commercial airliner, or by attaching a highly reliable escape system to an unreliable vehicle.

Two key design philosophies or guidelines can be postulated:

(1) No single failure shall cause an abort.

(2) No single failure during an abort will result in the loss of life of the crew.

Obviously certain items fall outside the scope of these rules. These are such passive subsystems as the ablation shield and the spacecraft structure as well as some large active elements having a background of high reliability such as the launch escape rocket.

What might be termed the Mercury approach to mission accomplishment and crew safety is outlined in the figures accompanying this report. It may be described conveniently under three main headings, the launch vehicle, the spacecraft and the operational procedures and philosophy.

The success of the mission and safety of the crew also depended on a number of other considerations such as the efficiency of the worldwide network of communications and the recovery operations, both of which are discussed in other papers.

Launch Vehicle

The launch-vehicle reliability and flight safety features are shown in figure 6–1. The main features indicated here are the use of an existing missile modified for Mercury requirements and augmented by a special pilot safety program and an abort sensing system. Although the following discussion centers around the Mercury-Atlas program, similar procedures were put into effect for the Mercury-Redstone program.

Existing Missile

The Atlas and Redstone missiles were chosen as launch vehicles because they were already far along in their development phases and would thus require only minor modification to adapt them to the Mercury requirements. This choice had a number of important implications as to reliability and crew safety, some favorable and some unfavorable. On the credit side, the particular vehicles chosen were well along on their development cycles, had considerable flight experience behind them, and had already demonstrated their abilities to meet the performance requirements. Another favorable feature of the Atlas launch vehicle was the fact that all engines were started, and satisfactory engine operation was verified, before lift-off.

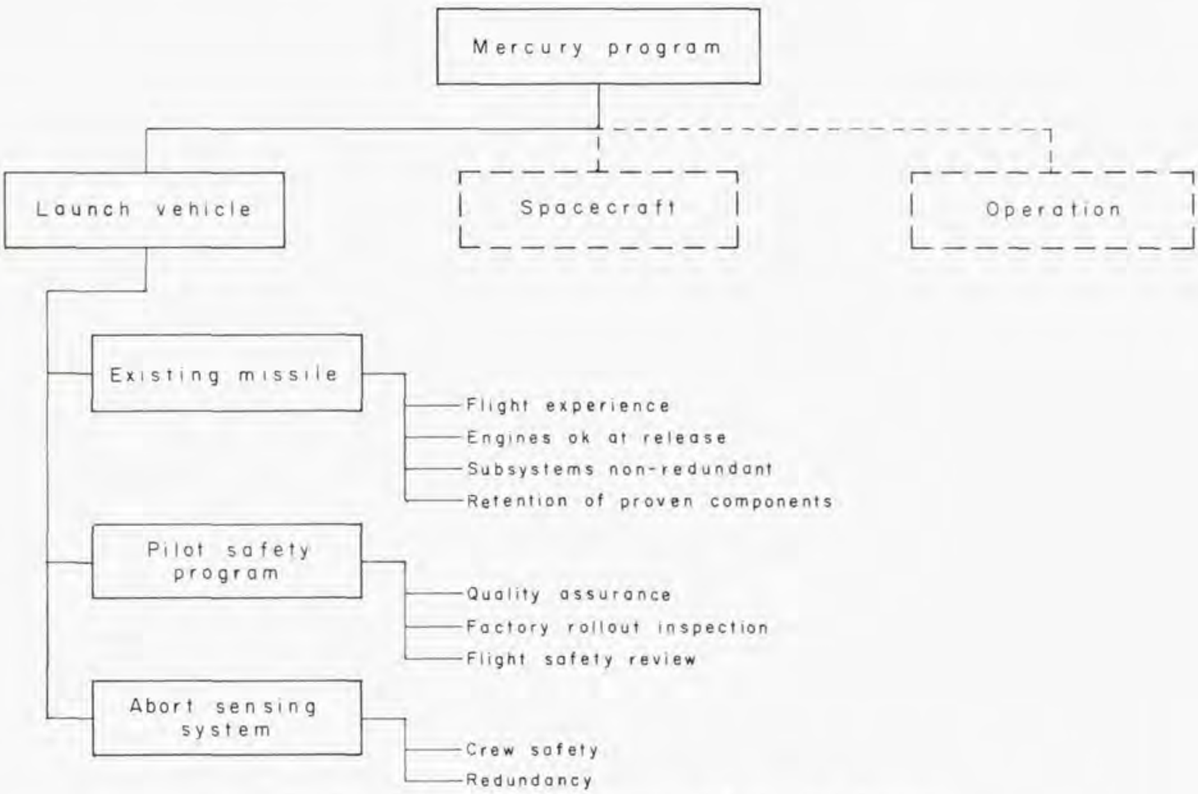

FIGURE 6–1.—Launch vehicle reliability and flight safety features.

Since the Mercury-Atlas vehicle was used as the launch vehicle for the orbital missions, the following discussion will be centered around this vehicle.

A determined effort was made to retain the proven components on the launch vehicle since the development of new components would have resulted in the loss of much of the advantage of using a developed launch vehicle.

Pilot Safety Program

The Pilot Safety Program (see fig. 6–1 and 6–2) was added in the Mercury Project to augment the reliability and safety of the basic Atlas system. This program was developed by the Air Force for the selection and preparation of the Atlas launch vehicles for manned Mercury flights. It was recognized that major design changes to increase the reliability potential of the basic design could not be accomplished within the life of the Mercury Project, and therefore special efforts would be necessary to make certain that the maximum reliability of which the design was capable would actually be achieved in Mercury operations. The program that resulted involved three parts, a Quality Assurance Program, a Factory Rollout Inspection Program, and a Flight Safety Review Program at the launch site.

The Quality Assurance Program consisted of two major areas: An educational program for contractor and sub-contractor personnel; and a critical parts selection program.

Training conducted by the contractor created an awareness of the importance of the Man-in-Space Program and the high reliability required of the Mercury-Atlas launch vehicle. High quality through careful workmanship was stressed.

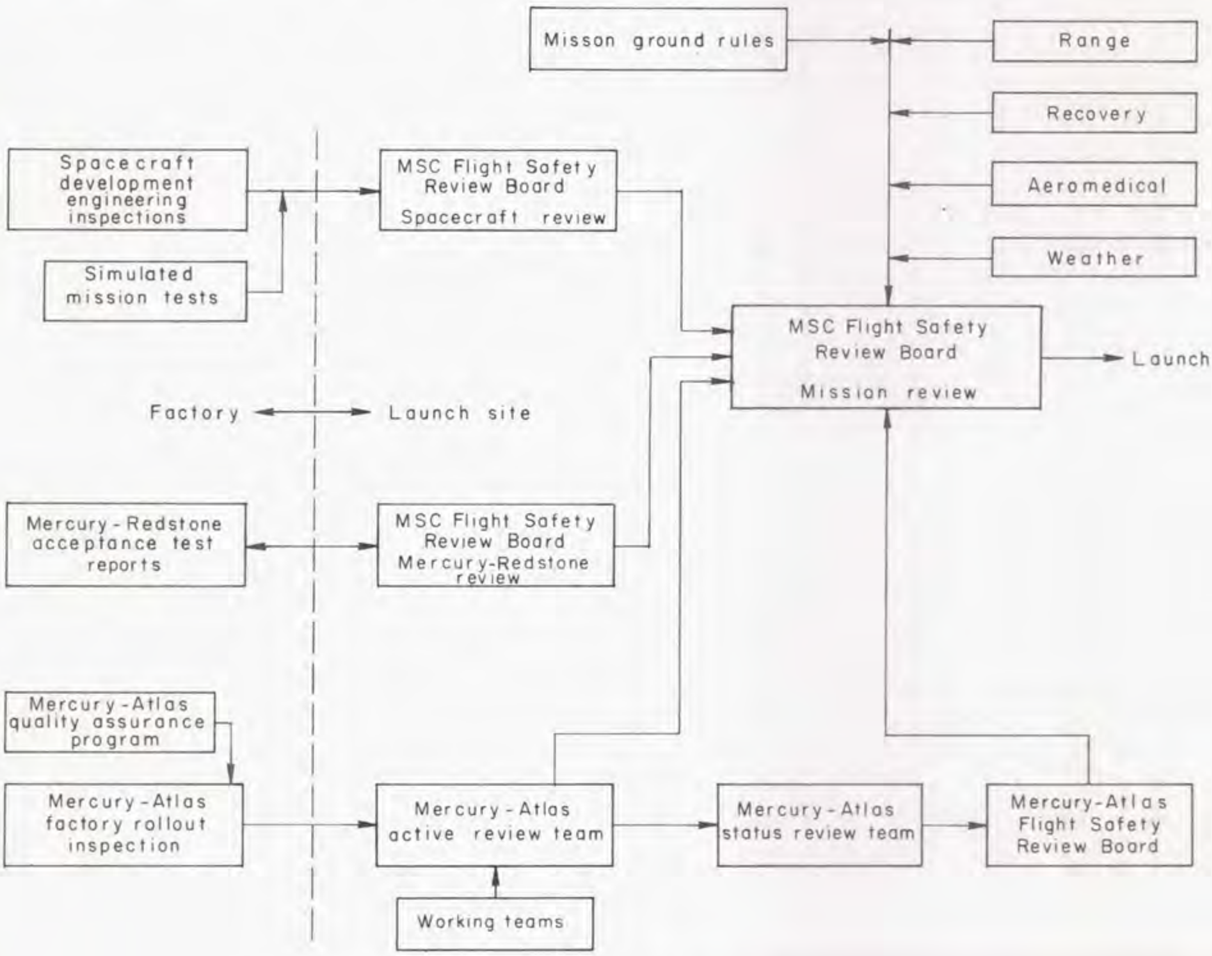

FIGURE 6–2.—Mission review activities.

The result of the critical parts selection program was the rejection of components and subsystems with excessive operating times, on nonstandard performance, or questionable inspection records. Choice of Mercury-Atlas launch-vehicle engines was limited to those standard Atlas engines whose performance parameters most closely met the exact specification requirements. Spare parts were also selected with the same care given to flight hardware. All selected units were specifically identified as accepted Mercury hardware and stored in a specially designated and controlled area.

The Factory Roll-Out Inspection assured that the Mercury-Atlas launch vehicle was complete, functionally acceptable, and ready for delivery. The technical roll-out inspection team consisted of specialists in the technical areas of each flight system. General launch vehicle progress was analyzed on a continuing basis, with special emphasis on hardware status and replacements.

A pre-roll-out inspection meeting determined vehicle status and potential problem areas. A tentative roll-out inspection schedule was established at this time, and composite test go-ahead was granted for final contractual Air Force factory acceptance of the Mercury-Atlas launch vehicle. After satisfactory completion of the composite test, a pre-acceptance meeting was held by the Air Force with associate contractors prior to the formal acceptance meeting to determine systems-performance status and acceptability of the launch vehicle to the Air Force.

After the final Rollout and Acceptance Inspection at the contractor's plant, a post-acceptance critique was held and a final report prepared to cover assembly and test history and all discrepancies uncovered and corrected up to time of delivery to the Atlantic Missile Range.

The contractor was also required to submit a detailed report covering critical item qualification status. A functionally complete launch vehicle was required prior to delivery.

The Mercury-Atlas Flight Safety Review determined the status of the launch vehicle flight readiness. Technical flight readiness was established by personnel from the Space Systems Division (SSD) of the Air Force and their associate contractors who met prior to planned launch for complete vehicle history review since arrival at AMR. The team determined that all possible efforts to insure a successful mission had been made and that the vehicle was in a state of technical readiness. Complete review of all facts yielded a "go" or "no-go" recommendation to the Mercury-Atlas Flight Safety Review Board, which was chaired by the Commander, SSD, for the manned orbital flights. This Review Board meeting was attended by NASA observers, including the NASA Operations Director and one of the astronauts. The findings of this board were subsequently conveyed officially to the NASA Operations Director in the Mission Review.

The total scope of the Pilot Safety Program resulted in expenditure of about twice the standard Atlas fabrication time, and more than three times the normal checkout time and attention.

Abort Sensing and Implementation System (ASIS)

The abort sensing and implementation system (ASIS) was conceived and developed to enhance crew safety. The functions of this ASIS were to sense impending catastrophic launch-vehicle failure, automatically generate an abort command, and activate the spacecraft escape system in sufficient time to assure astronaut safety. An abort signal would be generated if pre-selected tolerances of certain critical launch-vehicle performance parameters were exceeded. The ASIS was supplemented by manned ground and spacecraft abort capabilities.

Atlas flight test data were analyzed to determine which specific performance parameters should be monitored and to determine the abort threshold levels, to assure that sufficient time for escape would be provided and that false abort commands would not be generated.

Evaluation of ASIS reliability under extreme environmental conditions was carried out by an extensive ground-test and flight-test program.

ASIS reliability was provided by electronic equipment redundancies designed to preclude the possibility of system failures or inadvertent aborts. There were deficiencies in the ASIS discovered during the development flights, but corrections were made prior to use on the Mercury-Atlas flights. Early unmanned Mercury flights proved out the entire system; successful abort was initiated on the MA-3 flight, saving the spacecraft which was flown again on MA-4. There were no manned Mercury flights which required an abort action by the ASIS, nor were there any false ASIS abort signals.

ASIS was supplemented by the following manned abort capabilities:

(1) Off-the-pad aborts could be initiated by the test conductor, through direct electrical circuitry, until the vehicle had lifted 2 inches from the pad.

(2) From the point of 2-inch vertical ascent through the end of powered flight, an abort could be initiated through the Mercury Control Center (MCC) radio-frequency link.

(3) The mission could be terminated at any time throughout the entire powered flight by the astronaut.

(4) Indirect abort capability was provided the Range Safety Officer. The automatic airborne abort system could be activated by supplying a manual engine cut-off command. A 3-second airborne time delay was integrated with the airborne range safety command receiver to insure a safe separation of the spacecraft in the event that a command destruct signal became necessary.

Spacecraft

The size, complexity, and cost of the spacecraft and related operational activities including recovery precluded a program of using general flight testing to uncover design and systems weaknesses. It was necessary to produce the first and following spacecrafts with sufficient reliability to assure that each flight would complete its mission. The following discussion covers the reliability and flight safety features of the effort expended in Mercury to accomplish this result. The features are shown on figure 6-3 and may be described under the four head-

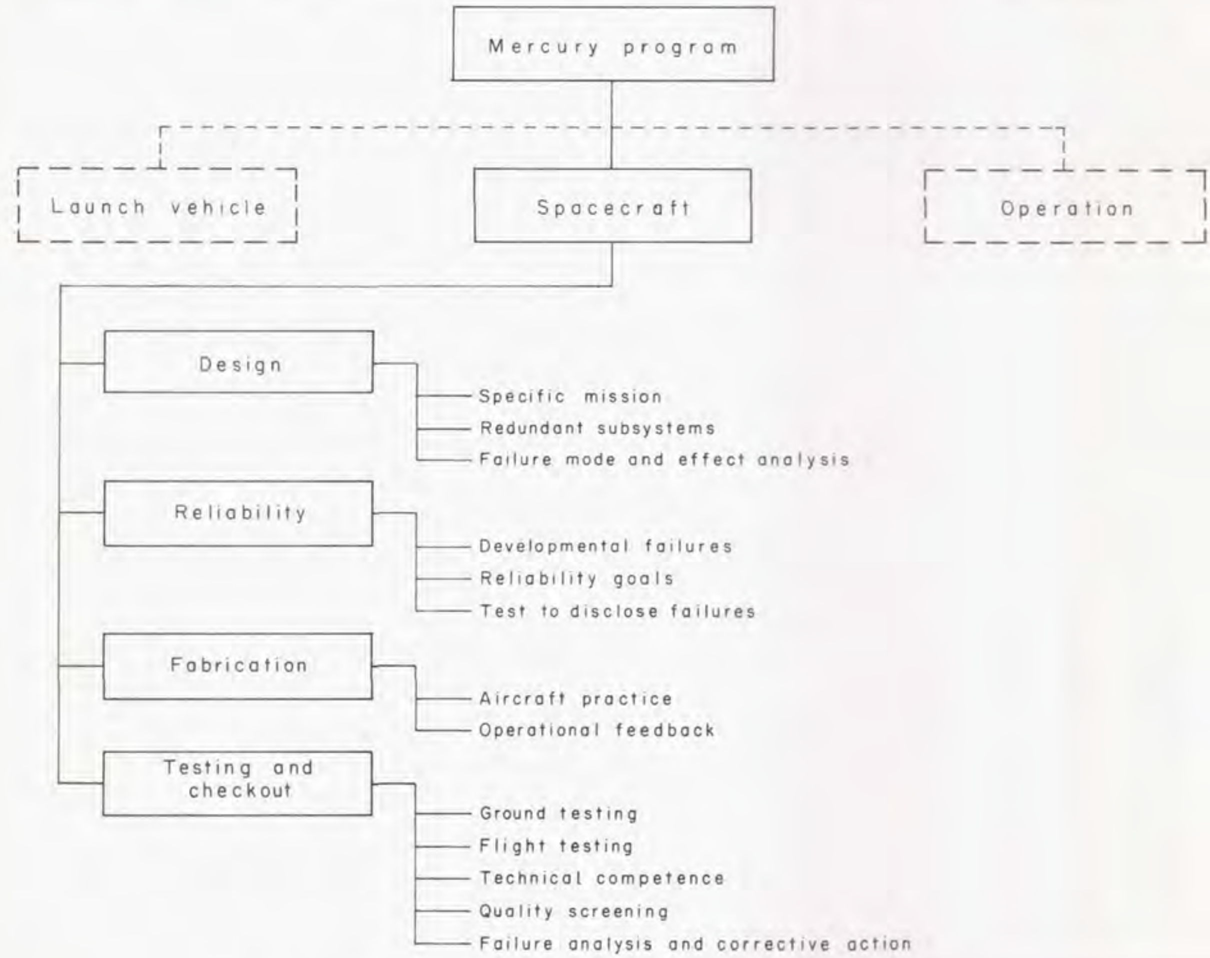

FIGURE 6-3.—Spacecraft reliability and flight safety features.

ings of design, reliability, fabrication, and testing and checkout.

Design

The spacecraft was designed specifically for manned orbital flight with virtually no background of applicable experience to serve as a guide. A very conservative design approach was adopted to provide redundancy in all critical subsystems where possible. The original design was required to provide for normal manned operation, unmanned operation, and operation with an incapacitated man aboard. Much of the redundancy, particularly in the smaller items such as explosive bolts, igniters, etc., was functional in both the unmanned and manned vehicles, but for manned flights the major subsystems such as the attitude control system and landing system relied on pilot operation of the backup mode; hence, the presence of the pilot substantially increased the reliability of the spacecraft in the manned missions.

There was an average of ten spacecraft component malfunctions or failures per manned spacecraft mission despite the level of effort to disclose and correct all anomalies prior to flight. However, in no case did these failures, some of which were critical, result in mission failure. The adopted design approach utilizing equipment redundancy and pilot back-up modes proved its effectiveness.

Insofar as reliablity and safety were concerned, components selected or fabricated for use in the subsystem were representative of the state-of-the-art at the time of the design freeze. Standard design practices were utilized for designing components for specific applications where proven components were not available.

The philosophy of designing redundancy into Project Mercury is best described by the following examples:

One-time-only operating devices.—A number of subsystems are required to operate only once during a mission, and thus the frequency of failure of these subsystems is independent of mission duration.

In order to be sure that the escape tower could be released from the spacecraft, and that the spacecraft could be released from the launch vehicle, the clamp rings were divided into three segments and held together by three double-ended explosive bolts. Figure 6-4 shows the

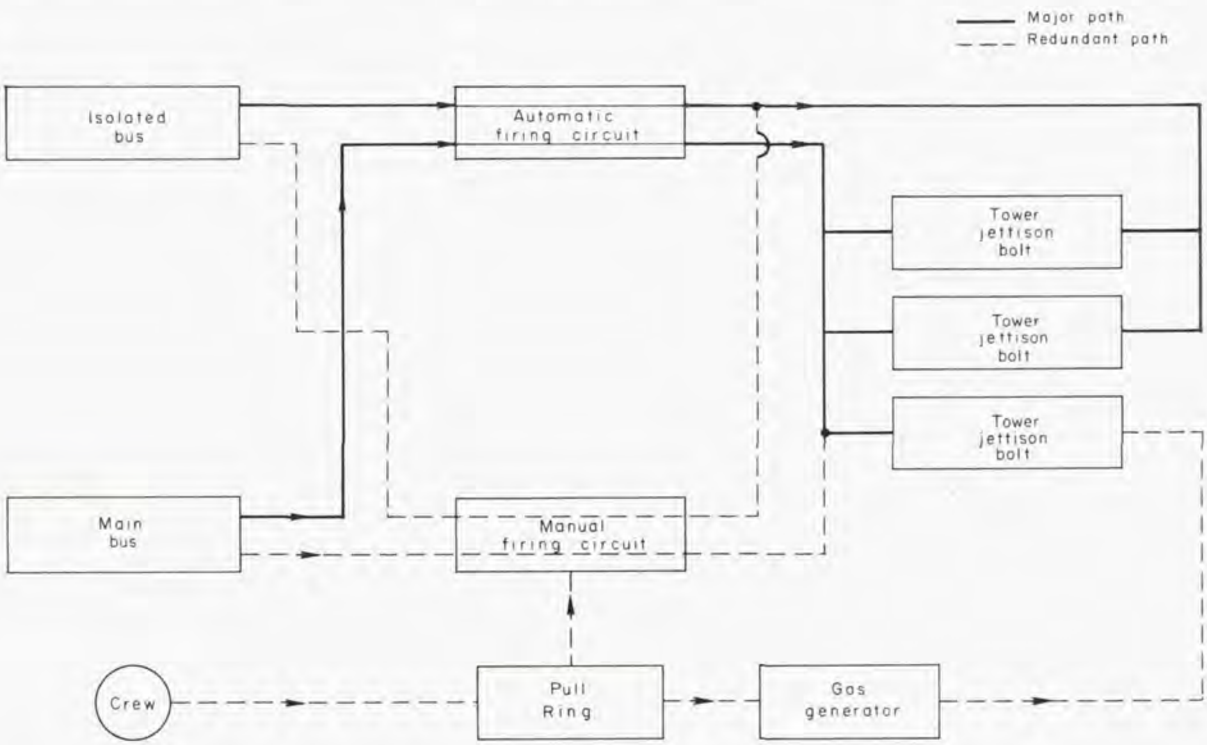

FIGURE 6-4.—Automatic and manual initiation of tower-jettisoning-bolt, pyrotechnics.

escape-tower clamp ring bolt-firing functional arrangement. Firing any end of any bolt could effect the release. The automatic system could fire one end of each bolt from one electric circuit and the opposite end of two bolts from a completely independent circuit; an astronaut manually operated backup could fire the opposite end of the third bolt through a percussion device, and in addition, could send electrical signals through the two automatic electric circuits.

For retroimpulse there were three solid fuel rockets with dual igniters fired by dual circuits. They could be initiated automatically, or by either astronaut or ground command. Only two of the three retrorockets were required to effect a satisfactory reentry.

The primary parachute system was fully automatic. It incorporated dual barostats, dual power sources, and manual backup of each main function in the sequence. The entire automatic system was backed up by an independent manually operated reserve parachute system.

Operating-time dependent systems.—A number of critical systems of the spacecraft had to operate more or less continuously throughout the flight. The frequency of failure of components in these systems would be, in general, proportional to the length of time they were operated and hence to the length of the mission.

The environmental system incorporated the basic redundancy of a full pressure suit in a controlled cabin environment. Manual controls were provided to back up the automatic control functions. An emergency O_2 supply was available to the suit as a further backup in the event of simultaneous malfunctions in both suit and cabin controls.

The attitude control system, which was particularly critical for retrofire, consisted of a primary automatic system backed up by dual independent manual subsystems, one of which was completely independent of the automatic system.

Failure mode and effect analysis.—A failure mode and effect analysis was performed for each subsystem to investigate the failure mode of components comprising the system and determine the significance to mission success and the corrective action to be taken. This analysis also included an evaluation to determine the action that should be taken in case the systems-performance indications displayed to the pilot and transmitted to the ground stations were in disagreement. An important consideration was the probability that the sensors and indicators may malfunction and thus incorrectly dictate the need of an abort.

A concentrated effort was made to identify single point failures; first, those which would in themselves be catastrophic or prevent subsequent operation; and second, those which would cause a premature operation.

An example of a subsystem revision resulting from this effort was the change in arrangement of the dual barostats that functioned to close the circuit to the parachute deployment sequence. Originally, the dual barostats were in parallel; a failure to the closed position of either would initiate the deployment sequence. The revision placed the barostats in series, thereby requiring both to fail closed in order to initiate premature deployment.

Reliability

An effort was initiated in the Mercury Project to make a quantitative reliability assessment and obtain an overall estimate of mission success and flight safety based on test time and failures that took place during the ground test program. The estimate of the reliability of the Mercury spacecraft utilized mathematical models of the subsystems together with failure rate data derived from actual test experience on the system parts and components.

In general, the results were not satisfactory because the applicability of the failure rate data was always highly debatable. It was a basic ground rule of the approach to manned space flight that a failure during development and preflight tests always resulted in a corrective action designed to eliminate all possibility of repetition of that particular type of failure. Hence, past failure data never applied directly to the then-current articles.

However, methods were evolved for setting up an analytical model to describe the operation of a complex system, and the computer programing on the IBM 7090 that eliminated lengthy and complex manual quantitative analysis. Those methods appear to have direct applications for assessing mission success and crew safety during the design stages of future space programs.

Mathematical models were used to some degree in the design stages of the Mercury Project. Catalogued values of failure rates that had been established by the manufacturers or various testing agencies as being representative of the random or statistical type of failure that predominates in fully developed parts comprised the inputs to these models. Reliability values obtained in this way tended to reflect the ultimate goal: that is, the minimum failure rate that may eventually be obtained with the design.

The first Mercury space flights with new systems could not be delayed pending statistically rigorous reliability tests to assure demonstration of reliability goals. The problem was therefore to decide, by a combination of engineering judgment, common sense, experience, and intuition, just when the last serious "early development" types and human-induced types of failure had been eliminated. The early development type of failure arose from design errors, interaction effects between parts and components, unanticipated environmental effects, or errors in estimating environments. The human-induced type were those associated with faulty fabrication, quality control, failure diagnosis, handling, installation, and carelessness.

As a result of the experience in the Mercury Project the role of numerical reliability assessment in manned space programs may be summarized as follows:

(1) It is desirable to specify an overall numerical reliability goal to insure that adequate attention is directed to reliability in the design stage. This goal should be apportioned or budgeted through a mathematical model down to the various subsystems and their components. The subsystem designer should be required to show that his subsystem is capable of absorbing the expected number of random or statistical type failures of parts without serious consequences or without exceeding his reliability budget.

(2) The logic flow diagrams which show functionally the systems sequence of action were especially useful since they represented primary and critical abort paths, crew inputs, and principal events. They reflected the basic ground rules relative to choice of alternate modes of operation and aborts. From these diagrams the effect of a component failure could readily be determined.

(3) Beyond this point the usefulness of formal quantitative reliability assessment procedures is debatable; the most effective approach from here on is to concentrate on establishing a testing program and quality assurance program that will assure detection and correction on all the unproven design and induced sources of system failure before flight.

Fabrication

Fabrication of the spacecraft was generally in accordance with the accepted aircraft production practices for small lots on the order of twenty articles. Air-conditioned clean room procedures were introduced in an effort to eliminate the introduction of contaminants or debris into components.

The results of operational experiences were fed back into the fabrication process by holding frequent Development Design Engineering Inspections (DEI). The purpose of the DEI was to assure that the Mercury spacecraft as engineered and manufactured was safe for manned flight. Emphasis was placed on attaining reliability and flight safety with existing Mercury hardware. To accomplish this objective, the DEI team was responsible for conducting suitable inspections for deficiences and initiating necessary corrective action. The DEI board was authorized to make final decisions on the acceptability of the spacecraft.

Preparatory to the DEI, the inspection team reviewed in detail engineering design, fabrication, and assembly, as well as component, system, and composite testing.

Testing and Checkout

Ground testing.—In addition to the standard type of qualification and acceptance tests, the following types of tests were conducted.

Demonstration tests: Demonstration tests were made to determine reliability, wherein several samples of each major subsystem were tested under simulated operational environments and duty cycles for a total operating time considerably longer than that of a single mission. The scope of these tests is shown in figure 6–5.

	Major subsystems	Typical test time or firings
1.	Environmental control system	1500 hrs
2.	Automatic stabilization and control system	2000 hrs
3.	Reaction control system - automatic	290 hrs
4.	Reaction control system - manual	112 hrs
5.	Horizon scanner	720 hrs
6.	Landing and recovery	38 firings
7.	Rockets	27-37 firings (ea type)
8.	Sequential system	400 cycles
9.	Communications (tranceivers, audio center, transponders, beacons, etc.)	1000 hrs (ea type)
10.	Satellite clock	3000 hrs
11.	Bolt, expl. clamp release	108-155 firings (ea type)
12.	Bolt, retrorocket release	106 firings
13.	Battery (3000 w, 1500 w)	20 discharge cycles (ea type)
14.	Ejector, antenna firing	145 firings
15.	Explosive egress hatch	67 firings
16.	Inverter, static	4000 hrs. (ea type)

FIGURE 6–5.—Spacecraft subsystems reliability tests.

The results of these tests were questionable since the equipment being tested did not always represent production-quality hardware. In addition, actual flight hardware was subject to conditions not contemplated in the reliability testing such as handling and shipping environments, installations in high density and crowded areas within the spacecraft adjacent to unrelated heat generating equipment, and contamination external to the subsystem as well as within the subsystem.

Safety margin tests: Safety margin tests were made wherein a number of component units were tested under progressively severe environments to determine the safety margin provided.

It was necessary for such tests as Project Orbit and subsystems tests at contractor's plant, followed by the intensive subsystems checkout at the Cape, to uncover weaknesses. These tests are discussed in the following paragraphs.

Ground test program: A continuous ground test program, using a complete spacecraft and identified as Project Orbit, was instituted at the contractor's plant about midway through Project Mercury. It became apparent early in the Mercury Project that malfunctions occurring at Cape Canaveral and in the flight made it imperative that design and fabrication weakness be disclosed as early as possible. A comprehensive test program was started in which, to the greatest degree possible, the mission was simulated in real time and included orbital heating and near-vacuum effects. Obviously zero g effects, launch time and vibration, explosive devices, launch escape rocket, tower and spacecraft separation, exposure of the ablation shield to reentry temperatures, parachute deployment, and landing could not be duplicated. However, cabin environment and operation of time dependent subsystems under normal and emergency cabin environment were closely simulated. The continuous aspect of this program conducted in an altitude chamber with all systems operating as they would in a mission not only disclosed the weaknesses but validated equipment revised as a result of the malfunctions. Consequently, the test demonstrated the performance of up-to-date configurations.

The tests were very effective in disclosing design weaknesses associated with interface problems, time dependent failures, and thermal balances involving heat sinks and heat removal. A typical example of the usefulness of Project Orbit is discussed.

A revision in the gyro design resulted when, during the operation of the autopilot under an emergency mode (decompressed cabin), a failure in the gyros caused by decreased heat dissipation under vacuum conditions was disclosed. The lubricant vaporized, and there was a breakdown in insulation windings. The problem was resolved by changing the lubricant to one having a lower vapor pressure, and by using an insulation that maintained its dielectric characteristic when subjected to high temperatures.

Spacecraft subsystems tests: Spacecraft subsystems tests at the contractor's plant were followed by extensive tests at Cape Canaveral. Altitude sensitive systems were tested in an altitude chamber at the Cape since such tests were not made at the contractor's plant for each spacecraft.

Flight testing.—Contributing much to the success of Project Mercury was the flight test program. Each flight of this test program was designed to qualify equipment and procedures for succeeding flights as well as ultimately for the manned orbital flights. Any malfunctions that occurred in a flight were analyzed, and corrected prior to the next flight. These early flights included (1) Beach Abort for qualifying the launch escape and landing system; (2) the Little Joe flights; (3) the Mercury–Atlas unmanned ballistic flights for qualifying the structure and ablation shield under severe reentry conditions, (4) the ballistic Mercury–Redstone unmanned, primate, and manned flights, and (5) the Mercury–Atlas unmanned and primate orbital flights.

The manned orbital flights progressed in a logical manner from a 3-orbit mission to a 22-orbit mission.

Technical competence.—A very important feature of the Mercury approach to flight safety was the assignment of personnel with a high level of technical competence to the performance and monitoring of all preflight tests and preparations at the launch site. Senior engineering personnel, in many cases key members of the original design team, moved to the launch site and developed the launch preparation procedures. This high level of competence also extended into the quality control and inspection areas at the launch site.

Quality screening.—The Mercury Project has featured extremely tight quality screening for deficiencies during all preflight checkout operations. This was accomplished by providing a system for effectively reporting unsatisfactory conditions to the contractor and to NASA management, to obtain conclusive corrective action, and to eliminate irregularities and deficiencies which adversely affect the spacecraft program. These anomalies were recorded on forms noted as Unsatisfactory Reports (UR's).

Failure analysis and corrective action.—The effectiveness of the contractor's failure analysis and corrective action program was evolutionary and improved considerably as the project went through its transition period from unmanned to manned flight. Later in the program, it became apparent that a streamline procedure was necessary for failure diagnosis and corrective action to assure effectivity in subsequent spacecraft. In many cases joint contractor-MSC teams analyzed a failure on-the-spot, or hand-carried the failed part to the supplier where a laboratory analysis of the failure was made.

In addition to individual failure reports on all failures, the contractor maintained an up-to-date status of all failures, submitting an IBM tabulation summary to MSC monthly. This tabulation included all unresolved failures, and was used to point out critical and recurrent problems.

Operations

Simulated Flights

There were several features and practices in the Mercury operation that are worth mentioning in connection with reliability and safety. A great deal of attention was given to rehearsals and simulations of complete missions prior to each flight. These simulations were made extremely realistic. They not only served to verify the feasibility of planned procedures and provide crew practice for the expected flight plan, but also included a wide range of emergencies deliberately introduced to show up areas where improved planning might be needed to eliminate all possibility of confusion or indecision.

Interface Control

With different groups responsible for the launch vehicle and the spacecraft, there was need for very special planning and procedures to insure proper handling of interface problems. It was found necessary in the field to establish a joint inspection team charged with the responsibility for witnessing all mating and other interface activities, measuring and verifying the adequacy of all physical clearances, inspecting all structural joints and electrical connections, and assuring that no debris was left in critical areas. Adequate access ports for field inspection were found to be an absolute requirement.

Special procedures were established for maintaining and periodically distributing one and only one official interface wiring diagram, reflecting the exact current status of the wiring on the vehicle at specified dates.

Flight Safety Reviews

The final item on figure 6–6, Flight Safety Reviews, deals with the problem of determining that the launch vehicle and spacecraft were in fact ready for launch. These activities are covered in figures 6–2 and 6–7. In Mercury, the philosophy was adopted that a launch would not take place with any unresolved difficulty. To insure this, preflight launch vehicle readiness and spacecraft readiness review meetings were set up. In these meetings, representatives from engineering, operations, flight safety, astronauts, and Cape inspection reviewed in detail with the specialists responsible for the checkout of each system, all malfunctions observed in the system, and all changes and corrections made. Two sets of contractor failure records were maintained: first, a segregation of failures from all testing into specific subsystems; second, a file of all failures associated with subsystems of a specific spacecraft. From these records, it was possible to determine any general weaknesses and to review the case histories of critical areas in any specific spacecraft. These data, together with the unsatisfactory reports (UR's) and record of anomalies occurring in the subsystems checkout recorded by MSC personnel at the Cape provided a major input in these meetings.

These detailed meetings on the major pieces of equipment were followed by a Final Mission Review meeting. This meeting provided a final

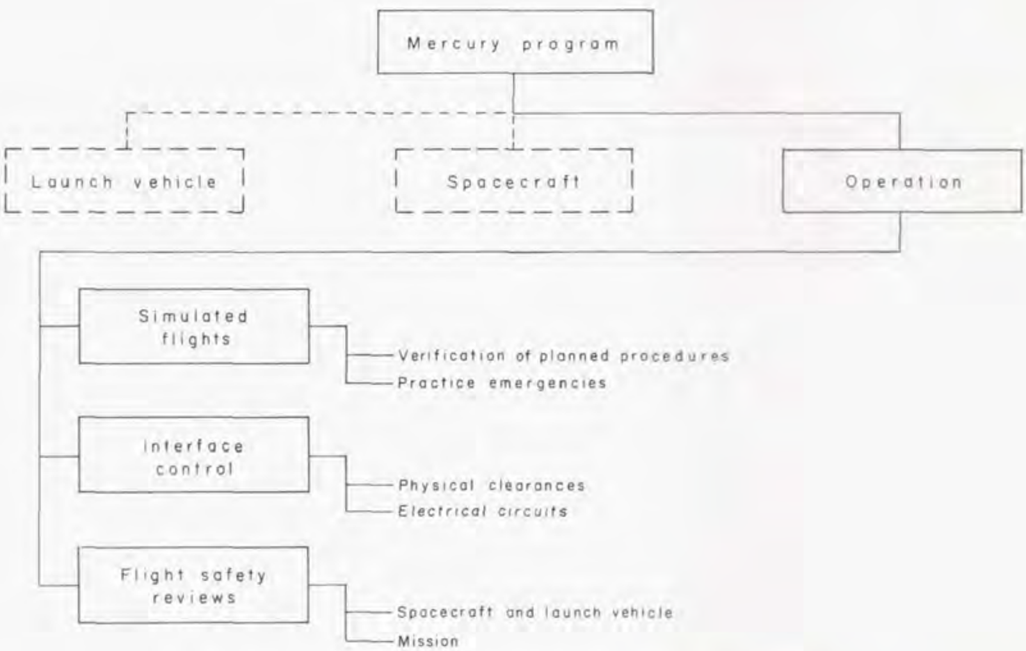

FIGURE 6–6.—Operational reliability and flight safety features.

confirmation of launch-vehicle and spacecraft readiness and established the readiness of the range, recovery, weather, and aeromedical elements.

These operating procedures were very effective in concentrating the attention of the best qualified technical talent available on the detailed engineering problems of each vehicle.

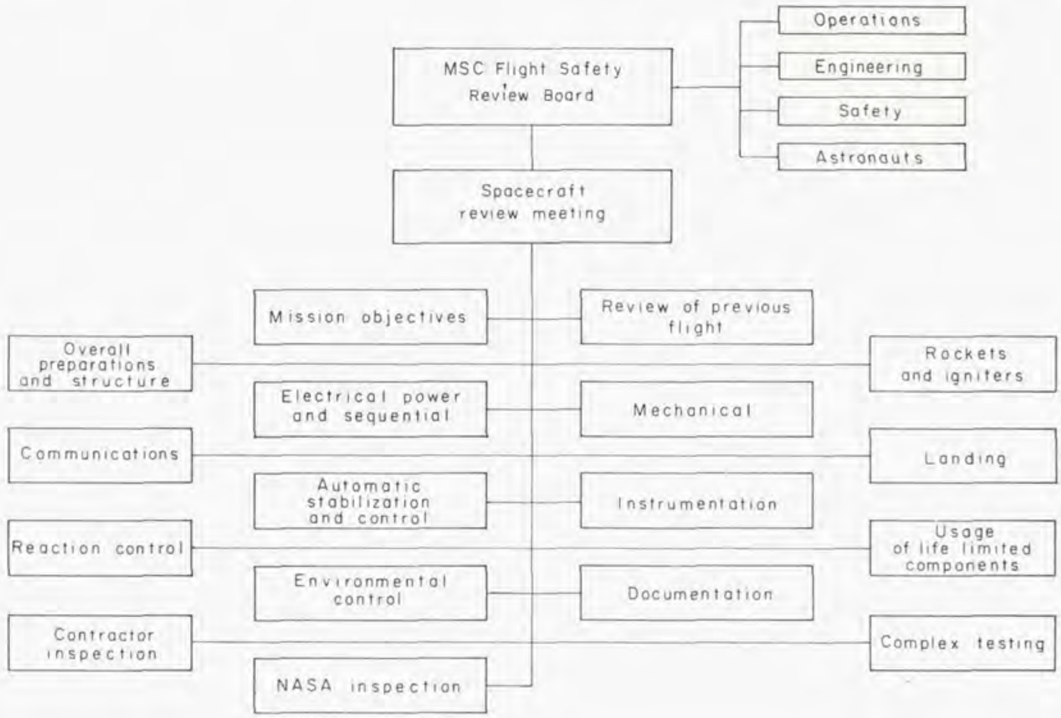

FIGURE 6-7.—Spacecraft review activities.

II

MISSION SUPPORT DEVELOPMENT

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7. TRAJECTORY ANALYSIS

By JOHN P. MAYER, *Asst. Chief for Mission Planning, Flight Operations Division, NASA Manned Spacecraft Center; and* CARL R. HUSS, *Flight Operations Division, NASA Manned Spacecraft Center*

Summary

A description of the mission analysis studies conducted for Project Mercury is given along with specific examples for the various mission analysis phases.

Aborted mission studies constituted about 90 percent of all mission-analysis studies conducted. These studies were necessary from a flight-safety standpoint and are considered equally applicable to future manned spacecraft projects. It was found that the basic mission design must be chosen in a flexible manner so that consideration can be given to the changes in mission constraints. Real-time computing has proved extremely valuable in Project Mercury; however, consideration must be given to changes in mission operational plans which cannot be effectively included in the Real Time Computer Complex.

Introduction

The mission-analysis effort in Project Mercury was conducted in several phases leading up to the flight missions. These phases include the mission analysis supporting the systems design of the spacecraft, the basic operational design of the Mercury missions based on mission requirements and objectives, detailed operational mission analysis for each specific flight, and the formulation of the mission logic to be included in the computer used for inflight real-time control of the missions.

Mission Phases

In figure 7–1 are shown the important phases of mission-analysis studies. In the early mission-analysis phase, the analysis was specifically for use in spacecraft system design. For example, the maximum loads and heating conditions were determined for structural design, and the spacecraft propulsion performance requirements were determined leading to the design of the retrorocket system. After the spacecraft systems were essentially designed, the mission-analysis effort shifted to the operational phase. In this phase the system design was reasonably fixed and the detailed mission design was then accomplished by taking into account all of the constraints, including spacecraft, launch-vehicle, and operational constraints. The objective in this phase is to design a mission within the capabilities of the actual spacecraft system developed. In this phase of the mission some feedback into system design was made, although these were small changes since the early design proved to be sound.

The next mission analysis phase was in the design of specific missions. In this case the mission analysis was specialized to handle the aspects of a particular mission by using the actual performance characteristics of the launch vehicle and spacecraft being used. This phase also included the analysis for the particular operational mission objectives and ground rules developed for these missions.

The next phase was the real-time mission-analysis phase, which started at the beginning of the launch countdown and lasted until the

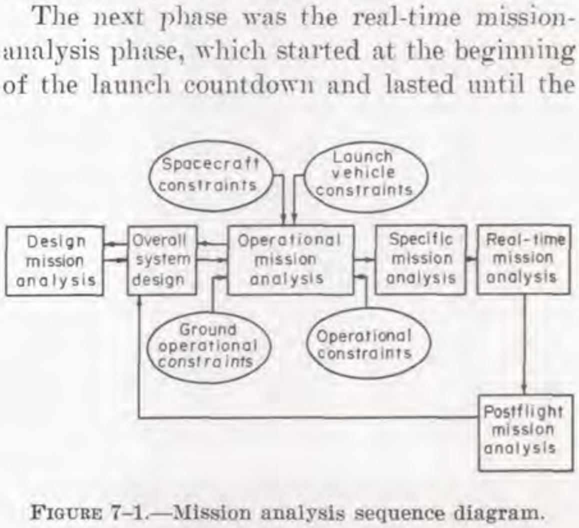

FIGURE 7–1.—Mission analysis sequence diagram.

vehicle was recovered after the mission. In this, calculations were accomplished in real time by a computer; however, the logic and equations used in this computer were developed in the preceding operational mission-analysis phase. Although every effort was made to anticipate all the possibilities that could affect the flight and include them in the real-time computer program, these possibilities were never fully established. Therefore, mission-analysis experts were used as flight controllers and also performed auxiliary computing using off-line computers other than those used in the real-time computing complex during the missions.

The next mission-analysis phase was a postflight analysis phase in which the information obtained from actual flights was fed back into the plans for future flights and, in some cases resulted in system modifications to the spacecraft, the launch vehicle, and the ground support system.

Some specific examples of mission constraints affecting the analysis are shown in figure 7-2. Some of the spacecraft constraints that must be considered are the performance of the spacecraft propulsion system, the spacecraft control system accuracies, and other system limitations. Some of the ground complex constraints to be considered are performance (which includes the effects of the locations of command stations and command ranges) and system limitations. Constraints involving the launch vehicle which had to be considered were performance, guidance accuracies, and systems limitations. In Project Mercury the systems limitations of the launch vehicle included heating and load restraints and the guidance radar look angle constraint.

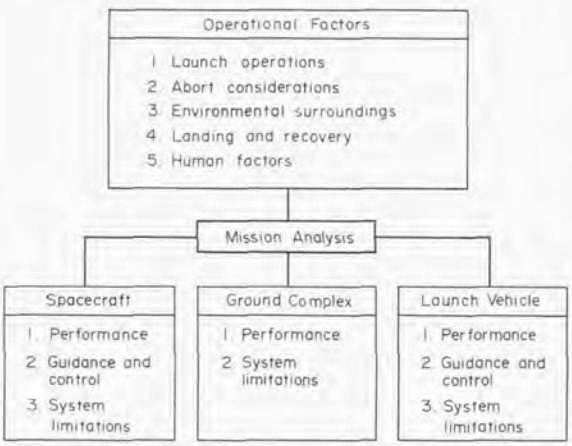

FIGURE 7-2.—Operational mission analysis.

The operational constraints to be considered in the area of launch operations are range safety limits, abort considerations, environmental considerations, landing and recovery considerations, and human factors. Some of the environmental factors that were considered were the effect of atmospheric and geophysic constraints and winds. Consideration had to be given to recovery and landing constraints for both normal and aborted missions and, in all cases, the human tolerances to acceleration loads and motions were considered.

Abort considerations resulted in about 90 percent of the mission-analysis studies. Studies were made to provide flight controllers with the information as to when to initiate aborts for maximum pilot safety. Studies were also made to determine allowable tolerances in order to obtain safe miss distances between the launch vehicle and the spacecraft and acceptable lateral loads. Also of importance were the studies to determine the abort recovery areas for all phases of the flight.

In order to illustrate some of the techniques used and the results accomplished in the mission-analysis area, a few specific examples from each phase will be discussed.

Design Mission Analysis

One example of the work performed in the advanced mission analysis phase is illustrated by a study of the immediate post-abort conditions. The selection of the escape-rocket offset involved a compromise between high lateral loads and low miss distances between the space craft and the launch vehicle in the high-dynamic-pressure abort phase of launch. For low offset values the probability of exceeding high lateral loads was low; however, the probability of obtaining low miss distances was high. For high values of the offset the opposite is true. Thus, the selection of the offset was made on the basis of minimum combined probability of occurrence of either events. In figure 7-3 the combined probability of exceeding either a dangerous lateral load or an unacceptable miss distance is shown plotted against the escape-rocket offset.

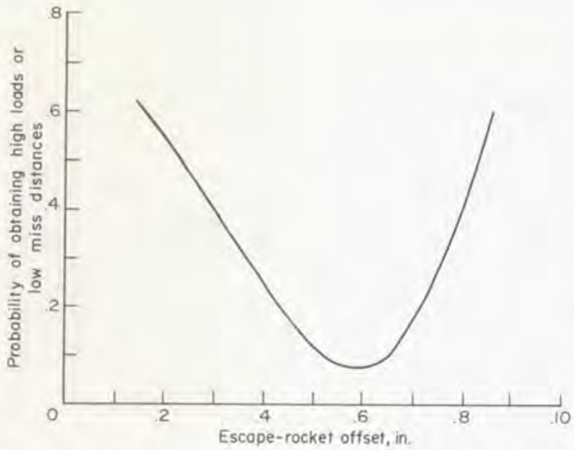

FIGURE 7-3.—Selection of escape-rocket thrust offset.

Operational Mission Analysis

A typical example of the operational mission analysis was in the selection of the Mercury orbital elements. The orbital inclination which governed the ground track for Project Mercury was selected because the network facilities established prior to Mercury could be used to good advantage, reentries for the first three orbital passes and the 16th to the 18th passes occurred over the United States, and the orbital ground track fell within the temperate region of the world. In addition, the specific Mercury inclination was affected by launch-abort recovery considerations.

The orbital altitude and shape of the Mercury orbit were selected based on launch-vehicle performance, accuracy, and abort operational considerations. These considerations are illustrated in figures 7–4 to 7–7. In figure 7–4 the orbital lifetime is shown plotted against apogee altitude for given perigee altitudes. For Project Mercury it was desired to have minimum lifetime of 36 hours for a 24-hour mission. Since the atmospheric densities at orbital altitudes were not well-defined at the time Project Mercury was initiated, it was believed that a conservative value for density must be used for estimating lifetime. The density used in this figure is considered to be a 3σ, or very conservative, dense atmosphere. From figure 7–4 it can be noted that for an adequate lifetime a circular orbit at an altitude of 105 nautical miles could have been selected, or an elliptical orbit having the same lifetime could have been selected, for example, an orbit having an 80-mile perigee and a 170-mile apogee.

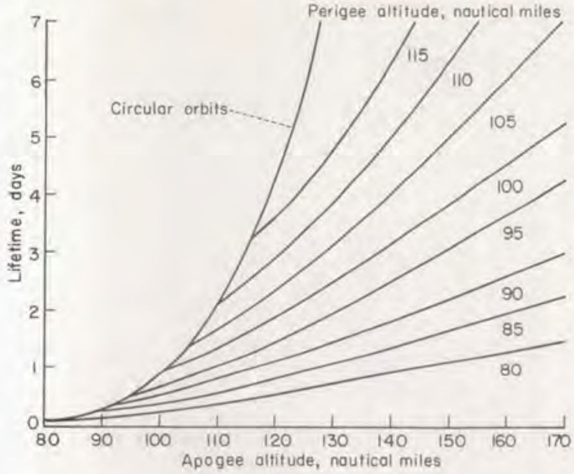

FIGURE 7–4.—Minimum lifetimes for elliptical orbits.

The next constraint to be considered is that of launch-vehicle performance. In figure 7–5 the staging time is shown plotted against the insertion or perigee altitude. The curves shown are given for a constant orbital lifetime; that is, the apogee altitude decreases as the insertion altitude increases. For a constant insertion altitude the performance, or excess velocity available above that required ($\triangle V_{min}$), increases with staging time until it reaches a peak value. For greater staging times the performance decreases. The minimum acceptable performance curves are shown in figure 7–5. The increment of velocity $\triangle V$ that defines the acceptable performance is the difference between the velocity at fuel depletion and the planned velocity. Therefore, all of the clear area in the figure would represent acceptable orbital insertion altitudes.

The launch-vehicle guidance accuracies are considered in figure 7–6. Since the Atlas launch vehicle used for the Mercury program was guided by a radio guidance system, the guidance accuracy was dependent to some extent on the radar elevation angle at cut-off. In figure 7–6 the minimum elevation angle E_{min} which was considered acceptable is shown. Again the clear area in the figure is indicative of acceptable orbital insertion conditions. Next, however, the operational considerations must be included. These are shown in figure 7–7. In this case the operational consideration which affected the orbital conditions was the requirement to avoid a landing in Africa for an abort from the minimum acceptable velocity. In this figure the position of the line shown is such that the spacecraft would not land in Africa if an abort were made at the no-go velocity, with allowance for the dispersions on the abort landing area. From figure 7–7 it may be noted that the operational consideration significantly affects the orbital insertion altitudes which could be used for Project Mercury.

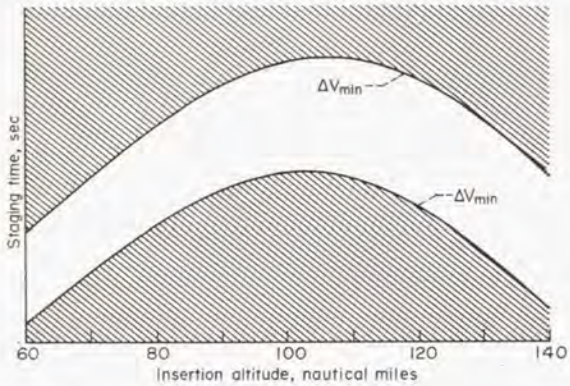

FIGURE 7–5.—Effect of launch-vehicle performance.

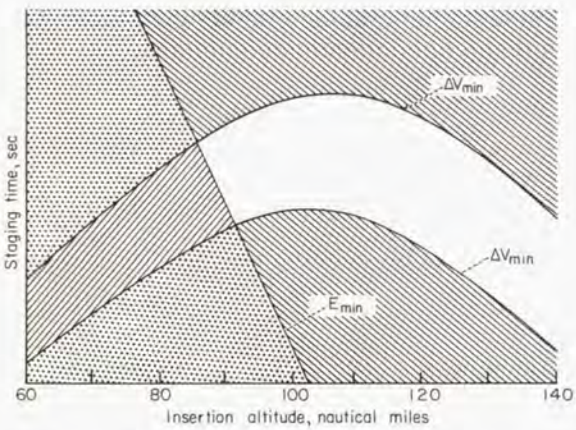

FIGURE 7–6.—Effect of launch-vehicle guidance.

As operational experience was gained in Project Mercury flights, confidence and knowledge in the systems made it possible to reduce to some extent, the original guidance and performance constraints. For example, the minimum elevation angle was reduced after obtaining a better understanding of the effects on guidance accuracy from operational experience with the guidance system.

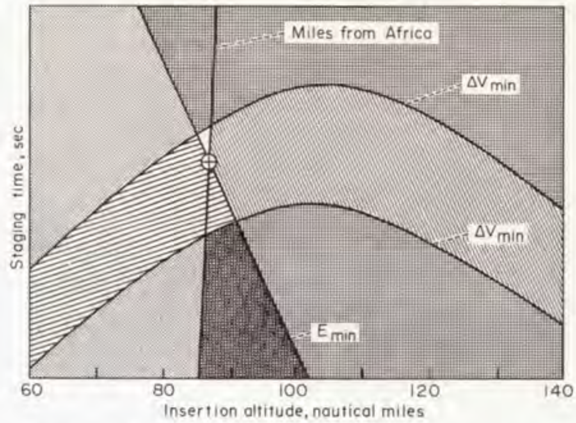

FIGURE 7–7.—Effect of operational constraints.

Specific Mission Analysis

A considerable mission-analysis effort is made in the design of each specific Mercury flight. Included in this effort are detailed trajectory calculations for the mission, dispersion calculations, calculations concerning aborts during all phases of the mission, and calculations of retrograde time to be used in the mission. When the flight day arrived, special mission-analysis studies were performed to support the flight. These studies included evaluating the wind effects on the loads on the launch vehicle and determining the landing areas of the spacecraft in aborted missions based on actual wind profiles. In figure 7–8 the effects of the actual winds on the abort landing areas at various times of the flight are shown for the MA–9

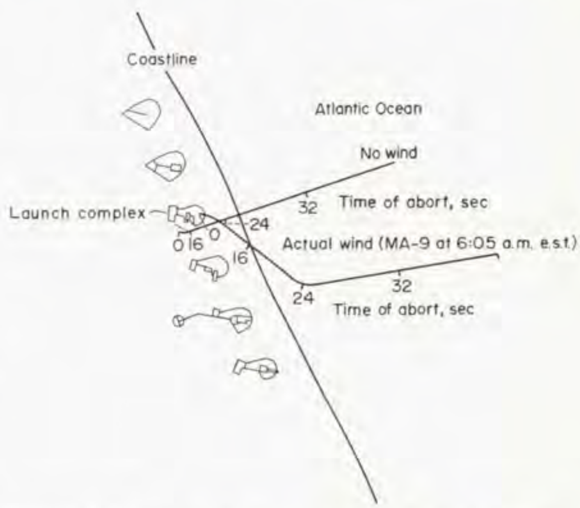

FIGURE 7–8.—Effects of actual winds on MA–9 abort landing.

mission. These calculations were made to enable the recovery forces to be positioned prior to the launch such that they could most easily make an emergency recovery should abort occur.

Real-Time Mission Analysis

General Computing Requirements

Real-time computing has proved very valuable in Project Mercury for use in flight control and monitoring. The basic computing requirements in real time are as follows:

(*1*) *Powered flight.*—Pertinent trajectory parameters were computed in order that the status of the launch could be monitored for any indication of an impending abort. The cut-off velocity was used to determine the acceptability of the orbital parameters based on preplanned criteria. In addition, landing points for possible aborts and radar-acquisition data were computed.

(*2*) *Aborted missions.*—For aborted missions the computer must be programed to select a target recovery area and if necessary compute the time for retrofire to land within this area.

(*3*) *Orbit.*—In this phase the orbital parameters were predicted with sufficient accuracy to establish the minimum lifetime of the orbit, to predict the retrofire time to land in normal and contingency recovery areas, to determine spacecraft orbital position, to determine acquisition data for all radar sites, and to predict the time of landing for use by recovery forces.

(*4*) *Reentry.*—During reentry the computer program recalculates and updates the landing point and time of landing, based on conditions at retrofire, in addition to predicting acquisition data for reentry radar stations.

Example of Go—No-Go Computation

The computation of the go—no-go parameters was probably the most important of the real-time computations. The selection of the Mercury go—no-go criteria which were used in the real-time computing program is shown in figures 7-9 to 7-11. In figure 7-9 the minimum energy for an acceptable Mercury mission is illustrated. The flight-path angle at insertion is plotted against the insertion velocity. The minimum acceptable orbit was defined as that orbit in which the spacecraft could safely complete one orbital pass and land. Because of the

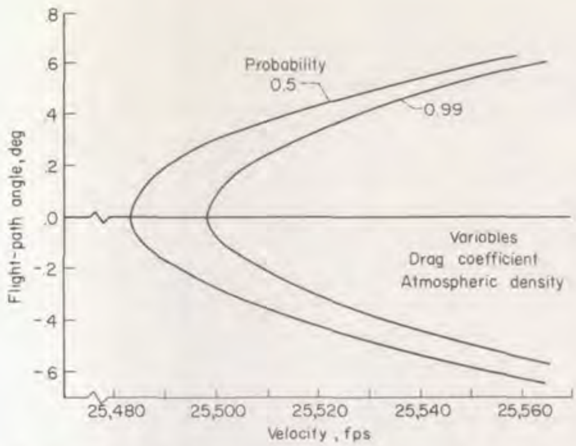

FIGURE 7-9.—Determination of minimum acceptable orbit.

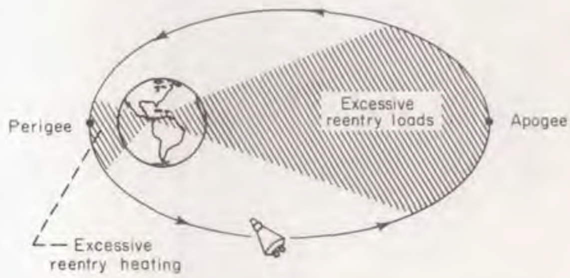

FIGURE 7-10.—Determination of maximum acceptable orbit.

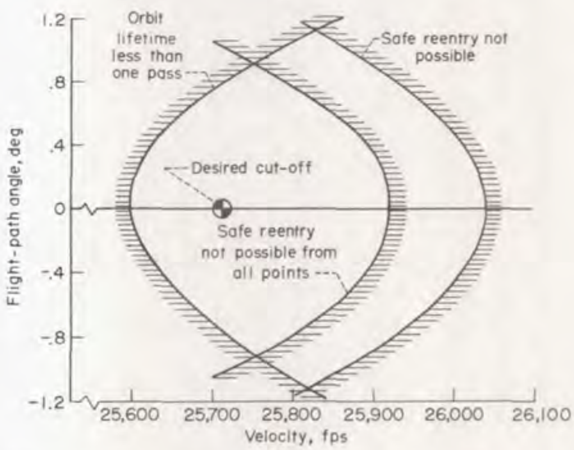

FIGURE 7-11.—Operational go—no-go orbital-insertion criteria.

critical flight safety nature of the problem, the minimum orbit was selected on the basis of a very conservative drag coefficient C_D and atmospheric density ρ. The symbol, $(C_D\rho)_n$, shown in figure 7-12 has been normalized and represents the ratio of the parametric drag coefficient-density product to a nominal value of this product. Therefore, values of $(C_D\rho)_n$ which are greater than unity are considered to be conservative. The 99-percent probability curve shown in figure 7-9 was the one selected for the go—no-go criteria. Therefore from a lifetime consideration the conditions would be "go" at velocities higher than this boundary; however, other constraints imposed a limit at higher velocities.

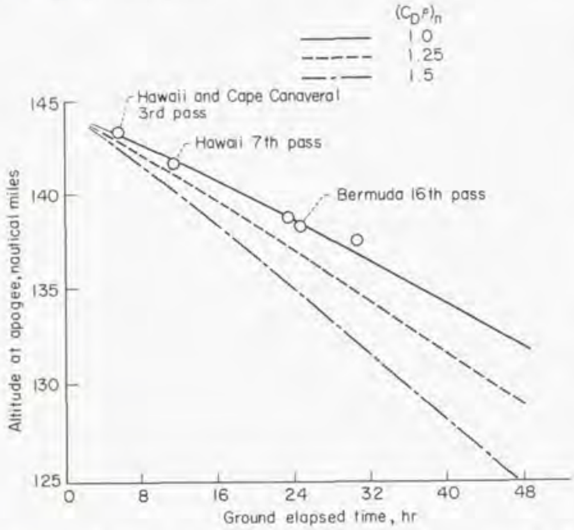

FIGURE 7-12.—Effects of actual atmosphere on MA-9 orbital lifetime.

In figure 7-10 the determination of the maximum energy orbit is illustrated. As the velocity is increased above orbital velocity the apogee increases approximately 1 mile for every 2 feet per second. When the velocity reaches a certain critical value, an area occurs near perigee such that, if the retrorockets were ignited, excessive heating would occur during reentry. As the velocity increases above this value this critical area near perigee extends over most of the orbit and another critical area for initiation of reentry appears near apogee. At this point if reentry were initiated, the reentry loads would become excessive. As the velocity is further increased, a velocity is reached in which these critical areas cover the entire orbital range and a safe reentry would not be possible from any point in the orbit. The operational go—no-go criteria that resulted from these constraints are shown in figure 7-11 where the flight-path angle at cut-off is plotted against the insertion velocity. The region for a minimum acceptable orbit lies within the boundaries shown. For all Project Mercury missions the cut-off velocities were well within the safe boundaries. For the MA-9 mission, for example, the cut-off occurred within the boundary of the symbol shown in this figure.

As was previously stated, some auxiliary computing was performed during each mission outside of the real-time computers. An example of this auxiliary computing is shown in figure 7-12 where the effects of the actual atmosphere on the orbital lifetime of the MA-9 mission are shown. In figure 7-12 apogee altitude is plotted against time. Because of the length of the MA-9 mission and the uncertainty of the density of the actual atmosphere on the day of this flight, it was thought necessary to attempt to determine the variation of the actual atmosphere from that used in preflight computations. This calculation was necessary in order to commit the mission to completing 22 passes at a predetermined time during the flight. The lines shown in the figure are for precalculated atmospheric densities which varied from that of the assumed atmosphere. The symbols in this figure indicate the actual apogee obtained during the flight and also that the actual atmosphere was very close to that used in the preflight computations. The actual orbital lifetime for the MA-9 mission would have been about 4.7 days if a reentry were not initiated using the retrorockets.

Concluding Remarks

The operational experience obtained in mission-analysis studies for Project Mercury has proved valuable for application to other manned space-flight programs. Aborted mission studies constituted about 90 percent of all the mission-analysis studies conducted for Mercury. Although the results of these studies were not required operationally, the amount of effort spent on abort studies is necessary from a flight-safety standpoint and will be equally applicable to future manned space projects. It is also evident that the basic mission design must be chosen in a flexible and manner so that consideration can be given to changes in the spacecraft launch vehicle or operational constraints. Real-time computing has proved extremely valuable in Project Mercury; however, it seems that consideration must always be given to changes to mission operational plans which cannot be effectively included in the real-time computing complex. Therefore, auxiliary inflight computing probably should always be considered.

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8. WORLDWIDE NETWORK SUPPORT

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Summary

Because the Mercury orbital flight program required effective ground control during the unmanned and manned phases, a worldwide tracking and telemetry network was developed. Early in the project, the requirements for the network in terms of systems, installation, site locations, testing, and training for network personnel were established. Maximum utilization was made of existing facilities, but additional stations had to be implemented because of a strategic need at certain points along the orbital ground track. In addition to the telemetry and tracking facilities, two important centers were established, those of the Mercury Control Center, which was the focal point for all flight control activities, and the Computing and Communications Center. System reliability and provision for ease of maintenance were primary guidelines during the network implementation. Because of the unique spacecraft tracking task, an acquisition aid device was developed to assist in the location and tracking at first contact with the spacecraft. As the telemetry, tracking, and computation functions of the network were being installed, the network was staffed to support even the early ballistic flight program. As the scope and complexity of the missions increased, the network was expanded and modified to accept the changing and more demanding flight control and monitoring requirements. In addition to the tracking and data reception capabilities of the network, a multi-frequency air-to-ground reception and remoting provision was necessary during the manned flight program. A requirement had been established to provide continuous tracking and communications during the launch phase, as well as voice communications with the astronaut within maximum prescribed time intervals. Throughout the Mercury-Atlas orbital flight program, the Mercury Worldwide Network provided adequate and timely support in each of its charged responsibilities. Voice communications, telemetry, and tracking were satisfactory for effective flight control and monitoring, and the computation and data handling facilities provided timely support during the critical retrofire and reentry phases of each of the manned orbital flights.

Introduction

Meeting mission objectives required that a worldwide tracking and ground instrumentation system be developed to provide a continuous flow of information to be used for mission control. The intent in this paper is to describe the evolution of the network in support of the various Mercury missions. Specifically, the paper discusses the development of network requirements and systems; installation, test, and training; the network configuration and later changes made in response to mission requirements, operations, and performance.

Development of Network Requirements

Approach

The task of implementing a tracking and ground instrumentation system was given to the NASA Langley Research Center (LRC). LRC formed the Tracking and Ground Instrumentation Unit to manage and direct this effort. This unit in turn utilized industrial firms to assist in determining the approach to be taken in meeting the requirements in certain critical areas and to augment the NASA team.

Basic Requirements

Basically, network systems were required to provide all functions necessary for ground control and monitoring of a Mercury mission from launch to landing. The function of the network was to end when the spacecraft had landed and the best possible information on the location of the landing point had been supplied to the recovery teams.

At the outset, the following functional requirements were established:

(1) Provision of adequate tracking and computing to determine launch and orbital parameters and spacecraft location for both normal and aborted missions.

(2) Voice and telemetry communications with the spacecraft with periods of interruption not to exceed 10 minutes during the early orbits, contact at least once per hour thereafter, and communications to be available for at least 4 minutes over each station.

(3) Command capability to allow ground-initiated reentry for landing in preferred recovery areas and to initiate abort during critical phases of launch and insertion.

(4) Ground communications between the ground stations and the control center.

Safety of the Mercury spacecraft and its occupant was made a dominant consideration. Speed and efficiency of installation were essential to meet the planned operational dates. Although no compromises with safety were made, economy was an important consideration in the overall plan.

Selection of Stations

Stations were selected on considerations of the flight plan and on the character of the spacecraft electronic systems consistent with the basic requirements. Because of factors relating to the earth's rotation and the lack of suitable geographic locations, certain compromises had to be made in selecting the total number and locations of the stations required for a three-orbit mission. These compromises resulted in gaps, primarily on the third pass, greater than the desired 10 minutes. For stations selected, see figure 8–1.

FIGURE 8–1.—Map showing the locations of the selected Mercury stations.

Two Centers were also required:

The Mercury Control Center (MCC), to be located at Cape Canaveral, was to provide equipment necessary to allow control and coordination of all activities associated with the Project Mercury operation.

The Computing and Communications Center, to be located at the Goddard Space Flight Center (GSFC), Greenbelt, Maryland, was to provide for communications control, switching and distribution; also, it was to provide all computations necessary to monitor and control the mission from launch to landing.

Such an arrangement of stations, supported by appropriate instrumentation, would provide for tracking, command, and monitoring capabilities in the highest probable abort phase of launch through insertion and for the critical reentry phase after orbital flight. It also allowed the maximum use of facilities at the National Ranges and of equipment at the Australian Department of Supply facilities at Woomera, Australia. The participating countries and ranges were as follows:

The U.S. Department of Defense provided use of facilities at the Atlantic Missile Range, Pacific Missile Range, White Sands Missile Range, and the Eglin Gulf Coast Test Range.

Australia allowed the use of certain existing facilities and construction, installation, and operations of the required new facilities. These arrangements were made through the Australian Department of Supply and were implemented by the Weapons Research Establishment.

United Kingdom permitted the construction of stations in Canton Island and Bermuda.

Nigeria agreed to the lease of land and permission to construct a station in Tungu and Chawaka.

Spain agreed to provide the land for the Canary Island station.

Development of Equipment Systems

Criteria and Equipment Functions

Basic equipment design and implementation criteria for this program were the result of several major considerations. One of these was economics: existing facilities were to be used wherever they met the Mercury location requirements. Thus, at six locations, a major part of the equipment, including most of the network's tracking radars, was already available. Another major consideration was time. Maximum use of existing, proven equipment was dictated by the necessity to avoid the long-lead times required for research and development. But the primary consideration, overriding all others, was the safety of the astronaut. Some of the design requirements stemming from this consideration follow:

(1) *Reliability* of components and units was required to be designed and engineered into every element of the equipment configuration, and adequate testing was required to prove this reliability.

(2) Despite rigid reliability requirements of units, *redundancy* was to be used extensively throughout each system and always at any critical point. Likewise, *diversity* was to be added to redundancy. Thus, a very reliable system was to be physically duplicated and then to be partially duplicated again by the use of an alternate frequency, location, or some other means of achieving diversity.

(3) Wherever possible, the network system should have the ability to verify its own proper functioning. Suitable monitoring and display devices were thus required.

There were also other requirements resulting from "overlapping" of two or more systems. One of these concerned interference. Determined efforts were made to minimize interference to non-Mercury users of radio frequencies; to reduce mutual interference between Mercury equipment so that there was no degradation of system performance under normal equipment operation; and, to minimize interference from non-Mercury sources by carefully selecting station locations and equipment placement. Interference studies and field measurements were to be undertaken as required. Radiated noise measurements were to be made at all sites.

Particular attention had to be given to system integration problems and to simplifications which might be possible; for example, without compromising reliability, the possibility of reducing the number of antennas at a given site by use of antenna-sharing systems had to be considered.

Finally, all equipment had to be able to withstand the environmental conditions found in such diverse climates as those of the desert at Woomera and the "salt air" of Bermuda.

To provide mission support, the equipment of the network had to provide the following major functions:

(1) Ground radar tracking of the spacecraft and transmission of the radar data to the Goddard computers

(2) Launch, orbital, and reentry computations during the flight with real-time display data being transmitted to Mercury Control Center (MCC)

(3) Real-time telemetry display data at the sites

(4) Command capability at various stations for controlling specific spacecraft functions from the ground

(5) Voice communications between the spacecraft and the ground, and maintenance of a network for voice, teletype, and radar data communications.

Development of the individual systems to meet these requirements is described in the following paragraphs. Some systems have been discussed in earlier publications (refs. 1 and 2); so they are only briefly described here, whereas other systems, especially systems requiring extensive design, are covered in more detail.

Radar

Mission requirements dictated the need for continuous radar tracking during launch and insertion to monitor the launch phase and to establish the initial orbital parameters on which the go—no-go decision would be based. During orbital flight, additional tracking data would be required for a more precise determination of the orbital parameters and time of retrofire for the desired landing point. As nearly continuous tracking as possible was necessary during the less predictable reentry portion of the flight to provide adequate position data on the spacecraft's landing point.

To obtain reliability in providing accurate trajectory data, the Mercury spacecraft was equipped with C-band and S-band cooperative beacons. The ground radar systems had to be compatible with the spacecraft radar beacons.

The FPS–16 radar (fig. 8–2) in use at most national ranges was selected to meet the C-band requirement. Although it originally had a range capability of only 250 nautical miles, most of the FPS–16 radar units selected for the project had been modified for operation up to 500 miles, a NASA requirement, and modification kits were obtained for the remaining systems. In addition to the basic radar system, it was also necessary to provide the required data-handling equipment to allow data to be transmitted from all sites to the computers. Details on data flow and computation are discussed subsequently in the computer section.

FIGURE 8–2.—FPS–16 radar installation at California.

The FPS–16 system originally planned for the network did not have adequate displays and controls for reliably acquiring the spacecraft in the acquisition time available. Consequently, a contract was negotiated with a manufacturer to provide the instrumentation radar acquisition (IRACQ) modifications. An essential feature of this modification is that it examines all incoming video signals, verifies the target, and automatically establishes angle-only track. Once the spacecraft has been acquired, in angle range, tracking in the automatic mode can be achieved with relative ease. Other features of the IRACQ system included additional angle scan modes and radar phasing controls to permit multiple radar interrogation of the spacecraft beacon. The addition of a beacon local oscillator wave meter permitted the determination of spacecraft-transmitter frequency drift.

Early in the installation program, it was realized that the range of the Bermuda FPS–16 should be increased beyond 500 miles. With the 500-mile-range limitation, it was possible to track the spacecraft for only 30 seconds prior to launch-vehicle sustainer engine cut-off (SECO) during the critical insertion phase. By extending the range capability to 1,000 miles, the spacecraft could be acquired earlier, and additional data could be provided to the Bermuda computer and flight dynamics console. This modification also increased the probability of having valid data available to make a go—no-go decision after SECO.

The Verlort radar (see figs. 8–3(a) and 8–3(b)) fulfilled the S-band requirement with only a few modifications. Significant ones were the addition of specific angle-track capability and additional angular scan modes. At Eglin Air Force Base the MPQ–31 radar was used for S-band tracking by extending its range capability to meet Mercury requirements. The data-handling equipment was essentially the same as for the FPS–16. Coordinate conversion and transmitting equipment was installed at Eglin to allow both the MPQ–31 and the FPS–16 to supply three-coordinate designate data to the AMR radars via Central Analog Data Distributing and Computing (CADDAC).

After implementation these radar systems performed as planned, and only minor modifications were made.

Active Acquisition Aid

Once the types of radars to be used were determined, it became evident that these narrow-beam, precision-tracking units would have difficulty in initially acquiring the small, high-speed spacecraft. Without externally supplied dynamic pointing data, the spacecraft would pass through the radar beam so quickly that the basic radar circuits and/or operators would have very little time in which to recognize the target and switch into automatic tracking.

Two basic types of solution to the radar-acquisition problem were considered. One was the use of an on-site analog computer which would be supplied with predicted spacecraft time and position data by teletype from the Goddard computers. The on-site computer would then generate dynamic-tracking data along the predicted orbit and supply it to the radar during the passage of the spacecraft. This approach was rejected because of the cost and development time necessary to provide suitable analog computers and because it was felt that complete dependence on teletype data for acquisition would not provide sufficient overall tracking system reliability.

The second solution to the problem was a new development called the "active acquisition aid." This device was designed to receive the spacecraft telemetering signals and automatically track the spacecraft in angle with sufficient accuracy to provide suitable pointing data to the radar.

The hardware to meet these requirements was developed around refurbished and modified SCR-584 radar pedestals, antenna, and receiver components. The major units of the final configuration used for Mercury are shown in figure 8-4, and figure 8-5 shows the acquisition aid antenna installation at Guaymas, Mexico.

(a).—Verlort installation at Bermuda.

(b).—Interior view of a Verlort radar van.

FIGURE 8-3.—Photographs of Verlort installations.

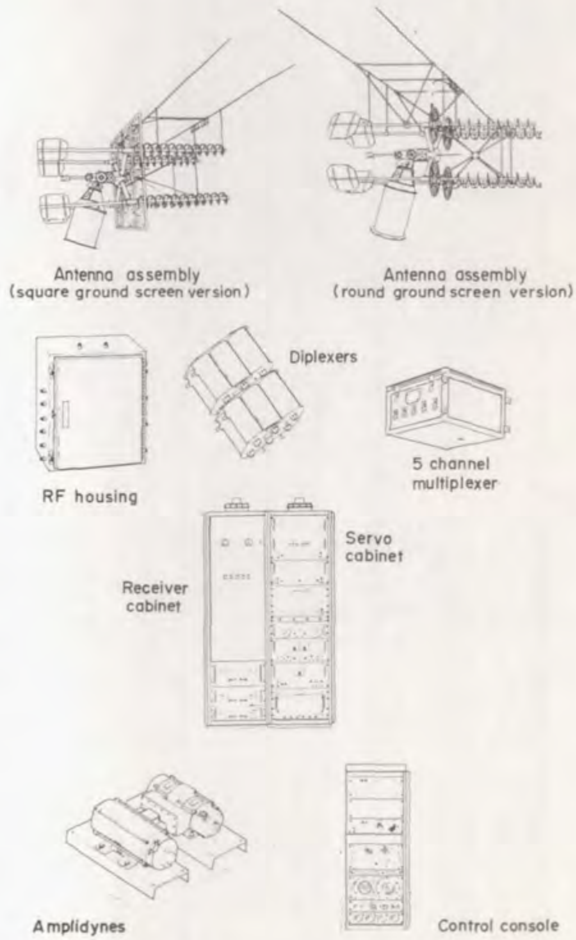

FIGURE 8-4.—Major units of the acquisition system.

Performance analysis.—Tests of the first systems delivered showed two major performance deficiencies. The first of these stemmed from the fact that the spacecraft-telemetering transmitter bandwidth was substantially wider than had been anticipated; the acquisition aid receiver was consequently unable to achieve phase lock. This deficiency was corrected by adapting another existing detector design to the Mercury equipment.

FIGURE 8-5.—Acquisition aid antenna installation at Guaymas, Mexico.

The second major performance problem was that the equipment could not meet tracking accuracy specifications on a continuous basis. Two principal factors contributed to the accuracy problem. The predominant one, especially at low and medium elevation angles, was that of multipath signal reception. The lesser factor was the inherent coarseness of the quadhelix antenna array and other RF components. Redesign of the antenna would have pushed beyond the state of the art and probably would have delayed the program. Use of another, existing antenna with less beamwidth and therefore less multipath susceptibility would, of course, have meant some sacrifice of one of the most desirable advantages of the system: that of being able to cover large areas of space in a short period of time.

Fortunately, early experience with the radars, particularly the FPS-16 which, equipped with the IRACQ modification, can lock on a target very quickly, indicated that the accuracy requirements of the acquisition aid could be relaxed; analysis of tracking requirements showed that with proper alinement, the equipment would provide sufficiently accurate data to the radars. The specified accuracy for the active acquisition aid was thus relaxed to require only tracking within the beamwidth of the particular radar with which it worked ($\pm 0.5°$ for the FPS-16 and $\pm 1.0°$ for the Verlort) for 2 seconds out of every 5 instead of $\pm 0.5°$ on a continuous basis.

With these changes, the initial performance deficiencies of the system were alleviated. However, in the course of the project, a number of other modifications to the equipment were found necessary to improve reliability, ease of maintenance, and ease of operation. Installation of hermetically sealed RF components, waterproof connectors, better antenna limit switching and mechanical limit stops, and bias regulators for the RF amplifiers was made to improve reliability. Test points and grounding switches in the voltage-controlled oscillator (VCO) and a connector board with many of the system test points in one convenient location were installed to improve the ease of maintenance. Changes to the antenna handwheels, relocation of controls, and installation of mode switches were made to increase the ease of operation.

In conclusion, it should be noted that although a number of problems of varying degrees of seriousness were encountered with the acquisition aid—most of them stemming from the necessity of developing a new system in an extremely short time—the equipment successfully fulfilled its intended function. Rarely during the latter Mercury missions did one of them fail to acquire and track the spacecraft shortly after horizon time and thereby aid the radar in acquiring an automatic track.

Computing System

Requirements.—Early in the design of the Mercury system it was considered mandatory to receive information on a real-time basis and to provide for instantaneous computation and display of mission data from lift-off to landing. To meet these requirements, new data transmission equipment and computer peripheral gear were required. A new concept in large-scale, real-time data processing was required to tailor computations to a computer cycle and to manage the priorities of the computations performed automatically.

In all phases of the Mercury mission, it was vital that the many different forms of calculations be performed with exact precision and the data be made available almost instantaneously. For example, in a matter of seconds after launch-vehicle cut-off and spacecraft insertion into orbit, the computers were required to furnish data based on tracking information for evaluating whether or not the mission should be permitted to continue.

Before the Bermuda submarine cable was installed, it was decided to supplement the Goddard-Cape Canaveral complex with a secondary computing station at Bermuda. Installed there was an IBM 709 computer that received the inputs of the Bermuda FPS-16 and Verlort radars. The role of Bermuda was twofold: it served as a backup remote control center during the launch phase and as a tracking site thereafter. Specifically, it performed the following computing tasks:

(1) Provided all the necessary trajectory information to drive the display devices in the Bermuda control center.

(2) Computed an independent go—no-go at insertion based on Bermuda data.

(3) Computed retrofire times to be used in the event of an abort to land the spacecraft in one of the designated recovery areas.

(4) Computed refined landing points for several abort cases.

(5) Computed orbital characteristics.

(6) Sent postinsertion conditions to Goddard.

After the submarine cable was installed in April 1962, the Bermuda computer was removed and all the computations listed above were programed in the Goddard computers.

System description.—Since the computing system was described in a prior publication (ref. 2), only a brief review is presented here.

During a mission, radar data from the network stations are transmitted by way of data circuits (ref. 2) to the communications center (fig. 8-6). Here, real-time equipment places the radar data from each tracking station automatically in the core storage of the computers. Two IBM 7094 computers operating independently, but in parallel, process the data. Should a computer malfunction during the mission, the other computer can be switched on-line to support the mission while the malfunctioning computer is taken off-line and repaired.

The computers provide trajectory information necessary for the flight control of the mission. At MCC, about 18 digital displays, 4 plotboards, and the wall map (fig. 8-7) are driven by the computers. This map shows the present position of the spacecraft and the landing point which would be achieved if the retrorockets were ignited in 30 seconds.

Development of new equipment.—To implement a real-time computing system of the complexity of the one considered for Project

FIGURE 8-6.—Computing center at Goddard Space Flight Center.

FIGURE 8-7.—View of Mercury Control Center showing wall map, plotting boards, and digital displays.

Mercury, it was necessary to design some specialized equipment. An example is the IBM 7281 Data Communications Channel (DCC) which automatically accepts inputs from a large number of data sources, places the information quantities directly at the disposal of the computer, automatically accepts calculated output data from the computer, and makes the information immediately available for transmission to many destinations.

For early missions, a duplexed configuration of IBM 7090 computers was connected by a DCC to radar stations, and sources comprising the real-time tracking and instrumentation system. For the MA-9 mission, a Triplex configuration of IBM 7094 computers, which were updated from the IBM 7090 configuration, was used.

Test and evaluation techniques.—Any system as complex as the Mercury network had to be thoroughly tested under conditions as close to actual operating conditions as possible. It had to be certain that the units and subsystems were functioning properly and that all elements were functioning together as a complete system. Thus, it was necessary to devise computer-controlled tests to check out all computer-related elements of the total system. Called CADFISS (Computation and Data Flow Integrated Subsystem) testing, this worldwide network test concept was employed in Mercury launch countdowns to determine final tracking and data processing system readiness.

Performance analysis.—A brief analysis of how the computing and data system performed during the manner orbital Mercury missions is presented.

Table 8-I shows FPS-16 and Verlort radar performance. Both radars approached their design limits while tracking an orbital target. The values were derived by fitting the data to the equations of motion. The data were far better than expected. Note that, up until the MA-9 mission, the standard deviation in elevation for the FPS-16 is twice that in azimuth, probably as a result of refraction errors. An improved correction for refraction was incorporated into the Mercury programs for MA-9. This is not apparent in the Verlort; apparently the much higher noise level concealed the refractive error. In many cases the data from certain FPS-16 and Verlort radars were better than the 0.1 mil and 1.0 mil criteria.

A comparison of the single-station FPS-16 orbital determination with the single-station Verlort solution shows that the FPS-16 is roughly four times as accurate in position and eight times as accurate in velocity determination.

The accuracy of the Mercury integration scheme, atmospheric model, and tracking data is demonstrated in table 8-II. The orbit, as determined by multiple station solution, was integrated forward to compare with newer tracking data. The vector changes in position and velocity were averaged and are presented in table 8-II.

The accuracy of the total system is demonstrated by the calculation of time-to-fire retrorockets. The spacecraft timing system is such that the rockets are fired at the integer second. With the spacecraft traveling at 5 miles per second, the landing point is known only to ±2.5

Table 8-I.—Radar Performance

Mission	Standard deviations—mission averages					
	FPS-16			Verlort		
	Range, yd	Azimuth, mils	Elevation, mils	Range, yd	Azimuth, mils	Elevation, mils
MA-6	8. 5	0. 23	0. 44	29. 0	1. 63	1. 35
MA-7	9. 8	. 22	. 40	33. 7	1. 62	1. 72
MA-8	8. 6	. 25	. 36	39. 6	1. 22	1. 34
MA-9	11. 2	. 27	. 26	20. 2	1. 36	1. 42

miles. The recovery forces are able to estimate their position to about ±2 miles. Thus, the total uncertainty may be approximately ±5 miles. Table 8–III shows the landing points predicted for the four manned missions. The center column shows the landing point established by radar tracking. The tracking information in MA–7 and MA–6 provided landing points within 15 to 20 miles of that reported by the recovery forces. This difference may have resulted from lift experienced by the spacecraft in reentry. The predictions for MA–8 and MA–9 are well within the area of uncertainty and show a nearly perfect retrofire and reentry.

Several years ago, a prediction such as that shown in table 8–III would have appeared very optimistic for the performance of the manned space-flight network. In considering performances as a whole, the network can be said to have performed considerably better than originally anticipated. The network tracking and computing system has successfully predicted the spacecraft landing points, and at all times has provided accurate information on the astronaut's position. For all of the Mercury missions, the network and computing system performed their basic functions normally and without exception.

Table 8–II.—Average Change in Position and Velocity

Mission	Change in position, yd	Change in velocity, ft/sec
MA–6	265	0.9
MA–7	266	1.1
MA–8	217	1.0
MA–9	[a]220	[a]1.6
	[b]1,040	[b]4.5

[a] First three passes

[b] Mission average—no data on 15 of 22 passes

Telemetry

Because the telemetry system has been described in reference 2, this section briefly describes only the design approach, modifications, and performance. To help orient the reader, a typical antenna installation at a telemetry station is presented in figure 8–8, and display and control consoles aboard a telemetry ship are presented in figure 8–9.

Table 8–III.—Results of Landing-Point Predictions Made by Computers

Mission	Predicted landing point	Reported pickup point of spacecraft
MA–6	21°31.2′ 68°52.9′	21°25.6′ N. 68°36.5′ W.
MA–7	19°24′ N. 63°52′ W.	19°30′ 64°15′.
MA–8	32°06′ N. 174°31.8′ W.	32°05.5′ N. 174°28.5′ W.
MA–9	27°22′ N. 176°29′ W.	27°22.6′ N. 176°35.3′ W.

FIGURE 8–8.—Antenna installations for the Telemetry and Control (T and C) Building Area, Guaymas, Mexico.

FIGURE 8–9.—Display and control consoles aboard the Rose Knot.

Design approach.—Obviously, the ground-station design requirements were established to be compatible with the spacecraft's telemetry characteristics. The basic type of telemetry system chosen early in Project Mercury was PAM/FM/FM. This system was chosen because it could provide the needed information and was a reasonably well proven state-of-the-art type which could be implemented on the ground stations with commercially available hardware. Implementation guidelines used are as follows:

(1) Two independent links were to be used to gain reliability. The equipment at each station was to provide independent receiving systems for the two links from the spacecraft. Separate preamplifiers, receivers, diversity combiners, filters, subcarrier discriminators, and the associated monitor and control equipment were to be provided. Separate monitoring of the data from the subcarrier discriminators of each system with commutated data not decoded was to be provided to permit the operator to select the telemetry system output to be displayed at a main control console.

(2) At the stations which were to have command transmitters, separate decoding and display equipment was to be provided for the two telemetry links. (This arrangement was necessary to provide reliability in determining that the proper commands were received at the spacecraft.) At all other sites, only one set of decommutation and output data display equipment was to be provided, with appropriate switching to the output of either receiving system.

(3) Provisions were to be made for separate magnetic tape recordings of the received outputs from each telemetry system to permit playback and reassessment of the data following a pass. These recordings also were to provide a permanent record of the data with an overall accuracy of 1 percent.

(4) Data-output display equipment was to be provided with the appropriate meters, lamp indicators, and direct writing records.

(5) Continuous data on IRIG channels 5, 6, and 7 were to be recorded and displayed on direct writing strip chart recorders with an accuracy of 2 percent of full scale. Each of these channels was also to be provided with a suitable events-per-unit time display. (This provision was needed by aeromedical personnel to monitor the astronaut's heart action and respiration.)

(6) Individual data outputs of the analog quantities handled on the commutated subcarrier (PAM) were to be displayed on meters with an accuracy of 2 percent of full scale. Display of the events data carried on the commutated subcarriers was to be in the form of lights. Appropriate translation equipment was to be provided to display the time measurements as in-line decimal digits in hours, minutes, and seconds.

(7) Monitor displays were to be provided to permit the operator to assess the outputs of both receiving systems at a station and to select the system to drive the final data output displays.

(8) A permanent recording system capable of rapid processing and display was to be provided to record all subcarrier discriminator outputs, all decommutated analog quantities, and received signal strength.

(9) The overall system-accuracy requirement was that system error not exceed 2 percent under field conditions.

System performance.—The telemetry and display system performance was outstanding throughout the project. During controlled flight, coverage time was generally horizon to horizon. Missions which had periods of drifting flight caused occasional signal dropouts due to nulls in the spacecraft antenna pattern. During reentry phases, both telemetry links were attenuated by the ionized sheath created by intense heat and ablation of the heat shield and reception was completely lost for periods of 3 to 5 minutes.

System accuracy (to the displays) of 2 percent, as originally implemented, was met satisfactorily. Summary data from remote sites which included the degradation factors of 2-percent meters, meter parallax, short mission meter scales (e.g., utilizing 50 percent of full-meter scale deflection), and reading error were generally within ± 3 percent of full-scale meter deflection.

Air-Ground Communications

A system was required at each site to permit direct communications with the astronaut. This system, termed the air-ground system, would comprise all of the ground-based transmitting, receiving, control, and antenna equipment required to establish two-way voice communications with the Mercury spacecraft. General requirements included communications reliability, ease of rapidly restoring system operation in case of failure, and the use of proven off-the-shelf equipment to reduce both delivery time and costs. The following paragraphs describe the specific requirements for this system, the system modifications, and a summary of system performance.

Requirements.—To provide a highly reliable system of communications which would be able to overcome difficulties arising from spacecraft equipment failure, atmospheric disturbances, and ground-equipment breakdown, the following specific requirements were established:

(1) Complete voice transmission and reception facilities for both HF and UHF operation were to be provided, with the HF equipment to serve as a backup facility for the UHF.

(2) Standby UHF transmitters were required for backup purposes at all stations.

(3) Standby HF transmitters were required for backup use at certain critical stations.

(4) Remote and local transmitter control was required for all transmitters.

(5) The means for operating these transmitters on tone modulation as well as voice was required.

(6) At those sites equipped with command transmitters, a voice-modulation capability for the command transmitters was required as an emergency mode of operation.

(7) A means was required for individual operation of the UHF, HF, and emergency-voice modes, as well as simultaneous use of the UHF and HF or the UHF, HF, and emergency-voices modes.

(8) At sites where transmitting equipment was to be installed in vans, provisions for moving the van from the transmitting antenna to a receiving antenna were required in case of transmitting antenna or pedestal failure.

(9) To offset space-fading effects and also to provide built-in equipment backup facilities, dual space and polarization-diversity equipment was required for UHF reception, and dual-space diversity equipment was required for HF reception. This stipulation, then, required that two complete and identical sets of antennas, transmission lines, and receiver elements for both the HF and UHF equipment be furnished at each site.

(10) Circular polarization of UHF transmitting and receiving antennas was required to offset signal attenuation caused by any skew attitude of the spacecraft antenna with relation to the ground antennas.

(11) Recording facilities were required for all transmitted and received audio.

(12) Varied distribution of all received audio and transmitter sidetones was required through monitor speakers and the station intercom system in order to satisfy the site operating requirements.

Performance.—UHF was used for primary voice communication throughout the project with very satisfactory results.

Because of wave propagation, HF communication proved too intermittent to be used as more than backup communication and could not be considered as a reliable means of extending communication beyond station horizon. The HF quality improved somewhat, however, after a dipole antenna was installed on the MA–8 and MA–9 spacecraft.

A photograph of the air-ground antenna and transmitter van installed at Guaymas, Mexico, is shown in figure 8–10.

Command

Requirements.—The criteria for the command equipment followed the general guide lines for all Mercury equipment. The basic requirement was the transmission of commands from certain stations to the spacecraft in order to provide a command backup for the manually controlled or internally programed events in the spacecraft. The range coverage of the command system was to be limited only by line-of-sight conditions to the spacecraft. The minimum normal range of the systems was originally set at 700 nautical miles.

This equipment was to employ a suitable coding technique to provide high reliability with particular attention to prevention of incorrect commands because of noise, interference, or transmitting equipment failures. All command sites would have dual FRW–2, 500-watt transmitters. The command antenna was to have at least 18-db gain, circular polarization, and to be steerable.

Modifications.—Bermuda, having coverage of the critical insertion phase, required the ability to "brute force" command signals to the spacecraft regardless of the spacecraft antenna position. A 10-kw RF power amplifier was to be provided for that purpose. Likewise, monitoring facilities that would provide failure sensing of this power amplifier were required. If failure occurred, antenna transfer to the operational 500-watt transmitter would be done automatically. Three existing sites already had this high power and failure switching capability.

FIGURE 8-10.—Transmitter van and antenna installation at Guaymas, Mexico, for command and air-ground voice.

It was necessary to remove the standard coder controller of the FRW-2 and substitute coder control units designed to be compatible with the coding technique employed in the spacecraft equipment and the input requirements of the FRW-2 coder KY-171/URW coder which was part of the FRW-2. Furthermore, the coder controllers were to be capable of remote activation and rapid changeover to any one of several codes which might be desired.

During the implementation phase of the program, ancillary equipment consisting of control and monitoring facilities was designed and fabricated. This equipment was necessary to provide the desired fail-safe features and degrees of flexibility this program required. Furthermore, at sites equipped with command vans, provisions were made to allow the transmitter van to be moved to the receiver antenna pedestal in case the command antenna pedestal failed.

Mission requirements made major command equipment additions necessary. The need for additional command coverage became apparent when the program was expanded beyond three-orbital-pass missions. Consequently, dual 10-kw command facilities were installed on the Rose Knot Victor telemetry ship. The basic equipment furnished was identical to that furnished previously to the land-based stations. Temporary dual 500-watt command facilities were also added to the Coastal Sentry Quebec Ship. Here again, the basic equipment furnished was identical to existing land equipment.

Another major change in the command configuration was the MCC-Bermuda tone remoting system which became practical only after submarine cable circuits were available between Bermuda and Cape Canaveral.

Performance.—As with the other systems, the command equipment functioned as planned throughout the project.

Ground Communications

Introduction.—Operation of this system was discussed in reference 2; therefore, it is only briefly reviewed in the present paper. Again the basic design criteria were used: reliability, cost, and speed of implementation.

Requirements.—A primary requirement for the tracking network was that the stations be tied together with an adequate and reliable communications center. This center was to act as the heart of a communications system which would perform the following functions:

(1) Transmit acquisition information from the computing center to the tracking and telemetry stations.

(2) Transmit commands and instructions from the MCC to the stations.

(3) Transmit digital tracking data from the tracking stations to the computing center.

(4) Transmit telemetry summary messages from the stations to the MCC.

(5) Provide high-speed data transmission between the computing center and the MCC for display purposes.

(6) Provide voice communications capability between certain stations and the MCC.

(7) Transmit mission teletype traffic throughout the network.

Both teletype and voice circuits were required. The teletype circuits usually operated at 60 words per minute and provided for transmission of all of the required types of information except high-speed tracking data and, of course, voice communications. These two were handled by voice-quality circuits with a pass band of 280 to 2,800 cps.

The network that was established to meet these requirements is illustrated in reference 2.

Because these channels traverse extremely long distances and employ a variety of transmission media, such as land lines of various types, submarine cables, and HF radio, it was necessary that the design arrangement and operating technique preserve their transmission capability. The chief factors involved were overall attenuation, bandwidth, distortion, noise, return loss, and echo.

Modifications and Performance.—Following are some of the major changes made after the initial configuration was established:

(1) The HF link to Bermuda was dropped after the cable became available, and two high-speed data circuits from Bermuda to Goddard were added.

(2) The network was expanded to include the switching, conferencing, and monitoring (SCAMA) voice capability to Canary Island, Kano, Zanzibar, Canton Island, the Rose Knot Victor, and the Coastal Sentry Quebec.

(3) Zanzibar became a primary HF link for the Coastal Sentry Quebec.

(4) HF backup to Guaymas was added.

The Mercury communications network included 102,000 miles of teletype lines, 60,000 miles of telephone lines, and 15,000 miles of high-speed data lines.

The ground communication system operated very satisfactorily for all missions. Performance figures for the MA–7 and MA–8 missions are listed in table 8–IV.

Table 8–IV.—Messages Handled During MA–7 and MA–8

	MA–7	MA–8
Total number of messages	1, 814	5, 587
Information flow time, min	Messages	Messages
0 to 5	1, 597	4, 335
5 to 10	169	878
Over 10	24	334
Undetermined	24	40
Message transmission time, min		
0 to 1	526	1, 073
1 to 2	625	2, 087
2 to 3	410	1, 151
3 to 4	128	569
4 to 5	40	134
Over 5	75	515
Undetermined	10	58
Garbled messages	2	2
Lost messages	0	0

Timing

A timing system was required to provide timing signals for all recorders in a common format, binary-coded time signals for radar data, strobe pulses for radar interrogation, and outputs for driving wall clocks and displays. The system was to have the capability of synchronizing with WWV timing with a resolution accuracy to within 0.001 second. The stability of the timing system was to be such that the local timing oscillator drift would not exceed 0.001 second in 48 hours.

The timing system which had been developed for the scientific satellite tracking stations was selected since it had proved to be reliable and accurate under actual field operating conditions.

The timing system performed satisfactorily throughout the Mercury Project, and only minor modifications were necessary to correct component failures and increase reliability.

Intercom

It was apparent at the outset that rapid and flexible voice communications (intercom) would be needed within each station. Station personnel who would need such communications were (1) the flight controllers, who would monitor the flight status of the spacecraft and the overall conduct of the mission and who would advise and assist the astronaut in making decisions as required, and (2) the maintenance and operations personnel, who would provide technical support to the flight controllers in the operation of the various tracking, telemetry, and communications systems.

The intercom system had to have the capability of interconnecting several different consoles or positions in a conference type circuit (loop) whereby several people would be able to carry on a discussion, with others being able to "listen in" or be called on for comments or information. Also, because of the varied activities of different positions, there had to be several of these conference loops so that simultaneous conversations could be carried on with each loop usually isolated to one system or activity. The system also had to connect to outside lines so that the flight director could have immediate contact with any of the flight controllers at any station through the worldwide communications network.

After implementation by using standard components, only a few minor modifications to the intercom system were necessary to obtain proper, reliable operation. The system met the project requirements in a first-rate manner.

Control Centers

Mercury Control Center.—The primary function of MCC was to provide a means of centralizing control and coordination of all the activities associated with a Mercury mission. Figure 8–11 is a view of the operation room of MCC. Mission control and coordination were conducted from MCC beginning at approximately 10 to 12 days before lift-off and continuing through the launch, orbital, reentry, and recovery phases. Communication, display, and control capability for MCC operation was provided in the various consoles, which are shown in figure 8–12. Many of the positions contained duplicate displays and controls to provide redundancy which was considered essential to the Mercury Project.

FIGURE 8–11.—Mercury Control Center as viewed from the observation room.

Bermuda Control Center.—In the earlier phases of the project, this secondary control center was required because the critical orbital insertion point of the spacecraft would be at a marginal distance and low-elevation angle from MCC, which might give unreliable data and would allow little time for MCC to determine go—no–go conditions. In addition, since Bermuda's vital tracking data needed for establishing insertion parameters had to be relayed by HF, a more fail-proof arrangement was needed. The Bermuda Control Center had the following basic functions:

(1) To command an abort in the event of critical spacecraft equipment failure or pilot difficulty late in the launch phase.

(2) To command an abort as directed by MCC in the event of certain propulsion or guidance system malfunctions.

(3) To control the mission independently in the event of communications failure with MCC.

Figures 8–13 and 8–14 show a view of the center and an equipment layout.

After the submarine cable to Bermuda was available, it was possible to remote the control data safely to MCC. The Bermuda station functioned as a remote station for the MA–9 mission with a minimum of flight-control staff.

Simulation Equipment

The development of a simulation system was established primarily to answer the need for an active training device for mission flight controllers. A secondary use for the simulation

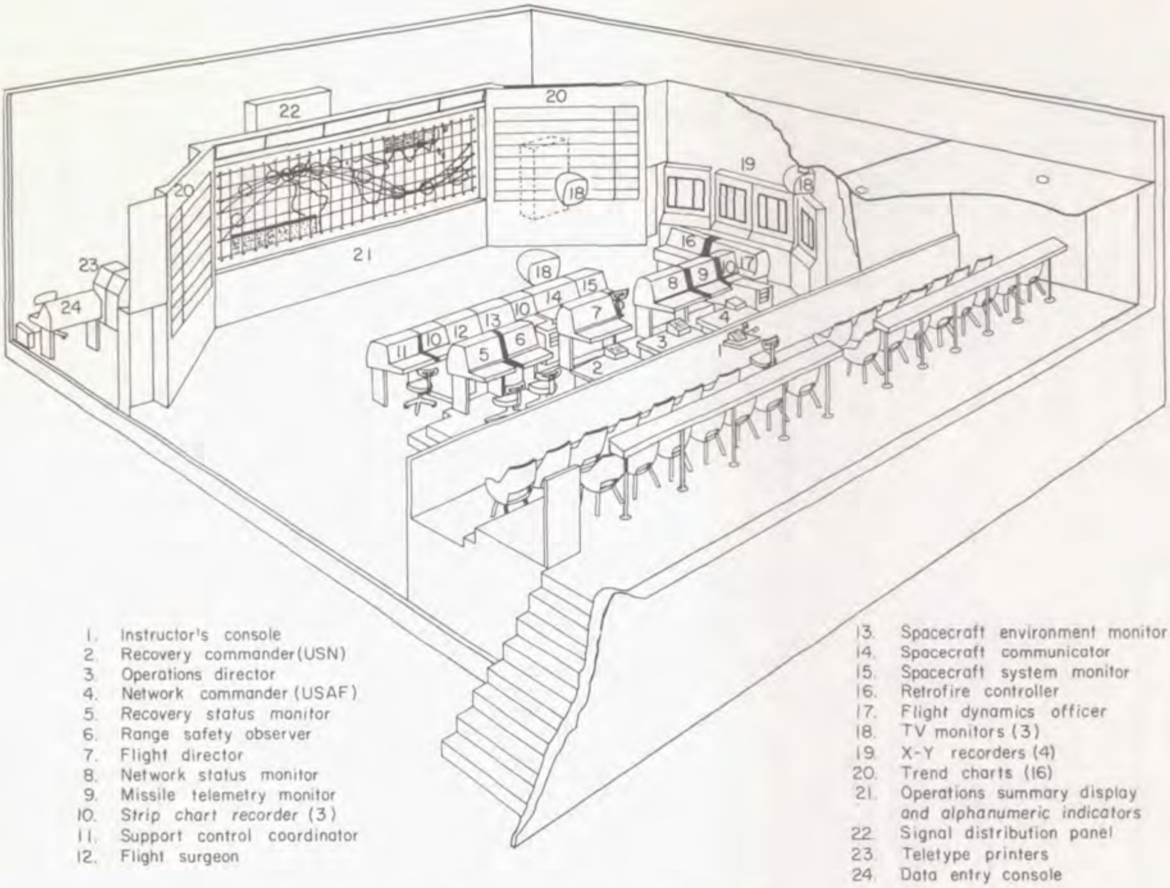

FIGURE 8-12.—Operations Room and Observation Room, Mercury Control Center.

FIGURE 8-13.—View of Bermuda Control Center.

system was the familiarization of the maintenance and operating personnel with the mission support required of them for a particular flight.

The simulation system was designed in two parts: the first and major part was the addition of specialized instrumentation and control consoles at MCC that could be used by instructors to provide the stimulus necessary to activate the MCC operational consoles; the second part was a separate remote-site simulator for the purpose of training flight controllers who would be ultimately assigned to stations other than the control center.

Equipment Documentation

Within a general requirement to furnish adequate instruction manuals for the network equipment, detailed specifications for individual manuals were prepared and the overall organization of this family of documentation was developed. The detailed specification called for new manuals to be prepared in accordance with the best commercial practices and established minimum content requirements for the acceptance of existing, off-the-shelf manuals. The most notable feature of the overall organization of the manuals was the concept of system manuals and equipment manuals. Equipment manuals covered individual units and subsystems, such as communications receivers, audio line amplifiers, and radar sets; and system manuals

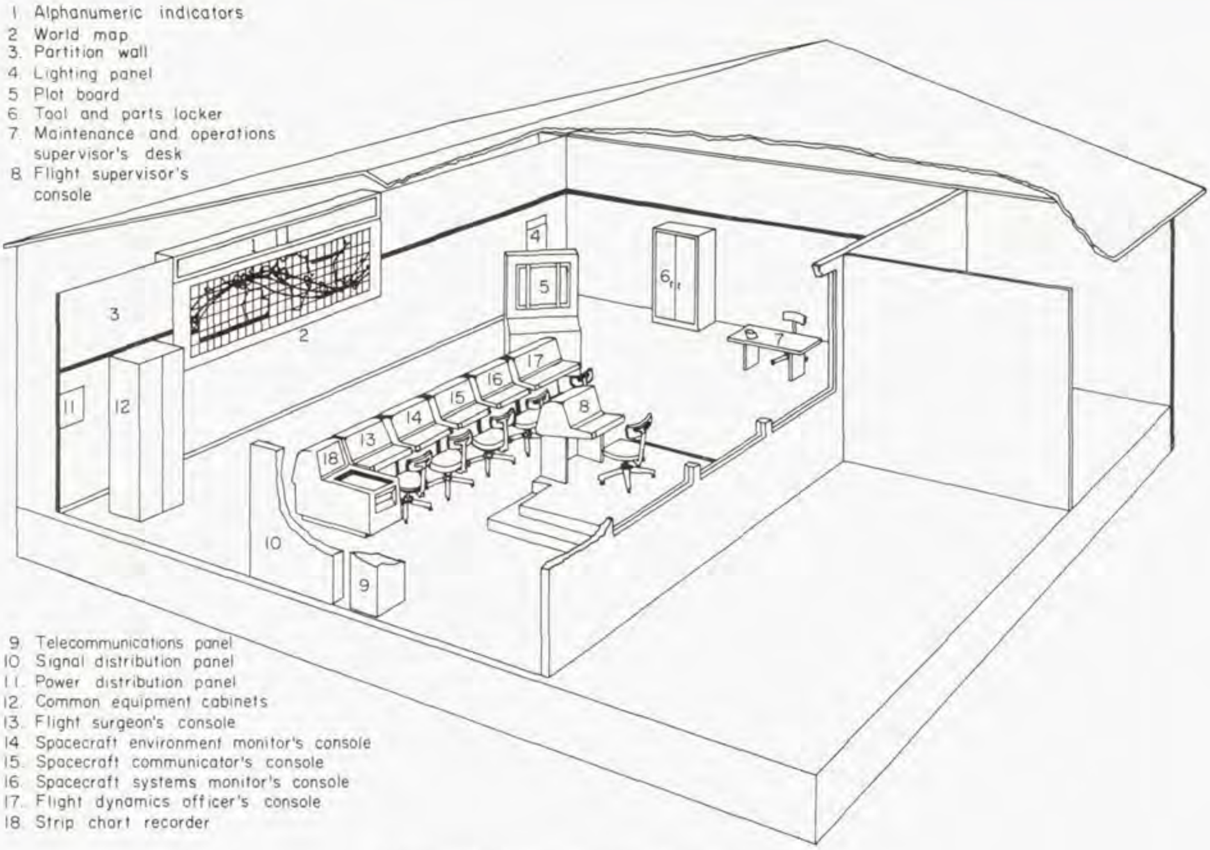

FIGURE 8–14.—Operations Room, Bermuda.

provided information on how the individual units and subsystems tied together to form the major network system. Altogether, approximately 450 separate manuals with copies totaling nearly 50,000 were supplied for use on the network.

Installation

The installation of ground instrumentation equipment actually began with the efforts of the teams who selected the sites for the remote stations. The general area for each station had been determined from the planned orbit charts, but selected areas required on-site inspection for the evaluation of local problems and land availability. Each station had to be considered from cost, adaptability, and accessability standpoints. Every attempt was made to use existing facilities, but where these were not available below the orbital paths, sites were chosen which presented the fewest problems while satisfying the necessary criteria.

The Project Mercury tracking stations required considerable land area to provide necessary isolation (separation) between transmitting and receiving antennas. The equipment covered a very wide range of frequencies and required specific terrain configurations to operate at maximum efficiency. It was determined that five of the stations and the control center could be located on national ranges where use could be made of existing facilities. One new station was to be located in Texas and two on shipboard. The remaining eight would have to be established on foreign or overseas territory.

Selection of the foreign locations was accomplished by two teams. The first, a management team which had representation from the U.S. Department of State, was to determine and resolve, if possible, all difficulties of a general nature such as political considerations, preference of local officials as to station location, and currency problems. In addition, contact was made with local contractors, material suppliers, and service companies. Labor sources were also investigated and data on living conditions were obtained. The management team selected a preferred and an alternate location for each station.

Data gathering was the prime function of the technical survey teams. Project personnel spent several days at each prospective site checking soil conditions, topography, water, sewage disposal, communications, transportation, electric power, and climate. A comprehensive report prepared on each site provided the basis for station selection and was used thereafter as a guide for equipment design and location.

The tight schedule made it impossible to stagger construction at the various stations. Although first construction operations were not started until April 29, 1960, all stations were under construction by midsummer, and construction was completed at the last station in Kano, Nigeria, in March of 1961.

Most buildings were constructed of prefabricated galvanized sheet metal supported by rigid steel frames. In addition to the buildings housing electronic equipment, most stations contained power buildings, cooling towers, air handlers, water chillers, and hydropneumatic tanks. Diesel generators were installed to produce power to back up commercial power.

Extreme precision was necessary in the positioning of every radar antenna. Each unit had to be surveyed to determine true latitude and longtitude with exact interrelation, and angles were established with a maximum allowable deviation of 6 seconds.

As construction of facilities was still underway at some stations, the equipment and the installation teams were arriving. The number of installers on a site team varied between 5 and 25, depending on the amount of equipment to be installed. A typical team consisted of the site manager, the team crew chief, a lead man for a subsystem or a combination of subsystems, several technicians, and one or two subcontractor advisors for specialized areas such as the acquisition system. Each team was also supported by a logistics man.

All installation team leaders were authorized to work with the local labor unions and utilize the local labor market to perform certain jobs beyond the capabilities of the installation team and its facilities.

Two depots—one on each coast of the United States—were established to provide logistics support for the overseas stations and to handle the customs details involved in such shipments. The depots served as staging areas for overseas shipments, whereas equipment destined for stations in the United States was shipped directly from the manufacturer. More than 1,000 tons of cargo were processed through the depots, most of it in preassembled units. A rigid receiving and inspecting system was set up at each station to check in all equipment before it was turned over to the installation team.

Spare parts provisioning was another logistics consideration. There had to be a reasonable on-site repair capability. Each industry team member supplied a 2-year supply of spares unique to his equipment and a list of recommended common item spares. From these lists a combined list of common item spares was drawn up to eliminate duplications. Common item spares were procured in accordance with the combined list and shipped to each site.

Thus, the concept of a network of stations became a reality with equipment and logistic support. The scope of design, construction, installation, and activation for the Mercury Network is shown in figure 8–15.

Figure 8–16 shows construction underway at Kano.

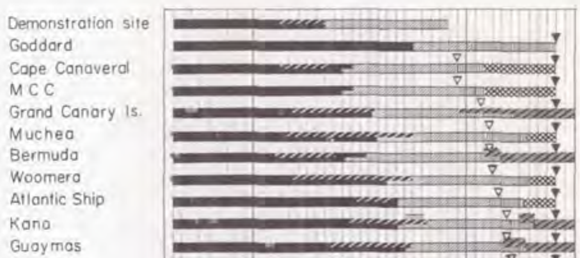

FIGURE 8–15.—Overall Mercury Network schedule.

FIGURE 8-16.—Construction of the receiver building Kano, Nigeria.

Testing

Demonstration site.—The necessity of testing and evaluating the ground instrumentation equipment as a complete system prior to its installation on a worldwide basis was recognized in the early planning stages of the Mercury Project. Equipment from more than 10 major manufacturers plus numerous subcontractors was involved, and it had to be determined that all interrelated problems had been solved and that the equipment would perform as a system.

The selection of NASA Wallops Station, Wallops Island, Virginia, as a test site was determined primarily because of its availability and its proximity to Langley Research Center at Langley Air Force Base, Virginia, and the Goddard Space Flight Center at Greenbelt, Maryland. A complete tracking station was installed, with the Mercury data conversion and acquisition equipment connected to the existing FPS-16 at the Wallops Station Launch Complex.

Representatives from the suppliers of equipment conducted tests at Wallops under NASA supervision. As a result of these tests, many changes were made to equipment in the prototype stage prior to worldwide deliveries. Also developed at the Demonstration Site were test procedures that were used throughout the network for acceptance testing of on-site equipment.

The test procedures were of four types:

(1) Mercury Unit Tests (MUT) were developed to provide acceptance of self-contained equipment such as the R-390 HF voice receiver or the Ampex FR-100B tape recorder. The unit tests covered every measurable aspect that could influence the reliability of minimum performance expected of the unit.

(2) Mercury System Tests (MST) were developed to provide acceptance of a complete system. These tests checked the action of each interfaced relay as well as system performance.

(3) Mercury Integrated Tests (MIT) were developed to provide acceptance of the station as an integrated complex. These tests assured successful interface of systems. They also revealed RF interference problems.

(4) Mercury Dynamic Tests (MDT) were developed to test the equipment under simulated operating conditions. As ground station equipment was installed and evaluated at the Demonstration Site, the need for a method of closely simulating spacecraft tracking soon became apparent. Small leased aircraft were used to check the tracking accuracy of the new acquisition aid, and it was found that certain modifications were necessary for the equipment to meet specifications.

Instrumented aircraft.—As a result of these and other special aircraft tests, it was decided that aircraft would be obtained and completely instrumented with actual spacecraft electronics (see fig. 8-17) to serve three functions:

(1) To qualify each ground system prior to worldwide equipment delivery so that compatibility between ground and airborne systems was assured.

FIGURE 8-17.—Interior view of aircraft showing a small portion of the test equipment.

(2) To provide a complete checkout of each station in the network so that operational readiness was determined.

(3) To provide continual testing and training throughout the Mercury Project.

Training

Prior to station assignment, selected senior engineers received specialized equipment training and later helped to install the equipment at the Demonstration Site. After assignment, these senior engineers were responsible for making their equipment operational and for indoctrinating the other team members. Training was largely accomplished by working with the equipment during installation and by playing an active role in conducting acceptance tests. As time allowed, semiformal classes were held in theory and maintenance.

Formal training.—Installation technicians were technically capable of performing maintenance, but operational requirements posed the need for a refinement of the team concept and a regimented reaction to the demands of mission accomplishment. Transition from installer and maintenance technician to operator was accomplished by a rigorous training program that included: formal indoctrination lectures on space-flight matters and on Project Mercury; on-the-job training combined with classroom drills covering operation of the equipment; local-station simulated missions; and network simulations using countdowns, live communications, and telemetry tapes.

The maintenance and operation capability of station personnel had to be continually upgraded, and replacement personnel had to be provided. Likewise, the station had to be exercised as an entity to assure that it could work as a cohesive unit during a mission.

Training center.—To upgrade individual capabilities and to provide replacement personnel, a training center was established at the Demonstration Site. The primary long-term objective of the Engineering and Training Center was to sustain or improve the level of competence of the personnel manning the Mercury network stations through a comprehensive training program in each of the equipment subsystems making up the station. It was also designed to give the necessary high-level training to replacement personnel so that network proficiency would not suffer from personnel attrition.

To supplement the training received at the center, cross-training packages of lesson guides, equipment exercises, and examinations were developed for use at all the Mercury network stations. These were used for training of personnel in secondary areas of responsibility to enhance the overall capability of each team at the stations.

Network Configuration

Arrangement for MA–6

Up to this point, network requirements and systems development and implementation have been discussed. The types of systems available at each site are listed in table 8–V. To illustrate how a Mercury station was arranged, a line drawing of the Hawaii station layout is shown in figure 8–18.

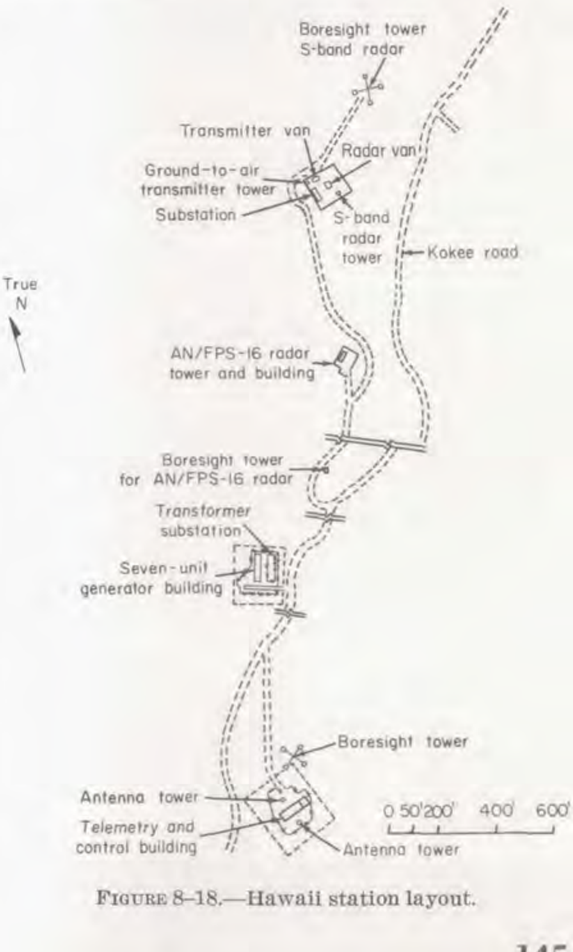

FIGURE 8–18.—Hawaii station layout.

Table 8-V.—Station Equipment

Station	Command control	Telemetry reception	Air-ground voice	FPS-16 radar	Verlort radar	Acquisition aid	Computer	Ground communications		Timing
								Voice	Telemetry	
Cape Canaveral (CNV–MCC)	x	x	x	x		x	B/GE IP7090	x	x	x
Grand Bahama Island (GBI)[a]	x	x	x	x				x	x	x
Grand Turk Island (GTI)[a]	x	x	x					x	x	x
Bermuda (BDA)	x	x	x	x	x	x	IBM–709	x	x	x
Atlantic Ship (ATS)		x	x			x		x	x	x
Grand Canary Island (CYI)		x	x		x	x		x	x	x
Kano, Nigeria (KNO)		x	x			x			x	x
Zanzibar (ZZB)		x	x			x			x	x
Indian Ocean Ship (IOS)		x	x			x			x	x
Muchea, Australia (MUC)	x	x	x		x	x		x	x	x
Woomera, Australia (WOM)		x	x	x		x		x	x	x
Canton Island (CTN)		x	x			x			x	x
Kauai Island, Hawaii (HAW)	x	x	x	x	x	x		x	x	x
Point Arguello, Calif. (CAL)	x	x	x	x	x	x		x	x	x
Guaymas, Mexico (GYM)	x	x	x		x	x		x	x	x
White Sands, N.M. (WHS)[b]				x		x		x	x	x
Corpus Christi, Tex. (TEX)		x	x		x	x		x	x	x
Eglin, Florida (EGL)[b]				x	MPQ-31	x		x	x	x
Goddard Space Flight Center (GSFC)							IBM–7090	Communications Center		

[a] No monitoring facilities; downrange antennas for MCC.
[b] Radar tracking station only.

Major Changes for Succeeding Missions

Changes for MA–7.—The second manned orbital flight, MA–7, was also planned as a three orbital pass mission. The network configuration was the same as that for MA–6 except for minor exceptions; there was no Atlantic Ship, and the Indian Ocean Ship was repositioned in the Mozambique Channel, off the east coast of Africa.

Changes for MA–8.—The MA–8 mission was planned to be a six orbital pass mission with landing to be made in the Pacific Ocean. For this mission, the former Atlantic Ship had a command system installed and was redesignated as the Pacific Command Ship (PCS) for positioning south of Japan. Three additional ships, the Huntsville, the Watertown, and the American Mariner, were made a part of the network and positioned near Midway to get reentry data.

Changes for MA–9.—Since it was decided to extend the length of the MA–9 mission to 22 orbital passes, it was necessary to modify the network so that adequate support could be provided. The following describes the changes that were required:

Equipment:

(1) All command sites were provided with additional command capabilities to give the site flight controllers the capability to turn on the spacecraft's telemetry transmitter, radar beacons, and an astronaut alarm. Other command changes included the addition of a complete system aboard the Coastal Sentry Quebec (CSQ) and an increase of the Rose Knot Victor (RKV) command power from 600 watts to

10 kilowatts. Figure 8–19 shows the two ships in the port of Baltimore for modifications.

FIGURE 8–19.—Rose Knot Victor and Coastal Sentry Quebec in Port Baltimore for MA–9 modifications.

(2) Mercury tracking site clocks showing "spacecraft elapsed time" and "time to retrofire" were modified to extend their reading time.

(3) Additional equipment was installed at California and Bermuda, allowing biomedical data to be sent (over land lines) to MCC display consoles.

(4) A telemetry automatic processing system that used a small general purpose computer (AN/UYK–1) was installed at Bermuda. The system was designed to accept PAM/FM/FM frames of 88 parameters every 800 milliseconds in real-time and generate special and regular summary messages. The output data were in a format which represented selected parameters in engineering units. A running tolerance check of all parameters was included and selected data were stored for postpass analysis.

(5) Receivers were installed at MCC, Canary Island, and the CSQ for reception of the slow-scan TV picture from the spacecraft. The installation at MCC and on the CSQ included record and display capabilities, whereas the installation at CYI was for record only.

(6) An additional IBM computer was added to the computer complex at GSFC, and the two 7090's already in operation were converted to 7094's.

Communications:

(1) The radio links to BDA were discontinued since the submarine cable was now operational.

(2) Communications to the CSQ at the new location were handled through a radio link which could operate through either Honolulu or Bassendean and thence by the usual path.

(3) Communications to the RKV were handled by RF links to Honolulu and New York.

(4) A new circuit was added to relay the Range Tracker data through Honolulu.

(5) The mission message format was changed to improve circuit operation and to facilitate accumulation of more data.

(6) New equipment arrangements were instituted at Goddard to permit CADFISS and operational programs to be conducted simultaneously.

Relocation of ships: The Coastal Sentry Quebec was relocated to the approximate position of 28°30′ N. latitude and 130°00′ E. longitude. The primary purpose of this location was to provide adequate retrosequence command backup during the 6th, 7th, 21st, and 22nd orbital passes.

The Rose Knot Victor was relocated to the approximate position of 25°00′ S. latitude and 120°00′ W. longitude. In this position, it provided optimum command coverage for passes not covered by other network sites. The RKV provided coverage with its 10-kw command transmitter during the 8th and 13th orbital passes.

Additional support: To provide the necessary coverage to support a mission of this duration it was necessary to add the following tracking facilities:

(1) The Range Tracker (C-band radar equipped ship) was stationed at 31°30′ N. latitude and 173°00′ E. longitude to provide reentry radar coverage for the 4th, 7th, and 22nd orbital passes.

(2) The Twin Falls Victory (C-band radar equipped ship) was stationed in the vicinity of 31°3′ N. latitude and 75°00′ W. longitude for reentry radar coverage for the 2nd and 17th orbital passes.

(3) The Ascension Island station provided FPS–16 radar tracking during the fourth orbital pass. Also provided were telemetry recording, air-ground relay, and ECG remoting.

(4) The East Island, Puerto Rico, station provided FPS–16 radar tracking.

(5) The Antigua Island station provided telemetry recording, air-ground relay, and ECG relay.

(6) Air-ground voice facilities were provided at Wake Island, Kwajalein Island, and San Nicholas Island. The Wake and Kwajalein sites provided an extension for the Hawaii air-ground facilities. California had additional coverage provided by the San Nicholas installation.

Network Operations

Time at the tracking station is generally divided into mission periods and nonmission periods. The mission period for Mercury comprised some 10 days prior to launch and the actual flight time. The nonmission period was the time between missions used for personnel training, equipment modification, testing, and checkout. The operations activities during the mission period are explained in the following paragraphs, with the MA–9 mission used as an example.

Precountdown

The MA–9 precountdown period for all network stations was scheduled as follows:

- F–7 day—Orbital mission simulation and reentry simulation
- F–6 day—Orbital mission simulation and reentry simulation
- F–5 day—Two reentry simulations
- F–4 day—Detailed system tests
- F–3 day—Equipment maintenance
- F–2 day—Orbital mission simulation
- F–1 day—Patching check and equipment maintenance

These various activities are described in the following paragraphs.

Simulations.—To the station, the simulations were full-dress rehearsals for the missions. With the entire network participating and all onstation systems in operation, authentic dry runs were conducted, complete with builtin emergency situations which had to be detected, analyzed, and acted upon in "real time" by the flight controllers and station personnel. Authenticity was gained by the use of taped inputs to the telemetry displays and events recorders and by the use of a communicator reading from a prepared script over the intercom loop that would ordinarily carry the real astronaut's voice. In addition to anticipated problems of spacecraft equipment malfunctions, the ground team had to cope with such remote possibilities as simulated heart attacks of the astronaut in flight.

Simulations would ordinarily cover launch and three orbital passes and might or might not cover reentry. Each simulation would take from 4½ to 6½ hours. Prior to MA–8, a full 18-orbital-pass mission was simulated in anticipation of MA–9 as a means of pointing out any major problem areas in personnel scheduling, sleeping, and eating plans.

Detailed system tests.—The detailed system tests (DST), mentioned earlier as being performed on F–4 day, were a group of standard procedures used to check and measure thoroughly the operational performance of each of the station subsystems. Since the same test was used for corresponding systems at all stations, and since results of previously run DST's were recorded, the current status of any subsystem could be easily evaluated by the DST performed just prior to the mission.

The DST procedures consisted of two parts: the instructions and the data sheets. Meter readings, voltage and current measurements, standing-wave ratios, and various other parameters were recorded on the data sheets which were returned to Goddard for analysis immediately after the mission. On the station, the cumulative results of the DST's were used in the determination of the station status, which was a factor in the decision to proceed with or delay the launch.

· *Maintenance day.*—F–3 day and F–1 day were left open for last-minute maintenance details, particularly in correcting any equipment deficiencies detected during the DST's. Final briefings were also held to correct any procedural problems pointed up by the previous simulations.

Network Countdown

The network countdown began 5 hours and 50 minutes prior to the scheduled launch. This time was devoted to computer and data flow checks, teletype checks, voice checks, and brief system tests. The Network Countdown document specifically scheduled each of these activities, and designated the stations and equipment positions to which a particular operation was applicable. The brief system test was a shortened version of the DST and was designed to lend assurance that equipment performance had not significantly deteriorated since the DST was run 4 days previously. Whereas the DST may have taken 12 or more hours, most DST's could be performed in less than 2 hours.

The Network Countdown also contained the "plus-count," a scheduling of pertinent activities to be performed before acquisition of the spacecraft and during the pass.

Flight Activities

After launch of the spacecraft, a time period of from about 5 minutes (at Bermuda) to 90 minutes (at Eglin) would elapse before the spacecraft passed over the station. The actual pass, the time from which the spacecraft appeared above the horizon until it was lost below the horizon, averaged about 7 minutes. Average time between passes was about 85 minutes. This time was devoted to equipment calibrations—setting up known levels and annotating the recorders so that later analysis would have known standards—and preparation for the next pass.

Prepass calibrations were begun 45 minutes before the start of the next pass. Twenty-five minutes prior to the pass the first acquisition message would be received. This was a teletype message sent from the control center advising the station of the time and coordinates at which it could expect to acquire the spacecraft. These figures were derived by the computers at Goddard based on the real-time radar data from the last station passed over by the spacecraft. The information permitted the acquisition and and radar operators to train their antennas to the spot where the spacecraft would first be "sighted." A second acquisition message was received 5 minutes prior to the spacecraft passage to communicate any inflight deviations during the intervening 20 minutes.

Acquisition would ordinarily take place within a few seconds of horizon time. Because of the wide beamwidth of the antenna used by the active acquisition aid, this system ordinarily was the first to acquire the target. At radar sites, the S-band and C-band radars would nonetheless search independently. At contact, all antennas were immediately slaved to the system which acquired first.

As the radar locked on target, it would then be set to track automatically, and, at operator discretion, it could be made the controlling system for the other antennas. At dual radar sites, data from the C-band radar—the most accurate of the two systems—was fed to the teletype for transmission to the computers at Goddard. If this radar lost track, data from the S-band radar were put on the line.

As soon as possible after the last pass over the station, the postlaunch instrumentation message was teletyped to the control center. It contained a tabulation of the times of acquisition and loss of signal for the various systems, the modes of operation, and a summary status report.

It was obvious that the length of the MA-9 mission would preclude the manning of all station equipments from launch to termination. The flight path was such, however, that all stations had periods when the spacecraft would not pass over them for three or more orbital passes.

Documentation guides.—Three documents provided the major guideline for station personnel activities during the pass. The Network Operations Directive 61-1, was produced jointly by MSC, GSFC, and DOD and it set forth the general operating procedures for all systems so that a standard action would be used in a given circumstance at any station in the network.

The second document, the Data Acquisition Plan, gave detailed instructions for recorder setups, pen assignments, patching arrangements, and plotboard assignments, and gave information for disposition of data records after the mission. A new Data Acquisition Plan was published prior to each launch. It was prepared by MSC with inputs from GSFC.

The third document was the Communications Operations Plan, prepared by GSFC. This was a detailed account of how the communications network was to function.

Performance

The Mercury network, throughout all orbital flights of the Mercury spacecraft, has clearly demonstrated its capability to keep track of a manned spacecraft and remain in communication with the astronaut. These capabilities are the direct result of the many months of planning, instrumentation installation and checkout, training, and the highly efficient performance of the equipment and personnel at all network sites during the actual missions.

There were six orbital flights of the Mercury spacecraft, one unmanned (MA–4), one with a chimpanzee aboard (MA–5), and four manned (MA–6 through MA–9). The network performance continually improved during these missions as more and more experience was gained. This progress was typified by the peak performance demonstrated during the last Mercury mission, MA–9. It lasted for nearly 22 orbital passes (fig. 8–20) with the spacecraft landing in the planned landing area near Midway Island in the Pacific Ocean. There were some minor equipment failures associated with the Mercury network, but they did not materially affect mission support or detract from the excellent performance demonstrated by the network throughout the flight.

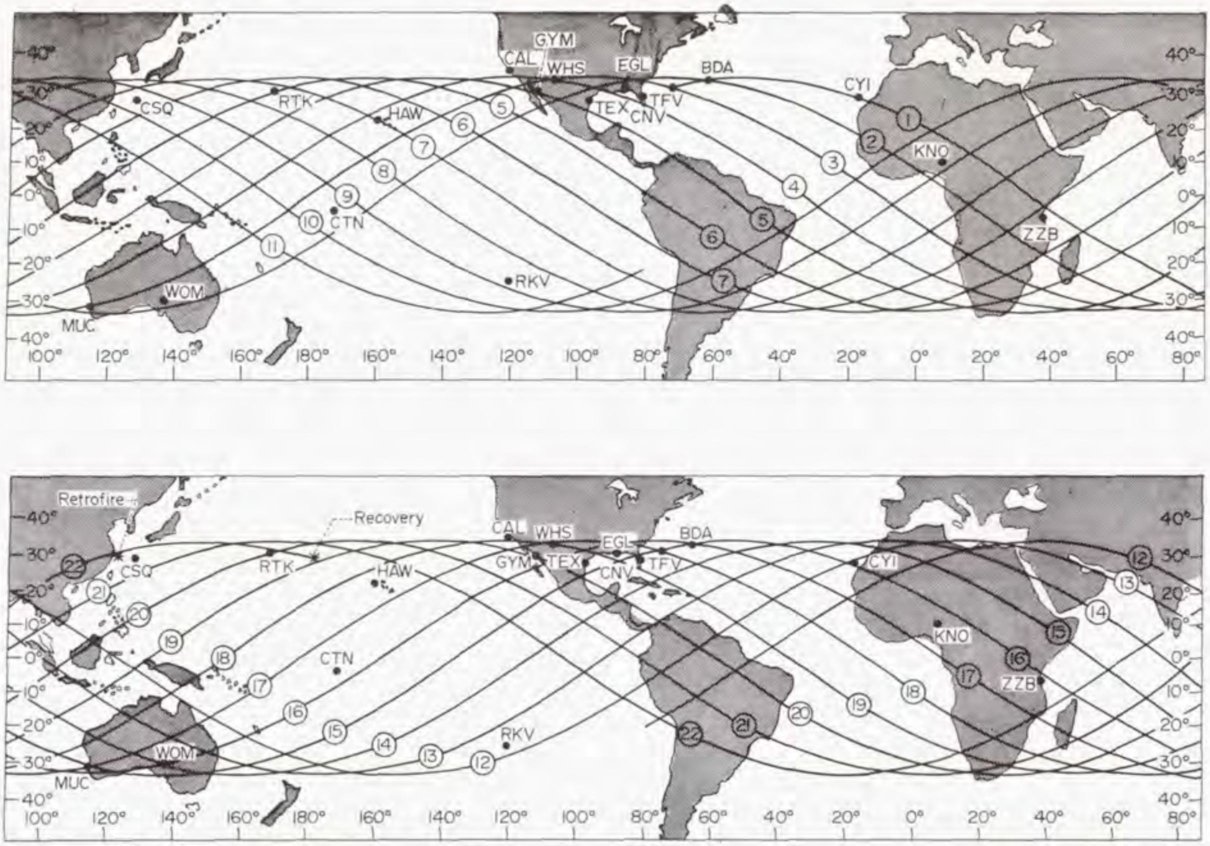

FIGURE 8–20.—MA–9 orbital charts.

A summary of network performance for the MA–9 mission is presented in the following paragraphs.

Radar Tracking

During the countdown on May 14, 1963, the radar at Bermuda failed to pass the CADFISS slew tests. Digital data were intermittently of poor quality in both the azimuth and range channels. Efforts to locate the trouble were ineffective, and the quality of the data gradually decreased. At T–15 minutes, the range data error exceeded the tolerable limits, and at T–13 minutes the mission was postponed for 24 hours. Subsequent investigation revealed a faulty preamplifier in the azimuth digital-data channel and a faulty shift register in the range digital-data channel. The simultaneous failure of both components complicated the failure analysis.

On launch day there were no radar problems, and the C- and S-band beacon checks prior to launch indicated no beacon problems. The network C-band radars tracked approximately 10 percent of the total mission time, which is 80 percent of the total time that the C-band beacon was turned on. The network S-band radars tracked 1.7 percent of the total mission time, which is 36 percent of the total time that the S-band beacon was turned on. The amount of radar data furnished to the Goddard computers was of sufficient quality and quantity to update the trajectories, and it was determined that the orbital parameters did not decay an appreciable amount. Initial tracking reports indicated that the C-band beacon was not as good as it had been on previous missions because of the heavier than usual modulation on the beacon replies. The heavy modulation experienced by the MCC and Bermuda radars during launch seemed to lessen as the mission progressed.

In addition to the normal Mercury Network radar sites, the following sites were used for the MA–9 mission: Ascension Island, East Island, Puerto Rico, and the radar ships Twin Falls Victory and Range Tracker.

Acquisition Aid

In general, the performance of the acquisition-aid systems at all stations was satisfactory and comparable to that of previous missions. Low-angle elevation tracking, below approximately 15°, was accomplished manually because of multipath conditions at most stations. The only major acquisition-aid problem experienced during the mission was on the Coastal Sentry Quebec, where failure of the elevation antenna drive system occurred prior to the 6th orbital pass. However, the antenna was positioned manually from the 6th through the 8th passes, and the malfunction in the drive system was corrected in time for acquisition in the 9th pass.

Computing

The MA–9 countdown began at midnight on May 14, 1963. The Goddard computer, equipment, interface, CADFISS, and trajectory confidence tests were all satisfactory. During the countdown, while using the "B" computer, some dropout was observed at the MCC. The high-speed output subchannel on the "B" computer communication channel was interchanged with the plotboard high-speed subchannel.

At the request of the Flight Dynamics Officer, the powered flight phase was supported with the "A" and "C" computers, then switched to the "A" and "B" computers during orbital flight. The "B" computer gave no indication of dropout during the rest of the mission. Liftoff occurred at 08:04:13 a.m. e.s.t.

The Atlantic Missile Range (AMR) I.P. 7094 and the General Electric-Burroughs guidance computers provided excellent data throughout the launch. A "go" decision was indicated by all three data sources.

In the orbital phase, during the periods when the spacecraft C- and S-band beacons were on, the tracking data received from the network sites were excellent. During the mission, spacecraft weight change data resulting from fuel and coolant-water usage were manually put into the computers.

The retrofire time recommended by the Goddard computers was 33:59:30 ground-elapsed time (g.e.t.), and retrofire was manually initiated at this time. After retrofire, the predicted landing point transmitted to the MCC from the Goddard computer was 27°22′ N. latitude and 176°29′ W. longitude. An attempt to refine this prediction with six frames of data acquired by the Range Tracker ship during blackout failed to yield a converged solution. The computed time of the blackout was from 34:08:16 to 34:22:30 g.e.t. The actual time of initial blackout was reported by the Range Tracker to be 34:08:17 g.e.t. The actual landing point was reported by the recovery ship to be 27°22.6′ N. latitude and 176°35.3′ W. longitude.

Although several minor computer problems were encountered and corrected throughout the flight, at no time during the mission did the computers fail to drive the digital displays and plotboards at the MCC. In addition, performance of the high-speed lines between Goddard and the MCC was excellent.

For the first time, CADFISS tests were conducted during the mission to determine the operational status of major equipment subsystems at network sites. These tests were considered necessary since mandatory equipment at many sites did not operate for prolonged periods of time when the spacecraft was out of range. All of these tests were successfully supported by the third Goddard computer while the other two

Goddard computers continued the operational support of the mission.

Two range ships, the Range Tracker and the Twin Falls Victory, were used to provide tracking data to the computers. The Range Tracker provided good tracking data during the 7th, 20th, and 21st orbital passes. During reentry the Range Tracker was poorly positioned with respect to the blackout zone and provided only six frames of data for this phase of reentry. An analysis of these data indicated a landing point which was about 3° or 180 nautical miles away from the correct landing point. Twin Falls Victory data readout was good on three passes.

Ground Telemetry System

The telemetry coverage for the mission was excellent. There were no major ground system failures, although some coverage was lost because of the manual switching procedure used onboard the spacecraft. In general, any deviation from nominal coverage can be attributed to spacecraft attitude or to the transmitters being turned off. The telemetry relay circuits from Antigua, California, Bermuda, and Ascension were satisfactory in all respects. During all passes over these stations when telemetry antennas were radiating, data were remoted to the MCC. During the third orbital pass, the telemetry was switched to the high-frequency link prior to the spacecraft's passing over Hawaii and remained on until it was over the California site, at which time telemetry was switched back to the low-frequency link. At all other times, the telemetry remained on low frequency. No telemetry system anomalies were noted during this period.

Air-to-Ground Voice Communications

The air-to-ground communications were of good quality. The UHF system was used as the primary communications system except for the scheduled HF checks. During periods of communication, UHF coverage varied only slightly from predicted acquisition and loss times because of the nominal orbital trajectory. As expected, air-to-ground communications could not be established during the communications blackout period. An Instrumentation Support Instruction was transmitted to the network outlining the use of the UHF squelch circuit as defined in the network documentation. A premission checkout and the mission results indicated that proper use of the squelch circuit eliminated background noise from open UHF receivers during periods of silence. This change also resulted in a reduction of noise level on the Goddard circuit during air-to-ground transmissions.

Relay aircraft in the Atlantic Ocean area reported good UHF reception from the spacecraft and good relay transmissions to MCC on the 2nd, 3rd, and 17th orbital passes. A relay attempt on the 16th pass was unsuccessful because of a severe thunderstorm in the vicinity of the relay aircraft. Communications from the MCC to the spacecraft through the relay aircraft were not attempted on the 2nd pass, and they were unsuccessful on the 3rd pass because the spacecraft had passed out of range. However, the relay communications were successful on the 7th pass. Ascension and Antigua Islands in the Atlantic were also available for relaying communications between the spacecraft and the MCC. Relay through Ascension was successfully accomplished for a period of approximately 6 minutes during the third orbital pass. The Antigua voice relay was not used during the mission.

In the Pacific Ocean area, communications were successfully relayed from Hawaii through Kwajalein and Wake Islands on passes 3 and 19, respectively. A voice-operated relay from the MCC through the Range Tracker was attempted on the 20th orbital pass. However, this attempt was unsuccessful because the transmission was made on the MCC-Hawaii remote air-ground position instead of the Goddard Conference Loop. This error apparently placed a 1700-cps tone on the circuit to the Range Tracker and resulted in keeping the automatic voice relay continuously closed; however, several transmissions from the astronaut were received in the MCC. Another attempt to use the relay on the 22nd pass was ineffective. As in the MA–8 mission, satisfactory communications were established in the primary landing area between the spacecraft and Hawaii by using relay aircraft.

Command System

The reader is referred to appendix F for a transcript of the MA–9 air-to-ground voice communications.

The command system for the MA–9 mission operated in a satisfactory manner, and the command control plan was followed very closely throughout the mission. Several malfunctions were noted at various sites, but command capability was never lost by any site during the time in which the spacecraft was passing over that site. The command carrier "on" indication from the Bermuda station to the MCC was delayed approximately 32 seconds on the first pass; however, it had no net effect on the mission since the onboard command receiver signal strength remained above the receiver threshold setting.

A total of 19 functions were transmitted from the command stations. All of these functions were received onboard the spacecraft with the exception of one telemetry "on" function from Muchea and the clock change from the Coastal Sentry Quebec. The telemetry "on" command from Muchea was not received because it was transmitted when the spacecraft was out of range of the 600-watt ground transmitter. The clock change from the Coastal Sentry Quebec was not received because the command tone was also sent before the spacecraft was within range of the ground transmitter.

The following ground-system malfunctions were experienced:

(1) The Rose Knot Victor had an intermittent problem in the beam power supply of the backup power amplifier. It was detected before lift-off and the equipment remained inoperative throughout the mission. The prime transmitter was used to support the mission.

(2) Guaymas had a failure in the filament transformer of the standby transmitter at 29:40:47 g.e.t. which damaged the power amplifier tube. The filament transformer and the power amplifier tube were both replaced and the equipment was operational by 32:05:47 g.e.t. The prime transmitter remained operational during this time.

(3) The Bermuda high-power transmitter came on with a 3.6-kw output but did not come up to full power. The station automatically switched to low power, 600 watts, at 00:06:31 g.e.t.

Ground Communications

All regular, part-time, and alternate circuits of the network participated in the MA–9 mission. Critical coverage was continuously established on these circuits during preflight countdown until the end of the mission for Adelaide, Muchea, Honolulu, New York, Mercury Control Center, and GSFC. For other sites, critical coverage was dependent upon standby status (critical coverage being allowed to lapse when the station was on a standby basis.

Upon review of the SCAMA log for the mission, it is apparent that this phase of communications was quite reliable. The few instances of poor readability were mainly a result of the station operation techniques and excessive background noise inside and outside the station.

Communications during the mission were nearly perfect. Every communication patch performed properly when needed. As anticipated, outages occurred on a few occasions when a station did not have the spacecraft "in view" or during otherwise unimportant communications periods.

Average total message delays during MA–9 approximated 2 minutes, compared with 3 minutes and 15 seconds for MA–8. This difference can be accounted for by the heavier traffic concentration of MA–8.

The MA–9 mission occurred during a period of high solar activity. Unlike MA–8, however, there were no geomagnetic disturbances and the propagation conditions were favorable.

Timing

The timing system performed satisfactorily at all stations except California. On passes 3, 4, 5, 16, 17, and 18, the serial decimal timing was in error in tens-of-seconds readout. The problem was corrected after pass 18 by replacing all tubes in the timing counter units and adjusting the phanastron in the time-comparison unit. During pass 20, the timing system was again defective since it indicated 21 hours rather than 20 hours.

707–056 O—63——11

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9. OPERATIONAL SUPPORT FROM THE DEPARTMENT OF DEFENSE

By MAJOR GENERAL LEIGHTON I. DAVIS, *U.S. Air Force, Department of Defense Representative for Mercury Support Operations*

Summary

The Mercury–Atlas 9 mission marked the successful conclusion of the nation's first manned space flight program to which extensive operational support had been provided by the Department of Defense. This support covers many assets uniquely available within the broad scope of this nation's military structure and includes such areas as early wind-tunnel studies, astronaut training facilities, parachute development, launch vehicles and launch operations, aeromedical assistance crews, network facilities, recovery forces, and public information.

Early in the program a need was recognized for a more precise planning and control of the many areas of DOD support to the National Aeronautics and Space Administration. A Department of Defense Representative for Mercury Support Operations was designated by the Secretary of Defense and was the sole point-of-contact within the DOD for coordinating all NASA requirements with DOD resources. A coordinating organization, the Mercury Support Planning Office, was established to administer the plans, policies, and directives of the DOD Representative.

Both the Redstone and Atlas launch vehicles developed by the DOD for other programs were modified and together with launch operations provided support for the Mercury flight program. Military facilities and persons associated with tracking and telemetry stations within the DOD complex were made available to complete the Mercury Worldwide Network. By far the largest DOD support effort in terms of people, was the level of recovery forces deployed for the various Mercury missions. This manpower level was approximately 14,000 people for the manned orbital missions. For those missions where an occupant was included in the spacecraft, DOD medical teams were deployed to provide assistance to NASA medical specialists. The global DOD communications complex was activated for use during Mercury missions to lend support in a variety of areas where high-speed information flow was required. This communications complex, in addition to facilities of the Mercury Worldwide Network, was especially valuable in coordinating the deployment and operation of the recovery forces for an orbital mission. The DOD also supported the NASA in disseminating and controlling Mercury mission information for public consumption through its public information organization.

Providing support to Mercury flights has contributed greatly to the Department of Defense's knowledge and experience in areas of launch, network, recovery, communications, and medical space operations. Future space-flight operations can be effectively supported by applying the experience and procedures derived during Project Mercury.

Introduction

Throughout the Mercury Project, the Department of Defense (DOD) provided valuable and timely support in critical operational phases of the project. As the project progressed and the scope of its activities increased, a need for a centralized coordinating agency within the DOD was recognized. The person in charge of this agency was designated the DOD Representative who had the sole responsibility of coordinating the resources of the various military organizations to satisfy the project requirements of the National Aeronautics and Space Administration. In this regard the DOD Representative was the primary point-of-contact for the NASA Operations Director in conjunction with specific requests for Mercury support.

Prior to the designation of a DOD Representative for Mercury support operations, operational support for the project was handled on an official but somewhat informal basis. The intent of this paper is to describe the operational support that was provided after the designation in 1959 of a DOD Representative for Mercury support operations. This designation also provided NASA with a single point-of-contact for the submission of their DOD support needs.

Early in the Mercury Project wind tunnel facilities such as the Arnold Engineering and Development Center, Tullahoma, and the crew training devices such as the Centrifuge at Johnsville, Pa., were also made available; however, these support areas will not be discussed. The support areas which are discussed comprise launch vehicles and operations, worldwide tracking, recovery, communications, aeromedical, and public information. These areas are discussed separately as they pertain to Mercury-Redstone and Mercury-Atlas mission activities and are followed by a summary of DOD support provided for each specific mission. Although the DOD provided launch, range, and recovery support for the first Atlas launch, named Big Joe, and for the Little Joe spacecraft development flights, these are not presented. The Big Joe flight was conducted to provide early aerodynamic and thermodynamic data by reentering a boilerplate spacecraft. A greater emphasis is placed on describing the gradual build up of operational support from the relatively simple ballistic flights, requiring assistance primarily in the area designated the Atlantic Missile Range, to the worldwide orbital missions requiring DOD medical, network, and recovery forces stationed around the globe.

This paper is intended only as a summary of the concepts and techniques employed in the various support areas relating to the Department of Defense. The Aeromedical Activities, Network Development and Performance, Recovery, Redstone Development and Performance, and Atlas Development and Performance papers should be consulted for greater detail in the operational aspects of these subjects.

Planning and Organization

The National Aeronautics and Space Administration had sole responsibility for conducting the Mercury project. The NASA Operations Director was designated as the single point-of-contact with the Department of Defense. The talents, resources, and facilities of the Department of Defense were used to assist NASA in attaining the overall objectives of the project. The Secretary of Defense approved DOD support of Project Mercury in areas of launch, network, recovery and bioastronautics.

The Commander, Atlantic Missile Range Test Center (AFMTC), was designated as the Department of Defense Representative for Project Mercury support operations by the Secretary of Defense and was made responsible to coordinate the efforts of the many DOD elements involved and to provide a single point-of-contact for NASA for the Mercury Project. The DOD Representative was authorized such staff as he might need to accomplish his duties and was required to make maximum use of existing DOD organizations and procedures. Broad plans of DOD support for Project Mercury were developed by the DOD Representative and published in an Overall Plan on January 15, 1960.

The Mercury Support Planning Office, consisting of representatives from the major participants in DOD support of Project Mercury, was created to administer the plans and policies of the DOD Representative. This office coordinated NASA's support requirements for Mercury with the DOD elements to insure that needed support in the form of talent, facilities, organization and other resources, was timely and sufficient to the extent compatible with DOD's primary defense mission. The Mercury Support Planning Office was the final coordinating staff office for the DOD Representative in all matters relating to DOD support of Project Mercury operations.

Department of Defense support was originally divided into two stages: preoperational and operational. The operational stage included launch through recovery phases and the preoperational stage included all other times during which DOD supported Project Mercury. During each of these stages, control of DOD support differed, and a separate functional organization was required. In the preoperational stage, the DOD Representative had responsibility for coordinating the action of DOD forces in Project Mercury activities. In the operational stage, full decision-making responsibility was exercised by the NASA Operations Director. In either stage, additional guidance was provided by direct contact between the DOD Representative and the NASA.

These planning, coordination and control procedures, set up in the early days of Project Mercury, remained basically unchanged until the end of the seventh Mercury-Atlas mission (MA-7). After MA-7, it was decided to amend the charter of the DOD Representative to insure a tighter control of the diverse DOD elements during mission operations, because of the expanding scope of the program, the need for a change in operational procedures and realinement of recovery communications. As a result, the duties and responsibilities of the DOD Representative were revised in June 1962. Significant changes were incorporated into the revised terms of reference for the DOD Representative which established two phases of operational support: the coordinating phase and the operational control phase which, at times, ran concurrently. The coordinating phase was that time during which plans were developed and resources arranged to support future operations. This phase was continuous and included training and simulation exercises preparatory to flight operations. The operational control phase included the launch through recovery aspects of the mission and began at 24 hours before the scheduled launch at which time the DOD Representative assumed operational control of the DOD forces, assets, and facilities used for support of Mercury operations. This phase terminated at the time the spacecraft and its occupant were recovered and turned over to NASA officials.

To provide for the centralization of overall operational control of the global recovery forces, the DOD Representative established the DOD Mercury Recovery Control Center at Cape Canaveral. Another method used by the DOD Representative for exercising operational control of the support forces was the publication of operations orders and directives prior to each mission. These orders proved to be an effective means for conducting these missions and contained a more detailed description of the procedures by which operational control would be exercised by the DOD Representative. Based on these orders, the supporting commanders prepared their individual directives for the control of their assigned forces.

Documentation

Several methods were used by the DOD Representative to evaluate DOD performance during the Mercury Project. Monthly status reports were submitted by the DOD Representative to the Secretary of Defense and Annual Reports summarized calendar year operations. Postmission reviews and preoperational conferences were held by the DOD Representative and attended by representatives from NASA, the National Ranges and DOD support forces.

Prior to each mission, the DOD Representative received readiness reports from the support forces and kept NASA informed as to the DOD's ability to support the mission. DOD forces were kept apprised of countdown status, lift-off time, flight progress, and landing information during an operation.

To consolidate and standardize the administrative and operational procedures for the DOD National Ranges, Operations Plan 60–1 was published in 1960. The procedures proved so effective for the early Mercury flights that a joint DOD/NASA document, Network Operations Directive 61–1, was published with a detailed description of the manner in which the DOD, NASA and the Australian Weapons Research Establishment (WRE) facilities would operate as an integrated global network in support of Project Mercury. The documentation flow which transferred information between NASA and DOD started with the NASA Program Requirements Document which requested specific items of support from the ranges. The ranges, in turn, replied with a Program Support Plan which specified how they would meet NASA's requirements.

Launch Support

Launch operations for Project Mercury were conducted at the Cape Canaveral Missile Test Annex of the Atlantic Missile Range. The Redstone vehicles were launched by NASA Marshall Space Flight Center assisted by members of the Army Ballistic Missile Agency. Other DOD participation in the Redstone launches was limited to standard launch complex and instrumentation support normally provided to missile programs by the AMR.

The DOD role in Atlas launches was extended to include the Atlas D launch vehicle, guidance system, and launch complex, and was provided by the Space Systems Division (SSD) of the Air Force Systems Command (AFSC). The 6555th Aerospace Test Wing of SSD located at Patrick AFB was given the responsibility for final installation, prelaunch checkouts, and actual launch of the Atlas launch vehicle to insert the Mercury spacecraft into a proper orbit.

Network Support

The mission of the Mercury Worldwide Network was to enable flight control people to monitor, by electronic means, the status and performance of the spacecraft, its systems, and its occupant and to communicate with the pilot. To accomplish this mission, NASA, with the assistance of the DOD, implemented a global tracking and telemetry network. This network required the use of certain existing DOD stations as well as the construction of additional facilities. As originally planned, the network consisted of 14 land-based stations, two DOD tracking ships, and a communications center.

A listing of the network stations is as follows:

Station number	*Station name*	*Operating agency*
1	Cape Canaveral	AMR
	Grand Bahama	AMR
	Grand Turk	AMR
2	Bermuda	NASA
3	Rose Knot	AMR
4	Canary Island	AMR
5	Kano	NASA
6	Zanzibar	NASA
7	Coastal Sentry	AMR
8	Muchea	WRE
9	Woomera	WRE
10	(Deleted)	
11	Canton Island	PMR
12	Hawaii	PMR
13	Pt. Arguello	PMR
14	Guaymas	NASA
15	White Sands	WSMR
16	Corpus Christi	WSMR
17	Eglin	APGC

The network was later modified on a mission-to-mission basis by other DOD facilities, including additional stations of the Atlantic Missile Range and two radar tracking ships. The DOD Communications Center was replaced by the NASA Communications and Computing Center at the Goddard Space Flight Center (GSFC) and some Mercury stations became identified by names more descriptive of their actual location.

During Mercury missions, the entire network was under operational control of the DOD Representative's network commander, assisted by the network status monitor, who advised the NASA Operations Director on the status of the network to perform its mission. Upon termination of the mission, operational control of the stations reverted to the respective range commanders or the NASA, as appropriate. After the network had been established, NASA provided the technical planning, augmentation, and modification of the network to complement the DOD operational control.

Instrumentation for the initial Mercury flights involved only the facilities of the AMR. The entire network, except for the Coastal Sentry, was first called up for support of MA–3.

The first time a Mercury network instrumented ship was used in support of a Mercury mission was during MR–3. The Coastal Sentry ship was located in the landing area for telemetry and communications between the spacecraft and the ground.

For the second manned flight, MR–4, the AMR Rose Knot ship, was deployed in the landing area. It was during MA–4 that most of the network stations had their first opportunity to attempt radar track. In general, radar track from the stations was poor and the Bermuda, White Sands, and Woomera data were not usable at Goddard. A postflight review was held at AMR and was attended by representatives from all of the radar sites. It was learned from this review that the antenna patterns for both the C- and S-band beacons were not good because of deep nulls in the antenna patterns. A decision was made to install an antenna pattern-phase shifting device on the spacecraft for the next mission. This device introduced a phase delay of 400 cycles per second to shift the antenna pattern and effectively smear over the deep nulls.

The installation of the phase shifter on the C-band antenna system for MA–5 proved successful. During the MA–5 postmission review, indications were that the radar coverage was much improved. This improvement was the result of the use of the phase shifter, the intensive training received by the radar operators between missions, and by the use of a radar controller on the handover net.

During the MA–7 flight, several stations reported amplitude modulation by the phase shifter on the C-band beacon; however, reentry data were smoother than on previous missions. The two relay aircraft obtained SARAH beacon bearings on the spacecraft and confirmed its location prior to sighting.

Failure of the magnetron driver unit on the Canary Islands Verlort radar caused a 15-minute hold in the MA–8 countdown. Some communications problems were encountered during periods of poor propagation conditions and aircraft relay was unsuccessful because the distance between spacecraft and aircraft was too great.

The launch for the Mercury-Atlas 9 (MA–9) mission was the first mission rescheduled because of network difficulties. Bermuda's C-band radar had unacceptable range data errors because of a faulty shift register in the range digital data channel and a faulty preamplifier in the azimuth digital data channel.

The network for MA–9 was augmented by the addition of the Twin Falls Victory Ship (AMR), the USNS Range Tracker (PMR), Antigua Island, Ascension Island, East Island, Wake Island, and Kwajalein Island.

Relay aircraft were equipped with high gain antennas and the spacecraft-to-ground voice relay was successful. Voice relay was also accomplished through Ascension, Wake, and Kwajalein. Radar aircraft of the Air Defense Command, used as part of the network for the first time, obtained a good skin track of the spacecraft during reentry, including blackout, and were able to obtain some contact during orbit. For the first time, stations were allowed to go on standby status during the orbital phase, and computer and data flow tests were conducted to confirm their return to operational status.

Recovery Support

During Project Mercury the DOD contribution to planned and contingency recovery operations expanded considerably. Starting with a concentration of all recovery efforts about a single planned landing area, recovery support multiplied until the DOD was supporting 32 planned landing areas and 51 contingency landing areas for the final Mercury mission. For MR–1A, the first unmanned ballistic flight, the recovery support forces consisted of 8 ships and 15 aircraft all located within 1,500 nautical miles of Cape Canaveral. Recovery support for the final MA–9 mission consisted of 28 ships and 171 aircraft.

Mercury-Redstone Series

The Mercury-Redstone series of four flights which required recovery support took place during the period December 1960 to July 1961. These missions all involved ballistic trajectory flights, with the primary planned landing area located directly downrange northeast of Grand Bahama Island. Naval ships and aircraft formed the recovery task force and were assigned stations within the designated recovery areas. Aircraft units from the Air Rescue Service (ARS) and the Air Force Missile Test Center (AFMTC) assisted the surface recovery forces. Contingency recovery commanders were designated and units of their commands were pre-positioned along the ballistic track to insure readiness should a contingency recovery situation have occurred.

Mercury-Atlas Series

Mercury-Atlas missions MA–3 to MA–9 were all planned as orbital flights varying from one orbital pass to the extensive 1-day, 22-orbit mission which concluded the Mercury program.

With the advancement from ballistic to orbital flight, the support provided by elements of the DOD substantially increased. No longer was it sufficient to consider only a downrange flight path, but now it was necessary to view the entire earth-circling orbital paths as potential contingency recovery operation areas. Although the number of planned landing areas increased from 1 to 32, the greatest expansion of DOD recovery effort occurred in the area of contingency recovery operations. The support of contingency recovery landing areas was primarily borne by aircraft, and in many instances by the same aircraft used in support of planned landing areas. The number of aircraft directly participating in recovery operations for this series increased from 22 located along the AMR ballistic track to 171 located at 30 land-based sites and onboard two aircraft carriers.

The unmanned flight of MA–3 was the first planned one orbital pass mission, but failure in the launch vehicle resulted in its destruction by the Range Safety Officer. The spacecraft escape system worked perfectly and the spacecraft was retrieved by a launch-site recovery-force helicopter, 200 yards off shore. This was the only time during the program that the launch-site recovery forces had to put into practice the many hours of training for just such an emergency.

Because of extensive slippages in the original scheduled dates for the orbital missions, two separate and distinct recovery-force deployments were required. The DOD recovery forces in support of these missions adjusted and substituted units as necessary to meet normal military commitments during the periods between recovery deployments. Despite these reorganizations, all recovery elements and units were ready and effectively performed their recovery missions.

The MA–7 mission of Astronaut Lieutenant Commander Carpenter, USN, terminated after a three-orbital flight with a 250 nautical mile overshoot of the primary landing area. Recovery was effected, however, about 3 hours after landing. A postmission review of this flight revealed the need for a change in recovery communications and operational procedures. This review led to the establishment of a DOD Mercury Recovery Control Center (MRCC) jointly staffed by Commander Cruiser-Destroyer Flotilla Four (CTF-140) and his deputy, Commander Air Rescue Service, who performed the recovery mission for the DOD representative. Furthermore, recovery communications equipment and procedures were changed for future missions so as to provide a more tightly controlled recovery organization capable of quick response to changing situations.

The last two missions of the Mercury Project, MA–8 and MA–9, constituted a culmination of all the lessons learned in previous missions, and reflected the flexibility of the recovery forces when the primary planned landing area was relocated from the Atlantic to the Pacific Ocean. The final flight had the greatest number of recovery forces providing support and required the closest coordination of effort. The Pacific recovery force trained intensively in preparation for these missions, and the smoothness with which the two operations were conducted reflected their efforts and refined procedures. In both flights the manned spacecraft landed within 4½ miles of the primary recovery ship and was recovered and on board within 45 minutes in each case.

Recovery forces supporting MA–8 were deployed with 19 surface units in the Atlantic and 7 in the Pacific. A total of 134 aircraft provided the planned and contingency recovery support for this mission. For MA–9, surface support forces in the planned landing areas numbered 15 ships in the Atlantic and 11 in the Pacific. Air support was provided by aircraft from the Army, Navy, Air Force, Marine Corps, and the U.S. Coast Guard. Commander, Middle East Force, provided a contingency surface recovery force of two ships for the north Indian Ocean areas.

Aeromedical Support

To fulfill the objectives of Project Mercury, the NASA requested the Department of Defense to provide certain medical support. The purpose of this support was to assure thorough on-scene medical care and a prompt and complete assessment of the astronaut's postflight condition.

On December 1, 1959, the Department of Defense Representative for Project Mercury Support Operations designated the Staff Surgeon, AFMTC, as his Assistant for Bioastronautics. The principal function of the Assistant was to plan, organize, and deploy worldwide medical support for Mercury flight operations in response to NASA medical requirements.

The Department of Defense provided medical support in the categories of administration, people, training, facilities, and equipment. The extent of this support is discussed to show the magnitude of such support.

Administrative Support

Administrative support included selection and deployment of medical resources and facilities and the formulation of medical support plans. The scope of this support included the following:

(1) Development of medical plans and programs.

(2) Acquisition, siting, and making operationally ready, the required medical facilities.

(3) Requisition, preparation, and deployment of all needed medical equipment.

(4) The preparation of plans to provide blood for an injured astronaut and procedures in case of non-survival of an astronaut.

(5) Medical staffing of a Forward Medical Station, an Operational Support Unit, and launch site recovery forces.

(6) Deployment of people and equipment to fleet recovery units.

(7) Establishment of specialty teams and alerting of specific DOD hospitals.

In addition, administrative actions were taken to procure medical specialists from Australia and the Public Health Service to support each mission. Arrangements were made for immunizations, distribution of publications to recovery medical forces, and training programs.

Training

For the later manned missions, 84 medical officers were trained by the AFMTC in June 1960 and in April 1963, 23 DOD medical officers were trained specifically for MA–9 by NASA.

People

During the program 233 medically trained people were made available by the DOD in support of Project Mercury flight operations. These people served in the following areas:

(1) As aeromedical monitors. The monitors were assigned to Mercury network tracking stations. Their functions were to monitor, using telemetry displays, the physiological condition of the astronaut.

(2) At Cape Canaveral, to provide emergency surgical support in the event of a launch site incident or disaster.

(3) On recovery vessels, to provide immediate on-scene medical assistance in the event of a medical emergency during recovery operations.

(4) At advanced medical units in high probability landing areas at Grand Bahama Island and Grand Turk Island.

(5) In the Bioastronautic Holding Facility in Hangar "S", Cape Canaveral, to assist in preflight preparations.

(6) A dietitian and food service supervisor were provided in the astronauts' dining facility to prepare and serve prescribed diets to the flight astronaut and his backup.

Facilities

The following medical facilities were provided:

(1) Cape Canaveral: Two blockhouses were modified to provide a forward Medical Station, a Medical Command Post, a Medical Communications Center, an astronauts' diet kitchen and dining room, and a ready room for the Medical Specialty Team.

(2) Downrange: Two prefabricated surgical hospitals and medical debriefing units were erected at Grand Bahama Island and Grand Turk Island.

(3) The Wilford Hall USAF Hospital, Lackland AFB, Texas; the US Navy Hospital, Portsmouth, Virginia; the Walter Reed Army Hospital, Washington, D.C.; the Tripler General Hospital, Honolulu, Hawaii; were designated as specialty team hospitals. Seven other DOD hospitals were alerted in high probability landing areas, to support the astronaut if needed.

Senior medical officers from the three armed services established the medical equipment needs in support of Project Mercury. The medical supplies and equipment were provided to NASA on a loan basis and will be available for support of future manned space flights.

The DOD medical participation in Project Mercury has been mutually beneficial in that the NASA received support otherwise unavailable to them and the Department of Defense medical services gained extensive experience in medical support operations. These trained experienced people represent a core of technically competent specialists to support future manned space programs.

Communications

The termination of Project Mercury was also the termination of an extensive communications complex used by the Department of Defense forces in support of this NASA project. This complex started with the early Mercury ballistic missile communications limited to that of radar and telemetry data needed within the confines of the Atlantic Missile Range (AMR).

As the project progressed to the orbital flights, communications grew in complexity to a point which involved the resources of the national ranges, Defense Communications Agency, and the equipment and facilities available to the separate commands, commercial agencies, and foreign governments.

Programs were initiated to provide communications that were uniquely required by the Mercury mission. Some of the equipment resulting from these programs was adopted by NASA for incorporation into future facilities support.

As Mercury missions advanced from unmanned suborbital to manned orbital flights, it became necessary for the DOD representative's staff to have communications specialists immediately available to assist in the overall DOD communications support as well as to participate actively in the operational phase of the missions. Beginning with the MA-7 mission, the function of the Communications Coordinator was performed for the DOD Representative by the Chief, Range Support Communications Division, AFMTC, assisted by other communications specialists in the AFMTC organization. The value of this group was fully realized during the course of the MA-9 mission. For this mission the most complex communications system employed in the support of the national space effort was implemented. From 48 hours before lift-off through test termination, this group of communicators supervised and maintained constant surveillance of the worldwide communications systems insuring that the best possible support and performance was afforded this Mercury mission.

Network Support

Communications for the Mercury suborbital flights consisted basically of the following:

(1) Launch pad intercommunications systems with associated circuitry to other Cape Canaveral instrumentation areas, such as command control, telemetry, radar, and central control. These systems were interfaced with those provided by NASA within the Mercury Control Center for internal communications.

(2) Voice, teletype, data, and timing circuits to Grand Bahama and Grand Turk Island tracking sites through the use of the AMR submarine cable.

(3) Ultra-high frequency (UHF) and high frequency (HF) communications between the spacecraft and ground with equipment provided by NASA and operated by the AMR at Cape Canaveral, Grand Bahama, and Grand Turk.

Additional communications support for the first manned suborbital flight consisted of a basic teletype and voice plan to provide for the passing of traffic to a recovery force consisting of 10 surface vessels and 11 aircraft in the Atlantic area. Teletype circuits connected the Mercury Recovery Control Center (MRCC) at Cape Canaveral to the three service communications centers, Andrews AFB, Ft. Detrick, and Cheltenham, in the Washington complex; the AMR submarine cable connected the MRCC with the recovery forces in Puerto Rico; and simple high-frequency single sideband (HF/SSB) voice communications connected the MRCC to the recovery ships and aircraft.

As the missions progressed into orbital flights, the NASA tracking network could not meet the need for expanded global tracking and communications requirements. The DOD augmented the existing NASA network by providing coverage at such stations as Antigua, Ascension, Pretoria, Kwajalein, Wake Island, and San Nicholas Island. DOD also provided range ships and aircraft specially configured for spacecraft voice relay.

During MA-8 and MA-9 the DOD provided communications support for the xenon flashing-light experiment being conducted at Durban, South Africa, by routing communications through the AMR station at Pretoria, South Africa.

The DOD Interrange tie line connecting Pt. Arguello, White Sands Missile Range, Eglin Air Force Base, and Cape Canaveral was widely used during the Mercury mission for radar handover and for intersite coordination. The value of this circuit was realized by both NASA and DOD elements for radar control. Beginning with the MA-6 and subsequent missions, modifications were made to include the sites at Guaymas, Mexico, and Corpus Christi, Texas. The line was extended to the Hawaii tracking site for MA-8 and MA-9.

To overcome problems associated with spacecraft-to-ground communications especially during the reentry period, the DOD initiated a developmental program on the use of airborne platforms as automatic relay stations. Special C–130 aircraft were configured with equipment capable of the receipt and automatic retransmission of the modes of communications, HF/UHF, available from the spacecraft or ground stations. Included in the program were various patterns by which the aircraft would fly so as to provide the best coverage and relay conditions. During MA–8 and MA–9 this system was also incorporated aboard the telemetry aircraft operated by the PMR in the Pacific area.

Shortly after MA–8, the AMR developed a technique for the relay of telemetry data by way of single-sideband radio. This system was successfully demonstrated in November 1962 from AMR stations Antigua and Ascension Islands to Cape Canaveral involving distances of 1,200 to 4,400 miles, respectively.

The system was offered to the NASA for use during MA–9 as a means of relaying real-time aeromedical data. The NASA accepted this proposal and the system performed successfully.

Recovery Support

In addition to the basic teletype and voice plan for passing communications traffic to the recovery force deployed in the Atlantic, provisions were also made for the handling of classified traffic by the installation of a secure teletype circuit between Patrick AFB and Cape Canaveral. The AMR submarine cable was used to interconnect the MRCC at Cape Canaveral with the recovery forces in Puerto Rico. High-frequency single-sideband (HF/SSB) voice communications were used between the recovery ships and aircraft in the Atlantic and MRCC.

For the MA–9 mission communications were needed to support 28 surface vessels, 171 aircraft, and various Recovery Control Centers and contingency forces deployed around the world. To tie this vast complex into an effective communications network, the communications resources of the DOD, with its inherent capability to interconnect with other governmental and commercial systems, were available to the DOD Representative's communications staff for support of MA–9.

The hub of the DOD recovery communications effort was the Mercury Control Center at Cape Canaveral. As missions progressed from suborbital to full orbital flights, the center was modified from one of limited communications support to an extensive and complex system which supported the 22-orbital flight (MA–9). This Center was designed to provide for the receipt of status information from worldwide deployed forces and for the passing of directions to the task force commanders. Desks were replaced by operational-type consoles equipped with communications systems capable of providing direct communications between the deployed forces and individuals on the recovery staff. Visual display equipment was provided for the rapid dissemination of information, as needed, within the MRCC and intercommunications links were installed for coordination between DOD and NASA elements.

General Support

As originally planned, the Mercury network communications system did not provide voice communications to network stations having an HF link connecting them with the Goddard Space Flight Center. In order to maintain voice communications with AMR range vessels operating under their control, the AMR established a voice circuit to two range vessels by using the unused sideband of the NASA SSB teletype circuit. This method of operation, commonly in use though not applied to the Mercury network, proved exceptionally useful to the flight controllers during early missions. This method of operation was extended to other Mercury stations so that during MA–9 voice communications were available to all sites.

Prior to MA–9, teletype communications from the Mercury Recovery Control Center were routed to the three military services communications stations in the Washington area complex. The basic service, although satisfactory, created delays when it became necessary to provide alternate routing or to correct technical difficulties and was also cumbersome in effecting coordination during the course of the mission. For MA–9, a plan was created which routed all teletype communications for the recovery forces through one station, Army East Coast Relay

Station at Ft. Detrick, for further dissemination by automatic means to the final destination. This new system proved very effective during MA–9 by providing a single point of contact for coordination purposes, a reduction of circuitry between Cape Canaveral and Washington, D.C., and an ability to react quickly to alternate routine requirements.

The Area Frequency Coordinator at AFMTC was given the responsibility for providing procedures and controls necessary to insure that the 11 spacecraft frequencies were protected from harmful interference. Critical times were established as being from 6 hours before lift-off through mission termination. The frequency protection plan, as developed, was applicable throughout a belt extending some 700 miles north and south of the predicted orbital paths. To provide the control agencies with timely information on implementation and termination of frequency protection, some 87 addressees were contacted by use of Address Indicator Group teletype messages. In addition to these actions, it was necessary during the course of Project Mercury to coordinate the assignment and use of 171 HF frequencies. Throughout the Mercury program a total of 43 cases of electronic radiation interference was reported and satisfactorily resolved or alleviated.

Public Information

Department of Defense support of the NASA public information effort on Project Mercury began with logistic support of news media covering the early launches. A press site which offered a direct view of the Redstone launch complex was built near the Mercury Control Center for the flights of Astronaut Commander Shepard, USN, and Astronaut Major Grissom, USAF (MR–3 and MR–4, respectively). A new, improved press site was constructed near the Cape Canaveral landing strip, near the Atlas launch complex, for the orbital flights.

Logistic support of the news media covering the Mercury activities developed into a general pattern with the greatest amount of support required at Cape Canaveral. The number of accredited news media representatives covering the flights increased with each launch until more than 700 covered the MA–9 flight. Support included transportation, escorts, communications lines (525 pairs of telephone lines and six wideband video lines from the Cape press site), shelter, and public-address systems. AFMTC had a full-time representative at the NASA news media center; and for MA–8 and MA–9, a DOD information officer was on duty at the Pacific News Center in Honolulu.

For coverage of recovery operations, news media representatives were positioned with DOD forces in the primary landing areas and communications channels were furnished so that real-time reporting was possible. Excellent cooperation was received from all DOD agencies in the preparation of information material and in the support of news media people by DOD forces.

After MA–8 and MA–9, NASA Headquarters convened in a meeting of the press pool representatives from all news media to critique the information aspects of the flights. The reports of the media personnel indicated that the logistic support furnished by DOD was sufficient and timely.

Review of Mercury Missions

The Department of Defense support discussed here is limited to that provided for the Mercury-Redstone (MR) missions and nine Mercury-Atlas (MA) missions during the Mercury Project. DOD support in the early phases of the Mercury Project was primarily in the areas of launch and network. As the project developed and missions became more complex in scope and objectives, DOD support expanded into the additional areas of recovery, communications and bioastronautics. The scope of this support, in terms of people, aircraft, and ships for the manned orbital flights is shown in tables 9–I and 9–II. A brief summary of each mission with regard to DOD support follows.

The first Mercury-Atlas vehicle (MA–1) was launched on July 29, 1960. The spacecraft was unmanned and was intended to land northeast of Antigua Island in the West Indies. Standard AMR tracking and data acquisition equipment was available and the recovery support consisted of units from the Atlantic Fleet (CINCLANT), Air Rescue Service (ARS), and AMR forces deployed as a task force. A structural failure occurred approxmiately 1

Table 9-I.—DOD Support for Project Mercury Manned Orbital Missions

Organization	People Activity	MA-6	MA-7	MA-8	MA-9
Commander in chief, Atlantic Fleet	Recovery forces in Atlantic	15, 000	10, 000	9, 000	6, 750
Commander in chief, Pacific Fleet	Recovery forces in Pacific	0	0	5, 000	6, 700
Atlantic Missile Range	Range support, three tracking stations, safety, telemetry aircraft, radar ships.	1, 300	1, 250	1, 250	6, 700
Base Support Division/Space Systems Division.	Booster, guidance, pad (Canaveral/West Coast)	500	480	455	430
European Command	Contingency recovery forces in Africa	215	265	215	300
Pacific Missile Range	Three tracking stations, telemetry aircraft, radar ship	195	165	310	345
Air Rescue Service	Contingency recovery inland area and Atlantic	160	210	210	485
Bioastronautics	Support of medical operations, Air Force, Army, Navy	160	130	95	100
White Sands Missile Range	2 tracking stations	80	80	85	75
Air Proving Ground Center	Tracking station	40	60	60	105
Communications	Air Force, Navy, Army Communications Centers	100	100	100	150
Commander Middle East Force	Contingency recovery (2 ships)	0	0	0	345
Pacific Command	Contingency recovery	160	160	100	100
Military Air Transport Service	Recovery aircraft (12 C–130's) Wx Recon	0	0	0	400
Caribbean Air Command	Contingency recovery	0	0	0	150
Miscellaneous	Radar aircraft, Air Photographic and Charting Service, Adm Aircraft, RF silence.	90	100	120	45
Total		18, 000	13, 000	17, 000	18, 000

Table 9-II.—DOD Aircraft and Ship Support for Project Mercury

Aircraft	MA-6	MA-7	MA-8	MA-9
Atlantic Area	82	74	65	65
Pacific Area [a]	12	12	41	58
EUCOM	16	16	16	27
Inland U.S.	4	2	4	4
CAIRC	0	0	2	5
Mauritius	4	2	0	0
Photo Recon	3	3	2	4
Weather Recon	1	1	1	4
Admin A/C	4	4	3	4
Total	126	114	134	171
Recovery ships	24	20	26	28

[a] Includes 4 aircraft from RAAF.

minute after lift-off. After a 2½ hour search by the launch-site recovery group, without success, activity reverted to regular salvage operations by AMR forces augmented by two Navy minesweepers. Approximately 98 percent of the spacecraft and some parts of the launch vehicle were ultimately recovered.

On November 21, 1960, the first Mercury-Redstone mission with an unmanned spacecraft using the Redstone launch vehicle was unsuccessful because premature engine cut-off activated the emergency escape system when the launch vehicle was a few inches off the pad. The launch vehicle settled back on the pad and was damaged slightly. The spacecraft was recovered for reuse.

The unmanned Mercury-Redstone 1-A mission (MR-1A) on December 19, 1960, was a reattempt of MR-1, and was successful. The recovery phase started with visual sighting by ship and aircraft lookouts and search and rescue and homing (SARAH) detection by search aircraft prior to spacecraft landing. A helicopter hoisted the spacecraft clear of the water 15 minutes after landing and deposited it onboard ship 17 minutes later.

The spacecraft for the Mercury-Redstone mission 2 (MR-2) was launched on January 31, 1961, and carried a 37-pound chimpanzee 420 statute miles downrange. The spacecraft was tracked by the AMR almost to landing, although it had overshot by about 100 miles. Ultra-high frequency (UHF) transmissions were detected by several recovery aircraft during the flight. Recovery aircraft located the spacecraft, and a helicopter returned it to a dock landing ship. Medical support people and materiel were provided on ships, at Cape Canaveral and at Grand Bahama Island to assist in medical operations.

The second Mercury-Atlas mission (MA-2) on February 21, 1961, was successful and the landing was northeast of Antigua Island. A recovery helicopter retrieved the spacecraft 42 minutes after launch and delivered it to a dock landing ship from which it was delivered to Roosevelt Roads, Puerto Rico.

The unmanned Mercury-Atlas 3 (MA-3) mission on April 25, 1961, was planned as a one-pass orbital flight with landing east of Bermuda. All network stations except the Coastal Sentry ship were called up to support the mission. The Recovery task force was deployed to cover the designated landing area. A recovery team from U.S. Commander in Chief, Europe (USCINCEUR) provided a contingency capability to 0° longitude. A failure in the launch vehicle resulted in the Range Safety Officer's aborting the mission 40 seconds after launching. The spacecraft was retrieved 200 yards off shore by a recovery helicopter which was deployed for this purpose.

The first manned Mercury flight, Mercury-Redstone 3 (MR-3) took place on May 5, 1961. After a successful reentry, the spacecraft, with Astronaut Commander Alan B. Shepard, Jr., USN, aboard, was sighted prior to its landing in the planned landing area by deployed helicopters. One of the helicopters delivered the Astronaut and spacecraft safely to the recovery aircraft carrier 26 minutes after landing. All phases of DOD support, including range, recovery, and medical, were excellent. For this mission the AMR Coastal Sentry ship was located in the landing area for telemetry and spacecraft-to-ground communications. Medical support consisted of aeromedical monitors aboard the Coastal Sentry Ship, emergency medical teams aboard recovery vessels and at the launch site, and a medical debriefing team at Grand Bahama Island. Aircraft of the ARS were on station to assist in search operations.

The second manned flight, Mercury-Redstone 4 (MR–4), was conducted on July 21, 1961. DOD support was comparable in scope to that of MR–3. For this mission the AMR Rose Knot ship was used in the landing area. The flight and landing phases were successful. After landing, premature actuation of the spacecraft side hatch resulted in an emergency situation in which the spacecraft filled rapidly with water and began to sink. Astronaut Major Virgil I. Grissom, USAF, egressed from the spacecraft, and, after a short but difficult period in the water lasting approximately 3 minutes, was hoisted aboard the recovery helicopter and delivered on board the recovery ship for medical examination 19 minutes after spacecraft landing. A second helicopter attempted to recover the sinking spacecraft. The weight of the flooded spacecraft exceeded the lift capability of the helicopter at full power and the pilot elected to release the spacecraft rather than to jeopardize further the safety of the helicopter and crew. The spacecraft sank in 2,800 fathoms of water.

A second attempt, to orbit an unmanned spacecraft, was scheduled for August 25, 1961. This mission was designated Mercury-Atlas 4 (MA–4). All network stations were scheduled to participate. Recovery forces were deployed similarly as had been for MA–3. Contingency support was increased in scope to include full deployment by forces from CINCLANT, and partial deployment by forces from USCINCEUR, CINCPACFLT, and ARS. Bioastronautic support included additional forces deployed for training in the launch-site area. Shortly prior to beginning the countdown, launch-vehicle problems were identified which resulted in a 3-week delay of the launch. All deployed forces were recalled, then redeployed for a September 12 launch. On September 13, the mission was successfully conducted with the spacecraft completing a one orbital pass and landing in the planned landing area. A C–54 search aircraft located the spacecraft and retrieval was accomplished by the USS *Decatur* and delivered to Bermuda Island. Network performance, with the exception of generally poor radar tracking, was good. The tracking problem was traced to the lack of operator training and poor spacecraft antenna patterns.

Mercury-Atlas 5 (MA–5) was scheduled for November 14, 1961, to carry a chimpanzee on a three-pass orbital flight. Recovery planning included the primary landing area at the end of the third pass, as well as the probable areas for landing at the end of the first and second orbital passes. Recovery forces were deployed accordingly and contingency recovery commanders planned for a full deployment. Additional medical forces included veterinary specialists for postflight care and examination of the chimpanzee, as well as a complete launch-site support team. On November 12, spacecraft problems resulted in a 2-week delay in the launch. During this period, recovery forces reverted to normal operational control, were reorganized, and redeployed for a November 29 launch date. The launch was successful and flight was normal until spacecraft problems prompted a decision to land the spacecraft at the end of the second orbital pass. Radar tracking was greatly improved through intensified training prior to the flight and better spacecraft antenna patterns as a result of a beacon modification. Reentry and landing proceeded normally and the spacecraft was sighted in the planned landing area by recovery aircraft about 260 miles south of Bermuda. It was retrieved within 80 minutes after sighting. The spacecraft and occupant were delivered to Bermuda.

Mercury-Atlas mission 6 (MA–6) on February 20, 1962, was the first manned orbital flight and involved three orbital passes. The spacecraft, with Astronaut Lieutenant Colonel John H. Glenn, USMC, aboard, landed about 166 miles due east of Grand Turk Island, approximately 4 miles from the recovery destroyer which retrieved the spacecraft 21 minutes after landing.

All network instrumentation remained operative and provided full coverage throughout the three orbital passes. Telemetry and communications were excellent in spite of some telemetry-recording and radio-propagation problems. Radar coverage was better than expected, exceeding the performance for MA–5. Although a 4-minute ionization blackout occurred during reentry, the C-band radars were able to maintain track of the spacecraft which resulted in an accurate prediction of the landing point.

The landing areas after passes 1, 2, and 3, were treated as primary recovery areas for this mission. The recovery task force comprising a total of 24 ships and 41 aircraft was stationed in the nine planned landing areas in the Atlantic Ocean. An additional 37 aircraft were standing by at Jacksonville, Florida; Bermuda, Lajes Air Force Base, Azores; BenGuerir, and Roosevelt Roads, Puerto Rico. Forces from USCINCEUR, CINCPAC, and USAF were deployed along the remaining orbital tracks for contingency recovery.

A full Bioastronautic Task Force, consisting of 159 medical people was provided by the DOD and deployed to support this mission. These people staffed or augmented 4 medical treatment facilities, 21 recovery ships, and 14 medical monitoring stations. The medical evaluation and debriefing of the astronaut was completed at the advanced medical treatment facility at Grand Turk Island on February 23, 1962.

The seventh Mercury-Atlas mission (MA–7) was launched on May 24, 1962. This mission was the second three-pass orbital flight. Astronaut Lieutenant Commander M. Scott Carpenter, USN, was the pilot for this mission. All network stations were scheduled to participate except the AMR Rose Knot ship which was undergoing modification for a command-control system. Only the landing area at the end of the third orbital pass was designated as primary for this mission, requiring support of only one aircraft carrier. The spacecraft was launched and inserted into a nominal orbit with exceptionally good precision. Just prior to retrofire, at the end of three passes, a failure in the automatic control system was noted. A manual retrofire maneuver was planned and the countdown was sent from the California site. Attitude errors at retrofire caused the spacecraft to overshoot the planned landing point by approximately 250 miles. A directional finding (D/F) bearing on the spacecraft was quickly obtained by search aircraft and a SC–54 arrived within 1 hour after spacecraft landing with an auxiliary flotation collar and other survival equipment. Helicopters were launched from the carrier U.S.S. *Intrepid* when the carrier was within flight range. Although an ARS SA–16 arrived on scene before the helicopters, the Task Force Commander decided to effect recovery by helicopter. The astronaut was retrieved 3 hours after landing and returned to the carrier. The spacecraft was retrieved by a recovery destroyer for delivery to Puerto Rico.

A postmission review held at Patrick Air Force Base, Florida, revealed the need for a more rapid flow of information between the Mercury Recovery Control Center (MRCC) at Cape Canaveral and the on-scene forces. Recovery communications equipment and procedures were changed for future missions so as to provide for a more tightly controlled recovery organization capable of quick response to changing situations.

On October 3, 1962, the eighth Mercury–Atlas mission (MA–8) was launched. This mission, planned for six passes, was successfully completed and the spacecraft, with Astronaut Commander Walter M. Schirra, USN, aboard, landed in the primary landing area approximately 4½ miles from the recovery aircraft carrier. For the first time in the Mercury Project, recovery forces were deployed in the Pacific Ocean for a primary landing northeast of Midway Island. The landing area in the Atlantic Ocean at the end of the third pass was also treated as a primary area in the event that a full six-orbital mission could not be completed. Contingency recovery forces were expanded to cover the additional ground tracks in the South Atlantic, Caribbean, and western Pacific Ocean. The AMR Coastal Sentry ship was positioned in the Pacific Ocean to monitor the planned retrofire maneuver. Two S-band radar ships from the Pacific Missile Range and an Army C-band radar ship were positioned uprange from the primary landing area for reentry tracking. The Bioastronautic Task Force consisted of 84 medical specialists assigned to the launch area, network stations, and recovery units. An additional 22 specialists were available on a standby basis.

Centralized operational control together with the cooperation of the DOD forces participating in MA-8 were instrumental in achieving an integrated and responsive organization.

The ninth Mercury-Atlas mission (MA-9) was launched on May 15, 1963. This manned 1-day mission was planned for 22 orbital passes with the primary landing area in the Pacific Ocean southeast of Midway Island. The MA-9 spacecraft, with Astronaut Major Gordon Cooper, USAF, aboard, was placed into a near-perfect orbit by the Atlas launch vehicle. After 33 hours of normal flight during which the major objectives were met, a malfunction in the spacecraft control system required manual control of the spacecraft during retrofire and reentry. This was accomplished successfully and precisely by the astronaut and the spacecraft landed in the primary landing area within 4½ miles of the recovery aircraft carrier.

There were a total of 26 planned landing areas in the Atlantic and Pacific Oceans for the MA-9 mission. These areas were selected so that the ships of the Atlantic and Pacific task forces could cover more than one area. A worldwide deployment of contingency recovery forces was required to cover the entire ground track of the spacecraft. All theater forces were augmented by long-range C-130 MATS airplanes. There were 98 aircraft deployed for contingency recovery by the Air Rescue Service (ARS), Caribbean Air Command (CAIRC), Pacific Air Forces (PACAF), and CINCUSAREUR. Two AMR network ships were positioned in the Pacific Ocean to give command-control coverage. Reentry tracking in the Atlantic and the Pacific was available from two C-band radar ships. The Bioastronautic Task Force included 78 medical people deployed, 32 specialty team members on standby, two specialty team hospitals, and 7 recovery support hospitals.

Support efforts of DOD also included the successful accomplishment of voice relays both in the Atlantic and Pacific. Relay to Mercury Control Center (MCC) of the astronaut's voice while in orbit was obtained by the AMR C-130's stationed near Bermuda. During reentry and after landing, voice communications were relayed through PMR aircraft to the Hawaii network site where it was patched through network voice circuits to MCC. Radar airplanes of the Air Defense Command stationed in the Atlantic and Pacific obtained skin track of the spacecraft. The network provided excellent tracking coverage throughout the flight, considering the lengthy operating period for the equipment and long working hours for site people. Thoroughness in planning and excellent performance of assigned missions by DOD forces were reflected in the success of the MA-9 mission.

Concluding Remarks

Many changes in procedures and techniques used in providing Department of Defense support were developed during the course of the Mercury Project. Many lessons were learned and put into effect during successive missions; however, only those significant items which may have possible application in supporting future manned space programs are described.

The organization for the coordination and control of the overall DOD participation in Project Mercury was highly satisfactory. The designation of a DOD Representative for coordination of DOD support for Project Mercury operations was effective in that NASA was provided with a single point-of-contact for the submission of their overall DOD support requirements.

The operation of the global Mercury network comprising DOD ranges, NASA stations, and two stations in Australia was a significant achievement in coordinated team effort and was only accomplished by the complete cooperation of all concerned. Network management and operational procedures were clearly defined and compiled in a comprehensive joint DOD-NASA Mercury Network Operations Directive which proved to be a very useful and effective document.

The demonstrated ability of several ranges to combine their collective resources effectively to support global missions proves the possibility of combining all such national missile tracking resources under a single management control for the support of all missile and space programs of all agencies.

The integration of radar-tracking equipment into a tracking system at the DOD missile ranges increased the capability of each range to support future missions. Technological experience and achievements of each range were pooled to permit all ranges to take advantage of such advancements or modifications.

The application of relay techniques for transmitting remote telemetry data from the downrange stations, derived from AMR experience in data transmission, was reported to NASA for possible adaptation to the wire and radio circuits of the Mercury network. Subsequently NASA secured a telephone line for data transmission between Pt. Arguello and the Mercury Control Center. During the ninth Mercury-Atlas mission the Mercury Control Center was supplied with a real-time display of electrocardiograph functions from the DOD sites at California, Antigua, and at Ascension. In addition to increasing the potential at each site by such improvements, a considerable saving in research and development costs was also realized by virtue of this exchange of technical information.

The use of radar-tracking aircraft during Mercury missions and especially the results obtained during the reentry phase of the MA-9 mission added significantly to the flexibility of network operations.

The use of the vast communications resources within the DOD and their integration into existing NASA and commercial systems to support network and recovery operations contributed significantly to the operational success of the project.

One of the more important considerations for support of Mercury operational planning was to provide for the safe and rapid recovery of the astronaut. Plans made by the DOD elements provided for the deployment of forces in a large number of strategic locations to cover possible aborts during all phases of the mission. Much of the effort in training was expended by forces that were deployed to act in contingency situations which essentially never developed. Their efforts, nevertheless, contributed to the success of the recovery mission.

Providing support to Mercury flights has contributed greatly to DOD's knowledge and experience in areas of launch, network, recovery, communications, and medical space operations. Future space-flight operations can be effectively supported by applying the experience and procedures derived during Project Mercury.

10. ASTRONAUT TRAINING

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Summary

Any training program must be based on three factors: the requirements of the job, the characteristics of the trainees, and the training facilities available. Each factor is briefly discussed and its effect upon the nature of the training program is indicated. Selection of the Mercury astronauts began in January 1959. They reported at the Manned Spacecraft Center in April of that year and took part in a group training program for the next 2 years. In April 1961, when the Mercury manned flight program began, a special preflight preparation program was conducted with each of the pilots and his backup designated for a flight. The remainder of the group took part in development and operational activities and did limited training to maintain the proficiency developed during the group training program.

The group training program consisted of five major areas: (1) basic astronautical science instruction, (2) systems training, (3) spacecraft control training, (4) environmental familiarization, and (5) egress and survival training. The specific preflight preparation programs involved: (1) integrating the pilot with the spacecraft, (2) specific systems training, (3) development and practice of the specific mission flight plan, (4) training with flight controllers, and (5) medical and physical preparation. All of the Mercury trainers and training facilities are briefly listed and discussed, and this section concludes with an evaluation of the training devices and of the various phases of the training program.

Overall, the Mercury training program appears to have been successful in providing experienced pilots with the detailed spacecraft operation and systems information and skills which were required for them to make the transition from airplanes to spacecraft. The program seems to have been well suited to the requirements of the Mercury Project and future programs will make use of the same basic techniques. In retrospect, some of the emphasis on environmental familiarization might have been reduced, and more complete simulation of the external view from the spacecraft should have been provided. However, the great majority of the trainers and training activities have been both beneficial and necessary to produce the level of readiness that was demonstrated in the flight program.

Introduction

The Mercury training program was the first opportunity to prepare individuals for space flight. In general, however, the techniques used were not basically new or unique to this project. Rather, standard training techniques and training equipment approaches which had been used for many years in aviation were adapted for preparing the astronauts for their flights. From the beginning, the role of the astronaut has been conceived as being active and highly similar to that of the test pilot who carries out the initial flights of new aircraft. While the Project Mercury drew heavily upon flight training methodology, there were certain specific requirements of this program which were significant in determining its basic form. It is perhaps worth keeping these requirements in mind in a review of the Mercury training procedures:

(1) The Mercury program was not a mass training program, only seven individuals were involved, and, therefore, it was possible to reduce the formality of the program and to use a number of shortcuts which would not have been

feasible in the larger aviation training programs.

(2) The participants in the training program were experienced individuals who were already well along in preparation for space flight. This not only greatly reduced the overall amount of training necessary, it was also possible to emphasize individual initiative and responsibility for their training status.

(3) The training program had to be flexible because the spacecraft which the astronaut was being trained to operate was under development and therefore was being modified according to mission requirements.

(4) The training program had to be designed to help feed back into the developmental process. The astronauts were expected to aid the development engineers by participating in the design and review of many of the spacecraft systems, and the training activities were frequently combined with systems tests to evaluate both onboard and crew equipment.

(5) Unlike flight training, actual training in space was not feasible. There was a complete dependence upon ground simulator training until the astronaut flew the mission for which he had been preparing.

(6) The training had to be designed to tie in with the training and preparation of other operational groups such as the flight controllers.

(7) The significance of the program to our national prestige, the very great interest of the public, and the large cost resulted in an unusually strong emphasis upon a very high level of reliability, perfection, and precision in the man's performance.

Training-Program Characteristics

Any training program must be based on three major factors: the job requirements, the characteristics of the trainees, and the training facilities which are available. These factors are discussed in the following paragraphs.

Characteristics of Mercury Astronaut's Job

While the Mercury spacecraft was designed to complete a limited preprogramed mission on a completely automatic basis, from the very beginning manual controls were also provided. It was recognized that the man could provide increased systems reliability and give flexibility to the mission by allowing for a greater variety of maneuvers and scientific observations. The decision to provide for complete manual operation was highly significant for the crew training program because it meant that there would be a requirement for an individual who could skillfully manage the vehicle, as well as merely tolerate the physical stresses of the flight.

The major tasks (refs. 1 and 2) which can be identified from an analysis of the Mercury vehicle and its mission, involve:

(1) Sequence monitoring—monitoring all of the critical phases of the space mission, such as lift-off, staging of the launch vehicle, the separation of the escape tower, the separation of the spacecraft from the launch vehicle, firing of the retrorockets, and deployment of the parachute.

(2) Systems management—operation of all of the onboard systems and the management of the critical consumable supplies to insure that any out-of-tolerance condition is recognized and corrected before an emergency situation develops.

(3) Attitude control—maneuvering the vehicle to the proper relationship to the earth or orbital path whenever it is required during the mission.

(4) Navigation—being able to determine the spacecraft's position in orbit at any time and determining the critical retrofire time.

(5) Communications—operating the radio links to keep the ground control center informed of his status.

(6) Research observations—carrying out the special activities related to research and the evaluation of spacecraft function under flight conditions. The difficulty of performing these tasks was increased by the presence of environmental conditions, such as high acceleration, reduced pressure, heat, noise, vibration, and weightlessness.

In addition to these tasks involved in the actual operation of spacecraft, the Mercury astronauts were expected to contribute to a number of areas in the Mercury program. These included four main areas:

(1) Design of the Mercury spacecraft.

(2) Development of operational procedures.

(3) Development of inflight test equipment. It was desired to carry out tests of the spacecraft function, of special advanced systems and components, and to do scientific research during

the space flight that required the astronauts' participation in the development of a number of specialized kinds of equipment.

(4) Contribution to public relations activities. The astronauts served as excellent spokesmen for the program and were an important aid in meeting the requirement set by Congress to keep the public informed on the space program.

Characteristics of Trainees

The job requirements discussed in the previous section required individuals with high skill levels, appropriate personality traits, and a high level of physical fitness. The requirements under each of these areas are summarized as follows:

(1) In the area of aptitude and ability factors, the individual needed:

(a) A good engineering knowledge

(b) A good knowledge of operational procedures typical of aircraft or missile systems

(c) General scientific knowledge and research skills.

(d) High intelligence.

(e) Psychomotor skills similar to those required to operate aircraft

(2) In the area of personality factors, the candidate had to demonstrate:

(a) Good stress tolerance

(b) A good ability to make decisions

(c) Ability to work with others

(d) Emotional maturity

(e) A strong motivation for the program

(3) The physical requirements included:

(a) Freedom from disease or disabilities

(b) A resistance to the physical stresses of space flight accelerations, reduced pressure, weightlessness, high temperatures, and so forth

(c) Medium size so that they could be adequately accommodated by the relatively small Mercury spacecraft.

Initial planning during the fall of 1958 resulted in the definition of five basic requirements for Mercury crew members: age, 39 or below; height, 5 feet 11 inches or below; graduate of a test pilot school; qualified to fly jet airplanes; with 1,500 hours of jet flying time; and a bachelor degree in science, engineering, or the equivalent. During the first weeks of January 1959, a selection board reviewed the records of 508 military test pilots and selected the 110 who met the above requirements. The 69 most highly qualified of these candidates were invited by the services to come to the Pentagon to receive a briefing on Project Mercury and to be interviewed by the NASA Space Task Group.

On the basis of these interviews, 32 were selected to proceed to the Lovelace Clinic for a week of detailed physiological examinations and then to the Wright Field Aeromedical Laboratory for a week of stress tests (refs. 3 to 6). Data from these two testing programs were summarized and reviewed at the Space Task Group during the first week of April 1959. In all, 18 men were found to be medically qualified without reservation and, of these, the seven most technically qualified were selected to enter training.

Training Facilities

Table 10–I summarizes all of the major training facilities used in the Mercury Astronaut Training Program. Included are training devices and other facilities used for significant areas of the training program. From the table, it can be seen that there were a large number of facilities used. This resulted from at least three factors.

(1) Since the program was a first effort of its kind, it seemed appropriate to try all facilities to get a better feel for the relative importance of various types of experiences to the training.

(2) It was generally impossible to simulate more than one or two of the environmental conditions at any given facility. Therefore, it was necessary to use many different devices to obtain experience with all aspects of the environment.

(3) Most of the training devices had to be simple and rudimentary because the simulation techniques for space flight were in their infancy, and the training program was based on an accelerated schedule.

Table 10–I also lists the availability, date, approximate training time per astronaut, estimates of cost, lead time, and support time for each of the major training devices. The scheduling of some types of training activities had to be held up pending delivery or completion of this equipment. Also as can be seen from the source or location of each device in table 10–I, these training facilities were spread out over

Table 10-I.—Trainer Summary

Identifying letter from fig. 10-1	Trainer	Primary purpose of trainer	Approximate date available	Approximate training time per astronaut, hr.	Approximate cost, dollars	Approximate lead time, months	Approximate support time, man-hours	Source	Assessment			
									Essential	Desirable	Early availability	Questionable value
a	Analog trainer no. 1.	Attitude control.	Apr. 1959	8	----------	0	200	NASA Langley Research Center.		x	x	
b	Proficiency airplane flights.	General performance proficiency.	May 1959	460	----------	0	60, 000	U.S. Air Force and inhouse.		x		
c	Centrifuge simulations.	Acceleration training; reentry control.	Aug. 1959	48	500, 000	4	15, 000	U.S. Navy, Johnsville, Pa.	x			
d	ALFA trainer	Attitude control.	Oct. 1959	12	50, 000	6	150	Inhouse	x			
e	Analog trainer no. 2.	Attitude control, pressure-suit training.	Oct. 1959	10	20, 000	3	200	Inhouse		x	x	
f	Navy slowly revolving room.	Disorientation familiarization.	Oct. 1959	1	----------	0	15	U.S. Navy, Pensacola, Fla.				x
g	Zero-g airplane flights.	Zero-g familiarization.	Dec. 1959	0. 7	----------	0	1, 000	U.S. Air Force		x		
h	Chapel Hill Planetarium	Star recognition training	Feb. 1960	28	----------	0	600	University of North Carolina	x			
i	MASTIF trainer	Disorientation familiarization	Feb. 1960	4	----------	0	300	NASA Lewis Research Center		x		
j	Egress trainer	Egress training	Feb. 1960	25	119, 000	10	1, 000	McDonnell Aircraft Corp.	x			
k	Procedures trainers (2)	Systems management, attitude control, mission training	June 1960	101	4, 000, 000	12	100, 000	McDonnell Aircraft Corp.	x			

l	ECS trainer	Environmental control system management	Nov. 1960	3	228, 000	12	1, 000	McDonnell Aircraft Corp.				x
m	Attitude instrument display mockup	Characteristics of attitude instruments	Jan. 1961	10	5, 000	4	50	Inhouse	x			
n	Ground recognition trainer	Periscope training and terrain familiarization	Apr. 1961	1	2, 000	3	5	Inhouse				x
o	Yaw recognition trainer	Out-the-window yaw angle recognition	Sept. 1962	2	1, 000	1	30	Inhouse	x			
p	Virtual image celestial display	Attitude control at night; star recognition training	May 1963	2	----------	12	75	Farrand Optical Co.	x			

the country. This resulted in a large amount of travel for the astronauts. As a result, their time was used somewhat less efficiently than if all the training facilities had been available from the beginning of the program at MSC. Most of these facilities are pictured in figures 10–1(a) to 10–1(p).

Training Chronology

Figure 10–2 presents a chronology of the Mercury training program. The astronaut selection program occupied the period from January to April 1959. The group training program ran for approximately 2 years, to April 1961. After April 1961, the manned flight program began. Prior to each flight, a preflight preparation program was conducted for the pilot and his backup. The length of this

(a) Langley analog computer simulator.

(b) Aircraft used for proficiency flights.

(c) Centrifuge acceleration facility.

(d) ALFA trainer.

FIGURE 10–1.—Photographs of various training facilities.

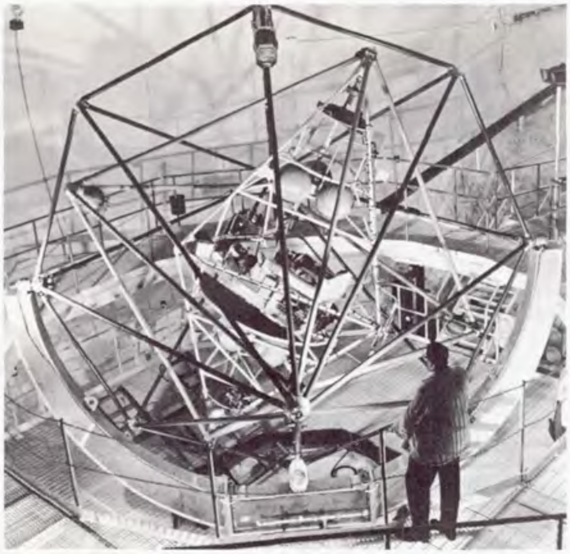
(e) Analog computer trainer no. 2.

(g) Zero-g airplane flights.

(f) Slowly revolving room.

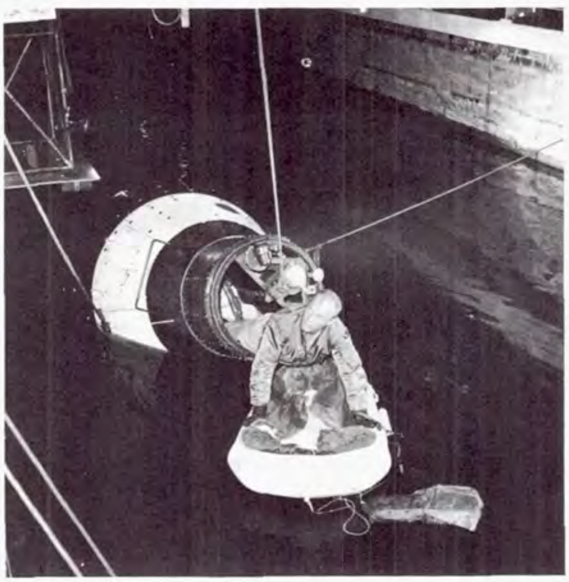
(h) Chapel Hill Planetarium.

FIGURE 10-1.—Continued.

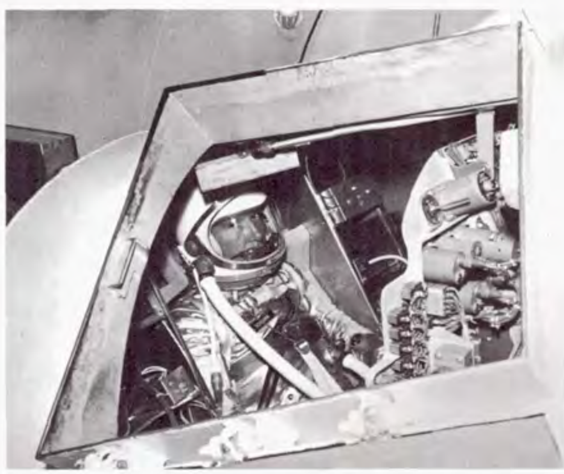


(i) MASTIF trainer.

(k) Procedures trainer.

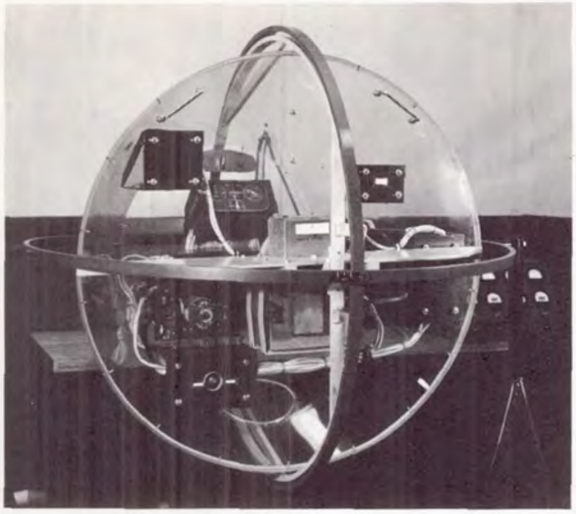


(j) Egress trainer.

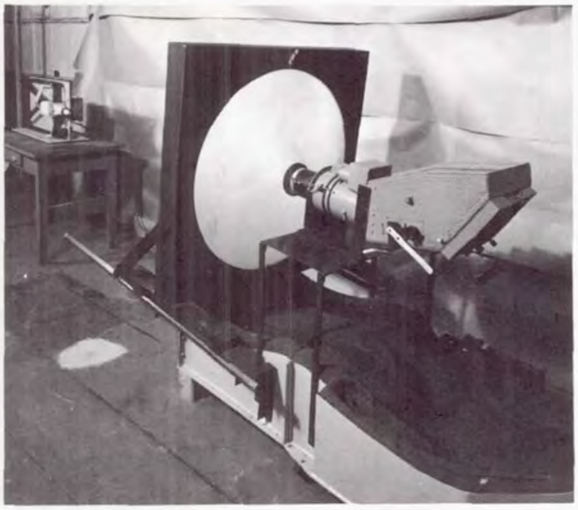


(l) ECS trainer.

FIGURE 10–1.—Continued.

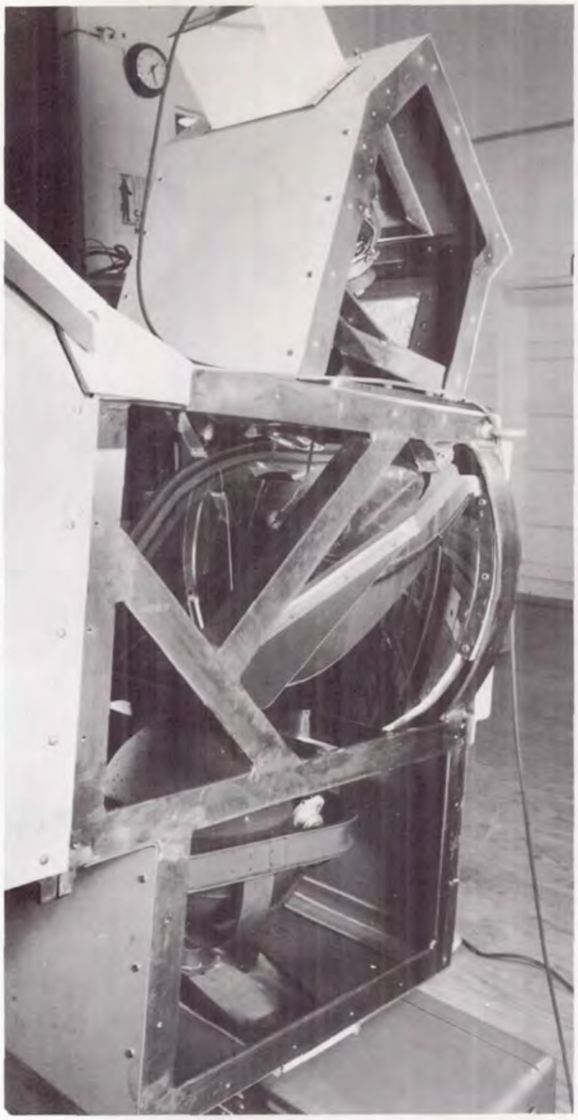


(m) Attitude instrument display mockup.



(n) Ground-features recognition trainer.

(o) Yaw recognition trainer.



(p) Virtual image celestial display.

FIGURE 10–1.—Concluded.

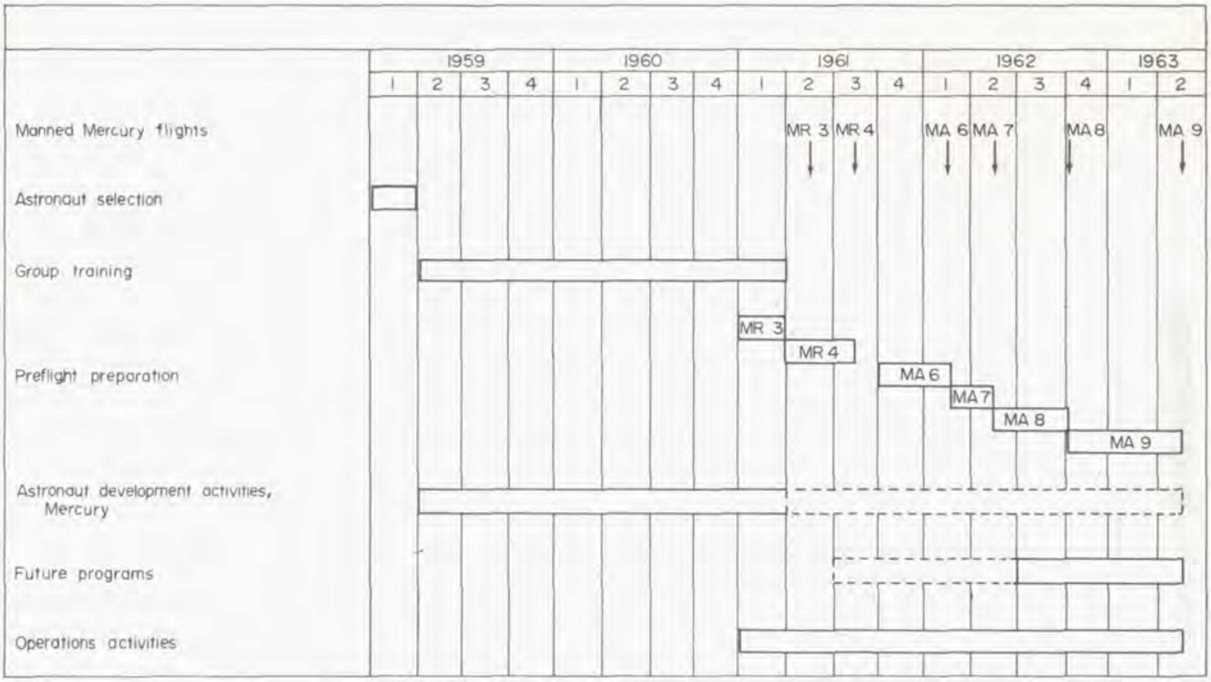


FIGURE 10-2.—Chronology of Mercury training program.

program depended upon the time available between flights and on the nature of the flight. In general, the backup pilot on one flight was selected as primary pilot for the next mission. In this way, the actual preflight preparation of each pilot encompassed close to 6 months—the first half as a backup and the second half as the primary pilot.

The pilots' contribution to the development activities in the Mercury program began soon after they reported to the NASA and had had sufficient indoctrination on the Mercury spacecraft systems. The astronauts participated in planning for the programs to follow Mercury which began in 1961 and became greatly accelerated in 1962.

Each man was assigned to a Mercury network station as voice communicator. Service in this capacity normally involved a minimum of 3, or more, weeks. This activity in connection with Mercury operations began with the manned Redstone flights in 1961 and became greatly amplified with the manned orbital flights in 1962 and 1963. After the termination of the group training program, they had to devote time to maintaining their proficiency, in addition to these operational requirements.

Group Training Program

The group training program consisted of five major areas which are described in the following paragraphs. Portions of this program have previously been described by Astronaut Slayton in ref. 7 and others (ref. 6 and 8).

Basic Science Program

An initial phase of the Mercury astronaut training program consisted of brief but comprehensive courses in the astronautical sciences. The astronauts had had considerable training in the aeronautical sciences, but most had not had an opportunity to acquire the basic knowledge in such subjects as rocket propulsion and space mechanics which were required in the Mercury flight program. Training in the space sciences enabled the astronauts to function better as observers of inflight phenomena and provided a basis for better understanding of the technical aspects of the Mercury spacecraft and vehicle systems. The series of courses listed in table 10-II was conducted with the cooperation of the NASA Langley Research Center. Time did not permit a more extensive program although it would have been desirable.

Table 10–II.—Lectures on Space Sciences

Subject	Hours
1. Elementary Mechanics and Aerodynamics	10
2. Principles of Guidance and Control	4
3. Navigation in Space	6
4. Elements of Communication	2
5. Space Physics	12
6. Basic Physiology	8

Systems Training

A large portion of the training program was devoted to familiarizing the astronauts with the Mercury systems. This knowledge was not only basic to all of their training activities but was the essential basis of their contribution to the development program. The primary requirements of this training were: to develop a basic understanding of the nature and characteristics of each system; to build on this understanding a knowledge of the system operation and function; and, finally, to develop, in the Mercury procedures trainers and the spacecraft, skill in managing the onboard systems.

Systems briefings.—The systems training began with a series of briefings given by specialists within the Space Task Group. The first set of lectures covered the Mercury systems and was followed by another group of lectures covering operational areas. These lectures were followed by a series of somewhat more detailed systems briefings by contractor personnel at the various contractor facilities. Periodically, throughout the 2 years of the group training program, systems lectures were repeated.

Contractor visits.—The astronauts visited contractor plants and other NASA centers in order to get a firsthand view of the developing hardware and of the operational facilities.

Manuals.—Documentation of the Mercury systems was a particularly difficult problem because the spacecraft was under development. The first set of systems lectures were used as the basis for the Mercury Familiarization Manual (ref. 9). This manual became the basic systems document used by the astronaut.

A second manual, which was developed later in the program and which emphasized the operational aspects of the systems management problem, was the Capsule (Spacecraft) Flight Operations Manual (ref. 10). This document was printed in a size small enough to be carried in the pocket of the flight jacket with the intention that it could be carried along on flights, if desired. In actual practice, it was not carried with the flight but was used during some trainer runs. A third publication used extensively in training was the Flight Controller's Handbook, which was developed within the Manned Spacecraft Center (see paper 15) and which provided a number of useful diagrams for analyzing system malfunctions.

Specialty Assignments.—To insure that the astronauts had available to them the most up-to-date information possible, they participated in the engineering reviews and other meetings on the spacecraft systems. Since no one man could cover all of these meetings, each astronaut was assigned to a specialty area (ref. 7). Each man attended meetings in his area and reported back to the group.

Mercury Procedures Trainers.—The bulk of the operational training in the Mercury systems was achieved on the Mercury Procedures Trainers (MPT). The name "procedures trainers" is actually a misnomer since these devices could better be classified as flight simulators. Initially, a very simple open-loop device had been considered for training in the basic launch procedures. This was to be supplemented later by a complete flight trainer. However, the time available for development and delivery of these training devices was so short that it was decided to combine the two into a single trainer. In this trainer, it was possible to simulate the operation of all of the Mercury systems and induce approximately 275 separate system failures (ref. 11). Provisions were made to pressurize the pressure suits. However, with the exception of the indicator readings, the actual environmental conditions in the cabin were not provided. Two of these units were procured in order to have one available at the launch site to be used in prelaunch training, while the other was used at the main training base at Langley Field, Va. These two procedures trainers differed slightly in their provisions for animating attitude control system, as is described later, but they were essentially identical in their capability to simulate the operation of onboard systems.

Initial training began by reviewing each system separately in the trainer. The normal operation of each system and all of the failures which could be simulated were demonstrated during this initial period. Following this, a series of both Redstone and Atlas simulated flights were made for each student, during which simulated emergencies were kept to a minimum in order to allow the astronauts to become familiar with the timing of the normal missions. Once they were generally familiar with the timing of the missions and the normal indications, the numbers and types of malfunctions were increased. By the end of the group training period, all the astronauts had made a large number of Atlas and Redstone runs and had had an opportunity to experience most of the major emergencies.

Environmental Control Systems Trainer.—Additional training in the operation of the environmental control system was provided by the environmental control systems trainer which was a heavy shell mock-up with a prototype spacecraft environmental system. The device used was delivered to NASA in November 1960 and installed in a man-rated vacuum chamber at the U.S. Naval Air Crew Equipment Laboratory in Philadelphia (fig. 10–1(l)). During December of 1960 and January of 1961, the astronauts participated in a program of system familiarization that included being exposed to a simulated reentry heat pulse and approximately 2 hours of the expected postlanding temperature. During these runs, the astronauts wore the pressure suits and became familiar with function of the suits when associated with the environmental control system. However, since a provision had been made for simulating the suit function in the procedures trainer, this type of training was not considered essential. This was particularly true since the astronauts received further first-hand familiarization to the environmental control system by participating in the preflight checkout of the spacecraft environmental control system at the launch site.

Attitude Control Training

A number of fixed and moving based simulators had to be employed because no single trainer was capable of simulating all of the tasks on all of the control systems under all environmental conditions (ref. 12). The function of each of the principal control attitude trainers is summarized in table 10–III. This table lists the attitude control trainers and the spacecraft control systems which could be simulated, the reference systems which were available to the pilots, tasks which could be practiced, environmental conditions simulated, and finally whether or not attitude tasks could be practiced in conjunction with other flight activities. Each of these trainers is briefly described in the following paragraphs.

Table 10–III.—Attitude Control Trainer Summary

Referenced to figure 10–1	Trainer	Control systems [a]				Reference systems				Types of tasks				Environmental conditions			Use while performing other tasks
		MP	FBW	RC	Mixed	Instruments	Window	Periscope	Mixed	Orbit attitude control	Retrofire	Reentry rate damping	Recovery from tumbling maneuvers	Linear acceleration	Angular acceleration	Pressure suit	
a	Analog trainer no. 1	x	x			x				x	x	x					
e	Analog trainer no. 2	x				x				x	x	x				x	
k	Procedures trainer no. 1	x	x	x	x	x	[b]	x	x	x	x	x				x	x
k	Procedures trainer no. 2	x	x	x	x	x				x	x	[c]					
o	Yaw recognition trainer						x										
m	Attitude Instrument display mock-up					x				x			x				
h	Ground recognition trainer							x									
d	ALFA	x	x			x	x	x	x	x	x				x		
i	MASTIF	x				x							x		x		
c	Centrifuge	x				x				x	x	x		x		x	x

[a] MP—Manual proportional.
FBW—Fly-by-wire.
RC—Rate command.

[b] Added to MPT no. 2 late in training program.

[c] Virtual image celestial display added to MPT no. 2 just prior to last flight.

Analog trainer.—The analog computer trainer provided the first simulation of the astronaut's manual flight-control task in Project Mercury. The simulator (fig. 10–1(a)) was set up by Langley Research Center personnel at the inception of Project Mercury and was used heavily during the first half of 1959, both for engineering feasibility tests and for introducing the Mercury flight control tasks to the astronauts.

Analog trainer no. 2.—The trainer was activated in the latter half of 1959. The simulator (fig. 10–1(e)) utilized a special-purpose a-c analog computer obtained from an obsolete F–100 gunnery trainer. Realism was enhanced by the use of an early type molded styrofoam couch and a prototype Mercury three-axis controller supplied by the contractor. Aside from providing the astronaut with his first opportunity to practice attitude control in the pressurized suit, this trainer was used to perform a number of engineering feasibility studies.

Mercury Procedures Trainers.—The Mercury procedures trainer no. 1, housed in the NASA Full-Scale Tunnel at Langley Air Force Base, Va., and trainer no. 2, housed in the Mercury Control Center (fig. 10–1(k)) at Cape Canaveral, Fla., were the most valuable flight-crew trainers used in the Mercury Project.

The decision to provide two trainers was found to be sound since, in addition to the astronauts' requirements, there were requirements to use both Mercury Procedures Trainers in conjunction with simulations in the flight controller training program. Trainer No. 1 was used in conjunction with the remote site simulator at Langley Air Force Base, Va.; and trainer no. 2, with the Control Center Mission Training Complex at the launch site. (See paper 15.)

Both trainers were delivered without analog computers for animating the rate-and-attitude flight instruments. Therefore, procedures trainer no. 1 was connected to the same computer used in the analog trainer no. 2. This computer allowed activation of all of the 22 possible combinations of manual and/or automatic attitude controls that were provided in the Mercury spacecraft. Three months after delivery, procedures trainer no. 2 was supplied with a small-capacity general-purpose analog computer which permitted activation of only the manual-control modes for the orbital phase of flight. Approximately 6 months prior to completion of Project Mercury, additional equipment was obtained to provide manual damping practice during reentry.

Trainer no. 1 had an active periscope display consisting of a moving dot on the face of a cathode ray tube which was activated by the hand controller and the analog computer. Very late in the project a new, versatile, virtual image display was also added to trainer no. 1. This display was used briefly for training prior to the last Mercury flight.

Virtual-image celestial display.—Because of the state-of-the-art of space flight external-view simulation at the outset of the Mercury project and the compressed time schedule, no external view other than that through the periscope was provided on MPT no. 1 at the time of delivery of the procedures trainers. However, considerable effort was expended in trying to develop new and versatile displays. One result of these efforts was the virtual-image viewing system (fig. 10–1(p)). The first working model of the system was delivered and installed on the MPT no. 1 in time for limited training prior to the MA–9 flight. This display could simultaneously accept inputs ranging from three-dimensional models to closed-circuit television or film strips. However, the only display available at the time of the MA–9 flight was a star view. The stars were produced by setting ball-bearings of various sizes into the surface of a 12-inch diameter, hollow magnesium sphere which was gimballed and driven by a computer. The ball bearings, upon illumination by a point light source, produce exceedingly realistic point sources of light of the desired brightness to represent the star fields.

Yaw-recognition trainer.—Prior to the MA–8 six-orbital-pass mission, there was considerable concern regarding whether or not the pilot would be able to detect his yaw position solely by use of the slow translation of terrain or clouds viewed out the window of his spacecraft. The pilot's ability to determine accurately yaw by using out-the-window references is all-important if his gyro altitude information was lacking during retrofire as in the MA–9 flight. In this case, Astronaut Cooper had to rely on his window scene to determine heading or yaw position accurately for retrofire. (See paper 17.)

In order to give the astronauts a preview of the out-the-window motion cues they would have in orbit, a yaw-recognition trainer (fig. 10–1(o)) was conceived, built, and activated in about 2 weeks. The trainer consisted of a 33-foot diameter convex-lens-shaped screen, one surface of which represented either the earth's surface or a constant-altitude cloud deck. This surface was made of polyethylene plastic and was used to display a real, moving image of simulated clouds produced by a film strip moving at the proper speed through a slide projector. The speed of the image movement duplicated the in-flight apparent movement between the spacecraft and the ground by having the observer view the scene from a point at the middle of the lens while standing 2 feet away from the surface. To heighten realism, the flight crews wore a box over their heads which had an opening which simulated the proper size and shape of the spacecraft window.

The MA–8 and MA–9 flight crews utilized the yaw recognition trainer prior to their flights. The other astronauts used the trainer subsequent to their flights. All of the pilots who had flown orbital flights reported that it duplicated almost exactly the visual yaw motion cues observed from the spacecraft.

Attitude instrument display mock-up.—The attitude instrument display mock-up (fig. 10–1 (m)) consisted of a half-scale transparent model of the Mercury spacecraft mounted within a four-gimbal all-attitude support. The mock-up contained the actual Mercury rate and attitude indicators without horizon scanner or ASCS logic hardware. The exterior covers of the attitude gyroscopes were removed so that the trainee could observe the manner in which the attitude gyros tumbled during simulated motions of the spacecraft. The device illustrated how the attitude indicators can read incorrectly as a result of various spacecraft attitudes occurring at times when the floating gyroscope axes are not parallel to the spacecraft axes. The major purpose of this training device was to teach the astronauts how to regain use of the attitude gyros and attitude indicating system if correct reference were lost as a result of the tumbling of the gyros or the interference of the "repeater" stops. This conceptual trainer was very useful and each flight crew spent several hours studying the maneuvers planned for their flights.

Ground-recognition trainer.—The ground-recognition trainer (fig. 10–1(n)) consisted of a prototype molded couch, an actual Mercury periscope, a back-projection screen, and a motorized slide projector. The slide projector displayed a colored, moving image of the earth on the screen. No cloud cover was simulated. The image was viewed through the periscope, located at the proper distance from the screen to simulate the geometry of a periscope in a Mercury spacecraft at 110 nautical miles altitude and aimed at the earth's nadir.

The purpose of the trainer was to familiarize the astronauts with the wide-angle optics of the periscope which caused a compression of the images of coastlines, rivers, mountain ranges, and other topographical features. This trainer was not used extensively because, to a certain degree, the scenes viewed were very similar to those that were seen through the periscope simulation of the ALFA trainer.

Air-lubricated free-attitude trainer.—The air-lubricated free-attitude trainer (ALFA) (fig. 10–1(d)), was designed and developed by engineers of the NASA Manned Spacecraft Center. This trainer moved on an air-bearing and had 360° of freedom in roll and 35° of freedom in pitch and yaw. The astronaut operated compressed air jets through a Mercury hand controller. Retrofire disturbance torques were also simulated with compressed-air jets.

Two attitude-control systems were simulated on ALFA: manual proportional and fly-by-wire. In the fly-by-wire simulation, only the low-torque jets (used for attitude control in orbit when attempting to minimize fuel consumption) were simulated. All three reference systems are provided. The periscope was simulated through a wide-angle lens and a system of mirrors which presented a view of a circular screen on which a map of the earth was projected from a film strip. The actual Mercury gyro package and instrument display were mounted on the trainer. The window display was simulated schematically by an illuminated strip to represent the horizon and small bulbs to simulate the stars.

Multi-Axis Spin-Test Inertia Facility Trainer.—The Multi-Axis Spin-Test Inertia

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Facility (MASTIF) trainer, created in February 1960 by personnel of the NASA Lewis Research Center, was utilized for a simulation training program of recovery from tumbling flight in February 1960. The trainer (fig. 10–1 (i)) consisted of a couch mounted inside three gimbals, a three-axis hand controller, and a rate display. The astronauts were spun at rotational rates of about 30 rpm about all three spacecraft axes simultaneously. At a prearranged time, the astronauts assumed control of a three-axis compressed nitrogen fly-by-wire attitude control system and brought the couch to rest by reference to a Mercury rate-indicator instrument.

The purpose of the trainer was to provide the best technique and improved confidence level for stopping inadvertent tumbling of the Mercury spacecraft. The training was considered valuable even though the possibility of its application was thought to be fairly remote.

Centrifuge Training

Four formal centrifuge programs were conducted at the Aviation Medical Acceleration Laboratory's centrifuge at the Naval Air Development Center at Johnsville, Pa., as part of the group training program (fig. 10–1(c)). The first two programs were combined engineering-feasibility and preliminary astronaut-familiarization programs while the last two were intensive operational training programs for the Redstone and the Atlas flights. The configuration of the centrifuge gondola and the computer control system varied between programs. The gondola was configured to simulate spacecraft for either orbital or ballistic missions. The simulated attitude control system was run closed loop and the centrifuge was run open loop. The astronauts wore full pressure suits and some runs were made at a simulated altitude of 28,000 feet.

Overall, the astronauts experienced an average of 45 hours on the centrifuge. These programs appeared to be extremely valuable both for training and in providing an opportunity for checking out items of personal equipment and for demonstrating the adequacy of the spacecraft instrumentation for viewing under acceleration.

Environmental Familiarization

Despite the general familiarity of the astronauts with the space flight environment and their demonstrated capability of performing effectively under stress, an attempt was made during the training program to provide additional familiarity with this environment. The following five requirements were thought to be conducive to good performance under space-flight conditions:

(1) The astronauts required a detailed knowledge of and confidence in the equipment which they had to operate in space. This was primarily provided through the systems training described previously. However, the environmental familiarization involving pressure chamber and centrifuge runs provided an opportunity to become more fully acquainted with the pressure suit, the couch and restraint systems, the bioinstrumentation and other items of personal equipment and to develop confidence that these items would perform their functions adequately in the space-flight environment.

(2) The astronauts also required a familiarity with the environment itself. Familiarity with the conditions of space flight minimizes the number of novel and possibly distracting stimuli which will be encountered in flight. Experience with these conditions also permits the development of the specific techniques for minimizing these environmental effects. For example, under acceleration it is necessary for the astronauts to learn a special breathing technique to minimize the tendency of peripheral vision to become blurred because of reduced oxygenation of the blood. During early training, this breathing technique required some thought and distracted the astronauts from their control tasks. However, as training progressed, the breathing became automatic and full attention could be devoted to the task.

The accommodation of the pilot to the effects of acceleration can be seen in figure 10–3 which

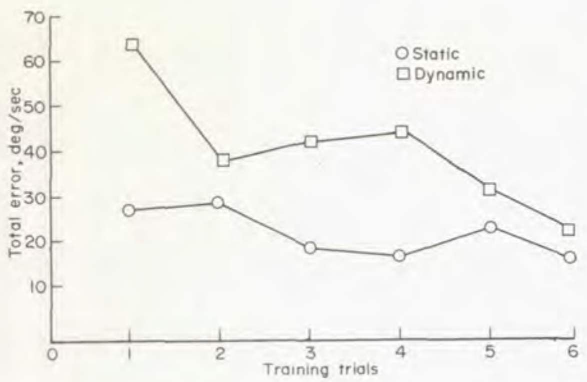

FIGURE 10-3.—Centrifuge retrofire training.

provides a comparison of the retrofire attitude control performance, under the simulated acceleration of the retrorockets and statically. The data presented are average values for all astronauts and show an increase in error with acceleration; however this initial effect tended to disappear with practice.

Table 10–IV summarizes the environmental conditions which were simulated during the group training program. The first column lists the various conditions experienced while the second gives the intensity of exposure encountered in suborbital and orbital flights. The third column summarizes the level experienced in training while the final column lists some of the trainers which were used to provide this experience. With the exception of weightlessness, all the environmental conditions were simulated during training at least to the level expected in a normal flight. Weightlessness condition cannot be simulated within the atmosphere for more than 60 seconds; however, the astronauts did, over several runs, build up an average of 40 minutes total weightlessness per man. In general, all of the environmental familiarization experiences were of value. However, with the exception of the linear acceleration experienced on the centrifuge and effects of suit pressurization, none of the environmental simulations were critical, including weightlessness.

Table 10–IV.—Flight and Trainer Environment Summary

Condition	Level in Flight: Normal (Redstone/Atlas)	Level in Flight: Emergency	Level Experienced in Training	Simulator
Weightlessness	Redstone, 5 min Atlas, 4½ hr		Up to 60 sec. Average of 40 min total weightlessness.	F–100F, C–131B, and C–135 aircraft.
Acceleration	Redstone, up to 11g Atlas, up to 7g	Up to 20g	All normal Atlas and Redstone Profiles and abort profiles up to 16g. Average of 70 dynamic runs per man.	Centrifuge.
Reduced pressure	5 psi for from 4½ hr to 34 hr	Pressurized 4.6 in suit.	Up to 6 hours in pressure suit; up to 3 hours in orbit condition; launch and reentry profiles have been experienced in at 5 psi and in pressurized suit.	Environmental simulator Centrifuge.
Heat	Capsule inner wall 275°, post-recovery period at 85°, 35 percent humidity.		Heat pulse up to 260° with normal recovery period.	Environmental simulator.
Rotation (Disorientation)	10°/sec		Up to 60 rpm	ALFA trainer; Pensacola rotating room.
Tumbling	None		Up to 54 rpm	MASTIF.
High Levels CO_2	Below 0.04 percent	Up to 3.5 percent.	Slow buildup to 3.5 percent	Submarine environmental tank.
Noise and Vibration	150 db outside spacecraft, 130 db inside spacedraft, 110 db at ear		90 to 110 db for normal Atlas launch period.	Centrifuge, Langley, Noise tests.

(3) A high level of physical conditioning was also required. Since, to meet flying requirements, the trainees had been maintaining themselves in good condition for a number of years, no formal group physical training program was initiated aside from a short period of instruction in scuba diving. Reliance was placed on each individual to keep himself in good physical condition and he was aided in monitoring his conditions by frequent physical examinations and by his own observations of his ability to perform adequately on the centrifuge and in other types of environmental training.

(4) A fourth requirement was the detailed planning and practice of emergency procedures until they could be rapidly and correctly executed. The majority of this type of training occurred on the procedures trainer, particularly during the period just prior to the flight.

(5) A final requirement for performing effectively under stress was to maintain their habits of altertness and their ability to react rapidly and think effectively in emergencies, which they had developed during their careers in flying. Since none of the training situations involved any significant amount of hazard, it was important that the astronauts have an opportunity to maintain their skills in meeting real emergencies. As a result they were provided with aircraft so they could maintain their flying skills (See fig. 10-1(b)).

Through these five steps, knowledge of the equipment available to their use, familiarity with the environment, physical conditioning, preplanning for emergencies, and the habit of constant alertness and readiness for action, the astronauts were provided with the basis for a high degree of effectiveness in performing well under the unusual environmental conditions associated with space flight.

In considering the problems of preparing individuals for performing effectively in a realistic environment, it is interesting to note that a number of programs, in which it was intended to use actual hardware in real environments in order to train the astronauts, were considered but were not put into practice because the training value appeared to be too small to justify the cost or safety hazards involved in their implementation. At the initiation of the Mercury program, it had been recommended that as part of the training program a series of balloon flights be undertaken in which the actual Mercury spacecraft would be carried to altitudes of from 80,000 to 100,000 feet. The plans for this program were carried for several months and the requirements studied in detail. The studies indicated that training value did not justify the risk or the cost involved in the program. Two other programs of a similar nature were also eliminated. One program involved placing the actual spacecraft on the Lewis MASTIF device for training in controlling attitude during retrofire. The MASTIF device was inside a full-scale wind tunnel, which could have been depressurized. Analysis also showed that it would be very difficult to reproduce the conditions of motion typical of space flight because of the very high inertia of the MASTIF gimbals. A final program of the same sort was a plan to place a flight Mercury spacecraft on top of the Redstone launch vehicle during static firing so that the astronaut could experience the actual noise and vibration typical of launch. Once again neither the risk nor the cost appeared justified in view of the limited training value. These three examples illustrate what seems to be a basic result of the Mercury training experience. Using actual flight equipment in simulated environments for training purposes alone generally involves too great an expense to be worthwhile. When only training is involved, mission simulators are most efficient. On the other hand, in the Mercury program, valuable training was achieved during the launch checkout of the actual flight vehicle in the pressure chamber at Cape Canaveral. In this case, however, the simulation benefited not only the training program but the checkout of the flight article.

Egress and Survival Training

The astronauts were provided with several training programs designed to prepare them to egress successfully, survive and be recovered under various contingency conditions. The egress and survival programs are summarized as follows.

Egress training, phase 1.—The first egress training program was conducted in February 1960, in which the egress trainer, spacecraft no. 5, (fig. 10-1(j)) and the NASA Langley Research Center Hydrodynamic Basin no. 1 were used. Each of the astronauts made several egresses through the top hatch with and without the pressure suits in calm water and in artificially generated waves up to 2 feet in height.

Egress training, phase 2.—The first full-scale open water egress program was conducted in the Gulf of Mexico near the Pensacola Naval Air Station in March and April of 1960. This program consisted of 1 day at sea, during which both top and side hatch egresses were accomplished, and a second day at the training tank for water-survival technique and drill.

Egress training, phase 3.—Underwater egress was accomplished at NASA Langley Research Center in August 1960, with the Langley Research Center Hydrodynamic Basin No. 1 again being used. Each astronaut made six egresses while the spacecraft was submerged. Half of these were accomplished while wearing the Mercury pressure suit.

Periodically, the astronauts were given refresher courses on proper egress and recovery procedures through briefings and participation in subsequent egress and recovery exercises.

In addition, each designated flight crew participated in a full-scale recovery exercise prior to each flight during which both top and side egress, survival equipment deployment, and helicopter pickup operations were accomplished.

Survival training, phase 1.—Water survival training was accomplished in conjunction with most of the water-egress programs and through briefings. The first water-survival training program was conducted at Pensacola, Florida, in March 1960. The training consisted of several briefings, a training film, and actual practice with the use of the survival equipment in the training tank and in the open sea during egress and recovery operations.

Survival training, phase 2.—In July 1960, the Mercury astronauts completed a 5½-day course in desert survival at the Air Force Survival School, Stead Air Force Base, Nevada. The course consisted of three phases: (1) 1½ days of academics oriented to survival operations in the North African or Australian desert; (2) 1 day of field demonstrations covering the utilization and care of available clothing and spacecraft and survival equipment; and (3) 3 days of remote-site training during which the astronauts applied the knowledge and techniques that they had learned during the briefings and demonstrations.

Preflight Preparation

Approximately 3 months prior to each flight, the designated pilot and his backup began specific preparations for the mission. The period of preparation was, however, somewhat variable depending upon the particular mission and the time between missions permitted by the flight schedules. Pilots participating in the earlier missions had the advantage that the training received in the group program was fresher and that less change had occurred in the vehicle configuration between the time of this program and their flight. Those participating in later flights experienced a lapse of intensive training from 1 to 2 years and had the problem that the spacecraft configuration had changed considerably in the interim, particularly as the mission length was extended. Thus, the preflight period of training became more and more significant. The final impression developing out of the Mercury experience was that on a day-for-day basis preflight preparation was the most valuable period of the training program. Experience indicated that the pilot was required to put in a 10- to 12-hour day for at least 6 days a week during this preflight period. Astronaut Cooper's activities during this time are shown in table 10–V. Since there were so many demands upon the pilot's time, a definite danger existed that important items of training would be pushed aside or overlooked unless care was taken to plan carefully in advance, and frequent training reviews were held to assure that all critical training items had been accomplished. During this period there are five major preparation activities for the flight crew. These activities have been described previously by Astronaut Carpenter (ref. 13).

Table 10-V—MA-9 Pilot Preflight Activities From January 1, 1963 to Launch Date

Date	Day	Activities
Jan. 2	Wed	Altitude Chamber Systems Test Review, blood-pressure checkout in altitude chamber, flying (TF-102A)
Jan. 4 to 7	Fri. to Tues	Altitude Chamber Systems Test
Jan. 10	Thurs	Flight-plan review, flying (TF-102A)
Jan. 12	Sat	TV systems test, flying (TF-102A)
Jan. 18 and 19	Fri. and Sat	Morehead Planetarium (celestial review)
Jan. 21	Mon	Weight and balance
Jan. 22	Tues	Systems briefings (ASCS and RCS)
Jan. 23	Wed	Systems briefings (communications and sequential)
Jan. 24	Thurs	Flight-plan and experiments review
Jan. 25	Fri	Systems briefings (electrical and ECS)
Jan. 30	Wed	Flying (F-102A)
Jan. 31	Thurs	Flying (T-33A)
Feb. 1	Fri	Launch vehicle rollout inspection
Feb. 2	Sat	Flying (T-33A)
Feb. 3	Sun	Flying (T-33A)
Feb. 4	Mon	Experiments status review
Feb. 5	Tues	Flight-plan review
Feb. 6	Wed	Couch fitting
Feb. 7	Thurs	Flying (T-33A)
Feb. 8	Fri	Observation of flashing beacon on T-33A
Feb. 11	Mon	Flight-plan briefing to Deputy Director for Mission Requirements
Feb. 12	Tues	Flying (F-102A)
Feb. 20	Wed	Flying (F-102A), flight-food testing
Feb. 21	Thurs	Experiments briefings
Feb. 23	Sat	Flying (T-33A)
Mar. 1	Fri	TV systems test
Mar. 4	Mon	Communication systems radiation test
Mar. 6	Wed	Weight and balance
Mar. 8	Fri	Flying (F-102A)
Mar. 12	Tues	Couch fitting
Mar. 13	Wed	Flying (T-33A, F-102A)
Mar. 14	Thurs	Communication systems radiation test
Mar. 15	Fri	Communication systems radiation test, Mercury Procedures Trainer
Mar. 19	Tues	Darkness and egress test
Mar. 20 to 24	Wed. to Sun	Simulated flight (Hangar)
Mar. 24	Sun	Flying (F-102A)
Mar. 26	Tues	Flying (T-33A)
Mar. 27	Wed	Flying (T-33A), Mercury Procedures Trainer
Mar. 28	Thurs	Flying (T-33A), Centrifuge—acceleration refamiliarization
Mar. 29	Fri	Mercury Procedures Trainer
Apr. 1 and 2	Mon. and Tues	Mercury Procedures Trainer
Apr. 4	Thurs	DOD-NASA MA-9 Review, Prepad RCS test
Apr. 5	Fri	Mercury Procedures Trainer, flying (TF-102A), Morehead Planetarium (Celestial review)
Apr. 6	Sat	Morehead Planetarium (Celestial review)
Apr. 7	Sun	Flying (F-102A)
Apr. 9	Tues	Flying (F-102A)
Apr. 10	Wed	Egress and recovery training
Apr. 11	Thurs	Egress and recovery training, survival pack exercise
Apr. 15	Mon	Flying (F-102A)
Apr. 16	Tues	Mercury Procedures Trainer, mission and flight controller briefing
Apr. 17	Wed	Mission and flight controller briefing
Apr. 18	Thurs	Alinement, weight, and balance; Mercury Procedures Trainer
Apr. 19	Fri	Mercury Procedures Trainer

Table 10–V—MA–9 Pilot Preflight Activities From January 1, 1963 to Launch Date—Continued

Date	Day	Activities
Apr. 22	Mon	Mechanical mate
Apr. 23	Tues	Simulated flight no. 1
Apr. 24	Wed	Electrical mate
Apr. 25	Thurs	Mercury Procedures Trainer
Apr. 27	Sat	Mercury Procedures Trainer
Apr. 29	Mon	Yaw demonstration (AF Hangar)
Apr. 30	Tues	Systems briefings (review)
May 1	Wed	Systems and operations examination
May 2	Thurs	Launch simulation, Mission Rules review
May 3	Fri	Examination questionnaire review, marked spacecraft's normal and emergency instrument limits
May 4	Sat	Launch simulation
May 5	Sun	Flying (TF–102A)
May 6	Mon	Flight configuration sequence and aborts
May 7	Tues	Network simulation, Flight Plan Procedures training
May 8	Wed	Launch simulation and RF compatibility tests
May 9	Thurs	Network simulation
May 10	Fri	Simulated flight no. 3, flying (F–102A)
May 11	Sat	Mission Status Review, flight-plan and experiments briefings
May 12	Sun	Network simulation, physical examination
May 13	Mon	Mercury Procedures Trainer, mission review
May 14	Tues	Countdown (canceled)
May 15	Wed	Launch

Integration of the Pilot and the Spacecraft

After the spacecraft had been delivered to the launch site, a primary opportunity was provided for the pilot to operate the actual controls of the spacecraft. The participation of the MA–9 pilot with the checkout activities of the spacecraft is listed in table 10–VI(a) and a summary of the time spent in the actual spacecraft of all

Table 10–VI.—Pilot Time in Spacecraft During Hangar and Launch Complex

(a) *MA–9 Pilot Time in Spacecraft 20*

Date	Test description	Duration, hr:min
Oct. 11 to 19, 1962	Integrated systems tests	06:45
Nov. 11, 1962	RCS–hangar	03:15
Jan. 5, 1963	Altitude chamber	06:45
Jan. 12 and Mar. 1, 1963	TV systems test	07:00
Mar. 4, 14, 15, 1963	Communications systems radiation test	04:45
Mar. 19, 1963	Darkness and egress	01:20
Mar. 20, 21, 22, 1963	Simulated flight, hangar	12:10
April 4, 1963	Prepad RCS test	00:50
April 18, 1963	Alinement, weight, and balance	04:00
April 23, 1963	Systems test and simulated flight no. 1	04:00
April 24, 1963	Electrical mate	04:30
May 3, 1963	Mark instrument normal and emergency limits	00:45
May 6, 1963	Flight configuration sequence and abort	03:00
May 8, 1963	Launch simulation and RF compatibility	05:00
May 10, 1963	Systems test and simulated flight no. 3	03:45
May 14, 1963	Countdown (canceled)	06:00

Table 10–VI.—Concluded.

(b) Approximate Time in Flight Spacecraft During Preparation Periods for Each Orbital Flight

Flight	Time, hr
MA–6	25:55
MA–7	45:00
MA–8	31:27
MA–9	73:50
Average	44:03

the orbital pilots is given in table 10–VI(b). This activity is essential, since:

(1) An opportunity was provided to make final adjustments of personal equipment, such as the pressure suit, survival equipment, food items, and check lists to satisfy the special requirements of the flight spacecraft and the pilot.

(2) These tests provided an opportunity to check out the spacecraft system with the man in the loop; thus, for example, the adequacy of the environmental control system was checked with the pressure drop resulting from the pilot in his suit.

(3) The pilot became familiar with the specific configuration and performance of his spacecraft. The settings for the cooling system or the feel characteristics of the control systems vary slightly from spacecraft to spacecraft, and the pilot had an opportunity to become familiar with these features of the vehicle he would fly.

(4) The pilot had an opportunity to gain further familiarity with the prelaunch checkout procedures on the launch pad. During this time, he learned his role in the countdown and became familiar with the instrument indications and the lights and sounds that accompany the various tests as the vehicle is readied for flight.

Systems Training

A second major area of activity of the astronauts during this period was in systems training for his spacecraft. This systems training began with one or more series of lectures by the engineers involved in the checkout of the vehicle. Each lecture covered a specific system in great detail, emphasizing operational techniques and functional interrelationships. These systems lectures were then followed by extensive practice in emergency procedures on the Mercury procedures trainer. A problem was encountered in modifying the Mercury procedures trainer no. 2 to keep it as close as possible to the configuration of each spacecraft. It was, of course, impossible to make them completely identical. However, in general, it was possible to alter the trainer so that as the spacecraft systems were modified, the changed performance would be reflected to the pilot during simulations. When modifications could not be made, it was extremely important to make the pilot aware of the differences between the trainer's operation and the flight operation so that he could keep them clearly in mind.

Table 10–VII(a) summarizes the MA–9 pilot's training on Mercury Procedures Trainer no. 2 whereas table 10–VII(b) shows the total amount of time spent on the Mercury procedures trainer by the pilots of the four orbital missions during their preflight training program. Also indicated in table 10–VII(b) are the numbers and categories of malfunctions experienced. These data give some indication of the amount of time devoted to recognition and correction of the many malfunctions which could be programed into the trainer. The relative emphasis to be placed on emergency procedures in comparison with normal mission activities is difficult to assess. This seems to be a characteristic which may be increasingly true in the future, since a major function of the man may be to correct malfunctions of the vehicle's systems.

Table 10-VII.—Summary of Time Spent on MPT No. 2 During Preflight Preparation Period

(a) *MA-9 Pilot*

Date, 1963	Type of training	Time, hr:min	Number of simulated missions	Number and type of simulated missions						Special training activities (a)
				ECS	RCS	Sequential	Electrical	Communications	Other	
Mar. 15	Flight checklist review	02:15	4	----	----	----	----	----	----	1, 3, 4
Mar. 27	Attitude control practice	01:45	1	----	----	----	----	----	----	1, 4
Mar. 29	Simulated systems failures	02:30	8	3	2	4	3	1	1	1, 2, 3, 4
Apr. 1	Simulated systems failures	02:30	5	2	----	5	2	1	1	1, 2, 3
Apr. 2	Simulated systems failures	02:00	3	----	2	5	1	----	----	2, 3
Apr. 5	Simulated systems failures	01:30	2	2	----	2	----	1	----	2, 3
Apr. 18	Simulated systems failures	02:15	4	2	1	4	4	----	1	1, 2, 3
Apr. 19	Simulated systems failures	03:45	6	1	1	4	3	1	1	2, 3, 5
Apr. 25	Flight-plan activities	02:00	2	1	----	----	----	----	----	1, 4
Apr. 27	Simulated systems failures	01:30	3	----	1	1	1	1	----	1, 2, 3
May 2	MCC–BDA simulation	01:30	2	----	----	2	1	----	----	2, 3
May 4	MCC–BDA simulation	01:30	2	2	----	1	1	----	1	2, 3
May 7	Network simulation and flight-plan activities.	05:00	2	----	----	----	----	----	----	1, 4, 5
May 9	Network simulation	01:00	2	----	----	----	----	----	----	1
May 12	Network simulation	01:00	1	----	----	1	----	----	----	1
May 13	Simulated systems failures	01:30	5	----	1	3	1	----	1	1, 2, 3
Total		33:30	52	13	8	32	17	5	6	

[a] The column numbers refer to the following activities:
1—Normal launches and reentries
2—Launch aborts
3—Orbital and reentry emergencies
4—Retrofire or reentry attitude control
5—Flight-plan activities

Table 10-VII.—Concluded

(b) Four Orbital Pilots

Flight	Number of Missions	Total Hours on MPT no. 2	Number and type of failures					
			ECS	RCS	Sequential	Electrical	Commu-nication	Other
MA-6	80	59:45	30	24	57	35	11	25
MA-7	73	70:40	24	11	43	26	7	32
MA-8	37	29:15	10	5	22	15	5	11
MA-9	52	33:30	13	8	32	17	5	6
Average	60	48:35	19	12	38	23	7	18

Flight Plan Development and Training

The pilot also participated in the development and practice of a mission flight plan, which varied considerably in each mission. (See paper 17.) The astronaut participated in this process to help insure that he adequately understood the requirements and that the specific procedures could be carried out without compromising other mission requirements. The flight plan activities were tried out in the Mercury procedures trainer to determine the best procedures and equipment configurations. Since it was highly desirable to give the pilot ample opportunity to practice the flight plan and to get experience with the experimental equipment prior to the flight, it was essential to finalize the flight plan and have the experimental equipment ready well ahead of the launch date.

In addition to the practice of the specific mission activities in the Mercury procedures trainer, a number of special refresher training activities were conducted. Normally, each of the flight crews received a short refresher training program on the centrifuge. In this program no attempt was made to provide a complete simulation of the Mercury instrument panel or control tasks. The pilots normally experienced from six to eight launch or reentry profiles in the centrifuge to help refresh them in their breathing and straining techniques.

The flight crews also normally received a planetarium indoctrination (fig. 10–I(h)) to help them review the celestial sphere as seen from orbit. Since these programs were held close to the flight date, it was normally possible to simulate the appearance of the sky on the actual day of the launch and to simulate some of the special astronomical phenomena to be observed during the flight.

Combined Astronaut-Flight Controller Training

A fourth area of training conducted during the preflight period was the combined training of the astronaut with the flight control groups. For this training the Mercury procedures trainer no. 2 was tied into the Mercury Control Center's simulation equipment so that the astronaut could communicate directly with the flight controllers and the vehicle parameters from the Mercury procedures trainer no. 2 would be displayed to the flight controller in the same form as the vehicle data during the flight. Two types of training runs were made. The first was the launch-emergency training sessions in which only the launch portion of the mission was simulated. Various types of emergencies were simulated, some affected the astronaut but most involved information displayed to the controllers. During this time the astronaut and the ground flight controllers had an opportunity to become familiar with each other's procedures and to refine the launch communications and emergency procedures. Following each run, a debriefing session would be held to critique the run and to modify any procedures which did not appear adequate.

Following the launch abort simulations, network simulations were run with the flight controllers. On these simulations the pilot, through the hardline, could be in direct communication not only with the launch control center but with the other flight-control sites in the United States and Australia. In these simulations the pilot would frequently take part, thereby providing some of the stations with an opportunity to become familiar with his particular voice and communication patterns. This was particularly significant for the medical monitors since they made use of voice communications as one of their major monitoring aids. While these sessions were highly valuable for the flight controller, they were less valuable for the astronaut since much of his time would be spent with the spacecraft in the orbital configuration with little or no opportunity to practice emergency procedures. As a result, the astronaut frequently went through a launch and perhaps one-orbital pass with the network simulation and then spent the rest of his time in the simulator, carrying out emergency procedures and other special activities in which he particularly needed practice.

Medical and Physical Preparation

A final area of activity during this preflight period was in the medical and physical preparation of the astronaut. During this period, the final physical examinations, establishing the fitness of the pilot for the flight, were given and the majority of the baseline data with which the inflight results would be correlated was collected. It was also during this period that the astronaut was placed on a special diet in order to prevent possible solid waste problem during the flight. Medical preparations for the flight are described in greater detail in paper 11.

During this preflight period each of the astronauts intensified their physical fitness program, bringing it to a peak shortly before the launch date. This physical activity was important not only in insuring a high level of fitness at the time of launch but it also served the purpose of giving the pilot an opportunity to relax from the pressing technical problems which occupied the majority of his day. Overall, the problem of maintaining good physical fitness and avoiding excessive fatigue during this period was a serious one.

Concern was expressed in some quarters that the repeated delays which often occurred in the launch date would produce anxiety in the pilot or result in a letdown in proficiency due to "over training" or loss of motivation. No such effects were noted with any of the pilots. Astronaut Glenn experienced the longest delay following a launch attempt (30 days) with no undesirable effects either by his own account (ref. 14) or as indicated by his trainer performance. His performance on the retrofire control task for the month before and after the postponement of his flight is shown in figure 10-4. As

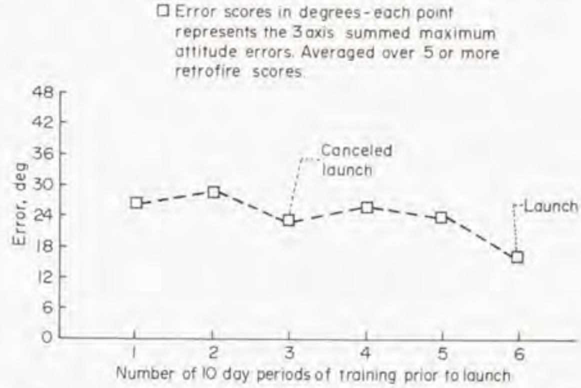

FIGURE 10-4.—Procedures trainer retrofire attitude control scores. MA-6 pilot.

can be seen there is no evidence of decrement in performance following the postponed launch.

Training Evaluation

The inflight performance of the pilot provides the best indication of the adequacy of the astronaut training program. Further verification was provided by comparing performance of specific maneuvers during flight with those on the trainers, and by having the pilots' comment on the value of the various training devices.

In those cases where specific flight maneuvers were practiced on the procedures trainer, comparisons can be made between the attitudes held in the trainer and those maintained in flight. This has been done in all previous flight reports in the sections on pilot performance (refs. 15 to 19). However, the number of these comparisons is limited since many periods of manual maneuvering could not be compared with ground data because the specific maneuver carried out during flight was not practiced under controlled conditions or because the maneuver involved attitudes outside the limits of the autopilot sensing system, in which case, attitude data would not be available from the gyro indicators.

A great deal of evaluative material was obtained from the astronauts during the debriefings following each mission. In general, the astronauts reported that while weightlessness was generally pleasant, there was a short period during the flight when they felt that they needed some time to adapt to both the weightless experience and to the novel view through the spacecraft window. (See paper 20.) Both of these features of the space flight were inadequately simulated during the training periods since the weightless condition could not be simulated for more than a minute and, until late in the program, there was no dynamic simulation of the view through the Mercury spacecraft window. This adaptation period, to the orbital flight condition, might have been reduced had it been possible to have a simulation of the external view and more prolonged weightless experience. In any case, this small adaptation period was not a serious problem for any of the astronauts.

The pilots were unanimous in indicating the importance of their participation in the checkout of the spacecraft during the period just prior to the flight. Many of them felt that this was the most valuable single portion of the training program. All of the pilots felt that the procedures trainer was the single, most useful training device. However, there were variations among them in the opinions of the amount of time required on the trainer prior to the flight. There was also general agreement that the centrifuge was the most critical environmental simulation device and that a short refamiliarization experience on the centrifuge prior to the flight was highly desirable.

The Mercury flight program was too limited to evaluate in detail all the many training devices and programs which were used in the astronaut training program. However, the best estimate of the authors as to the relative utility of the various trainers and programs are indicated in Table 10–I in the last column. In considering these ratings, the reader should note that they apply to programs with the special features of the Mercury training program listed in the introduction to this section. In addition to these ratings, the following general conclusions appear warranted:

(1) The devices and programs used in the Mercury astronaut training program were adequate to provide transition training for skilled pilots to the operation of a spacecraft.

(2) The program could have been shortened and made more efficient had adequate training facilities been available at the initiation of training and in one location.

(3) The most important environmental factors requiring simulation during the training were linear acceleration and the reduced mobility produced by the pressurized suit.

(4) Other environmental simulations were desirable but not critical to adequate flight preparation. This conclusion includes the weightless experience. However, it should be noted that training in weightlessness was relatively unimportant in the Mercury program because the astronaut was unable to move from the seat.

(5) Simulations involving actual flight hardware in realistic environments were studied and generally found to involve more cost and risk than could be justified by their training value, unless they were required for vehicle checkouts.

(6) Experience in the actual vehicle to be flown prior to the flight is a highly essential feature of the preflight preparation and is an exception to the foregoing generalization.

(7) Flight plans and all experimental and other movable equipment items which will be used within the spacecraft must be available and finalized well in advance of the launch date in order to permit adequate time for training in their use.

(8) A fixed-based simulator with dynamic displays is generally adequate for orbital flight training since angular and linear acceleration cues are relatively insignificant in the weightless condition. However, in certain cases motion may simplify the simulation problem.

(9) Two simulators are necessary in order to support both the general group training program at the central site and the preflight preparation program at the launch site.

(10) External view simulation on the full-mission simulator is essential since much of the orbital maneuvering will be done with the external view used as a reference.

(11) Integrated flight crew-flight controller training is essential to refine mission rules and communication procedures.

(12) Flexibility in the design of all trainer systems is essential in order to permit modification to fit the particular configuration of each flight vehicle.

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11. AEROMEDICAL PREPARATIONS

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Summary

The lessons learned from the operational medical program conducted in Project Mercury are discussed in this paper.

The objectives of the medical portion of the crew selection program were met, and detailed physical examinations on even select test pilot groups have found rejectable defects. Stress-testing has been made part of a selection-in-depth training program.

Medical training given to the astronauts has been of great value during inflight monitoring and discussion of medical problems.

Medical maintenance has included routine medical care, and annual and special physical examinations. Close association of the flight surgeon and the astronaut in training has produced an excellent preventive medicine practice. The flight crew surgeon is best fitted to determine the astronaut's readiness for flight, but a specialist team conducts the examination for baseline data to compare with postflight data. Preflight examinations were conducted before each checkout procedure and more formally at 10 days and 3 days before flight, and on flight morning. Longer missions with Pacific recovery caused modification of the postflight examinations. The importance of practice runs of most of the medical procedures was shown and a medical countdown was developed and integrated with the Mercury Control Center (MCC) and blockhouse countdown.

Complete isolation of the crew is impractical and has depended on a reduction of stronger contacts in the immediate preflight period.

Drugs were provided in injectors, and pills were available in flight and in the survival kit. The only drug used was the dextro-amphetamine sulfate on the MA–9 mission. The astronaut must always be pre-tested to any drug he may use. Scheduling of rest, activities, and exercise periods is necessary. A method of obtaining separate urine samples was successfully used. Dietary control of defecation was successful. Inflight food and water ingestion must be scheduled.

Medical monitoring was performed for flight-safety reasons and for aiding the surgeons in making go–no–go recommendations to the operations director. The value of range flight simulations and of the medical flight controller has been shown. Parameters monitored included body temperature, respiration, electrocardiogram, blood pressure, and voice. The comparison and correlation of readings with environmental data are stressed. Correlation of inflight events and physiological responses is very meaningful. The space-flight environment, while exposing men to numerous stresses, has produced no unmanageable physiological overload. Postflight orthostatic hypotension has been noted for a period of several hours.

Recovery operations have been modified from taking medical care to the astronaut to taking the astronaut to medical care. The support has been trimmed to require fewer highly trained personnel to "wait it out" at the launch site.

Project Mercury gave the opportunity to define more closely the medical problem areas as the future is anticipated with great expectations and confidence in man's ability to adapt to and conquer this new frontier.

Introduction

The development of an operational medical program for Project Mercury posed a challenge to the national aerospace medical community in line with that which the orbiting of man posed to the national engineering community.

The purpose of this paper is to review briefly and necessarily incompletely the medical operations and findings from all our manned space flights and to emphasize the knowledge acquired which may be applied to future programs. Details of the operational procedures and findings are documented in the several reports of the Mercury missions (refs. 1 to 12).

The nature of the challenge called for the development of some ground rules applicable to the medical aspects. It was determined that:

(1) The simplest and most reliable approach should be used.

(2) Off-the-shelf items and existing technology should be used wherever possible.

(3) Man was being thrust into a truly unknown environment, and his reactions to this environment were relatively unknown.

(4) A direct approach would be taken to the problem areas, and attempts would be made to provide the best protection and monitoring capable within the operational constraints of the mission.

Many lessons have been learned from this first experience of the free world with manned space-flight operations. The responsible medical community had honestly attempted to evaluate potential problems based upon knowledge at that time. In doing this, several possible problems were raised which, it appears, this program has answered to some degree. Weightlessness is a good example of the many barriers to man's entry into space which were raised prior to this program. Some of the dire physiological effects predicted as a result from exposure to this condition and therefore to be limiting to space flight were anorexia, nausea, disorientation, sleepiness, sleeplessness, fatigue, restlessness, euphoria, hallucinations, decreased g-tolerance, gastrointestinal disturbance, urinary retention, diuresis, muscular incoordination, muscle atrophy, and demineralization of bones. It will be seen that few of these remain of concern. Another area in which there were predictions of undesirable effects is in the psychological response to the isolation of space. The astronauts to date have not been isolated in space and have generally complained of too much earth contact. There has been no evidence of any breakoff phenomenon or aberrent psychological reaction of any sort. Thus, while no serious problems have developed, more information is needed on increased time periods in space and the conclusions of the present paper can only be based upon the duration of flights thus far flown. Each mission has been used as a means of evaluating the next step into space, and it is believed that the six manned missions in this program have laid the groundwork for future programs. Project Mercury gave the opportunity to define more closely the medical problem areas, and the future is anticipated with great expectations and confidence in man's ability to adapt to and conquer this new frontier.

Crew Selection and Training

The medical portion of the selection program had as its objectives the provision of crew members who (1) would be free of intrinsic medical defects at the time of selection, (2) would have a reasonable assurance of freedom from such defects for the predicted duration of the flight program, (3) would be capable of accepting the predictable psycho-physiologic stress of the missions, and (4) would be able to perform those tasks critical to the safety of the mission and the crew. The selection board found themselves viewing already trained test pilots somewhat in the same manner as cadets entering a training program are viewed. Small numbers were selected, leaving little excess for attrition. In view of these objectives, the group was culled by records review, interview, and testing until a final group was given a rigorous medical examination at the Lovelace Clinic in Albuquerque, New Mexico. This examination was followed by a stress-testing program at Wright-Patterson Air Force Base, Ohio. The results of these examinations were reviewed by the participating physicians, and the candidates were given a medical rank order. This rank order was then presented to a board which selected the original seven astronauts. In retrospect, it can be said that the results of this program were adequate in view of the fact that the assigned astronauts have successfully completed their flight missions. This early program has been of assistance in the development of current selection program. The stress-testing in the initial selection efforts has been deleted since it was found to be of little value in a group who had already been very thoroughly stress-tested by virtue of their test-pilot background. Stress-testing has become a part of the training program with a selection in depth carried on during the training. Thus, each exposure is mission-oriented and further is an additional selection test as well as providing baseline medical information. In the current programs, this technique is being used; and the astronauts understand that they are continually undergoing selection and that there may be attrition.

The premise that detailed physical examinations given to groups as select as test pilots will show up many physical defects which would interfere with a reasonable prediction of career length in the manned space-flight program has been confirmed in this program.

The training program has included a series of lectures on the anatomy and function of the human body, and the series has proven to be of great value during inflight monitoring and discussion of potential medical problems. Every attempt has been made to use engineering analogies where possible and to impress the flight crews with the fact that the human organism and its many systems must be monitored as thoroughly as many of the engineering systems if mission success is to be assured. There has been no formal physical training program but each astronaut has been charged with maintaining his fitness through programed exercise of his choice. A wide variety has been used by the group. Medical advice was offered and the importance of regular training periods was stressed during the preflight preparation period. A plateau should be reached and, although no specific level is specified, it is believed the astronaut is better prepared to withstand the flight stresses if he maintains a state of physical fitness.

Medical Maintenance and Preflight Preparation

The medical maintenance during this program consisted of the routine medical care similar to that provided specialized groups of aircraft pilots, annual physical examinations, and special physical examinations performed before procedures such as altitude-chamber runs, pressure-suit indoctrinations, and centrifuge runs. The flight schedule with its necessary preflight spacecraft checkout procedures, simulated flights, and launches, frequently exposed each flight crew member to several physical examinations within a given year. An attempt was made to make these physical examinations serve several purposes such as qualifying the individual for his annual physical, being ready to participate in a given procedure, and collecting baseline data. A close and frequent contact between flight crews and flight surgeons, with the flight surgeons monitoring participation in all stress exposures and training exercises, proved to be extremely valuable preparation for the flight mission. This close association also provided excellent preventive medicine practice among the flight crews. It is thought that the flight crews have certainly had no more illness than what would be expected in a routine pilot population; and the general feeling is that there was probably much less.

The preflight physical examinations were to serve two basic purposes. First, they should allow the flight surgeon to state that the astronaut was qualified and ready for flight. Second, they should provide a baseline for any possible changes resulting from exposure to the space-flight environment. The flight crew surgeon appears best qualified to determine whether the astronaut is medically ready for flight. Early in the program, the search for unexpected changes in body systems as a result of exposure to space flight dictated specialty examinations of various body systems. A team was assembled from the Department of Defense and included specialists in internal medicine, ophthalmology, neurology, psychiatry, and laboratory medicine. The same specialties have continued to be represented, but certain items of the examinations have been modified as knowledge of the lack of serious effects of flight on the astronaut was gained. Prior to the selection of a flight astronaut for a given mission, the medical records of those being considered are reviewed in detail and a medical recommendation given to the operation director. Following experience on the early missions, it was determined that a thorough evaluation of the flight astronaut would be made 10 days prior to the scheduled mission to assure management and the flight director that the astronaut was indeed ready for the mission. This examination included a medical evaluation of both the flight astronaut and his backup. Three days prior to the mission, the detailed physical examination was completed by the various medical specialists and the necessary laboratory work was accomplished. On flight morning, following a brief medical examination, a final determination was

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made as to the readiness of the astronaut for flight. This examination was principally concerned with noting any recent contraindications to flight which may have developed. While early in the program other specialists participated in this examination, on the last two missions, the participation was reduced to that by the flight crew surgeon.

The postflight medical examinations were initially made by the Department of Defense recovery physicians stationed aboard the recovery vessel. On the early mission, the astronaut was then flown to Grand Turk Island and was joined there by the team of medical specialists who had made the preflight examination and by the flight crew surgeon. As the flights became longer and recovery was accomplished in the Pacific Ocean, the plan was changed and one of the NASA flight surgeons was predeployed aboard the recovery carrier to do the initial postflight examination and debriefing. On the MA–8 mission, the Director of Medical Operations and the medical evaluation team deployed to the Pacific recovery site several hours after recovery, and this was not only a tiring experience, but necessitated that a great deal of the examination and debriefing be done prior to their arrival. The detailed postflight specialty examination was then conducted at Cape Canaveral when the astronaut returned from the recovery site. In some instances, this practice required the teaching of special techniques to the flight surgeon in order that early information could be obtained. Project Mercury has been most fortunate in having rapid postflight recovery and examination of the flight astronauts, allowing excellent comparison of postflight with preflight data. It would seem from our experience that the retention of any specialty examination team at a mainland launching or debriefing site would be the preferable plan of action.

Early in the preflight preparations, it was determined that there was a need for many practice runs of various procedures. These runs were accomplished by doing the actual flight-type preparation for centrifuge runs, spacecraft checkout runs in the chamber at Hanger S, simulated flights and launches, and procedures trainer exercises. The Mercury-Redstone suborbital flights were also extremely helpful in preparation for orbital flight. A medical countdown was developed with specific timing of the various events and coordination with the blockhouse and range countdown. In order to have no delay in the scheduled launch, a great deal of practice in this countdown was necessary. It has continued to pay dividends in the later missions. Backup personnel in the various medical areas are needed just as backups are needed for the various pieces of equipment. Experience has allowed the number of backup personnel to be kept to an absolute minimum.

Prior to the first launch, consideration was given to the necessity for isolating the flight crew in order to prevent the development of some communicable disease immediately prior to or during flight. It soon became evident, however, that such isolation was impractical in view of the numerous requirements upon the flight crew during the 2 weeks prior to launch. Many activities required the presence and participation of the astronaut, and the isolation was reduced to attempts to curtail the number of contacts with strangers. As the missions get longer and longer, the situation may have to be re-evaluated since the mission could last longer than the incubation period of some diseases. No difficulty was encountered during the Mercury program with the use of only a very modified isolation plan.

One of the basic concepts developed stated that there would be no drugs used as routine measures, but that drugs would be made available for emergency use. Injectors were made available which could deliver their contents through the pressure suit into the astronaut's thigh. During the first four missions, the drugs available in the injectors included an anodyne, an antimotion sickness drug, a stimulant, and a vasoconstrictor for treatment of shock. In the later missions, this was reduced to the antimotion sickness drug and an anodyne, available both on the suit and in the survival kit. An evaluation of the longer mission programed for MA–9 led to the decision to make available tablets of dextro-amphetamine sulfate, both in the suit and in the survival kit. Antimotion sickness and antihistamine tablets were also made available. The astronaut's mental and physical integrity were never in doubt during the mission. As the time for retrofire approached, a review of the mission tasks made it evident that the astronaut had undergone a long and rigorous work schedule from which he might be expected to experience considerable fatigue, even assuming ideal environmental conditions and full benefit from restful sleep. As has been reported, medication was used for the first time during flight when the dextro-amphetamine sulfate was taken prior to the initiation of retrosequence. Such drugs should be available and plans must be made for their availability both during flight and postflight in the survival kit. The astronaut must always be pretested for effect of the drugs which will be used.

Experience has shown that care must be taken to prevent astronaut fatigue during the final preflight preparations as well as postflight. Many individuals have matters of importance which must be decided by the astronaut during the final week of preparation; and as launch day grows closer, the demands on the astronaut's time increase. Careful scheduling of rest, activities, and exercise periods are needed; and much more attention must be paid to this scheduling in future missions. Since the effects of these variables were unknown, it was the flight surgeon's decision to administer 5 mg of dextro-amphetamine sulfate to the astronaut in order to increase the probability of peak performance during reentry. Experience has shown that 48 to 72 hours is a minimum time for a postflight rest and relaxation following a 34-hour mission. Seventy-two hours should be a minimum for future missions.

Early missions required only simple provisions for the collection of urine and blood samples. The short-mission durations made it entirely feasible to collect all the voided urine in a single container within the suit and to recover it after astronaut recovery. As mission duration increased, this became an unworkable procedure; and further, there was a desire to obtain separate urine samples for analysis. The last mission utilized a system for collecting five separate and complete urine samples for later evaluation. This system worked properly but will require modification for future missions. No blood samples have been obtained during flight. Every attempt has been made to combine the various blood requirements in order to require as few vena punctures as possible both preflight and postflight.

Early in the preparation period, a medical flight plan is developed and integrated with the overall mission flight plan. A good deal has been learned about realistic sampling in light of flight plan and in utilizing normal operational activities and reports as means of medical evaluation.

Dietary control has been utilized for approximately 1 week prior to each mission. The first several days were used to assure a normal balanced diet during the rather hectic preflight preparations. In order to prevent defecation during the mission, the low-residue diet was programed for 3 days prior to launch, and the time extended if the launch was delayed. This diet performed its task very satisfactorily during the entire Mercury program; still, indications are that any more prolonged period would seem unwise. The inflight food has consisted of the bite-size and semi-liquid tube food on the early missions. On the last mission, the freeze-dehydrated food was added. Problems with crumbling have been encountered with the bite-size food, and difficulty in hydrating the freeze-dehydrated food was encountered on the last mission. The assurance of palatable food is necessary, and proper containers and practice in their use appear indicated. It also appears necessary to schedule food and water intake on the flight plan and to check to see that it has been properly accomplished.

Medical Monitoring

The Mercury program provided the free world with the first opoprtunity for full-time monitoring of man in the space-flight environment. At the start of this program, the continuous monitoring of physiological data from a pilot conducting a mission was a very recent concept. At the time, there were no off-the-shelf items available to allow continuous and reliable physiological monitoring. It was decided to attempt to monitor body temperature, chest movement, and heart action (ECG). Standards required that the sensors and equipment be comfortable, reliable, compatible with other spacecraft systems, and would not interfere with the pilot's primary mission.

It should be realized that the biomedical sensors are used as a means of flight-safety monitoring. The primary purpose is to assist the monitoring flight surgeon in determining whether the astronaut is capable of continuing the mission from a physiological point of view. The information is used as a basis for making go-no-go decisions in the control center. No attempt has been made under the current operational conditions to perform detailed system evaluation or analysis.

A great deal of experience in medical flight control of an orbiting astronaut was obtained through the use of the many range simulations and the several actual flights. The participation in simulations and in flights prior to those which were manned proved to be extremely valuable training exercises for the actual missions. The medical flight controller has indeed shown himself to be a valuable member of the flight-control team. The development of mission rules to aid in flight control was necessary in the medical area just as in the many engineering areas. It is difficult to establish definite number-value cut-offs for various medical parameters, but this was done early in the program. Gradually, these rules were made less specific so that the evaluation and judgment of the medical flight controller were the prime determinants in making a decision. The condition of the astronaut as determined by voice and interrogation rather than physical parameters alone became a key factor in the aeromedical advice to continue or terminate the mission. This is as it should be and follows the lessons which were learned in general medicine wherein numerical laboratory values are not necessarily the final answer. Trend information as shown by at least three stations was shown more reliable than single values. In developing the flight-control philosophy prior to the first manned flight, it was thought that it would be necessary for the flight surgeon to talk directly to the astronaut very frequently in order to evaluate his physiological state. As operational experience was gained, it became obvious that this was not the case. Information inquiries were passed easily and smoothly through the spacecraft communicator with the flight surgeon retaining the privilege of talking directly should the need arise. It was also thought early in the program that the occurrence of most any medical emergency in flight would require an early or even a contingency landing. Again, as operational experience was gained with the range and with the planned recovery operation, it was determined that the best philosophy was one which held that the astronaut was in a very fast, air-conditioned ambulance on 100-percent oxygen and in most instances it would be better to return him in the spacecraft to a planned recovery area rather than to abort the flight in a contingency area where it might take hours or days to recover him.

The physiological parameters monitored and the sensor changes and problems may be summarized in the following manner. Body temperature was monitored in all missions through MA-9 with a rectal thermistor. Rectal temperature was found to be the most reliable measurement. The long duration of the last flight and a desire for more comfort resulted in this thermistor being modified for oral use. The range of the thermistor was also changed, so that when it was in the stowed position on the right ear muff it would record suit-outlet temperature. It worked very satisfactorily in this manner.

Respiration was at first measured by an indirect method by using a linear potentiometer and carbon-impregnated rubber. This method was changed early in the program to a thermistor kept at 200° F and placed on the microphone pedestal in the helmet. Neither of these methods gave reliable respiration traces during flight, and a change was made to the impedance pneumograph for the last two missions. This device gave very accurate respiration information during most of the flight.

Electrocardiographic electrodes were of a low impedance to match the spacecraft amplifier. They were required to record during body movements and to stay effective during flight durations of over 30 hours. These electrodes functioned well and gave very good information on cardiac rate and rhythm. The value of having two leads of electrocardiograph, even though they differed from the standard clinical leads, was repeatedly shown. This allowed easier determination of artifacts and was most helpful in determining the valid sounds on the blood-pressure trace by comparison with the remaining ECG lead. The electrode paste was changed from 30-percent calcium chloride in water mixed with bentonite to a combination of carboxy polymethylene in Ringer's solution.

The ten times isotonic Ringer solution not only retained the necessary conductivity and low impedance required, but also afforded decreased skin irritation after prolonged contact.

In 1958, the obtaining of blood pressures in flight was considered and then delayed as no satisfactory system was available. Definitive work began about the time of the Mercury-Redstone 3 (MR–3) flight, and the automatic system which used the unidirectional microphone and cuff was developed for use in the orbital flights. This system without the automatic feature was used on the MA–6 mission of Astronaut Glenn. During the MA–7 mission, all of the inflight blood pressures obtained were elevated, and an extensive postflight evaluation program was undertaken. It was determined that the cause of these elevations was most likely instrumentation error resulting from the necessity for very careful gain settings matched to the individual astronaut along with the cuff and microphone. A great deal of preflight calibration and matching of these settings was done prior to the MA–8 flight; and on both MA–8 and the last mission, MA–9, very excellent blood-pressure tracings were obtained.

Voice transmissions have been a very valuable source of monitoring information. The normal flight reports and answers to queries have been used for evaluation of the pilot. In order to insure that the monitors were familiar with the astronaut's voice, tapes of mission simulations with the flight astronaut as a pilot were dispatched to all of the range stations for use in preflight simulations. In addition to normal reports, verification of actual comfort level was very valuable in determining the importance of temperature readings obtained by way of telemetry. Inflight photography and, on the last mission, television views of the astronaut have been planned as additional data sources. In Mercury experience, both of these sources have proven to be of very little value in the medical monitoring of the astronaut because of poor positioning of cameras and varying lighting conditions resulting from the operational situation. A full face view of the astronaut in color on a real-time basis would be a good monitoring tool for it would approximate the clinical face-to-face confrontation of the patient.

The value of the comparison of multiple physiological parameters and their correlation with environmental data has been repeatedly proven. Abnormal or lost values attributed to instrumentation difficulty have frequently been obtained, but it has been found that interpretation of the astronaut's physiological condition could be made by the use of the parameters remaining or the correlation of those remaining with environmental data.

It has been interesting to note that a satisfactory amount of information on current astronaut status can be obtained with the use of such basic vital signs or viability measures. It is realized that the monitoring methods may be far from ideal. They did not provide the ultimate in the measure of man's physiological status. It would have been desirable to have a single parameter which would tell the ground monitor whether the nervous system of the pilot was capable of the peak mission performance necessary. To date, however, there is no such single or even multiple measures; and an attack must be made upon this problem from the periphery. It is believed that at present the raw physiological data cannot be replaced by computer evaluation. The basic idea of computer reduction has merit, and help is certainly needed in relieving ground medical monitors of long periods of observation. At present, however, there appears to be no useful system to meet this demand.

In the postflight report on the MR–3 mission (ref. 3), it was stated that "the remote monitoring on a noninterference basis of parameters such as temperature, respiration, the electrocardiogram, and blood pressure in active men fully engaged in prolonged and exacting tasks, is a new field. Hitherto, flight medicine has accepted the information concerning the well-being that could be derived from the pilot's introspection and conveyed by the invaluable voice link. For the rest it has relied on performance to tell how close the man was to collapse. It is to be hoped that some of the developments in automation necessitated by Project Mercury will find application in clinical medicine."

This hope is rapidly coming to fruition in the light of the wide activities in medical monitoring now being carried on in everyday medicine.

Physiological Responses to Space Flight

One of the basic objectives of the Mercury flights was the evaluation of man's physiological responses to exposure to this space-flight environment. These responses also had implications as to his performance capability in this environment. The stresses of this environment to which physiological responses are elicited include the wearing of the full-pressure suit although not pressurized in flight, confinement and restraint in the Mercury spacecraft with the legs at a 90° elevated position, the 100-percent oxygen 5-psi atmosphere, the changing cabin pressure through powered flight and reentry, variation in cabin and suit temperature, the acceleration force (g force) of launch and reentry, varying periods of weightless flight, vibration, dehydration, the performance required by the flight plan, the need for sleep and for alertness, changes in illumination inside the spacecraft, and diminished food intake.

Sources of data used in evaluating these responses have included the control baseline data previously referred to, data from the biomedical sensors received at both the Mercury Control Center and the range stations, voice responses at these stations and the detailed onboard tape, the film record of the onboard tape, answers to debriefing questions, and the detailed postflight examination.

In considering these physiological responses, it was found necessary to have a detailed inflight event history since the peak physiological responses are closely related to critical inflight events. This meaningful relationship is very well demonstrated in considering the pulse responses to the Mercury flights. The peak pulse rates during the launch phase has usually occurred at sustainer engine cut-off. This peak value has ranged from 96 to 162 beats per minute. The peak rates obtained on reentry have ranged from 104 to 184 beats per minute. This peak usually occurred immediately after obtaining peak reentry acceleration, or on drogue parachute deployment. Pulse rates obtained during weightless flight have varied from 50 to 60 beats per minute during the sleep periods to 80 to 100 beats per minute during the normal wakeful periods. (See table 11–I.) Elevated rates during weightless flight can usually be related to flight-plan activity. The respiratory rates have ranged from 30 to 40 breaths per minute at sustainer engine cut-off, from 8 to 20 breaths per minute during weightless flight, and from 20 to 32 breaths per minute at reentry. Changes noted in the electrocardiograms have included alterations in the pacemaker activity with wandering pacemakers and aberrant rhythm including atrio-ventricular nodal beats and rhythm, premature atrial and ventricular contractions, sinus bradycardia, atrial rhythm, and atrio-ventricular contraction. All of these "abnormalities" are considered normal physiological responses when related to the dynamic situation in which they were encountered. Inflight blood-pressure values and body-temperature readings have all been within the physiologically normal range.

Table 11–I.—Pulse Rates

Mission	SECO (Peak)	Weightlessness (Range)	Re-entry (Peak)
MR–3	138	108 to 125	132
MR–4	162	150 to 160	171
MA–6	114	88 to 114	134
MA–7	96	60 to 94	104
MA–8	112	56 to 121	104
MA–9	144	50 to 60 (sleep) 80 to 100 (awake)	184

The six astronauts who have flown have shown themselves capable of normal physiological function and performance during the acceleration of launch and reentry. The launch accelerations are those imposed by the Redstone and the Atlas launch vehicles. These impose a peak transverse acceleration load of 11g in the case of the Redstone and 7g to 8g in the case of the Atlas.

The vibration produced by launch or reentry has been well tolerated in all cases.

There has been no conclusive evidence of disorientation during flight; and while the astronaut may not have been oriented with respect to the earth, he has always remained so with respect to his spacecraft. The lack of earth orientation has posed no problem whatsoever. There has been no evidence of motion sickness in any of the flight astronauts.

The heat loads imposed by the environmental control system have on occasion caused discomfort but have not been limiting factors in the missions to date. The heat loads and decreased water intake have resulted in postflight dehydration. It has been learned that thermal control in the environmental system is of critical importance.

The Mercury missions were originally planned for altitudes which would not involve contact with the Van Allen Belt of radiation. It was therefore believed that radiation posed no problem in the conduct of these missions, and this was the case until the man-made radiation belt was noted just prior to the MA–8 mission. Personal dosimeters were added within the astronaut's suit and inside the spacecraft at this time in addition to the film packs which had originally been carried. The results obtained from this dosimetry on the last two flights revealed that the astronauts have received no more radiation dose than they would have received had they been here on earth and certainly less than that received during a chest X-ray.

The Mercury program has provided incremental exposures to weightless flight in order to obtain information on which to base predictions of reactions to more prolonged exposures. The crews have uniformly reported that the condition is extremely pleasant and restful. In fact, most of the crews think that it is the only time they have been comfortable in a pressure suit. They have conducted complex visual motor coordination tasks proficiently in the weightless environment. No evidence of body system disfunction has been noted during the period of weightless flight through any of the means of monitoring at our disposal. Food, in cube, liquid, and reconstituted freeze-dried forms, has been eaten normally. Urination has occurred quite normally in timing and amount, and there is no evidence of difficulty in intestinal absorption in the weightless state. Our one experience with sleep periods has raised the question as to whether brief periods of sleep in the weightless condition are more restful than the same periods in a 1g atmosphere. The MA–9 astronaut feels that they are. There is also some question concerning the effect of such a relaxing condition as weightlessness because a number of unscheduled naps occurred. This question will require further investigation on other flights. In the missions to date, there has been no evidence of the mobilization of calcium.

On the last two missions, some postflight orthostatic hypotension, or changes in blood pressure and pulse rate with change in body position, has been noted. This postflight condition has been investigated by the use of the tilt table during the last mission and these results confirm what was only a suspicion on the previous mission. Symptoms of faintness occurred following egress from the spacecraft, and the changes in blood pressure and pulse rate were present for some 7 to 19 hours after landing. In both instances, these changes have been present up until the astronaut retired for the night, a time period of approximately 7 hours; and they have always disappeared by the time of the first check after the astronaut has awaken. Thus, the orthostatic changes have lasted no longer following the more prolonged flight in the MA–9 mission than for the shorter flight; and in both instances, blood pressure and pulse rate have returned to normal while the astronaut was at bed rest. These findings do cause concern about prolonged exposure without some interim steps for further evaluation of this condition.

Recovery

The medical support of the overall Project Mercury recovery operation had to meet two basic requirements:

(1) The capability of providing prompt, optimum medical care for the astronaut, if necessary, upon his retrieval from the spacecraft.

(2) The provision for early medical evaluation to be made of the astronaut's postflight condition.

It was considered essential to establish a medical capability for any circumstance under which recovery could occur. The general concept was to provide the best care in the fastest manner possible. Details of the medical recovery requirements may be found in the appropriate NASA documents (refs. 1, 4, 7, 10, and 12). The original plans were necessarily based on anticipating the direst situation expected, and very correctly so. The extent of medical care which could be effectively administered to the astronaut during the recovery operation is governed to a large degree by the physical circumstances under which recovery occurs. Consequently, the level of medical support necessary at the different recovery areas varies according to the potential extent to which competent medical treatment can be administered in that area, and the most extensive medical support is properly concentrated in those areas where descent to earth by the astronaut is most probable. Access times for the various recovery areas were determined to be medically acceptable time periods to allow reasonable protection of the astronaut based upon accumulated knowledge of human survival, need for medical attention, and reaction to physiologic stress. Since the recovery forces are routine operational units diverted to this operation by the Department of Defense, it also became obvious that the medical support must be obtained through the cooperation of the Department of Defense. Civilian physicians are not available for deployment for the necessary time periods. It will be noted that one of the basic philosophy changes during the program involved a change in emphasis from taking medical care to the astronaut in the early missions to provisions for returning the astronaut to definitive medical care in the later missions. The medical support was provided for three basic categories:

(1) Rapid crew egress and launch-complex rescue capability during the late countdown and early phases of powered flight.

(2) Positive short-time recovery capability throughout all phases of powered flight and landing at the end of each orbital pass.

(3) Reduced capability in support of an unplanned landing along the orbital track.

In the launch-site area, this support included a medical-specialty team consisting of a general surgeon, an anesthesiologist, surgical technicians and nurses, a thoracic surgeon, an orthopedic surgeon, a neurosurgeon, an internist, a radiologist, a pathologist, a urologist, a plastic surgeon, and supporting technicians. In the early missions, these individuals were deployed to Cape Canaveral and were available should the need arise for their use either at Cape Canaveral or, in the event of a requirement for their services in the recovery area, they could be dispatched by aircraft. On the last two missions, it became necessary to develop a team at Tripler Army Hospital, Hawaii, to cover the Pacific area as well as a team deployed to Cape Canaveral to cover the Atlantic area. It became obvious that there were large numbers of highly trained physicians who were merely waiting out the mission in a deployed state with an unlikely probability that they would be utilized. Careful evaluation of the experience and of sound medical principles involving emergency medical care led to the conclusion that the specialty team could be maintained on standby at a stateside hospital and easily flown either to Cape Canaveral or a recovery site if their services were needed. There were surgical resuscitatives teams available at these sites. Other launch-site support was provided by a point team consisting of a flight surgeon and scuba-equipped pararescue personnel airborne in a helicopter. Medical technicians capable of rendering first-aid care were also available in LARC vehicles and in a small water jet boat stationed on the Banana River. A surgeon and an anesthesiologist with their supporting personnel were stationed in a blockhouse at Cape Canaveral to serve as the first echelon of resuscitative medical care in the event of an emergency. Physicians were stationed throughout the recovery areas aboard destroyers and aboard one aircraft carrier in the Atlantic and one in the Pacific. In the early missions each vessel was assigned a surgeon, anesthesiologist, and a medical technician team with the supporting medical equipment chest necessary for evaluation and medical or surgical care. As confidence was gained in the operations, this distribution was modified to assigning only a single physician, either surgeon or anesthesiologist, to the destroyer. Attempts were made to place a surgeon on one and an anesthesiologist on another vessel nearby. This would allow their teaming up if necessary. The general concept was, however, that they would provide resuscitative care only and then evacuate the astronaut to the carrier in their particular area. The carrier was provided a full surgeon, anesthesiologist, technician team. Hospitals along the orbital track were alerted for their possible use, and some near planned landing areas were briefed by NASA-DOD teams. These briefing are thought to be extremely valuable aids in assuring adequate medical support. Early in the missions, blood was drawn from donors and made available for transfusion at Cape Canaveral and in the recovery area. As the operation grew wider in scope involving the Pacific, and as more confidence was gained, dependence was placed upon walking blood bank donors who were typed, and drawn blood was available only in the launch site area.

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III

FLIGHT OPERATIONS

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12. SPECIAL INFLIGHT EXPERIMENTS

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Summary

The Mercury spacecraft, although not designed as a vehicle for performing experiments, was used to accomplish a program of special inflight experiments not directly related to mission objectives. The major constraints imposed on the experiment program by the spacecraft were the weight and volume requirements, and the consumables required such as attitude-control system fuel and electrical power. The program evolved from an early period when no planned experimental endeavor existed through the development and implementation of an inflight experiments panel specifically chartered to evaluate the growing number of proposed inflight experiments. The inflight experimental program carried out during the Mercury manned orbital flights is outlined in this paper and the results of these experiments are briefly presented. An analysis of the results of those experiments performed in the area of the physical sciences is presented in paper 19.

Introduction

A major objective of the Mercury manned space-flight program was the determination of man's ability to function in the space environment. The Mercury spacecraft was designed to sustain a man in space for a given period of time and to protect him against the accelerations and temperatures to be encountered during exit from and reentry into the earth's atmosphere. Because of the emphasis on the sustentation and protection of man in space in the design stages, practically no consideration was given to the employment of the spacecraft as a platform for specific inflight experiments. Astronaut safety was the prime design consideration; and, even in the latter stages of the Mercury Project, this concept was not compromised by the desire to perform experiments.

However, an inflight experiment program was evolved in the latter stages of the Mercury Project within the constraints imposed by the spacecraft and operational requirements. The experiments, in general, fall into three categories—biomedical, physical sciences, and engineering. The biomedical experiment program is described in paper 11 and is not covered herein.

This paper discusses the constraints placed on the Mercury experiment program by the spacecraft and the operational limitations, describes the procedures which evolved for the evaluation and implementation of experiments, and summarizes the Mercury inflight experiment program. An analysis of those experiments in the area of space sciences is made in paper 19.

Spacecraft Constraints

Weight

The maximum allowable weight of the Mercury spacecraft was dictated by the capability of the Atlas launch vehicle and by the requirement to achieve an extremely high probability of satisfactory orbital insertion. The entire 5-year history of the Mercury Project has been marked by a constant struggle to maintain the weight of the spacecraft within the weight constraints. Even without the addition of inflight experiments, the spacecraft weight was still increasing approximately 1 pound per week at the close of the program.

After the first manned orbital mission, when it was shown that man can function reliably in the space environment and is a competent technical observer, an increasing amount of spacecraft weight was devoted to the accomplishment of experiments. The battle to reduce the weight of the Mercury spacecraft had not been won by any means; but weight devoted to the performance of experiments was considered to be justified by the fact that Mercury became a part of a growing national program of scientific space exploration for peaceful purposes.

The weight associated with experimental equipment carried on each of the Mercury manned orbital missions is tabulated as follows:

Mission	Weight, lb
MA–6	11
MA–7	18
MA–8	22
MA–9	62

Volume

An observation of the Mercury spacecraft interior, particularly with the astronaut in place and wearing his pressure suit, impresses one with the compactness of the spacecraft and the lack of available volume. Several worthy suggestions for experiments were rejected simply because there was no space available to store the equipment required for the experiment. A relatively small hand-held camera, for example, became a major problem because of no suitable place to stow it for launch and reentry. Although the astronauts have had available to them a personal-effects container, this storage space was rapidly filled with food, flight plans, star charts, and other paraphernalia required for the flight. Astronaut Cooper on the MA–9 mission managed to squeeze into this bag two cameras together with associated film magazines and lenses, but he experienced a great deal of difficulty in extracting and storing his camera equipment. One planned experiment could not be completed because a piece of equipment could not be taken from the container.

Operational Limitations

On the two, three–orbital–pass missions, the short duration of these flights allowed little time for experimental observations. In general, on such a mission, the astronaut used the first orbital pass to acclimate himself to the space environment and verify proper systems operation. The major portion of the third orbital pass was devoted to preparations for retrofire and reentry. Thus, only part of a continuous 90-minute period was available for the performance of experiments. On both the manned three–pass missions, control–system difficulties forced the astronauts to devote their attention to flying the spacecraft. Although the time available was limited, both Astronauts Glenn and Carpenter were able to make observations of scientific interest. Even on the 34–hour manned 1–day mission (MA–9), the requirements for engineering and operational data, astronaut rest periods, communications, and other duties resulted in only a limited time available for experiments.

A major constraint on the selection of experiments for the Mercury spacecraft was the small amount of control-system fuel available for experiments. At least some degree of attitude control of the spacecraft was required for practically all of the experiments. After reserves were first established for operational requirements, in particular the retrofire and reentry maneuvers, the fuel available for experiments was allocated according to priorities established for the experiments.

Other limitations imposed by the spacecraft consumables were requirements for electrical power and for data–recording channels. While these limitations were not severe, they were additional considerations in the selection of experiments.

Some types of experiments require an extremely accurate control of spacecraft attitude. Such fine control was not designed into the Mercury spacecraft because of weight limitations and the necessity for conserving control-system fuel. The automatic-control system, for example, had a deadband of up to 11°. The manual-control system and the attitude and rate indications to the astronaut were such that the astronaut could control the spacecraft attitude within a deadband of approximately only 2°. These tolerances made the spacecraft unsuitable for certain types of experiments.

The optical qualities of the Mercury spacecraft window were limited to begin with, and even these qualities were considerably degraded by residue from the escape rocket which was normally ignited when the escape tower was jettisoned just after launch-vehicle staging. Future spacecraft will require some type of high-quality optical port if precision photographic experiments are to be conducted.

Evalution and Selection of Experiments

Prior to the MA–6 manned orbital flight, no formal procedures existed for the acceptance, evaluation, and incorporation of proposed experiments in the Mercury missions. Suggestions were made informally by organizations both within and outside of the Manned Spacecraft Center for certain types of observations or photography to be accomplished on the MA–6 mission. These suggestions were made directly to the office responsible for astronaut training activities; and, where possible, certain of the suggested experiments were incorporated into the MA–6 flight plan.

With the successful accomplishment of the MA–6 mission, the original objective of the Mercury Project was fulfilled. It had been proven that man could function effectively in space and be safely recovered. With the realization that the Mercury Project was now in a position to perform certain types of experiments of scientific value from an orbiting spacecraft, the Mercury Project Office became the recipient of a large number of proposals for such experiments. These proposals originated from divisions within the Manned Spacecraft Center, other organizations and centers within the NASA, industry, and educational institutions. It was soon evident that a special organization was needed to serve as the focal point of the effort devoted to inflight experiments.

In April 1962, the Manned Spacecraft Center officially established the Mercury Scientific Experiment Panel (MSEP). This panel was made up of representatives of the Mercury Project Office and all technical, operational, aeromedical, and scientifically oriented divisions of MSC. The MSEP was specifically charged with the following responsibilities:

(1) To evaluate inflight experiments proposed for inclusion in Project Mercury missions.

(2) To propose to the manager of the Mercury Project the order of priority in which acceptable experiments should be incorporated into the program.

(3) To seek out and foster the generation of suitable experiments from all available sources.

In carrying out these responsibilities, the MSEP formed a close working relationship with scientists in the NASA Office of Space Sciences and the NASA Goddard Space Flight Center.

The major considerations in the evaluation of proposals for experiments by the MSEP were: scientific, technical, and biomedical merit; weight of equipment; volume and location of equipment; attitude-control-system fuel required; electrical power requirement; instrumentation requirement; effect on safety of flight; state of readiness and qualification of equipment and effect on spacecraft schedule; and extent of changes required to the spacecraft.

The MSEP functioned effectively for the MA–7 and MA–8 missions. With the approach of the MA–9 manned one-day mission, however, it became increasingly evident that the scope of the MSEP should be enlarged to include consideration of scientific experiments for MSC's advanced programs and to encompass a broader background of scientific interest.

To accomplish this broadening of responsibilities, the MSEP was supplanted in October 1962 by the Manned Spacecraft Center In-Flight Experiments Panel (IFEP). The IFEP difers from the MSEP in that its membership was enlarged to include representatives of the other two spacecraft project offices and an ex–officio member from the NASA Office of Space Sciences. Its recommendations for the implementation of experiments are made to the Director of the Manned Spacecraft Center for approval. The chairman of the IFEP is the MSC Assistant Director for Engineering and Development.

It is the policy of the MSC to make maximum use, for scientific and research purposes, of the flights scheduled under approved spacecraft programs. In keeping with this policy, the Center encourages the development of worthwhile investigations which can be implemented on manned flights within the limitations of operational requirements and flight safety. To promote this policy, the IFEP has established formal procedures for the submission, evaluation, and acceptance of proposals for inflight experiments.

Implementation of Experiments

The IFEP recommends to the MSC Office of the Director the experiments for a given spacecraft mission. With the approval of the Director, these experiments become the official experiments for the mission. An experiment coordinator was appointed from within MSC for each of the approved experiments. His responsibility was the timely development and flight qualification of hardware required for the experiment. In general, the equipment required for an experiment was furnished by the organization which had proposed the experiment.

The Mercury Project Office was responsible for the integration of experimental equipment into the Mercury spacecraft. The experiment coordinator submitted the following documentation for an approved experiment:

(1) A firm schedule showing all significant milestones for the delivery of equipment

(2) A qualification plan in accordance with specified requirements

(3) A weekly status report

To prevent the spacecraft schedule from being affected by the integration of experiments, it was necessary to set the delivery date of experimental equipment well in advance of the scheduled launch date. In a normal prelaunch schedule for a Mercury spacecraft, the final checkouts of the spacecraft and its systems are made 8 weeks prior to the scheduled launch date. Once these tests were complete, absolutely no changes were made to the spacecraft except those dictated by flight-safety considerations. Therefore, the experimental equipment was required to be at the launch site 3 months prior to the scheduled launch in order to allow sufficient time for the installation and checkout of this equipment before the final spacecraft tests were begun. It was also imperative that the flight astronaut be thoroughly familiar with the equipment and trained in its use. It becomes apparent, then, that the selection and evaluation procedure for experiments must be completed many months before the scheduled launch of a spacecraft to allow time for the design, construction, and qualification of equipment before the required delivery date.

It was specified that the qualification environments and the levels of these qualification tests for experimental equipment be no less stringent than the qualification testing that was required of all Mercury spacecraft systems. The possibility of the compromise of a Mercury mission because of the failure of a piece of experimental apparatus could not be tolerated. Failure modes of the experimental apparatus were examined very closely to assure that such failures could have no degrading effect on the mission or on pilot safety.

The responsibility for integrating experiments into the mission flight plan and into the astronaut training activities was that of the MSC Flight Crew Operations Division. This division worked closely with other elements of MSC to develop a flight plan for each mission which would accomplish the mission objectives and would, at the same time, provide for the performance of experiments. It was necessary that the flight plan be completed in final form many weeks prior to a mission so that the training of the flight astronauts in the procedure trainers would conform with the flight plan. Once the final phases of astronaut training in preparation for the mission had begun, the flight plan could not be changed except for compelling reasons because late changes could seriously disrupt the astronauts' training status to the point where mission safety could have been affected. This, then, was the second reason why experiments must have been approved for a given mission many months in advance.

Mercury Inflight Experiment Program

With this brief background on how the experimental program in manned space flight has evolved, a review of the results of the Mercury experimental program will now be presented. These experiments generally can be divided into two major categories. The first category, that of special inflight experiments, is the topic of this paper. The second category, that of analysis of observations and comments on the space environment and astronomical phenomena, is discussed in paper 19.

Planned Inflight Experiments

The inflight experiments planned for and carried out during the Mercury Project can be grouped generally into several areas of study. These areas are: (1) visual acquisition and perception experiments, (2) general photographic experiments, (3) radiation experiments, (4) tethered balloon experiment, and (5) several miscellaneous studies which include investigations of fluid behavior under zero gravity and of the characteristics of various ablative materials under reentry conditions.

Visual Acquisition and Perception Studies

In future space flights it may be necessary for astronauts to acquire and track lighted targets either on the ground or in space to provide a backup capability for rendezvous and navigation. Visual acquisition of a target in space may also be used to back up the primary method of rendezvous with other space vehicles. Experiments were, therefore, undertaken on Mercury flights to evaluate the operational problems associated with visual acquisition from space of both earth-based lights and lighted targets ejected from the spacecraft.

Ground-light experiments.—Attempts were made on each of the manned orbital Mercury flights to sight known earth-based lights at night. These studies were expected to provide information on man's ability to acquire a fixed light source against an earth background and determine to what extent targets of this type would prove useful as navigational aids in space. An attempt was made by Astronaut Glenn to sight flares launched by mortars from the Indian Ocean Ship on the first and second orbital passes of the Mercury–Atlas 6 (MA–6) flight. The astronaut was unsuccessful in his attempts to see these flares, however, because of heavy cloud coverage in the area. Attempts were again made to acquire ground flares of 1,000,000 candle-power intensity over the Woomera missile range in Australia on both the Mercury–Atlas 7 (MA–7) and Mercury–Atlas 8 (MA–8) missions. These experiments were also unsuccessful on both flights because heavy cloud cover and poor visibility prevented the pilots from sighting these targets. A ground-based xenon light located at Durban, South Africa, was also used on the MA–8 mission to increase the probability of having favorable weather at one site. Unfortunately, rain and clouds obscured the light in South Africa as well as the ground flares in Australia. Another attempt to sight the xenon light was planned for the Mercury–Atlas 9 (MA–9) mission. By using statistics furnished by the U.S. Weather Bureau to determine a favorable location, the light was positioned at Bloemfontein, South Africa. Sightings were scheduled for the sixth orbital pass and in this case Astronaut Cooper was successful in acquiring the light.

The light assembly used for this experiment, shown in figure 12–1, was a pulsed xenon arc light consisting of three sections of six lamps each. The lamps were mounted in a shallow open-top box above a polished reflector and were operated by using a 50-cycle, 220-volt, three-phase a-c circuit. Each section operated independently from a single phase and flashed once every cycle. Thus, the three sections produced a total of 150 flashes per second, well above the response of the eye, and appeared as a steady burning light. The measured average intensity of the light was found to be between 30,000 and 35,000 candle power and required between 13 and 15 kilowatts of power for operation. The light could first be viewed at a slant range of 320 nautical miles from the spacecraft and was calculated to be as bright as a 3.5 magnitude star. Astronaut Cooper estimated the light to be third magnitude in brightness when first acquired, and he was able to retain it in sight for 30 to 40 seconds before it faded out. Thus, the experiment produced sighting results approximately as predicted and the light was considered of sufficient brightness to be used as a navigational landmark. A flashing light or some distinctive light pattern, however, was believed essential for identification of a target light for any future use. The rapid angular passage of the spacecraft over the ground will also pose a problem for use of

FIGURE 12–1.—Ground-light installation.

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ground targets of this sort as navigational fixes. Weather conditions on the ground also proved to be an important factor in using ground lights, and perhaps airborne lights carried above the weather region of the atmosphere would prove more dependable. More testing is needed to prove the operational feasibility of using airborne lights and to determine flash frequencies most desirable for acquisition and tracking.

Flashing-light experiment.—The problem of visual acquisition of other space vehicles directly relates to the rendezvous of two spacecraft. For visual sighting of another vehicle at ranges up to 100 miles, the problems of visual acquisition and tracking need to be identified and studied. Therefore, a study to investigate some of the problems of visual acquisition of a target vehicle in the space environment was carried out on the Mercury-Atlas 9 (MA–9) flight.

On this flight a flashing light was ejected from the spacecraft and viewed by the astronaut at varying distances in orbit. The light, its container, and the ejection mechanism were built by the NASA Langley Research Center, and the details of this assembly are shown in figure 12–2. The flashing–light unit was a 5.75–inch–diameter spherical assembly weighing about 10 pounds and equipped with two xenon–gas–discharge lamps located at opposite poles. The two lamps flashed simultaneously at a rate of approximately one signal per second. The beacon was designed to appear about as conspicuous as a second magnitude star when viewed at a distance of 8 nautical miles. As shown in the figure, the sphere was ejected from the container at a speed of 10 ft/sec by means of

FIGURE 12–2.—Assembly for flashing-light beacon.

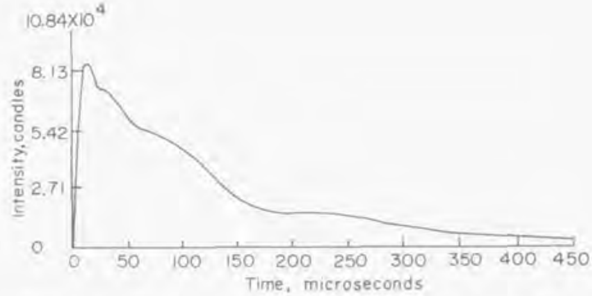

FIGURE 12–3.—Time history of a typical flash of the beacon.

a compressed spring acting against a piston when the canister covers were released. The light was powered by mercury-cell batteries, which were connected in series, and it delivered approximately 8 watt-seconds of power per flash.

A typical time history of one of the flashes is shown in figure 12–3. This figure shows that the light reached a peak intensity output of about 8.0×10^4 candles and that the light has a flash duration of about 100 microseconds at or above one–half peak intensity.

Extensive measurements were made by the National Bureau of Standards to determine the integrated light intensity and to establish that the distribution of the light was reasonably uniform in all directions and reasonably constant throughout its designed lifetime of 5 hours. Figure 12–4 is an example of this directional survey and shows the variation of integrated light output in candle–seconds per flash with light orientation. Distributional measurements of this type for varying viewing angles showed that the light output was reasonably uniform and produced a flash intensity of approximately 12 candle–seconds per flash. As shown by figure 12–4, regions near the 0° and 180° orientation showed some degradation in light intensity, with intensity falling as low as 8 to 9 candle–seconds in these regions. By using a value of 0.2 for the Blondel–Rey constant for threshold viewing of flashing lights, this light can be converted to an equivalent effective steady–light intensity of from 40 to 60 candles. This intensity corresponds to a light of second magnitude in brightness when viewed at a distance of between 7 and 8 nautical miles by using the commonly accepted value of 8.3 $\times 10^{-7}$ lumens per square meter for a first magnitude light. Visual air–to–air and ground–

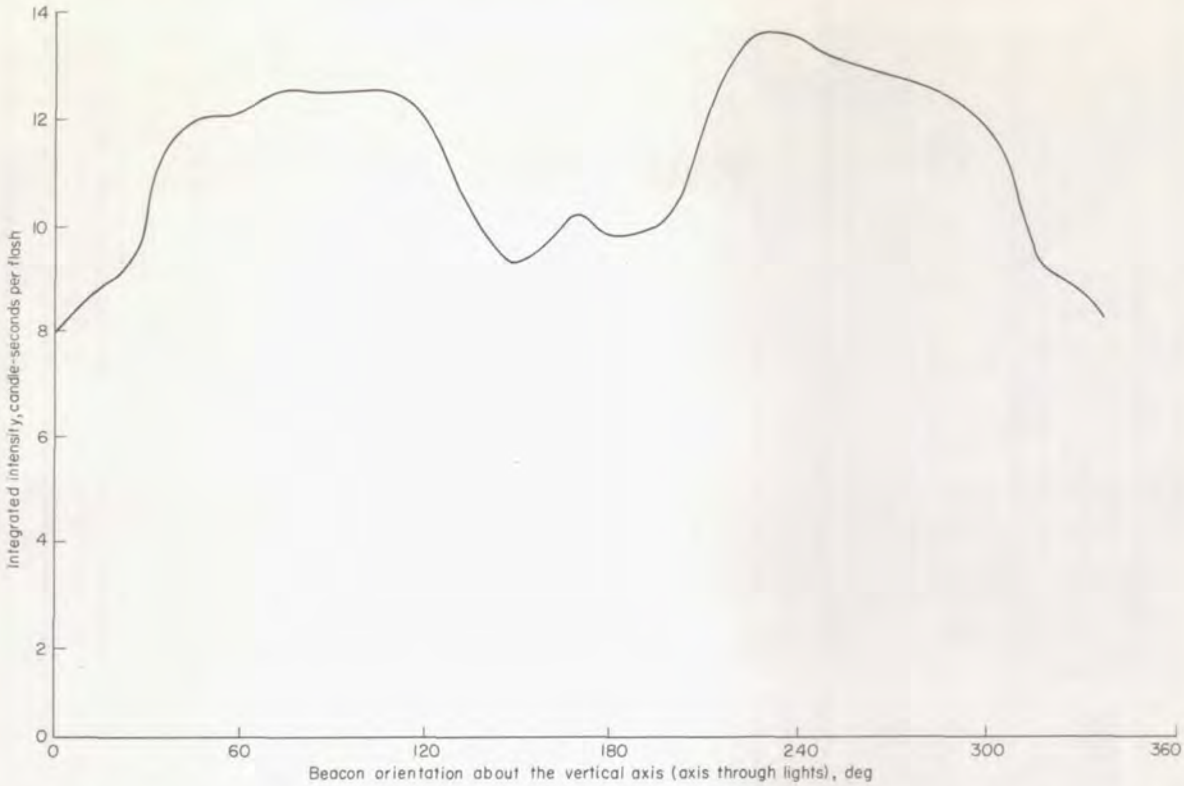

FIGURE 12-4.—Integrated intensity of the flashing beacon about an axis passing through the lights and inclined at 30° from the vertical.

sighting tests, with Astronaut Cooper as one of the test subjects, indicated that the light intensity was approximately the same as had been measured in the laboratory.

Trajectory studies of ballistic number, ejection angle, ejection velocity, and orbital position at ejection were made to determine the proper orbital conditions for deployment of the light. These studies showed that if the beacon were ejected 88° below the pitch horizon of the spacecraft at a velocity of 10 ft/sec, the desired trajectory would be obtained. Figure 12-5 shows the spacecraft attitude and canister location used to provide the desired ejection angle. The pilot controlled the spacecraft attitude to

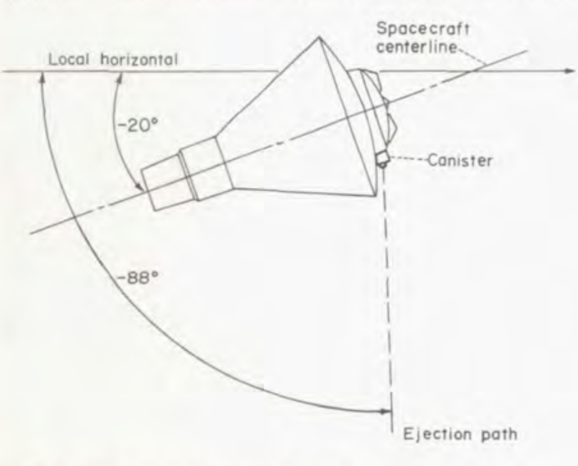

FIGURE 12-5.—Spacecraft orientation at beacon deployment.

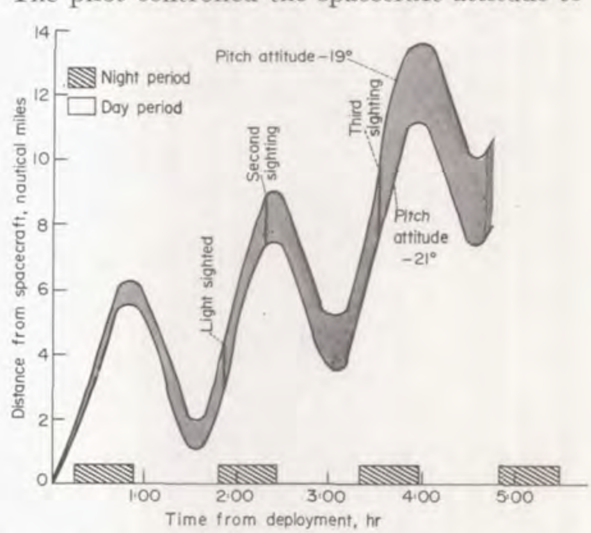

FIGURE 12-6.—Variation in separation distance between the spacecraft and the flashing beacon after deployment.

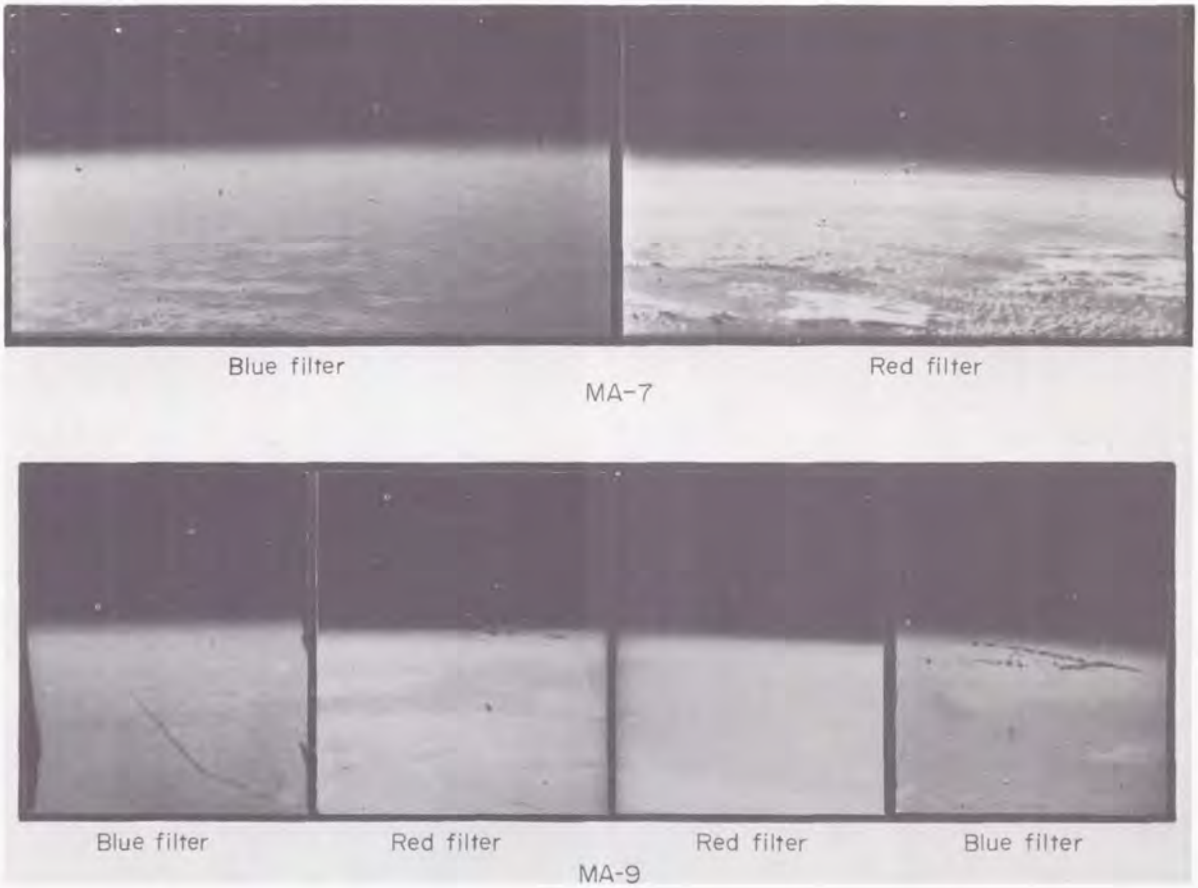

FIGURE 12-7.—Typical horizon definition photographs.

the desired position by using horizon-sighting markings on the window for aiming. The beacon was ejected 15 minutes prior to sunset on the third orbital pass and postflight records indicated the pilot controlled attitude to within $\pm 1°$ of the desired attitude. Figure 12-6 shows the calculated separation distance between the spacecraft and the beacon as a function of time after deployment. The band between the upper and lower curves represents the variation in range that might have occurred because of an uncertainty in ejection attitude.

Astronaut Cooper was unable to locate the beacon on the first night pass after deployment, probably because the spacecraft was not oriented closely enough in yaw to position the light in the field of view. During the second night pass after deployment the astronaut successfully sighted the beacon and was able to change the spacecraft attitude and then return to reacquire the light. During these sightings, noted on figure 12-6, the astronaut rated the light as about one star magnitude dimmer than had been expected. For example, when the beacon was between 7.5 and 9 nautical miles away at 2 hours and 14 minutes after deployment, the light was described as not very bright but discernible, about the order of a third magnitude star. The light was also seen during the third night at a range of between 9.5 and 11.5 nautical miles and was rated as very, very weak and just barely discernible.

In general, the flash was found to make the light easily distinguishable from stars. The beacon's intensity and flash rate appeared to be adequate for acquisition distances of up to 8 nautical miles at night which corresponded to a light intensity of about a second magnitude light.

General Photography

Horozin-definition photography.—Horizon-definition photography was conducted on two Mercury space flights to assist the Instrumentation Laboratory of the Massachusetts Institute of Technology (MIT) in determining the effectiveness with which the earth's sunlit limb could be used for navigational sighting during the terminal phase of advanced space missions. Photographic studies were carried out on both the MA–7 and MA–9 flights. A 35-mm Robot camera was flown in MA–7 and a 70-mm Hasselblad was used as the photographic device for MA–9. For both flights, a special red and blue split filter was inserted in the field of view just ahead of the film plane. This filter was used to provide information on the resolution and effectiveness of using the limb as a navigation aid at the two extremes of the visible spectrum.

Data obtained from these photographic studies are presently being analyzed by Instrumentation Laboratory scientists under the direction of Dr. Max Peterson. Limited results of the MA–7 flight have shown, as expected, that the earth's limb viewed through a blue filter has a somewhat higher elevation than when viewed through a red filter. This distinction is clearly evident in figure 12–7 which shows typical photographs obtained on both the MA–7 and MA–9 flights. The MA–7 flight results have shown that contrast and definition are improved when viewed in the longer wavelengths of the visible spectrum (see fig. 12–7). The limb viewed through a blue filter is expected, however, to provide a better navigational reference because the blue limb appears more stable and is not as subject to interference effects from clouds and other atmospheric conditions as is the red limb.

The MA–9 photographic study was conducted to provide additional information on the limb elevation viewed through the red and blue filters. It was also planned to obtain information for determining the radiance of the limb, for evaluating the effect of variations in scattering angle of incident light on limb height, and to establish the height of the limb above the surface of the earth. To accomplish these objectives, it was planned to take a series of photographs in the four quadrantal directions relative to the sun, of the setting moon near the earth's limb, and of the limb during the daylight period of most of an orbital pass. It was not possible to obtain the daylight-period photographs on the MA–9 flight because of operational difficulties during the period in which this photography was planned.

A preliminary analysis of the MA–9 photographs taken substantiates the initial results of the MA–7 flight. Although the analysis is not yet complete, it is expected that the limb radiance in both the red and blue portions of the spectrum can be fairly accurately established. An accurate determination of the height of the limb cannot be made by using data from the MA–9 flight, however, because the image of the moon is too distorted and indistinct. The film and dust layer which collected on the spacecraft window might well have contributed to this indistinct image. Although no significant difference in limb height was noted when the four quadrantal photographs were compared, much more data covering a wide variation in the angle of incidence of sunlight striking the atmosphere are needed to determine the effect of variation in scattering angle on limb height. In order, therefore, to establish the value of the earth's limb as a navigational reference, additional studies are needed to determine limb height and the variation in this height at different scattering angles of incident light.

Weather photography.—Weather observations and photography were carried out during the Mercury flight program to augment other meteorological information and to provide specific information that would be useful in designing advanced weather satellite systems. On both the MA–6 and MA–7 missions, cameras equipped with special film and filters were carried on board for photographing interesting meteorological phenomena. However, because of difficulties arising during each of these flights, no photographs were obtained. Meteorological data obtained on these missions were derived from the astronauts' observations and the general-purpose color photography.

Photographic experiments were conducted during both the MA–8 and MA–9 flights for the National Weather Satellite Center. These experiments were designed to examine some of the spectral reflectance characteristics of cloud, land, and water areas of the earth's surface as viewed from space. Figure 12–8 shows the camera and filters used on these two flights. The 70-mm Hasselblad camera shown in the figure was used for both missions. For the

FIGURE 12-8.—Photographic equipment used for Weather Bureau experiment.

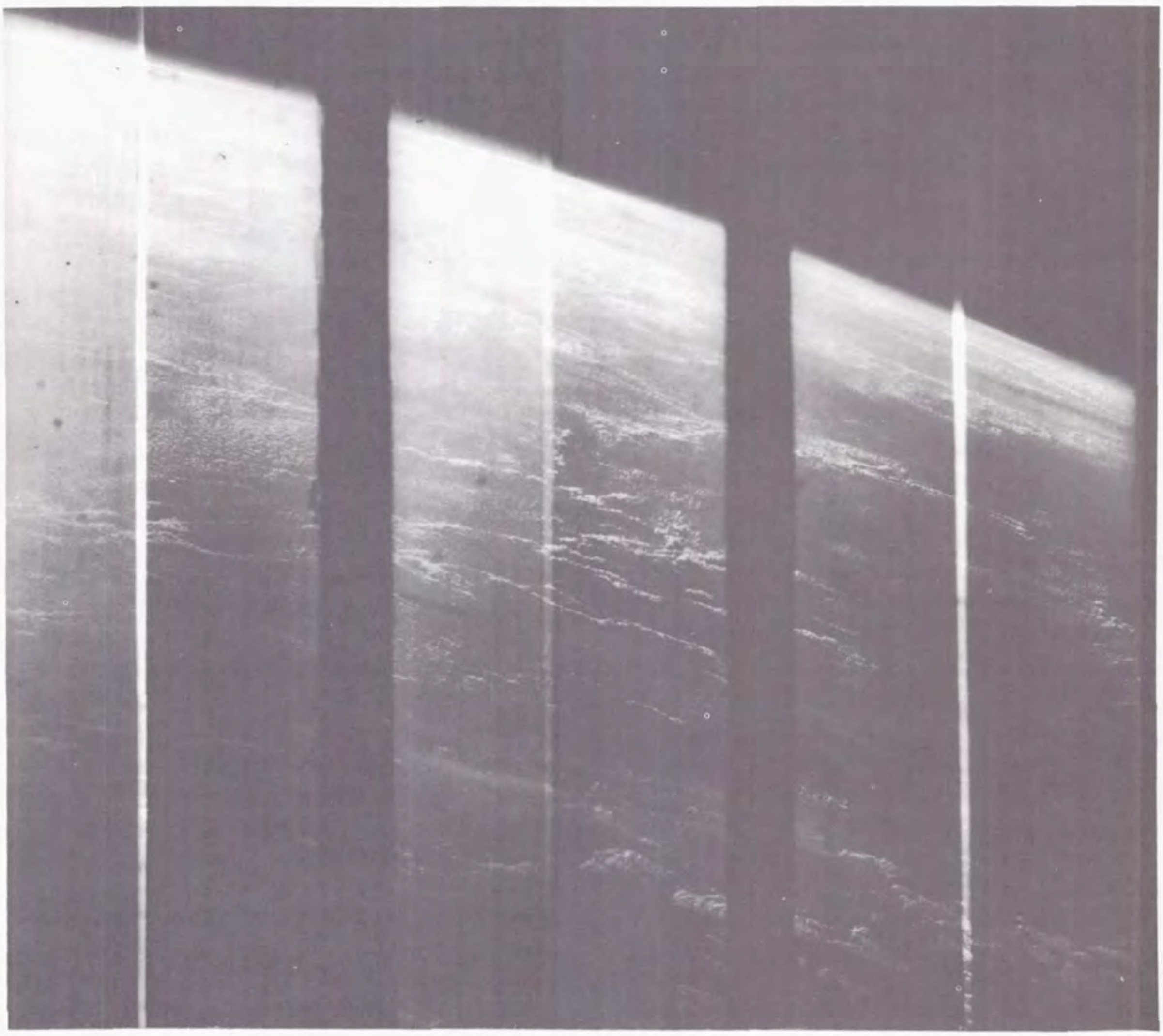

FIGURE 12-9.—Weather photograph of a region of the South Atlantic, southeast of Brazil taken by Astronaut Schirra on the MA-8 flight.

FIGURE 12–10.—Weather photograph of the Baja California area taken by Astronaut Cooper on MA–9.

MA–8 mission a wide bandpass Wratten filter consisting of six elements varied in range of spectral transmission from blue to far red. Neutral density was added to each of the color filters to produce a nearly uniform neutral density over the entire spectrum examined. Film sensitivity extended from 3,700 Å to 7,200 Å thus limiting the wavelength response to 7,200 Å.

Figure 12–9 is a photograph from the series obtained during the MA–8 flight and was taken over the South Atlantic on the fifth orbital pass. It was exposed at an altitude of 140 nautical miles viewing northwest toward the southeast coast of Brazil approximately 1,000 miles away. Analyses of this and other photographs of this series were carried out by Mr. Stanley Soules of the National Weather Satellite Center to provide design inputs to future weather satellites. Results from the MA–8 flight indicated that contrast increased with wavelength in the visible spectrum as shown by figure 12–9. These results indicate that the optimum wavelength for viewing the earth might be the near infra-red spectrum where scattering by atmospheric particles is relatively low.

The MA–9 weather photography was conducted to investigate this hypothesis by using infra-red film and a special filter shown in figure 12–10. This filter divided the infra-red spectrum from 6,600 Å to 9,000 Å into three parts. To accomplish this division of the spectrum, the filter was divided into three sections each having the bandpass width shown in figure 12–10, which is a typical photograph and was taken over southern Arizona looking westward. As pointed out by Mr. Soules in his analysis of these results, water has a very low reflectance in the near infra-red as shown by the dark portion on the left of the photograph covering the Pacific Ocean. Clouds and land have a very high reflectance; hence, coastlines and cloud patterns over water are easily discernible. However, as illustrated by the figure, clouds are more difficult to detect over land area because both the clouds and land areas covered with green vegetation have a high reflectance.

Terrain photographs.—Terrain photographs have constituted a portion of the general purpose photographs on each of the four manned orbital flights. However, they were specifically scheduled as a part of the flight plan on only the MA–8 mission. On the other three flights, terrestrial photographs were taken when the opportunity arose rather than as specifically planned activities. These photographs were taken to aid in building up a catalog of space photographs of various geological features such as folded mountains, fault zones, and volcanic fields, and to provide topographical information over a major portion of the earth's surface. They were taken on each flight by using high-speed color film in the general-purpose camera carried aboard for the flight. The following table lists the camera and exposure settings used on each flight.

Generally, the terrain photographs of the first three manned orbital flights were of poorer

Flight	Camera	Film	Exposure
MA–6	35-mm Ansco Autoset	Eastman color negative stock no. 5250	Automatic
MA–7	35-mm Robot Recorder	Eastman color negative stock no. 5250	1/125 at f/16
MA–8	70-mm Hasselblad	Super Anscochrome color ASA no. 160	1/125 at f/11
MA–9	70-mm Hasselblad	Ultraspeed Anscochrome color FPC 289	1/250 at f/16

quality than those obtained on the MA-9 mission, although some useful photographs were obtained on each of these flights. The reduced quality of the photographs on these first missions resulted primarily from the much poorer weather conditions that existed over the land areas of the earth and by the limited land area covered during the flights. It was quite fortunate that worldwide weather conditions during the MA-9 mission were much better than on previous flights; and because of the favorable weather and the fact that the flight covered many land areas of the world, excellent photographic coverage, particularly regions of the African and Asian deserts and the Himalaya mountains, was possible.

Preliminary analysis of these photographs has been made by Mr. Paul D. Lowman of the NASA Goddard Space Flight Center and is presented in paper 19. As a result of the analysis of these photographs, Mr. Lowman concluded that potentially useful geological and topographical information could be obtained from all terrain photographs taken during orbital flight. The quality and resolution of these photographs approached or equaled that of the black and white exposures from the best rocket flights.

Dim-light photography.—A dim-light photographic experiment sponsored by the School of Physics, University of Minnesota, was carried out for the MA-9 mission to obtain photographic data on two dim-light phenomena best observed outside the earth's atmosphere. These phenomena are the so-called zodiacal light and the night airglow. Photographs of the zodiacal light were needed to assist in determining its exact origin, geometric distribution, and relationship to solar radiation and flare activity. Data on the airglow were needed to define the layer further and to provide information on the solar energy conversion process occurring in the upper atmosphere.

Figure 12-11 shows a photograph of the 35-mm Robot camera as it was modified for this experiment. The camera was equipped with an automatic film advance and had a fixed lens with an equivalent speed of f/0.95. Exposures were timed manually, and the camera controls were simplified to improve operation by the astronaut in a pressure suit. Three small supports or "feet" (see fig. 12-11) were provided to aid the pilot in positioning the camera against the window for aiming.

Photographs, varying in exposure time from 1 to 30 seconds, of the zodiacal light were to begin immediately after sunset and were to cover the ecliptic region from sunset to about 30° of arc past sunset. Photographs of the airglow layer were to be taken periodically over an entire night orbital pass with exposures varying in duration from 10 to 120 seconds.

Unfortunately, the zodiacal-light sequence yielded very little useful data since all of these photographs were underexposed. A small de-

FIGURE 12-11.—Modified Robot camera used for MA-9 dim-light photography.

FIGURE 12-12.—Photograph of the airglow layer taken by Astronaut Cooper on the MA-9 flight.

lay in initiating the sequence or an error in exposure time could have caused these unsatisfactory results since the gradient in zodiacal light intensity varies quite rapidly near the sun.

The airglow photographs, however, were of quite usable quality. A representative photograph from this experiment is shown in figure 12-12. Preliminary analysis of these photographs by Dr. Edward P. Ney and associates at the University of Minnesota has shown them to be useful in determining surface brightness of the airglow layer. These photographs also were found to be valuable for assessing the height of the layer with varying latitude, in measuring the angular width of the band, and in determining angular displacement above the earth's horizon. Considerably greater discussion of this phenomenon is presented in paper 19.

Radiation Experiments

Some form of radiation measurement has been included on all Mercury space flights to record the dose received by the astronaut and to furnish experimental information on the space radiation environment over the Mercury altitude profile.

Generally, data obtained during these experiments were measured by the following method:

(1) Studies in which film or lithium-fluoride thermoluminescent detectors were used to measure the dosage to the astronaut.

(2) Emulsion packs and ionization chambers to measure the radiation level inside the spacecraft.

(3) A package containing Geiger-Mueller tubes to measure the electron flux external to the spacecraft.

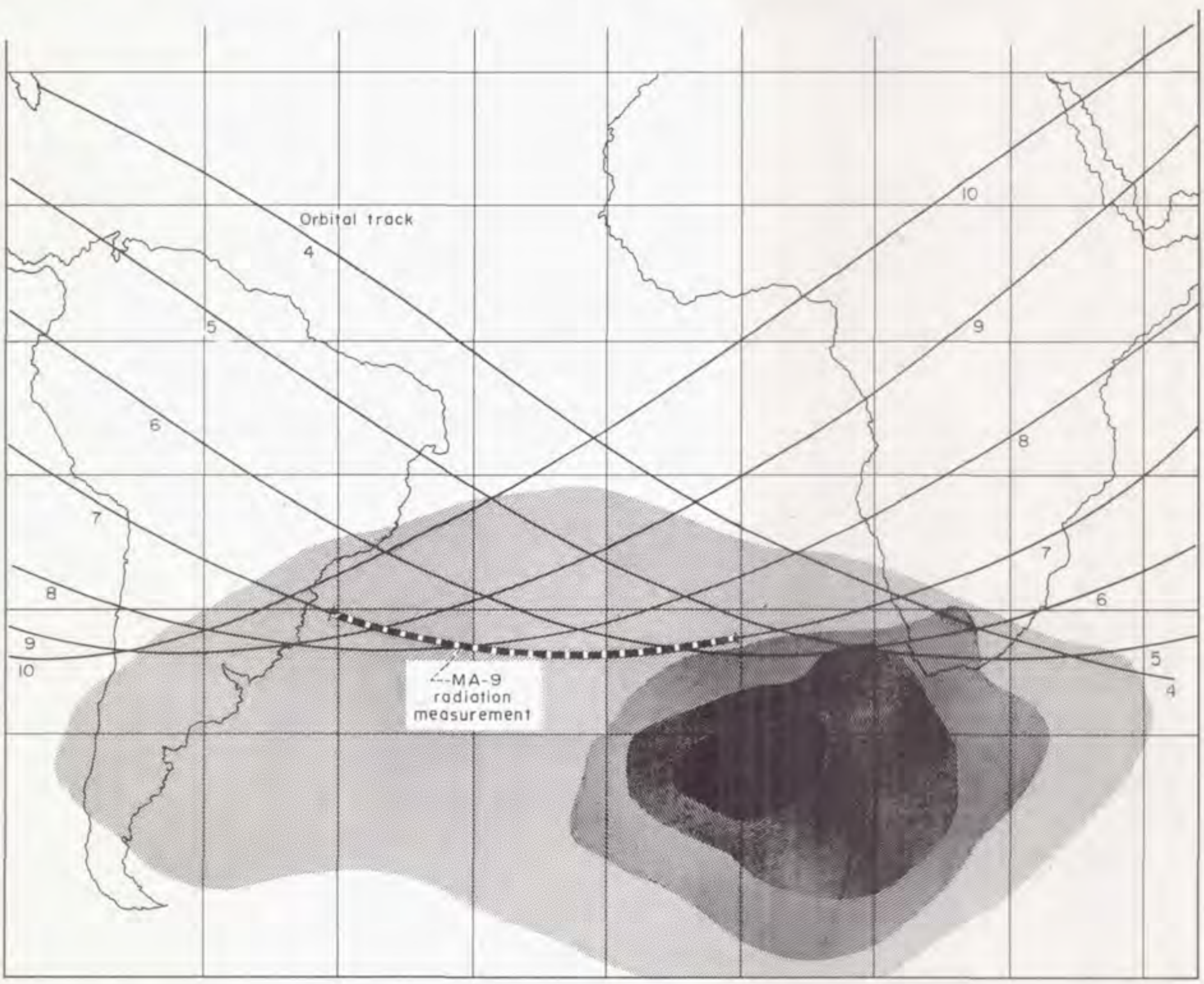

FIGURE 12-13.—Variation in predicted flux at 100 km in the anomaly of the earth's magnetic field over the South Atlantic on the MA-9 flight. Increased flux density shown by increase in amount of shading.

Film badges and thermoluminescent detectors used to monitor the electron dose to the astronaut were mounted on the helmet and on the chest and thigh of the astronaut's undergarments on each of the final two manned orbital flights. Evaluation of these detectors has shown that the radiation dosage received by the astronaut is quite low, less than that normally received by a man from cosmic radiation in 2 weeks on the surface of the earth.

Emulsion packs carried on the MA-8 and MA-9 flight at several locations inside the spacecraft as well as an ionization chamber mounted on the spacecraft hatch were used to assess the radiation level inside the spacecraft. Data obtained from these devices generally agreed with results derived from the film badges and showed a very low radiation level inside the spacecraft.

Radiation measurements were made on the MA-9 flight to map the electron flux in an anomaly of the earth's magnetic field occurring over the south Atlantic Ocean where the radiation levels are expected to reach a peak in the Mercury orbit. (See fig. 12-13.) Variation in between radiation intensity is indicated by the variation in shading in this region. Measurements were taken in this region on the seventh orbital pass as indicated by hatched region on this figure. Operational problems interfered to some extent with completing all of the scheduled measurements.

A package with two Geiger-Mueller tubes were mounted on the spacecraft retropackage as shown in figure 12-14 to measure these data. One tube was collimated to view along the spacecraft roll axis over a solid angle of approximately 0.8 steradian as illustrated in figure 12-14. The other tube viewed essentially a hemispherical area about a direction 40° below the roll axis.

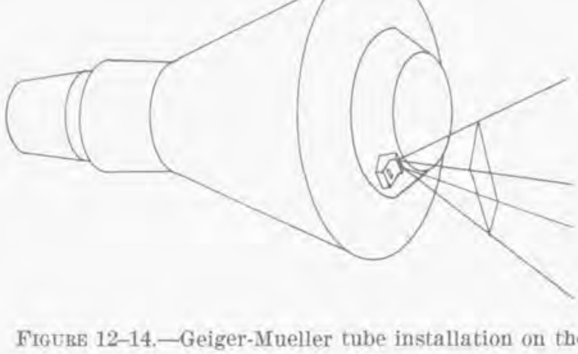

FIGURE 12-14.—Geiger-Mueller tube installation on the MA-9 spacecraft.

The uncollimated tube was shielded to reject all electrons having energy levels less than 2.5 mev to avoid saturation, and because the radiation level in the anomaly was much lower than anticipated the shielded tube was never energized sufficiently to record usable data. Usable data were recorded by the collimated tube.

Results obtained from these Gieger-Mueller tubes and emulsion package measurements from both the MA-8 and MA-9 missions, summarizing the decay of the artificial electron belt created by the July 1962 atomic explosion, are shown in figure 12-15. The solid curve defines the decay in percent of initial flux based on unpublished riometer data of Dr. Gordon Little of the National Bureau of Standards (NBS). The environmental measurements obtained on both the MA-8 and MA-9 flights are also identified

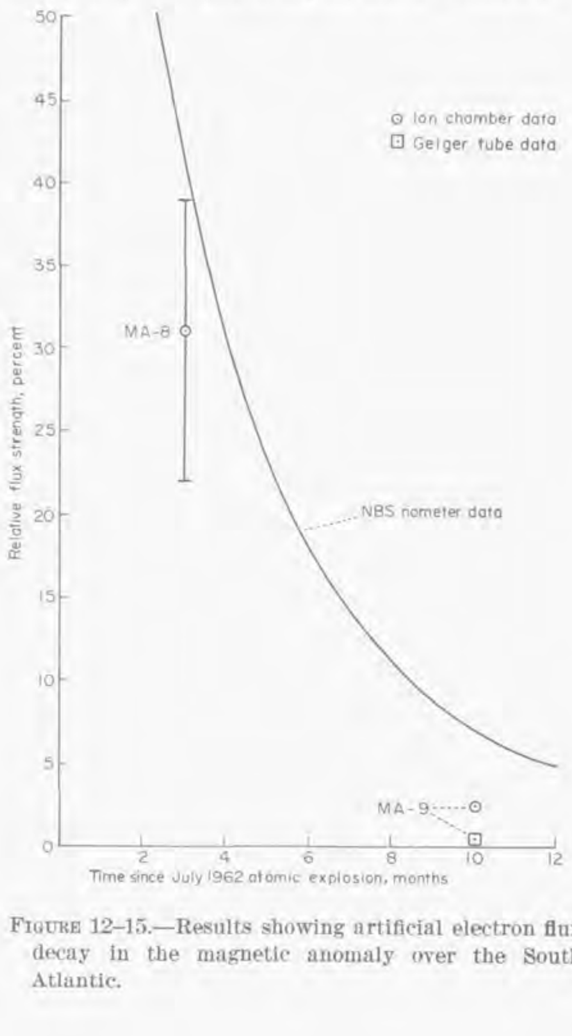

FIGURE 12-15.—Results showing artificial electron flux decay in the magnetic anomaly over the South Atlantic.

in the figure. The electron belt is shown to have decayed as predicted by several orders of magnitude during the time period between MA–8 and MA–9 flights, possibly because of atmospheric collisions or other processes.

Tethered Balloon Experiment

A 30-inch mylar inflatable sphere was packaged in the antenna canister of both the MA–7 (see ref. 1) and MA–9 Mercury spacecraft. These balloons were to be ejected, inflated, and towed at the end of a 100-foot nylon line through one orbital pass to measure the drag experienced by the balloon throughout the orbit. The measured drag could then be readily converted into air density over the Mercury altitude profile. In addition, it was hoped that the astronaut could obtain some sightings yielding visual data on objects in close proximity to the spacecraft.

The design, construction, and qualification of the equipment used on this experiment were carried out by the NASA Langley Research Center. The components of the equipment are shown in figure 12–16. The results of this experiment conducted during the MA–7 flight are contained in reference 1. Briefly summarized, the balloon was deployed satisfactorily but was only partially inflated; hence, little useful data were obtained on this flight.

By a thorough investigation of the MA–7 failure, it was concluded that the balloon failed to inflate because one of the seams connecting the many gores comprising the balloon skin pulled apart.

The experiment was believed to have been of sufficient value to be repeated on a later Mercury flight; therefore, new equipment was developed and qualified for the MA–9 flight. Careful control of balloon construction was maintained throughout the development program and numerous deployment and inflation tests were conducted by the Langley Research Center to insure the quality of the device. These tests were conducted with the flight equipment under conditions which closely simulated the space environment without a single failure. Numerous squib firings were made, without a single failure, to insure that either one or both of the squibs used to unlatch the cover of the canister would accomplish this task. The assembled unit was carefully checked after installation on the spacecraft and was found to be satisfactory. It was, therefore, believed that this experiment was well qualified for flight, but unfortunately the balloon failed to deploy in flight. Failure was attributed to some malfunction in the squib-firing circuit that released the hatch cover of the balloon canister. The exact cause of this malfunction could not be determined because the circuit was contained in the spacecraft antenna canister which is jettisoned prior to landing.

FIGURE 12–16.—Balloon canister assembly.

Miscellaneous Studies

Study of liquid behavior at zero gravity.—An experiment sponsored jointly by the NASA Lewis Research Center and the NASA Manned Spacecraft Center was developed to examine the behavior of fluids of known properties in a weightless state by using a given container configuration and was flown on the MA–7 mission (see ref. 1). Basically, this experiment was intended to provide data that would complement and extend work already carried out at the Lewis Research Center. Data obtained from this study were expected to provide information relating to the tankage and fuel transfer requirements on future space missions.

The results of this experiment are well defined in reference 1 and other NASA publications dealing with this subject. It need only be noted here that the limited results obtained on this experiment generally tended to verify past experimental and theoretical data obtained from laboratory studies.

Study of various ablative materials on a Mercury flight.—Several advanced ablative materials were flown on the cylindrical section of the MA–8 spacecraft to evaluate the thermal performance of each. These materials were

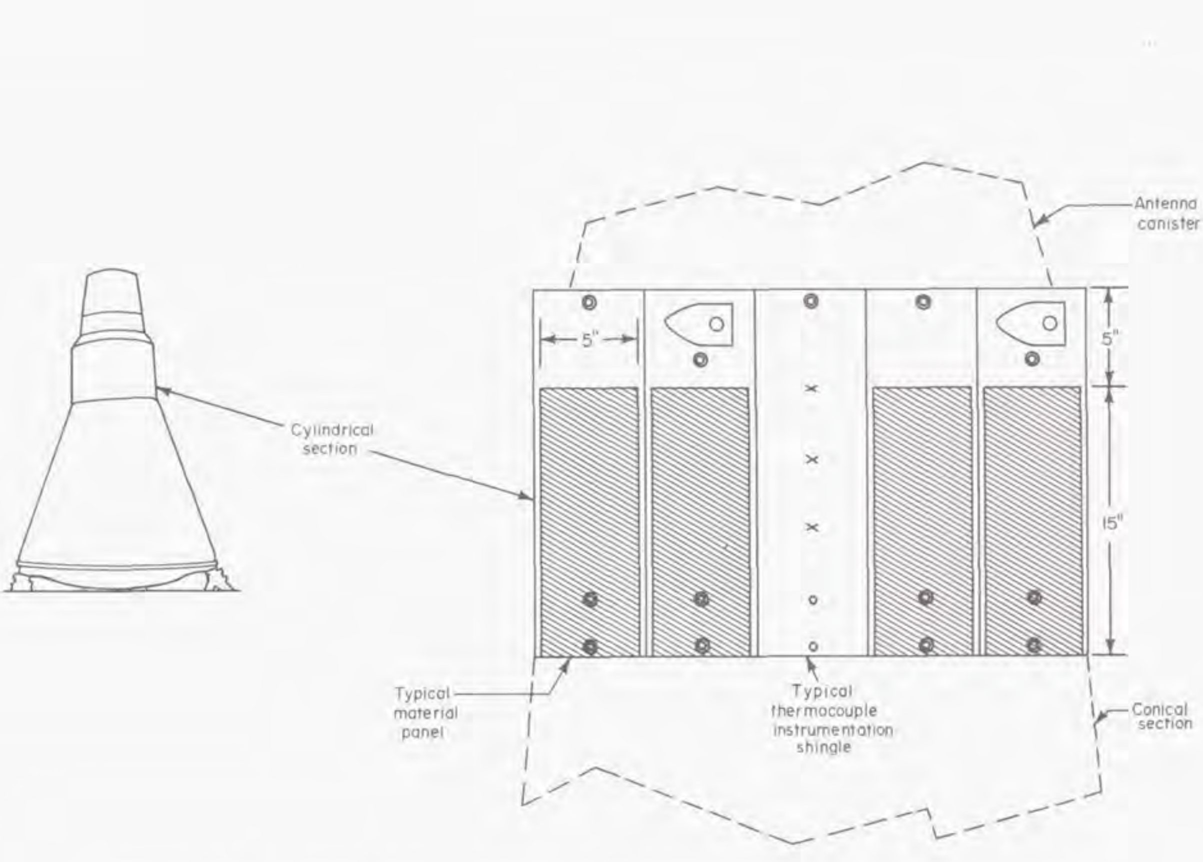

FIGURE 12-17.—Location of ablation panels on the Mercury spacecraft used for the MA-8 flight.

located as shown in figure 12-17. Each ablative panel was 15 inches long and 5 inches wide. Each sample was centered on a beryllium shingle and was attached to the shingle at the cone-cylinder junction of the spacecraft. The materials were bonded to each of these shingles, and temperature-sensitive paints were applied to the rear face of the shingles to assist in determining the temperature profiles present along the ablation panels during reentry. (See ref. 2.)

Upon completion of the MA-8 flight, each strip of ablative material was removed from the spacecraft and examined to determine char depth and temperature distribution and to examine the material for delaminations, pitting, and cracks.

It was not possible to compare the panels collectively because of significant circumferential variation in heating around the cylindrical section, probably caused by a spacecraft angle of attack of 2° during high heating. As expected, all samples showed an increasing thermal exposure and char depth with length aft (away from the blunt end) along the specimen. No material, regardless of the heat rate to which it was exposed, showed any marked superiority in performance over that of the other specimens although the elastomeric materials did prove superior to hard ablation materials in limiting the growth or delamination of intentional cutouts. Surface effects and imperfections noted during preflight ground testing were also evident during the postflight analysis, but to a lesser extent. However, the scaling effect when comparing the relatively large specimens flown with those tested in a ground facility has not been established.

Micrometeorite studies.—Examination was made of all the spacecraft flown on manned orbital flights during the Mercury Project for evidence of micrometeorite impact encountered in orbit. Macroscopic surveys were made of the beryllium shingles and the window of the MA-6, MA-7, and MA-8 spacecraft before and after flight in an effort to determine if any micrometeorite impacts could be detected. Microscopic

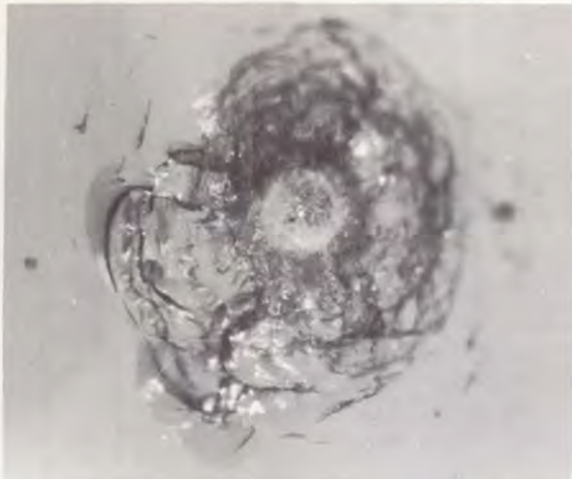

FIGURE 12–18.—Photograph of the surface pit on the window of the MA–9 spacecraft. X42, top and bottom lighted.

surveys were made of the areas in which any indications of impact were noted. As a result of these examinations, no evidence was found that could be construed to be a micrometeorite impact.

Microscopic mapping of the vycor window of the MA–9 spacecraft was performed before and after the mission. During the postflight survey, one small surface pit was detected on the outer surface of the MA–9 spacecraft window. A photograph of this pit is shown in figure 12–18. This surface pit has the circular shape, depth to width ratio, and general characteristics of a hypervelocity impact in basalt. Further analysis is in progress to ascertain whether or not the pit resulted from a micrometeorite impact or was caused by spacecraft debris encountered during reentry.

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13. FLIGHT DATA REPORTING

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Summary

During the progress of the Mercury Project an effective method evolved for the postflight data processing, analysis of systems performance, and timely reporting of the results of the analyses. This method was a compromise between the conflicting requirements of completeness, clarity, and technical accuracy on the one hand and an early publication date on the other. It was learned that there is a need for extensively planning the report preparation effort and establishing procedures for expediting data processing in order to provide engineering data rapidly and in readily usable forms. It was also learned that for a report to be effective, it must be factual, carefully written, and edited.

Introduction

The success of a complex technical endeavor, such as Project Mercury, depends to a great extent on the ability to analyze and report rapidly the very large amount of information which is generated. Rapid availability of information was essential to maintain the Mercury schedule, since the developments from any mission might need to be implemented for subsequent missions.

Extensive planning and scheduling was done to facilitate the acquisition and preparation of data. The flight data and information were examined to determine weaknesses and malfunctions in the performance of manufactured systems and human organizations, and to verify the proper performance of these systems and organizations. When these analyses had been made, they were summarized and a brief, accurate, and factual report was written so that the management of the program would have available all significant information to aid in making necessary decisions. This primary report of the results for each flight, the Postlaunch Memorandum Report, is discussed in detail in this paper.

This paper describes the techniques employed to process raw data into usable form, to obtain the overall analysis of mission results, and to report those results to management.

The processing of certain data, such as the trajectory information from the radar tracking network, and the numerous reports that were made by the spacecraft contractor and other supporting organizations after each mission, are not discussed in this paper.

Scope

Data Sources

The flight data with which this paper is primarily concerned were those data available from the spacecraft onboard tape recorders since these tapes contained the most complete data and were available for quick processing. The onboard tape included information pertaining to the operation of the spacecraft systems, the astronaut's physiological conditions, the pilot's voice communications, and other special measurements. A list of typical measurements is presented in table 13–I. Most of this information was also transmitted to the ground and recorded by range network stations, and some of the information was displayed in real time to monitoring personnel. These range-recorded data have often become critical to the analysis conducted after the flight, in addition to serving as a complement for the onboard recorded data. Since the spacecraft sank in deep water following the Mercury-Redstone 4 (MR–4) flight, the onboard-recorded data were not recovered, and the range-recorded data became the only source of information from this flight. In the Mercury-Atlas 9 (MA-9) mission, the tape supply of the onboard recorder was insufficient to provide continuous recording for the entire mission; therefore, the range-recorded data were used to supplement the onboard-recorded data.

Table 13-I.—List of Typical Recorded Flight Measurements

Flight accelerations in three axes
Physiological measurements
Body temperature
ECG
Blood pressure
Respiration rate and depth
Events (approximately 20)
Environmental control system
Oxygen supply pressures
Suit pressure and temperature
Cabin pressure and temperature
Static pressure
Heat exchanger temperatures
Oxygen and carbon dioxide partial pressures
Electrical system
Instrumentation reference voltages
Main, standby, and isolated bus voltages and current
Fans and ASCS bus a-c voltages
Inverter temperatures
Communications system
Command receiver signal strength
Command receiver on-off
Reaction control system
Automatic and manual fuel pressures
Fuel line and thruster temperatures
Stabilization and control system
Control stick positions
Spacecraft attitudes (gyros)
Spacecraft attitudes (horizon scanners)
Automatic system high and low thruster actuation
Spacecraft attitude rates
Onboard time
Time since launch
Time of retrosequence initiation
Time since retrorocket ignition
Structural heating
Heat shield temperatures
Retrorocket temperatures
Shingle temperatures
Experiments
Balloon drag
Radiation flux density

The pilot's comments recorded during the mission and in postflight debriefings were an important source of information. This information was used in many cases in defining the performance of the spacecraft or launch vehicle systems when the measured data were lacking or permitted ambiguous interpretations. Even more important, the pilot's debriefings and reports were the only source of information regarding many of his observations.

Additional sources of information during various flights were provided by a variety of cameras which were carried onboard the spacecraft and used to photograph the instrument panel, the astronaut, the view through the spacecraft window, and, for the unmanned Mercury-Redstone and Mercury-Atlas flights, the view field of the periscope.

Analysis

The analysis of the flight data began at the launch site during the flight and continued until the Postlaunch Memorandum Report (PLMR) was completed. The analysis of problems requiring study beyond the publication date of the PLMR was continued to completion, and the method of reporting the final results is discussed in the following section of this paper.

Reporting

The results and analyses for each mission were (or will be) presented in five formal NASA reports, which are listed in table 13-II.

The first of these reports, issued in the form of a telegram approximately 2 days after the end of the mission, gave a broad overall summary of mission results as they were known at that time. For most of the flights this report was issued within a day of the end of the mission in order to disseminate the available information as quickly as possible; however, for the MA-9 flight it was found that more time was needed to gather and summarize significant information, and as a result this telegram was issued 3 days after the end of the flight. This first report had a very limited distribution, going only to those organizations directly concerned with the mission.

The second of these reports, also issued in the form of a telegram approximately 6 to 10

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Table 13-II.—Mercury Postflight Reports

Type of Report	Approximate period to report completion, days[a]						Classification	Content
	MR-3	MR-4	MA-6	MA-7	MA-8	MA-9		
Telegram (preliminary)	1	1	1	1	1	3	Confidential	Broad overall summary of mission results as known at that time.
Telegram (Interim)	[b]	[b]	7	7	9	10	Confidential	Updated version of preliminary telegram describing status and problem areas.
Postlaunch Memorandum Report (PLMR)	11	10	11	14	19	26	Confidential	Contains all detailed spacecraft data and description of resolutions of problem areas or status of investigations of unresolved problems. This report contains 95 to 98 percent of all important information that would come from the mission.
Public Release[c]	30	30	44	80	90	130	Unclassified	Summary report of mission results for distribution to the public.
Technical Memorandum (TM) or Working Paper (WP)	41[d]	60[d]	[e]	[e]	[e]	[e]	Confidential	Official presentation of detailed analysis of mission. This report is an updated version of PLMR with latest information and in a format suitable for distribution to the technical community.

[a] Elapsed calendar days from end of mission to completion of final review and editing.
[b] Interim telegrams were not used for MR-3, and MR-4.
[c] See references 1 to 5 and this document.
[d] WP.
[e] TM, in preparation.

days after the end of the mission for the more recent manned missions, had a dual purpose. The first purpose was to show any significant changes to the information contained in the first telegram, and the second purpose was to describe the status of the analysis of the mission results at that time with emphasis on any problem areas. Any problems encountered during the mission were of particular interest since such problems might have a direct effect on the schedule or the prepartions for the next mission; as a consequence, little time was spent in this second telegram discussing systems that had exhibited satisfactory performance. This telegram had the same limited distribution as the first telegram.

The third type of report, the PLMR, was bound into one or more volumes depending on the amount of information contained. This report was completed in a period of 10 to 26 days, and contained 90 to 95 percent of the significant information that would come from the flight. The amount of time needed to complete the report depended primarily on the amount of data collected during the mission. This report was the most important of the postflight reports in terms of its usefulness to the program management in the timely prosecution of the program. This report had a relatively wide distribution within NASA.

The fourth of these reports was a summary of the important highlights of the mission, with classified information deleted to permit release to the public (see refs. 1 to 5).

The fifth of these reports was issued as a working paper (WP) for the Mercury-Redstone manned flights. The WP was used for rapid dissemination of information, and the format and quality of presentation was not suitable for general distribution outside NASA. For the manned Mercury-Atlas flights the fifth report will be issued as a Technical Memorandum (TM), suitable for distribution outside NASA. These TM's (one for each mission) will be distributed within the scientific community after publication. Both the WP's and TM's contained, or will contain, the significant information published in the PLMR's plus any additional results that became available after publication of the PLMR.

The remainder of this paper will be limited to discussion of the preflight and postflight activities related to the PLMR.

Report Planning and Organization

Planning

In the early days of the Mercury Project, the planning and organization for postflight analysis and reporting of mission results did not need to be very elaborate, and these plans were made known to the participants on an informal verbal basis. A NASA Project Engineer was responsible for all aspects of a particular flight.

For the first few flights, such as the pad-abort flight and early Little Joe flights, the flight time was measured in minutes, with a relatively small amount of data collected. The analysis and reporting effort, though intensive, was correspondingly small in terms of the number of people involved and the total amount of time spent when compared to the later orbital flights. All of this analysis and report preparation was done at the launch site at Wallops Island, Virginia.

The plans for organizing the analysis and reporting efforts continued on an informal basis through the Little Joe phase of the Mercury Project and extended into the Redstone and Atlas phases. As the flight time, amount of data, and number and complexity of the systems to be analyzed increased, and the number of personnel grew, it became difficult and then virtually impossible to disseminate by verbal discussions and telephone calls the work assignments, schedules, changes in plans, et cetera, to the participating personnel. To circumvent these difficulties, informal memorandums came into increasing use. As a result, prior to the MA–5 flight a data processing, analysis, and reporting schedule was prepared for the first time, and was in the form of a five-page memorandum. This memorandum, which was distributed to all participating personnel and to the necessary organizations, outlined the schedule for data processing and noted when and where various types of data would be available, the assignment of individuals to various sections of the PLMR, and the detailed schedule for the writing and editing of the various sections of the report. This procedure was found to be effective, and the memorandum grew steadily in scope and detail as the need for additional information became evident through the subsequent orbital missions. For the MA–9 mission this memorandum had grown to 31 pages. It contained such things as personnel assignments, data-availability and report-preparation schedules, schedule of the pilot's postflight activities including debriefings, locations of various facilities where people would be working on data analysis and report preparation, and a definition of the responsibilities and work scope of the organizational elements participating.

Organization

The organization of the effort of the analysis and reporting went through a continuing evolution as the Mercury flight program proceeded, up through the PLMR for the MA–5 flight. By this time, a method of organizing the effort had evolved which was satisfactory in producing in a short time a reasonably complete and factual report, written with sufficient clarity.

As in the case of the dissemination of the plans, the organization of the effort for analysis and reporting was relatively small and informal for the first few flights of the Mercury Project. The effort was headed by the NASA Project Engineer for that particular flight, who largely determined the scope of the analysis effort and edited the various sections of the PLMR.

During a part of the early phase of the Mercury-Atlas and Mercury-Redstone flights, as the analysis and reporting became more complex because of the increasing complexity of the flights, additional NASA organizational elements became more deeply involved in the analysis and reporting. Because of this, there was a movement to create an editorial board consisting of one member from three or four of the major organizational elements involved, with each member having equal responsibility and authority. One of the early Mercury-Atlas reports was prepared under the direction of a three-man editorial board but this arrangement was quickly found to be unworkable mainly from the standpoint of settling policy and procedural questions that inevitably arose during each analysis and reporting effort. The method of managing this analysis and reporting effort reverted for the next flight to an arrangement with a single organization responsible for the effort. This arrangement was kept throughout the remainder of the Mercury Project.

Prior to the first manned Mercury–Redstone (MR–3) flight, the increasing responsibilities for data analysis and reporting had resulted in the assignment of key technical personnel to duties on editorial boards or Senior Editorial Committees headed in each case by the appropriate project engineer. The function of this editorial board was to actively participate in the planning and monitoring of postflight systems testing, data analysis, and editing of sections of the report.

The membership of the editorial board during the early flights changed from flight to flight, but usually one or more members were the same for at least two flights in order to provide continuity and some consistency of effort. The PLMR editorial board for MA–5 and a majority of the systems-performance analysts were for the most part the same people who had served in those capacities for the PLMR for MA–4, and these personnel assignments remained relatively constant for the remainder of the Mercury Project.

As an example of the organizational arrangement of the reporting team, figure 13–1 shows

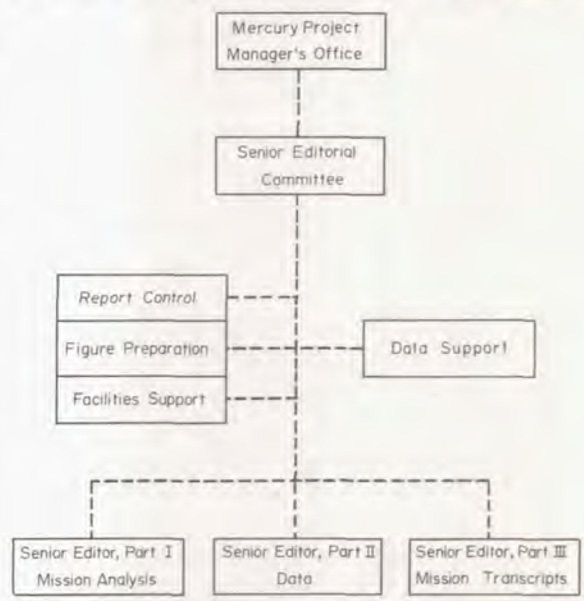

FIGURE 13–1.—Functional relationships for editorial and support personnel.

the major elements of the task organization for the MA–9 report. The Senior Editorial Committee members and the supporting members were drawn from various elements of the NASA Manned Spacecraft Center, and for the period of the PLMR preparation the members reported functionally to the Chairman of the Senior Editorial Committee. As each member's part of the task was completed, he returned to his parent organization.

The functions of the elements shown in figure 13–1 are described briefly below:

The Manager's office provided the overall directions for the postflight test program. In addition, the Manager's office reviewed the PLMR for technical accuracy, completeness, and policy, immediately prior to printing.

The Senior Editorial Committee comprised the senior editors of the separate parts of the report and the MA–9 backup pilot and these persons directed and coordinated the detailed efforts of postflight testing, analysis, and reporting. The members of this committee also performed a continuous review and editing of the individual sections of the report in an effort to maintain continuity and technical agreement among the sections of the report. The Chairman directed the planning of the overall reporting effort prior to flight, provided intermediate and final editorial reviews of major portions of the report, acted as official representative of the Manager's office, and coordinated the report preparation effort continually through the Senior Editorial Committee.

The Senior Editor of Part I, *Mission Analysis*, gave overall direction to a team of subeditors and system specialists who performed postflight analyses, and tests required to explain inflight systems malfunctions. These sub-editors participated as required with the system specialists in the analysis of the data from the mission and the preparation of this part of the report which summarized the overall results of the mission.

The Senior Editor of Part II, *Data*, gathered data-processing requirements prior to flight, planned and provided data processing, presentation, and distribution. In addition, he directed the analysis of data quality and was responsible for the preparation of the flight data section of report.

The Senior Editor of Part III, *Mission Transcripts*, managed the preparation and editing of the various voice transcripts for both flight communications and post flight debriefings, and planned and conducted the postflight scientific debriefing.

The functional organization shown in figure 13–1 was used in the overall management of the mission analysis and reporting. A more detailed breakdown of the functional organization of the Part I effort is shown in figure 13–2 to illustrate the depth of organizational detail needed. The personnel for each assignment were drawn from throughout the Manned Spacecraft Center, with assistance from other NASA centers and contractors as needed.

The need for a well-planned organization can best be illustrated by noting that for the MA–9 PLMR analysis and reporting effort, contributions were made by personnel from fourteen NASA organizations, four contractor major organizational elements, numerous organizations of the Department of Defense, the U.S. Weather Bureau, and several colleges and universities. During this analysis and reporting period, approximately 20,000 man-hours were spent by approximately 130 people in producing a 1,000-page 3-volume report in 26 days.

Analysis of Mission Results

Data Processing

To meet the needs for processed data to be used for analysis and reporting purposes in the shortest possible time, several decisions were made as experience was acquired. The maximum use would be made of electronic data processing to provide data in the most readily usable form. Where necessary, manual effort would be used, in addition, to provide the data in a format which would require the least additional manipulation on the part of the analyst. In processing the data the initial format would be made as nearly as possible of a quality that would be suitable for final report use. In this way the data would be prepared for its various types of usage by photographic reproduction rather than by recomputing, rescaling, and replotting. The requirements of the analysts would be determined as far as possible well in advance of the generation of the data in order that the parameter arrangements, scale selection, and priority might be determined. As

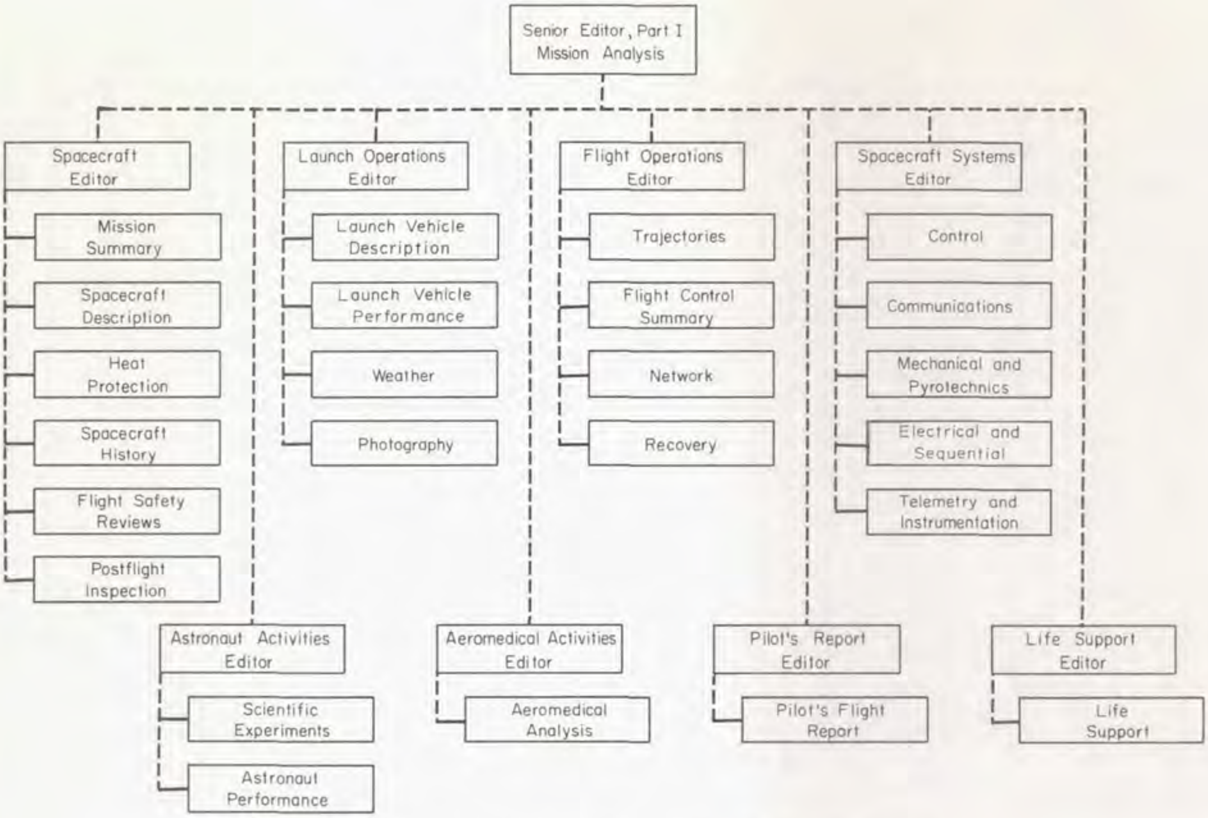

FIGURE 13-2.—Typical functional organization for Part I of report.

successive flights were made, formats were standardized to enable comparison between the data from various flights, thus providing an additional constraint.

When the electronic data-processing method became operational, a decision was made to process all applicable data during one effort for each flight. To permit parallel processing, several copies of the onboard tape were prepared. If the processing results were to be accurate, the tape copying had to be carefully checked. To accomplish this, oscillographic records were prepared from the master and tape copies. These oscillographic records were visually compared. If visual inspection indicated any differences, the records were compared by superimposing records over a back-lighted glass plate. If there were any significant differences between the records, the tape copy was rejected.

The automatic data-processing capabilities were not easily obtained. Data reduction processes may introduce errors at many points in the system. The accuracies of the basic spacecraft data system were sufficiently high to require more care in the reduction of the data than was the general practice. Utilization of experiences gained from the preceding flights were required to obtain the product quality and processing efficiency attained on MA-9. The Mercury experiences have indicated that significant improvements in quality and efficiency can still be attained.

The initial effort to use automatic processing methods was begun with the off-the-pad abort and Little Joe tests. In this effort, time-history plots were prepared from telemetered data by using analog plotting methods. The differences between the oscillographic-type records and the analog plots were that the time axis was compressed and engineering units could be read from the analog plots. The compression of the time axis accentuated the scatter in the data, however, and the processing methods themselves added some additional scatter. As a result, the electronically processed data lacked the desired accuracy. In these cases, the analysts continued to use the oscillographic recordings as a primary source of data.

To improve the quality of the processed data, various techniques of reducing scatter (filtering) were applied and some of the plotted data were smoothed by line fairing. The requirements for the postflight analysis were still not satisfied by the electronically processed data, since vital information might still be lost as a result of data filtering or line fairing. Nevertheless, it was recognized that here was a method which provided all of the flight data in a standard format and in a compact form suitable at least for indicating major trends.

The use of digital computers for the data processing increased as the Mercury Project continued. At first the computer-processed data were used for checking analog plots and later some of the data were plotted from computer-prepared cards by using a small card-fed digital plotter. The data obtained from the digital plotter were hand faired to provide a trace comparable to the analog processed data.

The greatest "bottleneck' 'encountered in data preparation was in the plotting of data. Initially, one analog plotter was used in preparing the Mercury data. Only one parameter could be plotted at a time and the time to plot was the same as real time. At the time of the MA–5 flight, four analog plotters were in use and they were operated at a speed of eight times real time.

Because of the difficulty in making corrections to the analog plots when graph paper was used, it was decided to plot on a clear plastic film. This innovation speeded the plotting process by making it possible to erase an error rather than replot several parameters on a new page, and by providing a means for superimposing analog plotted data onto digitally plotted data for related parameters. The plastic film was also less affected by temperature and humidity changes than was graph paper.

It was not until the MA–6 mission that digital computers and digital plotters became the primary processing tools. Prior to this mission, the computer was used to prepare tabulations of data in engineering units, and some digital plots were prepared. But now a faster general purpose computer and a magnetic-tape-fed plotter were available. It became the exception rather than the rule to use analog plotters. With these faster tools available, it was practical to sample the data and it was much easier to apply nonlinear calibrations. By this time the electronically processed data had become acceptable, since comparisons of both methods had shown them to be equally accurate.

Also by this time most of the data requirements had become well established through discussion with systems analysts. These requirements included a definition of the parameters of interest, their grouping for analytical purposes, the time periods of concern, the plotting scales, and the priority of processing. Thus by the time of the first manned orbital flight the basic equipment, methods, and standards were established. Further improvements were made but these were improvements in methods rather than equipment. The most important of these improvements were:

(1) The plotting density was reduced, thus speeding up the plotting and improving the appearance of the plot. This required more thorough checking to insure against the loss of data during transients. To overcome this fault a variable plotting density was used; that is, each data point was compared with the previous data point. If the difference was more than a predetermined amount, both the previous point and the present point were plotted. If the difference was less than the predetermined amount, a point was plotted at fixed intervals of time.

(2) Instead of rewinding a plotter tape to plot a second parameter on a page, time was saved by plotting the second parameter in reverse.

(3) Special photographic techniques were used to minimize replotting. Analysis plots, normally made with expanded horizontal scales for detailed work, were photographically reduced in the horizontal axis without reduction in the vertical axis. Thus working plots were compressed in length for use in the reports without it being necessary to replot.

(4) A developmental program was initiated to permit the determination of heart rate by digital means. Such a method became a necessity on the longer flights in order to obtain a complete time history of heart rate. The method developed provided the time between beats so that an average over any selected period of time could be obtained. Statistical treatment of these data was thus made possible.

(5) Much valuable information was voice-recorded during flight by the astronaut but its value was to a great extent dependent upon having an accurate knowledge of the time a statement was made. Early methods required that a typed transcript of the voice record be timed with the use of a stopwatch and the voice tape; this method was adequate for the short-duration flights. For the three-orbital manned flights, timing was accomplished by use of the typed transcript and an oscillograph record containing the voice patterns and time from lift-off in 1-second intervals. By simultaneously relating the voice transcript to the voice patterns while listening to the voice tape, an accurate time for each communication was determined. For the longer 6-pass and 22-pass orbital flights, a method was developed to automate this process to some extent. A magnetic tape recording of the voice, with spacecraft time recorded on a second track, was played while an operator followed the typewritten text. At the first word of each communication in the text, the operator pressed a switch to compute and record the time. This process permitted the rapid preparation of a complete and accurately timed transcript of all of the pilot's voice communications.

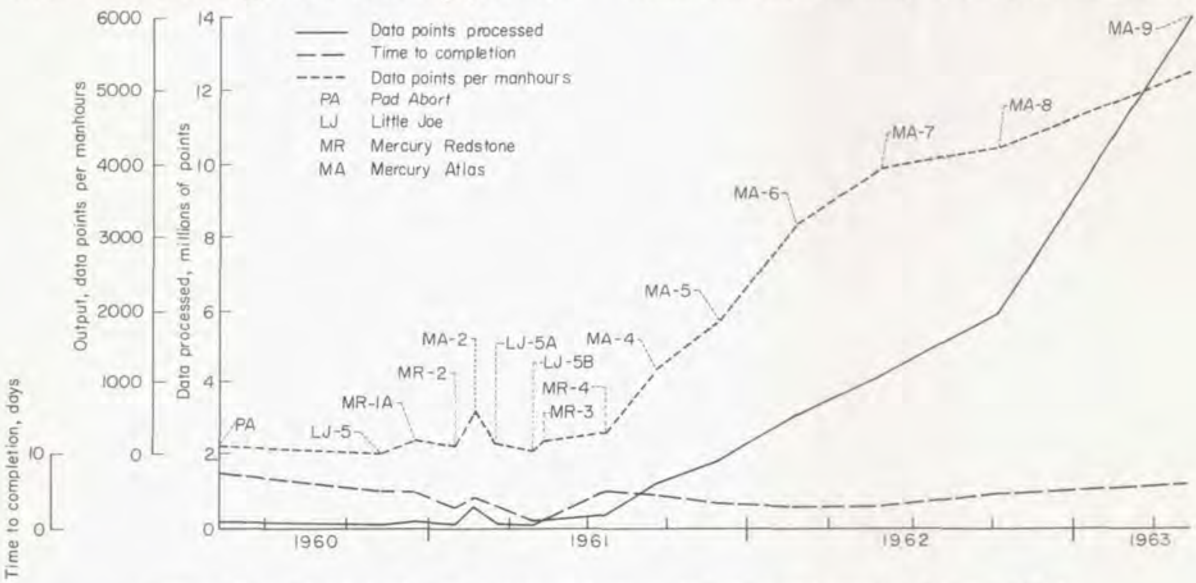

FIGURE 13-3.—Number of data points and processing time and rate for Mercury flights.

Figure 13-3 provides some statistics related to data processing for each flight. As may be noted, the number of data points processed increased rapidly for the longer duration flights; for example, 14 million data points were processed for MA-9. However, the total processing time was held nearly constant at 5 days as the productivity of manpower increased and procedures were improved. Figure 13-4 shows a comparison of the time required for manual processing as compared with semiautomatic and automatic data processing for a given sample of data.

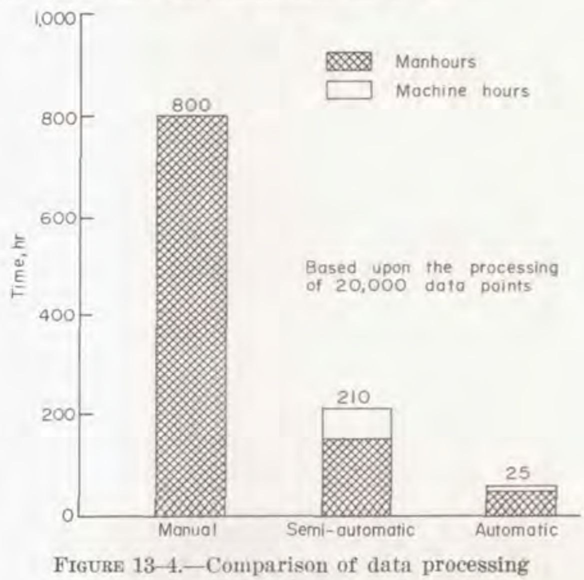

FIGURE 13-4.—Comparison of data processing techniques.

Systems Performance Analysis

Most of the analysis of the Mercury systems' performance was made either at Wallops Island, Virginia, or Cape Canaveral, Florida, by NASA and contractor personnel who were responsible for the spacecraft preflight preparations and checkout and who were familiar with these systems. The majority of the analysts had extensive experience in appropriate specialty fields.

As discussed in the Data Processing section of this paper, the major portion of the analysis of the early flights in the Mercury Project was made by using oscillograph records and hand-processing only those portions of the records that seemed to be significant. This hand-processing was time-consuming and several days were required to obtain an appreciable amount of data in the form of engineering units plotted against time. The conversion to electronic data processing was a most important factor during the later missions in permitting a rapid assessment of the mission results; without this electronic data processing, an incomplete analysis would have resulted if the same flight schedule had been maintained.

Toward the end of the Mercury Project a few data-comparison plots were prepared by using the electronically processed data. The purpose of such plots was to display time histories of the data for a particular system in a manner to allow very rapid comparison of the nature of the data on previous missions, showing at a glance the normal scatter and variations for both proper and improper system performance. The very limited amount of data prepared in this comparison-plot form was found to be an extremely useful tool for the analysts, the editors, and technical management personnel.

During the analysis and reporting period of the earlier flights, various types of work weeks were tried. The maximum number of hours worked by individuals was limited to 60 except in unusual circumstances. Work days ranging from 8 hours to 12 hours each, in combination with 5-day to 7-day work weeks, were utilized at various times. Experience showed that a schedule of 10 hours a day, 6 days a week, was a good arrangement to accommodate both the schedule and the participants' non-work-con nected responsibilities.

In the analysis of the data, it was found that mission-oriented technical personnel were needed to supervise and direct the analysis and ensure that the overall effort would be integrated and fully coordinated. Few of the spacecraft systems could be analyzed as to their performance without considering the performance of other systems and the particular phase of the mission in question. For example, the temperature of the pilot's pressure suit was directly controlled by the operation of the suit heat exchanger; however, there was an indirect effect resulting from the temperatures in the spacecraft cabin, which in turn were affected by the operation of the cabin heat exchanger, the amount of electrical power being used (heat generation), and whether or not the spacecraft was in the sunlight or in the earth's shadow. Thus an analysis of the suit temperature could not be made without considering possible effects from these secondary sources of thermal disturbance.

Postflight Tests

It was extremely important that immediate action be taken to determine the causes of any system malfunction or failure and the corrective action to be taken, since this information was necessary in order to support subsequent missions.

A person or group was assigned to determine the reason for the malfunction, and these investigations often became quite detailed and time-consuming. It was found to be necessary to require, whenever practical, that the malfunction be repeated with the same or an identical piece of equipment in laboratory tests to demonstrate that the cause of the malfunction was fully understood. In addition, when the flight equipment had been modified to preclude future malfunctions of that type, it was again demonstrated in ground tests with the simulated inflight environment that the modification would do its intended job.

An example of postflight testing that could not be accommodated to the above philosophy of duplication on the ground of inflight malfunction was occasioned by the MA-1 inflight structural failure. It was impossible to duplicate this failure in ground testing, since the inflight loads spectrum resulting from vibration, acceleration, aerodynamic drag, unsteady airflow, and noise could not be simultaneously applied in ground tests. The postflight investigation was therefore centered around tests on the structure of the front end of the launch vehicle, and on the adapter between the spacecraft and the launch vehicle. These tests, and a concurrent analytical investigation, did not conclusively define the exact cause of the failure but did show that strengthening the front end of the launch vehicle and stiffening the adapter would be sufficient to prevent a similar failure. These changes were incorporated in the MA–2 mission, and the flight demonstrated that the modifications were satisfactory.

Report Preparation

The preparation of the PLMR actually began just prior to the mission when some sections of the report that dealt with preflight activities were written. The main body of the report containing the sections of technical significance was generated during approximately the last 5 to 10 days prior to issuance of the report. During this time, the rough drafts were prepared and examined for accuracy, completeness, and absence of conjecture, by appropriate members of the report editorial staff.

As in the case of data analysis, it was found that mission-oriented technical personnel were indispensable in performing the editing functions. The editors were technically experienced personnel and most had degrees in appropriate specialized fields of study. They were temporarily relieved of their various technical duties in their organizations to serve as editors. There was never any attempt to use non-technical people as editors of technical parts of the PLMR, since the nature of the editing task was such that the use of technical personnel in this function was mandatory .

The experiences in the PLMR reporting indicate that three main factors contributed heavily to the rapid completion of the reporting phase:

(a) All reporting participants were relieved as completely as possible of their day-to-day responsibilities so that they could devote full time to the reporting task. In addition, when possible they were physically relocated to a place away from their usual duty locations in order to minimize distraction by non-reporting duties.

(b) A steady and intensive work week schedule was utilized, consisting of approximately 10 hours per day, 6 days per week.

(c) The editors exercised close and constant supervision of reporting personnel in their tasks of writing the sections of the report, with emphasis on the need for completeness, clarity, accuracy, and absence of conjecture or speculation.

It was quite difficult, of course, to separate key technical personnel completely from day-to-day duties, since these duties needed their continuous attention. However, it had to be done to a large extent, or the postflight analysis for a mission would have proceeded at a relatively slow pace and the program schedule could have suffered. The steady and intensive work schedule of 10 hours per day and 6 days per week, necessary to meet the analysis and reporting schedule, was maintained for two to three weeks on occasion without any apparent ill effects on the work output.

As the reporting of the Mercury mission results progressed from flight to flight it became increasingly clear that a strong editorial policy would have to be followed in order to insure that the PLMR's would be effective. One reason why this strong editor policy was necessary was that quite often it was necessary to dicuss different facets of a subject in different sections of the report, with the sections being prepared by different authors; a strong editorial hand was needed in such cases to make sure that the various discussions were consistent with each other and with the facts. Another reason was that the various sections of the report needed to have a reasonable consistency in the format, and amount of summary material and depth of discussion relating to the systems' performance and their effect on the overall mission results; a strong editorial hand was again needed to implement and enforce these requirements.

From experience it was thought that a single person should perform the final editing task; however, as the reports became larger and more complex with the longer flights, it also became apparent that one person could not edit all sections of the report in the short time available. The compromise used in the reports of the last few flights was that one person (the Chairman of the Senior Editorial Committee) edited the technically important sections of the report, and the supporting sections of the report were edited by an editorial assistant or one of the members of the Senior Editorial Committee. This arrangement worked quite satisfactorily, although the work load on the Chairman was very great, particularly during the few days just prior to final typing and printing of the PLMR.

During the period just prior to printing the report, the senior editorial committee reviewed and edited all sections of the report. This review was accomplished to insure that the various sections were compatible in the discussions and treatment of common subject matter. The report was then reviewed in detail by the staff of the Project Managers Office for accuracy and technical emphasis. It was found that the various reviews and editings of the sections of the report and the report as a whole were necessary, although publication of the report was delayed somewhat by this process. Experience showed that the most useful report resulted from a compromise between the conflicting requirements of completeness, clarity, and technical accuracy on the one hand and an early publication date on the other. It was also found that a report was ineffective if it was not complete, clear, and factual.

Conclusions

As the Mercury Project progressed from the relatively simple flights to the more lengthy orbital missions, the postflight data processing, mission analysis, and reporting, went through a steady evolutionary process. A number of lessons were learned and are summarized as follows:

Data Processing

(1) Electronic data-processing equipment can accurately process quantities of data that are impossible to accomplish in the same time with manual methods.

(2) Analysis requirements must be determined in advance and data processing must be planned to supply these needs.

Analysis

(1) Mission-oriented technical supervisors are needed to supervise the analysis in order to insure integration and coordination of the effort.

(2) Extensive time-history data are essential to the analysis of spacecraft system performance.

Reporting

(1) A report should have all of its technically important sections edited carefully by one person if the report is to be of maximum usefulness.

(2) A report, to be useful, must be a compromise between the conflicting requirements of completeness, clarity, and technical accuracy on the one hand and an early publication date on the other. Such a report is ineffective if it is published quickly but is not complete, clear, and factual.

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14. SPACECRAFT PREFLIGHT PREPARATION

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Summary

This paper presents the evolution of test philosophies and procedures used in preflight checkout of Mercury spacecraft at Cape Canaveral, Fla. The impact on preflight operations of tight schedules, mission changes, discrepant performance of ground and spacecraft equipment, and new information gained from ground testing and flight are discussed. Included in this discussion are numerous examples to illustrate the kinds of problems that were encountered and their effects on preflight operations. In addition, this paper presents the lessons learned in preflight preparation and checkout over the 4-year span of the program.

Test operations personnel learned that only formalized testing with all inter-dependent systems operating simultaneously would provide a flight-ready spacecraft. Tests emphasized astronaut safety and included participation of the astronaut as often as possible. Few substitutes for actual flight equipment were permitted during spacecraft assembly, rigging, and testing. Such matters of quality control as cleanliness, component limited-shelf and limited-operational life, and equipment failure, influenced the test philosophy. Validation and troubleshooting of spacecraft systems revealed the need for many more test points to be provided for in-place testing. Repair and bench testing of failed equipment reemphasized that the equipment needed to be made more accessible for removal and reinstallation. Rapid feedback of test results and failure analyses to design and manufacturing personnel was necessary and led to the increase of inspection and on-the-spot failure analysis. Digital checkout equipment was developed and proved that digital computer systems were superior to analog methods in providing information and control to test engineers.

Introduction

Preflight preparation and checkout experience began at Cape Canaveral in 1959 with the Big Joe boilerplate spacecraft. This spacecraft was the first to be launched in Project Mercury. The Big Joe spacecraft was designed and built by the National Aeronautics and Space Administration (NASA) to determine the aerodynamic and heating characteristics of the Mercury shape.

In the following year, a variety of test and checkout equipment and the first production spacecraft arrived at Cape Canaveral. During the next 2 years, the techniques and procedures for preparation and checkout of spacecraft for manned flight were developed and refined.

By the time of the early manned flights, these preparations and procedures had been proved through operational experience. A formal but flexible operations routine had evolved, incorporating close coordination with design, mission management, manufacturing, and quality control groups. For example, components were inspected and tested before installation; and work to be done on the spacecraft was described in detailed work sheets. This procedure controlled the disturbance of spacecraft components and assured that the status of the spacecraft configuration was known at all times. Detailed test procedures had been written, and step-by-step test results recorded. Checklists had been established to guide spacecraft assembly and configuration before each test.

Spacecraft Assembly

In preparation for spacecraft testing, component mockups and simulators were constructed and used as substitutes for components that were fragile, dangerous to handle, or in short supply. However, it was found that these mockups and simulators could not be constructed accurately within a reasonable cost and time schedule, and therefore they proved to be of marginal value.

For example, wooden pyrotechnics mockups did not properly establish cable fits, and substitute escape towers did not establish clearances. This resulted in delays and difficult working conditions when modifications had to be made while at the launch pad. Other simulators did not work because of the high packaging density and multiple interfaces inside the Mercury spacecraft.

Ultimately, it was deemed necessary to fit-check all flight items simultaneously, and, where substitutes had to be used, exact flight types were required. Because better facilities for mechanical modifications were available at the point of manufacture, experience indicated that complete assembly of the spacecraft should be accomplished at the factory; this was true even for those components which had to be removed for shipment.

Test Preparation

General

In the early planning stages of Project Mercury, it was thought possible to deliver flight-ready spacecraft to Cape Canaveral, conduct a single, total spacecraft test in the hangar, and launch very soon thereafter. However, it was demonstrated that more preflight preparation was required at the launch site and formal procedures evolved from experience.

Before spacecraft testing was begun, very careful preparations were made. Each step had to be formalized through configuration documents, checklists, and test procedures. The ground-support equipment was tested to prove its readiness. Test complexes were checked for compatibility with the particular spacecraft. The spacecraft was put into test position and its configuration conformance to test plans was established; of particular concern were proper cabling and plumbing of all systems. Then the spacecraft was connected to the complex and testing was begun.

Various efforts were made to accelerate preparation of the spacecraft; for example, when the spacecraft was idle, as during periods when data were being analyzed, efforts were made to continue work on the apparently-unaffected systems. However, it was found that this work would adversely affect the test setup and thereby the spacecraft preparation schedule. Mercury components were so closely packed that there was little room for a man to work inside the spacecraft without accidentally damaging such things as cables, tubing, connectors, or cameras. Generally, it was ruled that only test-associated work would be done on a spacecraft while it was being tested.

Early in the program before systems interrelationships had been completely analyzed, some equipment was damaged when tests of one system influenced another. For example, reaction control system (RCS) valves in a dry state overheated when activated by the automatic stabilization and control system (ASCS).

As test crews and planners gained experience in attending to these many details, test plans became more reliable. Offsetting this experience were the number of modifications made to the spacecraft to accommodate mission flexibility and safety and to improve systems performance. As a result, plans and procedures were constantly changing.

Test Philosophy and Procedure

Gradually, a set of guidelines evolved which were used as the basis for all testing. Two principles served as foundations for checkout procedures throughout this evolution. The safety of the astronaut was considered foremost, and secondly, all philosophy was directed toward a test plan which would guarantee a flightworthy spacecraft at lift-off. These were expanded to six principles which were applied to all spacecraft tests.

Building block approach to testing.—The operational status of each system and each component in the system was functionally verified before that system was operated concurrently or in conjunction with another system with which it might have an interface.

End-to-end testing.—During testing, the initiating function and end function took place sequentially as would actually occur in flight. The use of artificial stimuli was minimized. Implementation of this guideline was most evident in the hangar-simulated flight test.

Isolation and functional verification of all redundancies.—All redundant signal paths were isolated and functionally proven by end-to-end tests. These included redundancies between the spacecraft and launch vehicle and redundancies within the launch complex.

Interface testing and verification.—There were two basic interfaces in Mercury: The spacecraft to launch vehicle and the space vehicle to ground complex. These interfaces included RF, hardwire, and mechanical features. Tests involving these interfaces were consistent with the test philosophy previously discussed, namely, end-to-end testing and testing of all redundancies.

Mission profile simulation.—Simulated mission tests, which included the spacecraft, launch vehicle, and ground complex, were designed to approach functionally actual mission conditions as nearly as possible. This procedure included simulating real-time functions through orbit insertion. The astronaut was aboard for these simulations and functioned as he would during the actual flight. These simulated flights were made both in Hangar S and at the launch pad. Figure 14–1 shows preparations being made for a simulated flight test of a spacecraft in the altitude chamber.

FIGURE 14–1.—Spacecraft being prepared for simulated mission test in altitude chamber at Cape Canaveral.

The astronaut as an integral part of the system during tests.—The astronaut was considered part of the total system and functioned during systems test and mission simulations as he would during the actual mission. This resulted in a dual advantage. The system tested was closer to flight configuration when the astronaut was included, and the astronaut became intimately familiar with the spacecraft and spacecraft system. Figure 14–2 is a photograph of a spacecraft on the RF tower for communication tests. This test, with Astronaut L. Gordon Cooper, was made to determine voice clarity under simulated flight conditions.

FIGURE 14–2.—Astronaut Cooper in spacecraft on RF tower for communications test.

Component Acceptability

Components of proven design were planned for use in Project Mercury. In order to insure that only properly-operating items of these proven designs were used for flight, not only spare parts but also many components installed in the spacecraft were subjected to testing at

Cape Canaveral. Numerous component failures were experienced during these spacecraft tests; in addition, during 1962 and 1963 approximately 50 percent of component spares were rejected after testing. These failures were discovered by rigorous preinstallation acceptance (PIA) tests which in most cases exceeded the test conditions that could be achieved after component installation. These tests increased confidence that replacement components in a state of incipient failure would not be installed in Mercury spacecraft.

Control of the stock of spares also was tightened to assure that qualified replacements were available when troubles occurred. Spares which were significantly affected by shelf life were periodically tested and returned to stock. In special cases, the inspection was extended to the source. Vendor and component manufacturing plants were visited by engineers and inspectors to convey the nature of problems and to encourage higher quality of work.

Component acceptability and rejection rate was governed by such factors as performance criteria modification, the delivery of partially qualified items, and inadequate shelf life of some components.

Modified Performance Criteria

During systems tests of Mercury spacecraft, the effects of electrical-current surges demonstrated the need for performance criteria modification. These current surges, resulting in momentary variation (transients) of the battery voltage, occurred during testing and were attributed to the normal starting of mechanical-electrical systems, such as the orbital timing device or the spacecraft cameras. As a result of these voltage transients, energized timers would occasionally exhibit early time-out, interference would appear in instrumentation amplifier outputs causing faulty indications, and noise would appear in the astronaut voice channels. The solution to these problems required inclusion of a special battery for the maximum altitude sensor, the addition of capacitors to circuits with time relays as a protective measure to prevent early time-out, and the replacement of components with like items that demonstrated low susceptibility to voltage transients.

Extensive voltage-transient tests were added to spacecraft checkout procedures to prove equipment immunity to these effects. These procedures were frequently quite involved.

High voltage problems were encountered in ground power supplies. Electrically-regulated power supplies operating over long lines tended to react and surge to high voltages and cause loss of remote sensing, and they were abandoned in favor of lead-acid batteries.

Partially Qualified Equipment

Equipment not fully qualified for flight when delivered included tape recorders, ECG amplifiers, water traps for the environmental control system (ECS), and impedance pneumographs.

Tape recorders were brought to acceptable status by careful shop asembly and testing. The electrocardiogram (ECG) amplifiers were redesigned and rebuilt. Internal voltage regulators and feedback loops were modified. Rebuilt units were requalified in detail. Later, new models were specified for vendor development based on experience with the originals.

In some cases, flight systems had to be modified to accept new components, and special systems tests had to be devised to be sure that the effects of the modification were not serious. For example, the environmental control system performance depended upon closely balanced pressures and flow, and testing of the system was conducted to insure that the addition of the water trap did not degrade system performance in the MA–9 spacecraft.

Shelf Life

Many components procured for the Mercury Project proved to have inadequate shelf life because of the time period required to complete the program. Such items as rockets had to be refurbished because of an 18-month shelf limit established by the vendors. A system was established whereby equipment that utilized rubber O-rings was periodically exercised or returned to the vendor for replacement of time-critical components. For example, the Environmental Control System (ECS) negative-pressure relief valves were operated at prescribed time intervals, and the Reaction Control System (RCS) relief valves were reconditioned by the manufacturer.

Another problem involved deterioration of the solder connections of nichrome bridge wires to the electrical connectors of many pyrotechnic initiators. This deterioration resulted in a gradual increase in the resistance of squib circuits. This was precluded by establishing a time limitation of 6 months between date of soldering and actual use.

Test Equipment and Procedure Changes

The need to prove the acceptability of spacecraft equipment required many changes in procedures and test equipment at the Cape. Component and systems simulators were used less and less in spacecraft testing even to the point of requiring participation of the astronaut, fully suited.

Bench simulators were made more realistic. Voltage-transient generators and ECG simulators were added to the Cape's test equipment. Battery source impedance and load impedances were more carefully simulated as was line noise character. There was, also, an increased tendency to operate equipment on the bench in exact connection with production models of their companion components and systems. Camera solenoids and transmitters were properly connected to and operated with instrument systems during final bench tests before spacecraft installation.

Quality Assurance

Some equipment and components such as rockets and pyrotechnics could not be fully validated before use. Reliability of these items was almost entirely dependent upon good design, workmanship, and qualification. This workmanship requires great patience and attention to detail even under the tedium of production lines. Considerable progress has been made in promoting this extreme attention to detail which directly contributes to the success or failure of each spaceflight mission and the safe return of the astronaut.

In the MA–9 mission, the three retropackage umbilicals and one of the two spacecraft-to-adapter umbilicals failed to separate from the spacecraft. Each of these contained two squibs, and initiation of either squib should have resulted in explosive disconnection. Postflight analysis revealed that the umbilicals failed to separate from the spacecraft because the squibs were not loaded with the appropriate charge.

As the Mercury Project matured, it became evident that the use of proven and qualified components did not result in the reliabilities desired to satisfy man-rated system requirements. A more-rigid quality control procedure was required in all aspects of component and system assembly. The need for this requirement was typified by the number of discrepancies (performance or configuration deficiencies) to be corrected for the MA–9 backup spacecraft. A total of 720 system or component discrepancies were recorded, of which 526 were directly attributed to a lack of satisfactory quality of workmanship. Of this number, 444 required specially-scheduled time to correct.

Additionally, flight-safety considerations required that inspection be made of all parts and components scheduled for the space-flight program. These inspection requirements extended from the parts vendor to the Cape in order to locate and reject every defective or marginal part.

As a result of inspection, fourteen 1,500 watt/hour storage batteries were rejected for case leakage during preparation for the MA–8 mission. Several incidents of leakage were due to tooling holes not being plugged during manufacture. Others were from case cracks or undetermined sources. Also, an inspection of battery vent-pressure relief valves revealed dimensional deviations in valves after assembly, and improperly applied potting adhesive. Three of these valves failed to operate at proper pressures. These defective batteries were rejected following inspection at the Cape.

Five failures were experienced on gas-pressure regulator assemblies in the MA–8 reaction control system (RCS). An investigation of the failed assemblies revealed that internal scratches, inadequate cleanliness, and improper torquing of end caps were contributing causes of these failures.

Also in the RCS, an examination of failed gas-pressure vent valves revealed damaged O-rings. In one case an O-ring was found to be scuffed, while in another case the O-ring had a metal fragment driven into the material.

The MA–8 spacecraft was demated from its launch vehicle and returned to Hangar "S" to replace the manual selector valve in the RCS due to a leakage encountered during a preflight pressure check of the system. Upon removing the valve, it was noted that the valve had been installed out of alinement so that an excessive side-load was induced into the valve internal parts.

During an inspection of the escape-tower wiring for the MA–6 primary and backup spacecrafts, it was found that the electrical connectors had improperly-soldered joints. Additionally, it was discovered that improper insertion of the conductor wire into the solder had been made as a result of the use of an 18-gauge wire with a 20-gauge solder pot.

In Project Mercury, thousands of man-hours were expended in testing, calibration, assembly, and installation of a variety of hardware that later failed to meet performance specifications or that malfunctioned during systems tests in a simulated space environment. When malfunctions occurred or when these components failed to meet specifications, it was necessary to remove, repair, or replace them, a procedure which could have been avoided in a large percentage of cases if adequate attention to detail during manufacture or thorough inspection before delivery had been exercised.

Component Accessibility

Mercury spacecraft were literally packed with equipment and components were installed three deep in some instances. Limited interior working space, which posed a severe handicap to preflight preparation, resulted in a certain amount of wiring and equipment damage during normal work and test operations. Repair was a continuing work item during all phases of spacecraft modification and checkout. Any system affected by these repairs or modifications had to be reverified by test.

Extensive changes and modification were caused primarily by component or subsystem malfunction, as well as extension of mission requirements.

As an example, it became necessary to replace MA–6's life-limited carbon dioxide absorber in the ECS, since more time than had been planned was required to check out the system. This replacement required no less than eight major equipment removals and four revalidations of unrelated subsystems. It caused an overall delay of nearly 12 hours. By way of comparison, it took only an hour and a half to replace the carbon dioxide absorber itself. Ten and one-half hours were used to gain access to the absorber and then to restore the spacecraft to its original condition.

The number of removals of equipment is an index of the amount of modification, repair, and servicing required as the program progressed. Figure 14–3 exemplifies the amount of work required at Cape Canaveral.

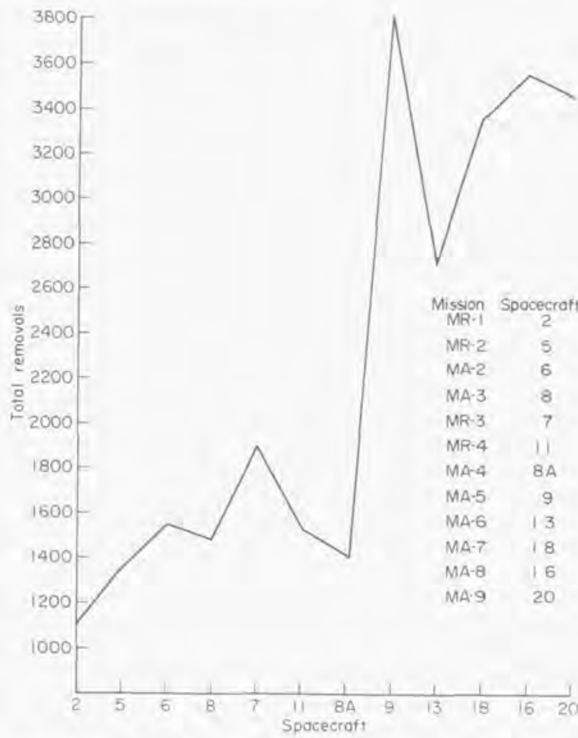

FIGURE 14–3.—History of equipment removals for Mercury spacecraft for rework service and replacement.

Cleanliness

Early in the Mercury program motion pictures of the inside of a spacecraft in orbit showed washers, wire cuttings, bolts, and alligator clips floating in the cabin. The cabin fan became plugged on an early unmanned flight with similar free-floating debris.

Such evidence led to more care in the habits of technicians working inside the spacecraft. A periodic tumbling of the spacecraft to dislodge and expose dirt and loose objects became standard practice at the Cape. Figure 14–4 shows a spacecraft in the tumbling fixture during a cleaning operation, and figure 14–5 shows the debris removed.

FIGURE 14-4.—Spacecraft being tumbled to remove debris left during work periods.

FIGURE 14-5.—Debris removed from spacecraft during tumbling.

Technicians generally were not aware of the strict cleanliness required in handling components of the ECS and RCS systems. It became necessary to specify handling procedures for these highly dirt-sensitive components. Many parts were kept in sealed plastic bags until installation was to begin, at which time ultra-clean handling methods were used. Vendors have delivered many items of spacecraft equipment which contained wire ends, solder balls, and stray hardware. Such items as gums, powders, lubricants, chips, and hydrocarbons have appeared on components where they could not be tolerated for proper operation. Hydrogen peroxide systems have yielded some decomposables which could have caused extreme reaction. Breathing oxygen and drinking water also have been contaminated. As a result, all consumables were chemically analyzed before being put into their spacecraft containers, and a variety of equipment which was found to contain contaminating deposits was carefully inspected and cleaned before being used. This equipment included astronaut suits, valves, hoses, and tubing.

Provisions and Procedures for Troubleshooting

It can be seen from the preceding discussion that there was a great need for troubleshooting spacecraft components both in spacecraft and on the bench. As a consequence, facilities at the Cape were expanded to include a malfunction investigation laboratory, staffed with experienced specialists in such areas as X-ray, spectroscopy, microscopy, and chemistry. Also, because of the need to qualify many spacecraft components, a laboratory of test equipment was developed and fully equipped with environmental chambers, shaker table, accelerator, impact tester, and pressure testing equipment.

Absence of Test Points

In Project Mercury, it was necessary to add ground support equipment to that provided with the spacecraft and to devise means for testing individual components in the spacecraft. Test points were not available and interconnecting cables and tubing had to be broken into for tests. This invalidated the very circuit or pressure system that was being tested.

Preplanned Troubleshooting

In Project Mercury it became necessary to plan exact steps and equipment configuration before troubleshooting was begun. Expected values in response to stimuli that had been carefully defined were listed in documents prepared in advance. It was found that preplanned troubleshooting procedures significantly reduced testing time.

In addition to drawings and standard spacecraft test procedure, the contractor provided logic diagrams and detailed drawings and specifications of systems and components. Systems consisting of many separate circuit elements were detailed by separate subsystem diagrams showing all wire routing throughout the spacecraft. As an example, instrument systems were broken down to show each sensor and

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its signal conditioning and cable connections. This was in addition to overall system cabling diagrams and detailed drawings of repairable items including mounting details that were provided. These drawings were invaluable for troubleshooting.

Scheduling

To accomplish spacecraft preflight preparations and checkout within schedule objectives, it was necessary to increase the number of spacecraft undergoing preflight preparations at Cape Canaveral from one to two, or three, at any given time. This approach provided additional time for preflight preparations of each spacecraft without a corresponding increase in the time interval between successive missions.

Preflight Preparation

Preflight preparations and checkout operations included: (1) modifications to update the untested spacecraft configuration based upon knowledge gained from previous flight experience; (2) modifications as extensive as reworking a spacecraft from a suborbital configuration to an orbital configuration to increase spacecraft systems capabilities for extended mission requirements; and (3) changes and modifications resulting from component or system malfunctions during preflight testing.

Changes of considerable magnitude were made at the Cape only because it was more efficient and less time consuming than returning the spacecraft to the factory. In any event the final flight configuration of any particular spacecraft could not be entirely determined until successful completion of the preceding mission. This required that final configuration changes be accomplished at the Cape if the schedule was to be maintained.

On the average, spacecraft modifications accounted for more than half the time that the spacecraft remained at the Cape prior to flight. Examination of the average time that the spacecraft spent at Cape Canaveral shows that 60

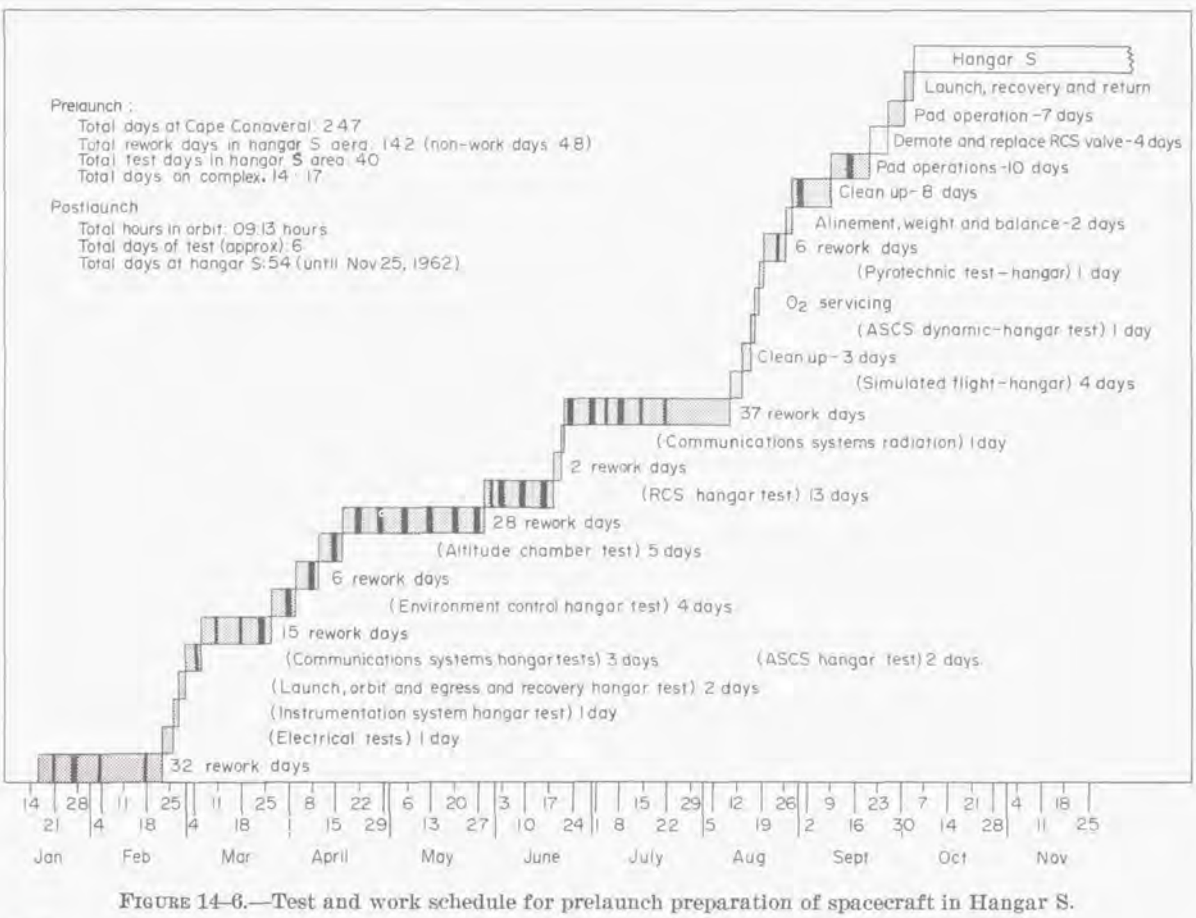

FIGURE 14-6.—Test and work schedule for prelaunch preparation of spacecraft in Hangar S.

percent of the total time involved modification, repair, assembly, service, and inspection. Only 25 percent of the time was spent in hangar tests and 15 percent for all work and testing at the pad.

When converted to months, these percentages show approximately 3 months for hangar work, 1⅓ months for actual hangar testing, and 1 month on the launch pad, for a total average time at the Cape of approximately 5⅓ months.

The Mercury-Atlas spacecraft averaged 33 more hangar work days, 6 additional hangar test days, and 4 additional days on the pad than the Mercury-Redstone spacecraft. This small increase in test and pad time indicated that the increased complexity of Mercury–Atlas missions was offset by increased experience, and therefore there was little effect on time required for hangar testing or total pad time. Figure 14–6 shows how the time was divided between testing and other work in the preparation of spacecraft 16 (MA–8).

Operational Life

Equipment having a short operational life caused many problems in meeting spacecraft checkout schedules. Dissipating chemicals, such as lithium hydroxide which was used to adsorb carbon dioxide in the astronaut's breathing-oxygen circuit, exemplify this problem. The carbon dioxide and oxygen partial-pressure sensors are another example. The latter had to be installed late in the countdown and required some spacecraft disassembly for installation. If holds occurred during the countdown, a new removal-activation-calibration-installation cycle had to be completed.

Spacecraft cameras also posed short-life problems in the Mercury Project. Most of the camera shutter and film advance mechanisms failed frequently. Complicating matters further was the fact that the camera solenoids caused momentary deep reductions in battery voltage because of periodic pulsing. In addition, excessive back-voltages in the coils caused failures of programer switches. Because cameras placed transients on other systems, these systems had to be tested often to establish their ability to accept these transients. This extended use, in turn, burdened the cameras and their failures accelerated. Spare cameras soon became unavailable.

Failure Analysis

Rapid failure detection and corrective action were basic requirements in maintaining program schedules. Facilities were provided to permit extensive failure analyses at Cape Canaveral where failure conditions were intimately known to engineers and technicians. These analyses provided a basis for accurate feedback through quality control channels. However, the lack of spares often made it impossible to take the necessary action required in order to meet preflight preparation and test schedules.

Evolution of Digital Checkout Equipment

One of the more time consuming problems during Project Mercury was that of spacecraft preparation for testing. This required connecting a large number of cables to the installed equipment, largely by breaking cables and tubing. As shown in figure 14–7, many of these cables were draped around the spacecraft and through the hatch. Not only did this tend to invalidate systems being tested, but it required much detailed planning and preparation of the spacecraft and test equipment. Each time the spacecraft was moved, the entire test complex had to be torn down, putting another strain on equipment in the spacecraft.

FIGURE 14–7.—Spacecraft in Hangar S.

A study of digital equipment proved that data conversion provisions could be built into the spacecraft and permanently wired to test points. Pulse code modulation—a form of digital data—allows compression of data so that hundreds of measurements can be sent over one cable. By this means, test configuration problems can be greatly reduced. Spacecraft can be moved from place to place with much less breakdown and buildup of test configurations.

As the Mercury Project progressed, many different methods of data presentation and distribution were investigated. Through these efforts, it was demonstrated that data of the pulse form could be consistently transmitted by radio frequency or by cable. The receiving and conversion equipment which was used for about 4 years proved to be a reliable and accurate means for presenting data to test engineers.

In an effort to make data more immediately useful to these engineers, printers and digital displays were added. It was gradually realized that this immediacy was of prime importance to men who had to make constant decisions as to the state of their systems. These studies of improvements needed in spacecraft checkout led to the design of a digital computer-controlled system capable of automatic checkout of manned spacecraft. It also had the capability of use as a completely manual system controlled by test engineers miles from the spacecraft, thereby allowing a natural evolution to automatic checkout. An experimental model was assembled and proved during hangar and pad tests of Astronaut Cooper's spacecraft.

Technical, Configuration, and Mission Reviews

Close coordination between preflight operations personnel and those of other organizations, including contractors, subcontractors, vendors, the Department of Defense, the ground complex, the network, and other NASA centers was maintained continuously to insure that interface compatibility of operations planning as well as equipment left no significant problems unresolved.

Throughout Project Mercury, a continuing series of technical, configuration, and mission review meetings were conducted to resolve problems, to initiate action where necessary, to coordinate activities on a wide variety of matters affecting each Mercury mission and to provide technical direction where required. In addition, engineering specialists from these organizations met frequently at Development Engineering Inspections (DEI) at the spacecraft manufacturing plant to review in detail the hardware being produced so that results of current experience were reflected in this hardware. Each of these efforts provided management a valuable tool for directing effort along the desired channels. A significant management device employed during the project to assure mission success was the spacecraft Flight Safety Review meeting held prior to each launch. At this meeting, every activity connected with the spacecraft was discussed in detail between management and engineering specialists to determine the flight readiness of the spacecraft. The criteria established for this review was that a Mercury launch would not take place in the face of unresolved difficulties that might affect mission success or flight safety.

Conclusions

The foregoing discussion has presented in detail the lessons learned in preflight preparation and testing during the Mercury Project. The conclusions that have been drawn from this experience follow:

(1) Test procedures incorporating the techniques of end-to-end testing, interface verification, and astronaut participation should be documented and continually updated.

(2) Spacecraft should be completely assembled at the factory, using a minimum of simulated hardware.

(3) The number of component malfunctions during testing proved the need for better quality control and inspection procedures.

(4) The lack of test points, spares, and formalized troubleshooting procedures often hindered rapid malfunction analysis and corrective action.

(5) Limited shelf life and operational life of components create spares problems and possible delays in launch schedules.

(6) Pursuance of exacting cleanliness procedures reduces the possibility of component and system malfunctions.

(7) An automatic checkout system can provide complete real-time test documentation and better control of test operations by test engineers than an analog system.

15. FLIGHT CONTROL OPERATIONS

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Summary

An organization was established at the beginning of Project Mercury to provide support to the astronaut in all phases of the mission. This organization was to monitor and direct the mission to insure a greater margin of safety for the astronaut, provide support necessary for mission success by extending the analysis capability of the astronaut, and record data for detailed postflight analysis.

To be able to accomplish the assigned tasks, it was necessary to plan operational requirements, generate documentation for real-time use, and train personnel specifically for the job of flight control.

As the program progressed from the planning stages through manned orbital flight, flight control progressed in its ability to provide better support.

All Mercury flights were successfully supported by flight controllers at the Mercury Control Center and sites located throughout the world. During the program a number of difficulties occurred which required changes and improvements to methods used in the early flights. Most of these difficulties were corrected and flight control provided the necessary support to contribute significantly to the success of the program. Because of the experience gained in the Mercury program the flight control organization is now more qualified to progress to the more complex programs planned for the future.

Purpose of Flight Control

At the beginning of the Mercury program, it was recognized that a ground-based crew would be needed to aid the astronaut in monitoring the spececraft systems, to evaluate systems performance, and to advise the astronaut on the proper action necessary in case of a spacecraft malfunction. Also, the ground crew would have the capability to command reentry of the spacecraft in unmanned vehicles and in manned vehicles should the necessity arise. In addition, it was necesary that the flight control organization record information for postflight analysis. The major objectives of flight control were:

(1) Assist the astronaut during critical mission phases where additional close monitoring and direction would insure a greater margin of safety.

(2) Provide support as required in conducting the flight plan to contribute to mission success.

(3) Extend the system analysis capability of the crew and make available experts in all vehicle systems should they be needed to support the crew.

Flight control is the team work existing between the spacecraft crew and a worldwide ground crew to accomplish manned space flight. This task covers the entire premission preparation phase and terminates with the recovery of the spacecraft and crew. Flight control was broken into five separate tasks:

(1) Preparation of the ground and flight crews prior to launch, which includes the detailed development of Flight Plans, countdowns, Mission Rules, and training of personnel in vehicle systems and ground network operations.

(2) Execution of mission control, which includes the direct supervision and coordination of all aspects of mission real-time ground support and the control of the launch vehicle and spacecraft crew during flight.

(3) Supplement the vehicle systems analysis capability of the spacecraft crew, primarily by the compilation, reduction, and evaluation of telemetered and voice data from the spacecraft and its crew.

(4) Assistance to the spacecraft crew in attaining the mission objectives. This task requires participation in the development of an optimum flight program, provision and coordination for real-time ground support necessary for execution of this optimum Flight Plan, modification of the Flight Plan in real time as required, and assistance in preparation for subsequent mission phases.

(5) Participation in postmission analysis, recommendations, and the preparation for subsequent flight programs.

History of Communication Between Ground and Pilot

The development of a complex vehicle requires the parallel development of a test and control organization to provide the support necessary to accomplish the test objectives.

The advent of air-ground data links has allowed a ground-based crew to monitor the test in progress, to modify the flight if necessary, and to recommend the most expeditious course of action to be taken in the event of a contingency situation. The missile age brought about the development of a ground-to-air data link by which information and commands could be sent from a monitoring ground crew to the vehicle to modify its flight plan.

In the early planning stage of Project Mercury, it became evident that an extensive tracking and data-acquisition network would be required. The presence of man in an orbiting satellite demanded that considerably different requirements be placed on the tracking network than had previously been necessary for unmanned vehicles. The most significant of these requirements was that it was now imperative that the network respond rapidly to contingency situations to insure adequate safety of the astronaut. In order to meet the new requirements and to analyze the progress of the flight, the tracking network combined previously used methods of monitoring. These methods are telemetry and radar and voice communications which are discussed as follows:

(1) Telemetry and radar, which were used to monitor and track satellite and missile systems, provided a means in Project Mercury not only of analyzing launch vehicle performance and trajectory progress but also of monitoring spacecraft systems and making medical analyses of the astronaut's physical status.

(2) The voice conversations between the astronaut and the spacecraft communicators around the world proved to be invaluable. The ability of the astronaut to make observations and relay them to the control center, to verify telemetry data, to update the retrofire timer, to exchange information with the ground, and to carry on discussion of problem areas proved to be the best tool for flight-control analysis. Voice communications also proved to be a primary method of making a medical analysis of the astronaut's physical status.

Development of Flight-Control Operations

Network Requirements

In the planning stages for manned flights, the design criteria for the tracking network were established. These requirements were:

(1) A central control facility able to coordinate a worldwide network of tracking stations.

(2) Continuous monitoring of the powered-flight phase of the mission.

(3) A worldwide network capable of monitoring a spacecraft while in orbit.

(4) Voice, telemetry, radar tracking, and command capability at the time of retrofire for a planned reentry.

(5) A recovery force capable of astronaut rescue in case of an emergency as well as recovery after a normal reentry.

Development of Detailed Flight Control Operational Planning

As preparation began for manned space flight, it became apparent that a need existed for a well-trained control organization in order to perform the flight-control tasks previously mentioned. As in the case with any engineering or scientific undertaking, the ability to control a mission successfully is primarily a result of premission planning.

Documentation.—At the beginning of the project, the different organizations connected with the Mercury program published a number of documents in which the method that should be used to accomplish the flight-control task was described in detail. Some of the documents were revised and used in Astronaut Cooper's flight. However, the majority of the documents proved to be too cumbersome for real-time use and too difficult to keep updated for use by the flight-control organization. Consequently, some of these documents were revised, others were discontinued, and new ones which would be more adaptable to use in real time were written. As a result of the experience gained by the use of these documents, several specifically designed for flight control were published.

The most difficult task of flight control is that of being prepared to make a real-time decision. A real-time decision by flight control could result in an action to change the entire mission. The action based on this decision may range from a slight variation of the flight plan to immediate termination of the mission. The documentation to be used by flight control personnel not only must have all necessary information available to research a problem, but also must contain information that can be quickly located, if time is limited. The most significant documents that evolved through experience and use were Mission Rules, Flight Plan, Flight Controller Handbook–1, and the Trajectory Working Paper.

Mission Rules: A fundamental approach to the analysis of systems failures in any flight-test program is to formulate a set of probable component failures and their respective countermeasures which may either rectify the problem, provide for the safety of the occupant, or protect the equipment. This compilation of preplanned actions for each flight is called Mission Rules. In no other document are the actions of the crew and the flight control teams so well defined. Each rule is carefully scrutinized by the flight controllers and astronauts for possible ramifications which need more clarification. This document shows the integrated actions of the spacecraft crew and ground-support personnel which are required to establish an efficient team that may be called on to take life-saving actions should an emergency situation arise.

These Mission Rules are put to the final test during the extensive series of simulations prior to the mission. Some of the rules may be modified as a result of the realistic situations created by the simulation. A Mission Rule Review is held the day before launch to assure a consistent interpretation and a complete understanding of the rules. A page from the Mission Rules for orbital reentry is shown in table 15–I.

Flight Plan: The Flight Plan for the manned Mercury missions consisted of a time-referenced step-by-step list of the astronaut's activities during an individual mission and the necessary supporting information. It was basically written as a guide for the astronaut in conducting the mission, but it also served as a focal point for the coordination of all the inputs into the mission and the coordination of the ground-controller activities with those of the astronaut. In addition, it served as a basis for premission training, simulations, system tests, and detailed management in meeting the mission objectives.

The formulation of the Flight Plan required the coordination of inputs from many organizations into a sequence that not only met the mission objectives and ground rules, but also could readily be performed by the astronaut. The inputs into the Flight Plan were concerned with the astronauts, the spacecraft systems, flight controllers, medical requirements, and experimental considerations. As these inputs were received, they were arranged to meet the requirements of astronaut usage, reliability, priority, Mission Rules, and ground control. In order to obtain the maximum amount of useful information from the flight, the Flight Plan was continuously coordinated with and reviewed by the various input organizations and finally approved by the Operations Director.

The Flight Plan, as an operational document, served several purposes. Primarily, it provided the astronaut with a coordinated schedule of his activities during the mission. It also outlined part of the astronaut's preflight training. The Flight Plan further served to inform the flight controllers of the astronaut's planned activities and was used as a tool to help coordinate the activities. In addition to the activity schedule, the Flight Plan provided the normal and emergency procedures and checklists for the control of the spacecraft and procedures for conducting experimental and medical activities. During the mission it provided a basis from which changes could be made because of system malfunctions or alterations in the requirements. Also, it provided nonoperational organizations with information concerning the activities scheduled for an individual mission. See table 15–II for sample page from flight plan.

Table 15-I.—Mission Rules—Orbital Reentry

Revision	Item Condition—Malfunction	Ruling	Notes, Comments, Standard Operation Procedures
	8. Failure of one suit fan.	8. Continue mission.	
	9. Failure of both suit fans.	9. Select EMER O_2 rate ASAP and reenter at next planned landing area.	
2	10. Smoke, fumes, unusual or annoying odors in suit circuit.	10. Switch suit fans. If this does not clear up the fumes or smoke, go to EMER O_2 rate and try further to isolate cause. If cannot isolate, reenter next planned landing area.	10. Check suit PCO_2 reading.
	11. Smoke, fumes, fire, unusual or annoying odors in cabin.	11. Close faceplate, attempt to isolate cause. If source isolated and no other Mission Rules are violated, continue mission. If fire, decompress.	
	12. Faceplate will not reseal. a. Cabin pressure above 4.6 psi. b. Cabin pressure below 4.6 psi.	12a. Reenter next planned landing area. b. May require contingency landing area reentry or ASAP reentry if cabin pressure below 4.0 psi.	12. Astronaut should get spacecraft in RETRO ATTITUDE and prepare to reenter.
	13. Conditions for selection of EMER O_2 rate.	13. Astronaut should select EMER O_2 rate when: a. Suit pressure below 4.0 psi. b. Respiration rate increasing to 40 breaths/min. c. Unsatisfactory operation of suit heat exchanger that is not corrected. d. Rise in partial CO_2 reading to 7.5 mm Mercury. e. Smoke, fumes, unusual or annoying odors in suit circuit.	

Table 15–II.—Excerpt From Flight Plan

Orbit	AOS	Site mode	LOS	Action	Remarks
21	32:05	ASCS Orbit		A—Turn ON cabin fan and cabin coolant flow for precooling prior to reentry.	
21	32:15	ASCS Orbit	32:20	A—Radiation experiment ON for 5 minute period.	
21	32:22	ASCS Orbit		A—Tape recorder—PROGRAM. Take horizon definition photographs.	
21	32:23	CSQ ASCS Orbit	32:30	A—TV ON for pass. Oral temperature. Blood pressure.	The astronaut cannot talk for a period of 3–5 minutes during oral temperature taking.
21	32:40	HAW ASCS Orbit	32:46		
22	33:33	ZZB ASCS Orbit	33:39	A—Tape recorder—CONTINUOUS. Complete stowage and preretrosequence checklists. Check manual proportional and FBW-high thrusters if required. Readout fuel and O_2 quantities.	
22	33:57	CSQ ASCS Orbit	34:03	A—TV ON for pass. C and S-band radar beacons. CONTINUOUS. Report checklists—COMPLETED. CSQ—Confirm astronaut ready for retrosequence. Confirm retrosequence time setting. A—Squib switch ARM at retrosequence minus 5 seconds.	

Flight Controllers Handbook: The first document designed specifically for flight controllers was published in December 1960. This book was designed to contain operational information needed by a flight control team to analyze spacecraft systems problems. Schematics, logic diagrams, and other publications were used to prepare schematics oriented for operational utilization. This document, entitled Flight Controllers Handbook No. 1 (FCH–1), was used from the MA–3 mission until the end of the Mercury Project. During this time, the FCH–1 was modified and revised to include more system details. The final document contained highly detailed functional schematics of spacecraft systems, yet the arrangement of these schematics along with notes explaining details provided information very adaptable to real-time use. The schematic diagram, shown in figure 15–1, was taken from the Flight Controller's Handbook.

Trajectory Working Papers: Real-time decisions concerning flight dynamics are of paramount importance to the astronaut's safety and to mission success. Should the flight trajectory vary from the precalculated nominal during launch, there is no time for analysis, and corrective action must be immediate. In order to aid the flight controllers in making these fast decisions, a flight dynamics document was prepared to provide a ready reference of charts, curves, tables, and other data illustrating the expected normal trajectories, calculated allowable limits, and timed sequence of events. This document contained not only information pertaining to all the conditions necessary for insertion of the spacecraft into orbit, but it also contained curves for calculating retrofire times and making reentry landing predictions. Table 15–III and figure 15–2 are examples of information contained in the Trajectory Working Paper.

Training.—In November 1960, training courses were organized for NASA personnel who were to become flight controllers. The classes covered basic spacecraft systems. Because of the limited number of personnel available to man a worldwide tracking network, it was necessary to borrow personnel from other organizations to be used as flight controllers on a part-time basis. However, it was soon discovered that this arrangement was not adequate. Since these people were responsible to their own organizations except during a mission, they were not available for premission planning and postmission analysis. In addition, the flight-control tasks interfered with their responsibilities to their own organizations. As a result, it was determined that full-time flight controllers were needed. The first full-time team of systems monitors came to NASA in January 1961, and new techniques of instruction were incorporated through the experience gained in the preceding class. These systems monitors learned the spacecraft and ground systems and conducted the succeeding flight-controller training classes. The following facilities and aids were used in the flight-controller training program: classroom lectures, Mercury procedures trainer, and training documentation.

An updated formal training course was held in April 1962 and consisted of 156 hours of classroom lectures on spacecraft and ground systems. The original NASA flight controllers were the instructors and were responsible for the training lesson plans. The FCH–1 manual was the primary source of information for the lectures on spacecraft systems. Within one year, a total of six classes were conducted without any significant changes in the format.

The Mercury procedures trainer was utilized in training flight controllers in network operational procedures, spacecraft communications, and systems analysis. The first Mercury procedures trainer was installed at Langley Air Force Base, Va., in 1960 and became operational the latter part of the year. The remote site console simulator was also installed at Langley. For a description of the procedures trainer and the simulator, see paper 10. This remote-site simulator was designed to operate from outputs of the spacecraft procedures trainer for simultaneous site-vehicle training. Initially, the procedures trainer was used primarily by the astronauts for systems training, and there was limited availability for use by the flight controllers. In 1961 a Mercury procedures trainer was installed at Cape Canaveral, and more time was then available for the Flight Controllers to train on the one at Langley. The trainer configuration was continuously updated to make it identical with the spacecraft used for the real-time operation.

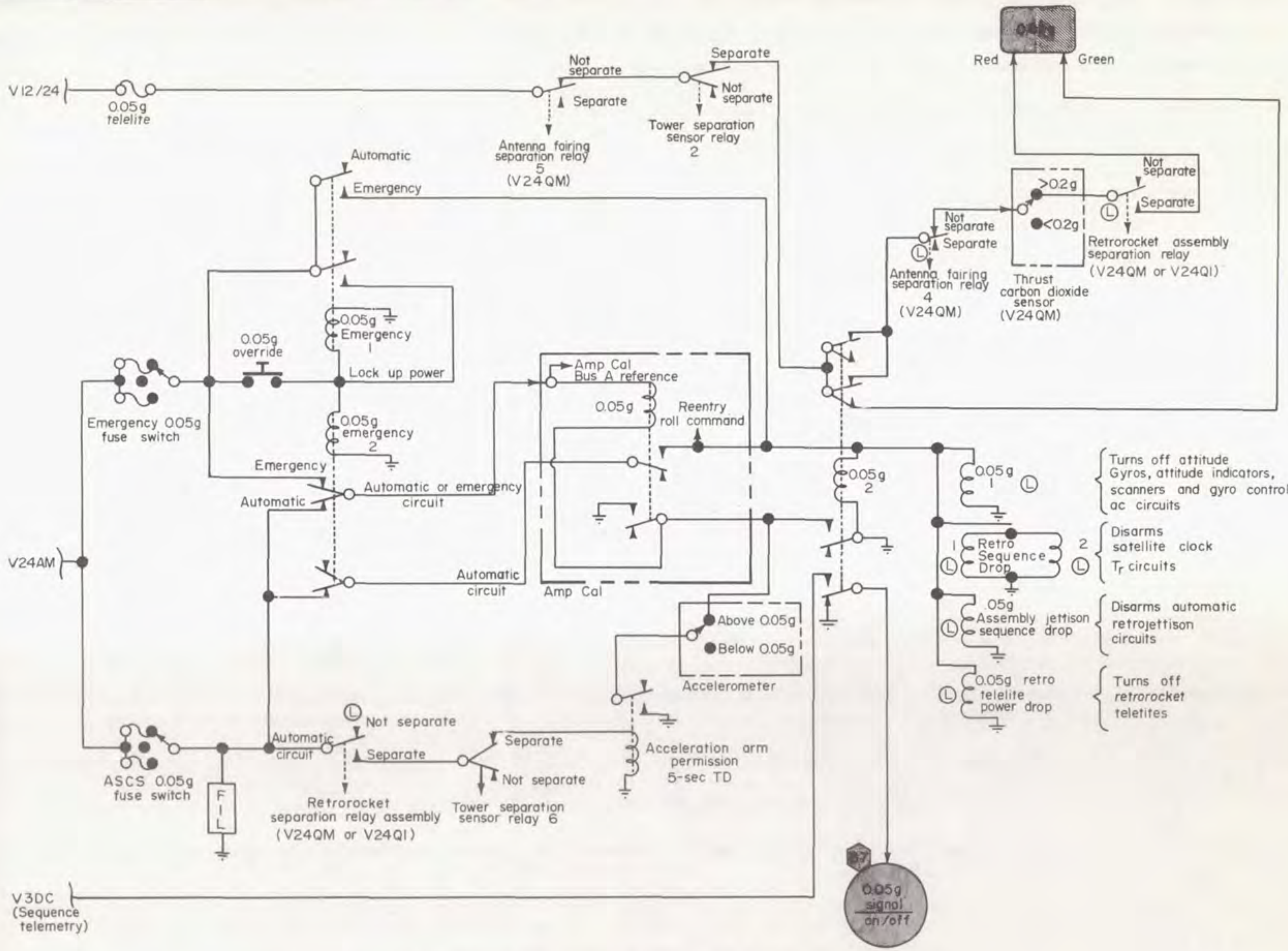

FIGURE 15-1.—Schematic diagram of 0.05g sequence.

Table 15-III.—Sequence of Events for Abort Trajectories [a]

Time of abort, min:sec	Time of event, min:sec										Recovery area
	Tower jettison	Retro-pack jettison	Blackout (start)	Begin reentry (0.05g)	Reentry flight-path angle at 0.05g, deg		Blackout (end)	Drogue parachute automatic deploy at 21,000 ft	Main parachute deploy at 10,000 ft	Landing	
					Space-fixed	Earth-fixed					
00:00	00:07	00:00	----------	00:10	----------	----------	----------	00:10	00:10	01:15	A
00:10	00:19	00. 10	----------	00:22	----------	----------	----------	00:22	00:22	02:18	A
00:20	00:31	00:20	----------	00:34	----------	----------	----------	00:34	00:34	04:12	A
00:30	00:43	00:30	----------	00:46	----------	----------	----------	00:46	01:46	05:33	A
00:40	00:54	00:40	----------	00:57	----------	----------	----------	00:57	01:43	06:09	A
00:50	01:06	00:50	----------	01:08	----------	----------	----------	01:45	02:21	07:07	A
01:00	01:18	01:00	----------	01:24	----------	----------	----------	02:28	03:04	07:50	A
01:10	01:41	01:10	----------	01:41	----------	----------	----------	03:21	03:57	08:43	A
01:20	02:07	01:20	----------	02:07	----------	----------	----------	04:24	05:00	09:46	A
01:30	02:19	01:30	----------	02:42	----------	----------	----------	05:23	06:00	10:45	A
01:40	02:29	01:40	----------	03:36	−9. 812	−12. 94	----------	06:21	06:57	11:43	A
01:50	02:39	01:50	----------	04:46	−17. 77	−21. 93	----------	07:13	07:49	12:35	A
02:00	02:49	02:00	----------	05:48	−19. 327	−22. 81	----------	08:09	08:45	13:31	A
02:10	02:59	02:10	----------	07:05	−20. 810	−23. 01	----------	09:22	09:59	14:45	A
02:20	03:09	02:20	----------	07:30	−20. 327	−23. 07	----------	09:46	10:23	15:08	A
02:30	03:19	02:30	----------	07:22	−19. 321	−29. 18	----------	09:44	10:21	15:06	A
02:35. 7	03:24. 7	02:35. 7	----------	07:23	−18. 801	−21. 10	----------	09:40	10:16	15:02	A

[a] Times based on normal abort trajectories. For dispersed trajectory, the sequence changes.

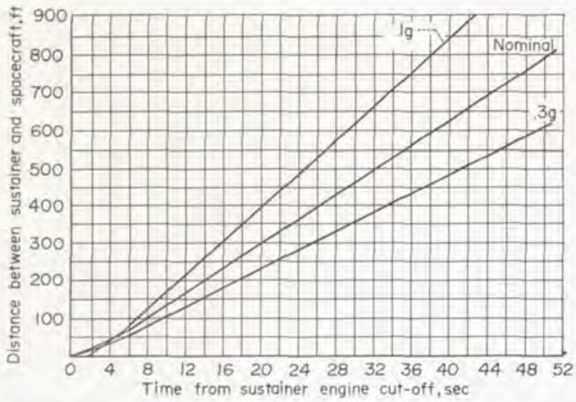

FIGURE 15-2.—Separation distance as a function of incremental time from SECO for different thrust sensing levels during nominal thrust conditions.

A flight plan was written which deviated from the normal Flight Plan in order to give the flight controllers experience in a contingency situation. A typical simulation picked up the last five passes of the spacecraft and during that time three flight controllers practiced simultaneously: one as the astronaut, one as the spacecraft communicator, and the third as the systems monitor.

In order to apply some of the defined procedures and to gain experience in the operation of the spacecraft systems, the Mercury procedures trainer at the Mercury Control Center (MCC) was used for launch and network simulations involving the MCC and the remote sites.

The primary objective of the launch simulations was to train the MCC flight controllers and the astronauts as a team by means of simulated launch experiences in order to develop their ability to perform correctly in any situation during the launch phase. In order to provide a realistic simulation, the launch trajectory was determined and prerecorded on tape with the additional capability of introducing an abort at any time by the operations staff, the astronaut, or a simulated automatic launch-vehicle abort. A complete voice network was exercised within the MCC and to the astronaut for complete familiarization of communication procedures. The telemetry backups of the MCC trainer allowed the flight controllers at MCC to view actions taken by the astronaut without a fixed simulation program. This practice resulted in a more realistic flight simulation than that afforded by the taped simulations used at the remote sites.

A full network simulation was first used for the MA-3 mission and was the basic final mission preparation tool utilized in all subsequent flights. The flight controllers were sent to their stations approximately 2 weeks before the scheduled launch date. Before the launch, three or four simulations were conducted to give the flight controllers experience in the use of correct procedures, coordination of the efforts of all support groups, and to exercise systems analysis capabilities. For the MA-9 mission, a real-time simulation of 18 orbital passes was performed to determine if any network operational difficulties existed which could affect the success of a long-duration mission. Thus, the problem areas were uncovered and solved before deployment for the MA-9 flight. After each simulation, there was a briefing in which the flight controllers explained their actions and any problems were reviewed. As a result, many changes to operational procedures and documentation were made.

The flight controller's detailed systems-analysis capability coupled with his understanding of the network equipment were the basic requirements necessary to perform his job. A brief examination of an orbital station passage will permit a better understanding of the real-time aspects of flight control.

Prior to radar and voice acquisition of the spacecraft at a particular site, the flight-control team at that site received systems status reports and monitored the air-to-ground transmissions between the spacecraft and other network sites. Trend plots were prepared and acquisition messages were received from the Goddard computers. The flight controllers at the site were generally briefed by the Mercury Flight Director prior to contact. At the expected acquisition and the approximate horizon time, the spacecraft communicator attempted UHF contact with the astronaut. Almost simultaneously the telemetry supervisor announced contact, and shortly thereafter, solid telemetry lock was obtained. The spacecraft communicator took the astronaut's systems status report; the aeromedical and spacecraft monitors evaluated systems status. After completion of the preliminary systems assessment, the flight-control team concentrated on any potential problem areas. If a problem existed, the data were rapidly evaluated and notification was sent to the MCC and network by either voice or teletype. If time did not permit or if loss of communications with the MCC did not allow instructions to be given by the Flight Director, the flight controller had to be prepared to advise the astronaut. In order to provide the proper advice to the astronaut, the flight controller must rely on his knowledge of Mission Rules and spacecraft systems.

Flight Control Chronology

The ability of the ground crew and the astronauts to work together as a team has contributed greatly to the success of Project Mercury. The astronauts' confidence in the flight-control organization and its ability to advise and direct their actions when problems occurred greatly simplified the flight control task.

MR–3 AND MR–4

America's first manned space flight, Astronaut Shepard's flight (MR–3), was performed satisfactorily despite the tension involved with the first manned launch.

The flight-control operations of Astronaut Grissom's flight (MR–4) were smoother than those of the MR–3 flight, indicating the benefits obtained from flight-test experience. Information provided by all sources allowed a good analysis of the flight to be made in real time. From launch through landing, the flight was completely normal from the standpoint of flight control. However, early release of the spacecraft hatch caused the spacecraft to flood with water after landing and it was not recovered.

MA–3, MA–4, AND MA–5

Although the MA–3, MA–4, and MA–5 flights were unmanned, they provided valuable experience to the flight-control team. In MA–3 and MA–4 a mechanical man was used to exercise the Environmental Control System. In MA–5, a chimpanzee was on board.

The MA–3 flight of April 25, 1961, was the first attempt to orbit a Mercury spacecraft; however, because of a launch-vehicle guidance malfunction, the mission was aborted shortly after lift-off. From the viewpoint of the flight control organization, a tremendous amount of experience was gained from this orbital attempt. For the first time, flight controllers were deployed to remote sites. As a result, many difficulties were experienced with logistics and communications. Originally, the MA–3 mission was to have been a suborbital flight, but 3 weeks prior to the actual launch, the mission profile was changed to an orbital flight. As a result, problems were encountered with transportation, currency, passports, and travel orders.

The remote-site flight controllers on the MA–4 mission were able to acquire, evaluate, and transmit real-time data; however, problems developed because of the delay in preparation of summary and postpass messages. The major concern during this mission was the inability of the sites to acquire C- and S-band radar tracking. The inability of the sites to acquire C-band radar tracking was attributed to poor spacecraft antenna radiation pattern which was corrected for later flights. Failure to track S-band at several sites was determined to be the result of personnel error. This difficulty was corrected by further training of the maintenance and operational personnel at the remote sites.

For the MA–5 mission, the telemetered data from the spacecraft were of good quality and all sites received total coverage. Data transmission from all sites was good, and the Goddard conference loop was utilized for the first time to provide real-time voice data to MCC from sites that had access to a telephone cable for voice capability. The MA–5 mission was originally scheduled for a three orbital-pass mission, but a series of problems caused termination of the flight at the end of the second pass. The apparatus used to measure the chimpanzee's psychomotor responses malfunctioned. In addition, there was a suit and cabin temperature increase; however, a control-system malfunction causing high fuel usage was the reason for termination of the flight. If the flight had been allowed to continue an insufficient quantity of fuel would have been available for retrofire and reentry. The decision to terminate was made and executed in 12 seconds in order to be able to bring the spacecraft into a planned landing area. The decision was made, and the California spacecraft communicator commanded retrofire. The MA–5 flight proved to be a fine example of the importance of being prepared to make a real-time decision and to act on it immediately.

MA–6

Because MA–6 was the United States' first manned orbital flight, the events which occurred are quite familiar. At the beginning of the second orbital pass over Cape Canaveral, the telemetry data indicated that the heat shield had become unlatched. This indication caused a great deal of concern to the ground crew because of the possibility that the heat shield was loose. While he was in contact with the Hawaii station during the third pass, Astronaut Glenn was asked to put the landing-bag switch in the automatic position to determine if the landing-bag deploy light would come on. The astronaut did not get an indication which meant that the problem was probably an instrumentation failure. However, after further analysis it was decided that the safest approach was not to jettison the retropackage so that the retropackage straps could hold the heat shield in its proper position during reentry until sufficient aerodynamic force was exerted on the shield to hold it in place. Another problem was a partial failure of the automatic stabilization and control system (ASCS), but this problem was handled very adequately by the astronaut's using manual backup and fly-by-wire (FBW) control.

MA–7

For the MA–7 mission, the air-ground contact procedures were reviewed and negative reporting procedures were initiated to eliminate unnecessary conversation with the pilot and network teletype traffic. The only major systems problem was the improper functioning of the ASCS. Astronaut Carpenter was forced to perform a manual retrofire since attitudes could not be controlled by the ASCS.

MA–8

As far as the flight was concerned, the MA–8 mission was a "textbook flight," in which no problems of any importance developed. As a result of the excellent performance of Astronaut Schirra and the spacecraft, the flight-control task became one of monitoring, gathering data, and assisting the astronaut with the Flight Plan.

MA–9

Permission.—The flight controllers began deploying for the MA–9 mission on April 30, 1963, and by May 5 all teams were at their sites.

Onsite prelaunch preparation began with launch simulations at Cape Canaveral and Bermuda. A total of ten launch simulations were conducted, five on May 2 and five on May 4.

The network simulations began on May 7 with two simulations being conducted on that day. In the first simulated mission, the systems-analysis capabilities of the flight controllers were exercised by a failure of the FBW high thruster control followed by a loss of cabin and suit pressure integrity. The second simulated mission contained a 1-second-late sustainer engine cut-off resulting in an overspeed insertion which caused a higher than normal apogee. These conditions tested the ability of the flight dynamics officer and retrofire monitors to calculate new reentry areas and retrofire times. Also, all the flight controllers were tested in their ability to adjust to an abnormal sequence of acquisition-of-signal and loss-of-signal times.

On May 8 the first simulation contained noisy and intermittent telemetry data, and the flight controllers were required to obtain data from backup recorders. The second mission contained a leaking regulator in the manual fuel pressurization system. During the second orbital pass a Military alert was simulated, which caused a reevaluation of the Mission Rules concerning loss of two-way communication with the spacecraft.

The first mission of the third day of simulations, May 9, was primarily an aeromedical monitor exercise with the astronaut experiencing a simulated heart attack. The second mission of the same day contained another systems problem with a failure of the main fans inverter and the standby inverter. Reentry was initiated by the California station when the Guaymas station experienced a failure of the air-ground transmitting capability. Landing was approximately 1,100 miles downrange from nominal because of a failure of the third retrorocket to fire.

The last simulation was on May 12 and an attempt was made to exercise both the range maintenance and operations personnel and the flight controllers. During the mission the 10.5-kc voltage-controlled oscillator drifted in frequency, and this action required the telemetry ground-station operators at the remote sites to adjust the discriminator center frequency control constantly, and the flight controllers to analyze the pulse-amplitude-modulation wave train on the backup recorders.

Throughout the simulations, the intent was to provide the flight controllers and support personnel with the atmosphere of an actual mission. For that reason, each mission began with lift-off, and reentry was determined by the condition of the spacecraft and the astronaut without regard to any set pattern of orbital or reentry simulations.

The performance of the site simulation teams, and particularly the astronaut simulators, was outstanding throughout the MA–9 simulations. Probably the most often heard criticism of the MA–9 simulations was the fact that 3 consecutive days of network simulations were scheduled. This rigorous schedule imposed extremely long hours on the maintenance and operations personnel as well as the flight controllers.

Mission.—The network countdown for MA–9 was initiated on May 14 at 2:00 a.m. e.s.t. The spacecraft–launch-vehicle countdown proceeded normally. The network radar-computer data test was completed on schedule, and the mandatory equipment at all stations was operating satisfactorily with the exception of the Bermuda FPS–16 radar, which had failed the slew tests in both azimuth and range. The slew tests were scheduled to be rerun for Bermuda, and the "C" computer at Goddard was standing by to check the Bermuda data. Bermuda estimated that it would take an hour to isolate the problem. Reruns of the radar-computer data tests indicated the azimuth and elevation data were good; however, some dropouts were experienced in range.

At T–60 minutes, a series of short-duration holds, eventually totaling 2 hours, were called because of problems with the diesel generator used for moving the gantry. The fuel system on the diesel was changed and the count was resumed at 9:09 a.m. e.s.t.

The Bermuda radar had passed the test performed during the hold; however, there was still a 14-percent error rate in the range data. Continual status reports were obtained from Bermuda, and the performance of the radar was marginal for the T–45 minute liquid-oxygen status check. A final slew test was performed with Bermuda at T–20 minutes, and the error rate on these data was unacceptable. It was determined at this time that the radar would not be able to support the mission and the launch attempt was canceled at 10:00 a.m. e.s.t.

The Bermuda station began immediate troubleshooting of the FPS–16 system, and the Goddard computer was placed on a standby status to run data slew tests with the radar when it was repaired. The problems were isolated to the preamplifier in the azimuth digital data channel and the shift register in the range digital data channel.

The count was recycled for 24 hours and the network count was resumed at 2:00 a.m. e.s.t. on May 15. All primary network systems were operational when the countdown was initiated.

The confidence summaries transmitted by the network to verify the site patching and calibrations were very good. No major discrepancies were noted in the network voice communications; however, Zanzibar, Canton Island, Rose Knot Victor, and Coastal Sentry Quebec stations were influenced by propagation and several repeats were required from the stations. The May 15 countdown was continuous except for a short hold for the launch vehicle ground support equipment. The countdown was resumed within approximately 4 minutes and lift-off occurred at 8:04:13 a.m. e.s.t.

The powered-flight phase was normal, and all launch events occurred at the expected time. The performance of the guidance and data systems was excellent. A clear go condition was evident at insertion, and orbit lifetime was not considered to be a problem. All vehicle systems performed satisfactorily through launch and the air-ground communications were better than those of the previous mission.

After spacecraft separation from the launch vehicle, the astronaut manually performed a FBW-low turnaround maneuver. Shortly after the completion of this maneuver, the Bermuda station advised the MCC that they had observed approximately a 6° F rise in cabin and suit dome heat-exchanger temperatures. The astronaut was informed of this situation and increased the coolant flow. When the astronaut acquired voice communications with the Canary Islands station, he said that the dome temperature warning light had come on, which indicated that the suit dome temperature was below 51° F. The astronaut was required to monitor this temperature throughout the flight and to make frequent adjustments to the coolant control valve. The cabin temperature rose from 94° F at launch to approximately 118° F when the spacecraft passed over Muchea as a result of the exit heat pulse; subsequently, this temperature began to decrease slowly to a value of between 90° F and 100° F. All spacecraft systems were functioning normally, and MCC advised the Guaymas station to transmit to the astronaut the go decision for seven orbital passes. Throughout the flight, cabin air temperature appeared to vary slightly as a function of the spacecraft a–c power configuration. During the periods when the ASCS 115v a–c inverter was powered for an appreciable time, the temperature rose to a maximum value of 105° F; and when this inverter was powered down, the temperature decreased slowly over a period of several orbital passes to a value between 85° F and 95° F.

The first discrepancy occurred over Cape Canaveral at the beginning of the second orbital pass. When the telemetry was commanded by the ground, a series of repetitive telemetry calibration signals occurred. It was decided that the programed telemetry calibration function would be turned off during the sleep period so that it would not interfere with normal telemetry.

At the beginning of the fifth orbital pass, the astronaut turned the cabin fan and cabin heat exchanger off as indicated by the Flight Plan. It was noted subsequently that turning off the cabin cooling did not materially affect the cabin temperature. The astronaut opened the outlet port of the condensate trap, and whenever this trap was activated, it is believed that the system performed satisfactorily. It was noted early in the flight that the actual power consumption was less than predicted. This surplus electrical power was utilized to obtain more beacon tracking during the later phases of the flight. The C-band beacon was powered up three times prior to passes over the Hawaii station to enable tracking by the Range Tracker ship.

Fuel usage was also less than expected, and all reports indicated that the astronaut was managing his fuel supplies exceptionally well. The astronaut made several attempts to deploy the tethered balloon, in support of air-density studies and visual tests; however, all attempts were unsuccessful. After ground analysis of this system, it was decided that no further attempt would be made to deploy the balloon.

The most serious trouble of the flight was reported over Hawaii during the 19th orbital pass. The Hawaii spacecraft communicator contacted the astronaut and received a report that the 0.05g green telelite had come on and that the astronaut had placed the ASCS 0.05g fuse switch and the emergency 0.05g fuse switch to off. The main concern at MCC was to establish the state of the amplifier-calibrator (auto pilot) unit and to determine what functions of the ASCS were lost as a consequence. There was no need for planning early mission termination at this time as no Mission Rules had been violated and there was an effective control mode remaining on both the automatic and manual control systems.

After analysis and discussion of the problem, it was decided that the first step was to have the astronaut power up the ASCS bus as the spacecraft passed over Guaymas. Subsequently, over Cape Canaveral, the gyros were slaved to the horizon scanners; and after about a minute of operation, no gyro or scanner deviation from the gyro caged condition was noted. This situation indicated that the gyro and scanner power actually was off and that the 0.05g circuit was latched up. It was realized at this time that a manual retrofire would be required and that a checklist must be prepared for the astronaut. The remote-site flight control personnel on standby status were called to their stations and advised to be prepared to attempt to relay communications to the astronaut if directed by the MCC.

While he was in contact with the Coastal Sentry Quebec, the astronaut was requested to turn on the telemetry and C-band beacon to allow the Range Tracker to check its radar data. These data were very important since the retrofire maneuver would be performed manually. While the spacecraft was passing over the Hawaii station, the astronaut was requested to place the ASCS 0.05g and emergency

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0.05g fuse switches to the on position and to select the ASCS automatic mode to verify the 0.05g event. If the spacecraft began to roll as it would normally do when the 0.05g indicators were valid, the ASCS would be latched in the reentry mode. The astronaut verified this roll rate and the 0.05g event which were again confirmed by telemetry over the Guaymas station.

At this point the flight controllers knew the exact configuration of the ASCS logic and the required configuration for reentry. After completion of these tests, it was determined that the ASCS would provide proper attitude control and roll rate for reentry after the normal 0.05g event time. The manual retrofire checklist was completed and thoroughly reviewed by the MCC flight control team. This checklist was relayed to the spacecraft via the spacecraft communicator on the Coastal Sentry Quebec and written down by the astronaut. The astronaut was advised to "take Green for go" which was a coded means of telling him to take a dexadrine pill. The purpose for taking the pill was an added precaution to be sure that he was alert for the manual retrofire maneuver. The flight surgeon was not concerned over the astronaut's condition but he was not certain the astronaut was thoroughly rested from his sleep. On acquisition by the Zanzibar station on the 22nd orbital pass, the astronaut reported that the ASCS inverter had failed and the standby inverter would not start. These failures meant that the pilot could no longer have automatic control after 0.05g but would have to introduce the reentry roll rate manually. The failure of the inverters to start required that a revision be made to the checklist previously transmitted to the astronaut. The revision consisted of changing only one switch position on the earlier checklist.

Prior to retrofire, the Coastal Sentry Quebec acquired the spacecraft and the reentry procedures were reviewed. The astronaut was given time hacks at retrofire minus 60 seconds, minus 30 seconds, and a 10-second terminal countdown. The telemetry immediately confirmed the retrofire and the astronaut indicated that his attitudes were good and confirmed that all three retrorockets had ignited. Reentry blackout was confirmed by the Range Tracker ship within 2 seconds of predicted time which indicated that the landing point would be close to nominal.

The network flight-control teams performed well during this flight. Communications between the ground and the astronaut were precise and conveyed the necessary information. The flight control teams utilized the proper contact and reporting procedures that were developed for this flight test. The operations messages provided much useful real-time data, and no difficulty existed in determining the precise status of the spacecraft, the astronaut, or the mission. The entire mission period from deployment through recovery was an extremely smooth and well coordinated effort. The cooperation between the flight astronauts and the flight control personnel had a significant influence on the success of the MA–9 mission.

Concluding Remarks

The flight control organization has played a significant role in the first space flights and has made a major contribution to the success of the Mercury program. A wealth of experience and information has been gained from the project. Some of the more important are as follows:

(1) Documentation used by flight control had to be easy to update, contain detailed information, yet be put together in such a manner that the information could be found quickly in real time.

(2) People could not be borrowed from other organizations on a part-time basis to be flight controllers. It not only disrupted their own organizations but prevented them from being able to devote the required amount of time to the flight control task. As a result, it was learned that full-time flight controllers were a necessity.

(3) It was also discovered that a flight controller had to have the following special qualification: The flight controller must be a technically trained individual. It became apparent he should be an engineer or oriented toward engineering with a wealth of experience in system analysis.

(4) It was also found that a continuing program of training was necessary to keep flight controllers proficient in knowledge of spacecraft systems and operation procedures.

(5) The network and launch simulations held prior to the actual mission were found to be a necessity. In simulations, mistakes are made

and corrected. Simulations are run until the entire network is functioning as a team and complete confidence is gained in the ability of the flight controllers to respond correctly to any emergency.

(6) Because of the experience gained in Mercury it has become obvious that the more complex missions of Gemini and Apollo will require more automation. In order to be able to process the information in real time and arrive at a proper decision, it is necessary that more data processing aids be utilized.

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16. RECOVERY OPERATIONS

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Summary

The basic philosophy for the recovery phase of Project Mercury was to provide a positive course of action for any conceivable landing situation that could develop, and to provide recovery support according to expected needs and the probability of such situations occurring. Throughout the program this philosophy was continuously reviewed as experience was gained and mission complexity increased. Although certain improvements and changes were made in recovery equipment and techniques, there was no significant change in the basic philosophy originally adopted and all recovery operations were highly successful.

Introduction

This paper presents a general review of the recovery planning and operations conducted for Project Mercury. A discussion of the overall recovery philosophy and a brief description of the location and retrieval techniques that were planned and used for spacecraft recovery are included.

Recovery Philosophy

In reviewing Project Mercury recovery operations, it is appropriate to go in some detail into the basic philosophy upon which recovery planning was based. The foundation of this philosophy was the premise that a positive course of action to provide safe recovery of the astronaut would be planned for all conceivable landing situations, including provisions for the most expeditious return of the spacecraft. The type of action to be taken was determined by the probability of occurrence and location of the landing. For this purpose, possible landings were divided into five general categories, as follows:

(1) The first category included landings which might occur during that period of the mission from arming of the launch escape system prior to launch until that point after launch where an abort would result in a landing within 12 miles of the launch site at Cape Canaveral. This area is referred to as the "Launch Site Abort Landing Area."

(2) Aborts subsequent to this time and prior to insertion of the spacecraft into orbit would result in a landing in one of several planned "Pre-orbital Abort Landing Areas."

(3) After the spacecraft was committed to orbit, Planned Landing Areas were selected so that a landing could be made in the vicinity of predeployed recovery forces at approximately 100-minute intervals through the flight.

(4) The "Primary Planned Landing Area" was that area where the flight would be ultimately terminated, if possible.

(5) Finally, a landing might occur at any place along the ground track as a result of an emergency situation. This emergency might not permit the spacecraft to reach one of the planned landing areas and, therefore, would result in a contingency recovery situation. A location capability was provided along the entire ground track of the flight. To reduce the search area, when some choice of spacecraft landing point remained available, so-called preferred contingency landing areas were designated. These areas were intermediate locations along the ground track between planned landing areas that either were adjacent to land areas or location forces.

The degree of support in terms of the number of ships, aircraft, and personnel planned for each of these landing areas was determined by the degree of probability that a landing might occur. Hence, since the greatest probability of a landing was in the primary landing area, the greatest level of support was provided here. The amount of support provided for contingency landings was considerably less, consistent with the much lower probability of a contingency landing.

It can readily be seen that extensive recovery forces were necessary to support this philosophy. In keeping with the National Space Act, maximum utilization was made of Department of Defense (DOD) capabilities, with a minimum of interference with their normal operational functions. (See paper 9.) Although standard DOD ships and aircraft could be utilized, the requirement existed for specialized equipment to support the Project Mercury recovery operation. The special equipment necessary was provided by the NASA. Indoctrination and training programs were conducted to establish and qualify recovery procedures and familiarize the forces involved with the use of specialized equipment and techniques.

This basic philosophy for recovery planning was continuously reviewed throughout the program, particularly in light of experience gained from each successive mission and with regard for the increasing complexity of forthcoming missions. Nothing developed to justify any significant change in the basic philosophy originally adopted, although certain improvements and changes were made in the equipment and techniques used in support of the recovery plans.

There are three major phases in the recovery operation: location, retrieval, and postrecovery activities. The location phase began with the notification of the recovery forces that a landing was imminent and the general area in which the landing could be expected. As the landing progressed from retrofire through reentry to actual touchdown, information from the Mercury Worldwide Network provided a predicted landing point.

Search aircraft, both airborne and on station in the planned landing areas or staging from a contingency deployment site, then proceeded toward this point conducting an ultra-high frequency/direction finding (UHF/DF) electronic search for the spacecraft recovery beacon or personal survival beacon enroute. Upon receiving a signal, they would then home in on it until close enough to conduct a visual search, aided in daylight by dye expelled from the spacecraft or by a flashing light at night.

In the absence of a reliable network landing-point prediction, alternate sources could be called upon for such information. Some geographical areas were blanketed with either HF/DF or SOFAR networks which could determine the general location of spacecraft landing within their limits of coverage. For landings outside those areas, where no other specific location information was available, location would be accomplished by searching the ground tracks along which the landing could have occurred.

In the early part of the project it was desirable that the retrieval of the spacecraft could be accomplished by either ships or helicopters. All ships utilized in the program had the capability of lifting the spacecraft from the water. Those ships not having a lifting crane could, with a minimum of modifications, utilize their existing boat davits to lift the spacecraft (fig. 16–1). Helicopters with the capability of lifting the spacecraft were equipped with special hooks and lifting slings (fig. 16–2) to provide them with a man-rated retrieval system. Early in the project, when uncertainties about the condition of the spacecraft and occupants were the greatest, helicopters were considered the most desirable means of retrieval because of their ease of access to the scene of the landing and the rapid method of spacecraft retrieval.

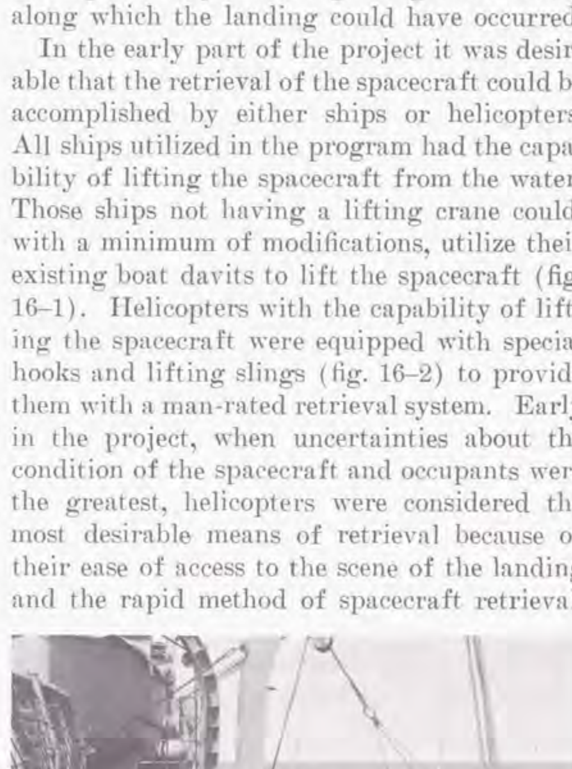


FIGURE 16–1.—Modified davit and hold-off rig on destroyer.

FIGURE 16–2.—Spacecraft being lifted from water by helicopter.

Procedures were established whereby the astronaut would be retrieved by the same helicopter that picked up the spacecraft. It was not possible to have helicopters in all the landing areas, however; so in those areas of lower landing probabilities only ships, with retrieval capability, were provided.

This philosophy existed throughout the early development flights at Wallops Island and through the Redstone program. The helicopter retrieval method by its very nature required maximum demands on both personnel and recovery equipment. The experience of MR–4, when the helicopter was able to hook the spacecraft but was unable to retrieve it successfully, pointed out the limitations of this method. It was apparent then that this method exposed itself to many hazards that were not desirable.

During the early development flights, a concurrent program for development of an auxiliary flotation collar was underway. The attachment of this collar (fig. 16–3) to the spacecraft

FIGURE 16–3.—Auxiliary flotation collar.

provided increased flotation capability to the spacecraft under all water-landing conditions. The collar also provided a suitable working platform for rendering assistance to the astronaut, and it also served as a platform from which the astronaut could be retrieved by helicopter. The spacecraft, even with an open hatch, was seaworthy when fitted with the auxiliary flotation collar.

After the suborbital flights had been completed, the following technique was instituted as the primary retrieval method. After spacecraft location, either swimmers or pararescuemen, deployed by helicopter or aircraft, would attach the flotation collar to the spacecraft. The astronaut could then exit the spacecraft or remain within as he chose. Medical assistance could be given and spacecraft systems could be secured as well. Retrieval of the spacecraft was to be made by surface ships and use of the helicopters was primarily intended for retrieval of the astronaut only.

Following retrieval, the post-recovery activities of the astronaut include: personal medical attention as required; physical examinations; a medical debriefing and technical debriefings with trained specialists in these fields; and scheduled rest periods. Following retrieval of the spacecraft, trained personnel secured the spacecraft systems, conducted initial postflight inspections, and removed the onboard data for rapid delivery to Cape Canaveral. The spacecraft was then transported by special airlift to Cape Canaveral for detailed inspection and analysis.

The recovery plan for contingency area landings included the deployment of pararescue men by parachute as soon as possible after the spacecraft had been located by search aircraft. For water landings the auxiliary flotation collar, also dropped by parachute from the search plane, was then attached to the spacecraft so that the astronaut could emerge to await rescue. Rescue of the pilot and retrieval of the spacecraft were then to be accomplished by the most expeditious means available under the circumstances. Had the spacecraft been located by an aircraft not carrying pararescuemen, or had local conditions precluded their jumping to the spacecraft before the aircraft had to leave the landing area, drop buoys were provided to assure relocation of the spacecraft. These buoys were fitted with radio beacons compatible with the UHF/DF equipment in the search aircraft.

Many other preparations were made to insure a safe and rapid recovery. For example, a worldwide recovery communications network was established utilizing both DOD and commercial facilities. This extensive communication network was required to provide for rapid reporting and coordination among the recovery forces, Area Command Centers, and the Recovery Control Center at Cape Canaveral. A worldwide weather reporting and analysis system was also established to provide pertinent meteorological data in the recovery areas, so that action could be taken to delay the launch or move the recovery area in the event of adverse weather conditions.

Table 16–I provides pertinent recovery facts for all Project Mercury missions and shows how the various preparations described above were useful in each case.

Table 16–I.—Summary of Recovery Operations for Project Mercury

Flight	Launch date	Description	Range, nautical miles	Recovery forces		Location method	Retrieval by	Remarks
				Ships	Airplanes and helicopters			
Little Joe series (9 flights)	October 4, 1959, to April 28, 1961	Suborbital	10 to 169	3 to 4	3 helicopters (typical) (plus 2 airplanes on LJ II)	Visual and electronic	Ship *or* helicopter	Little Joe and Beach Abort-Development flights made from Wallops Island. Retrieval by helicopter or ship was accomplished on all successful flights and qualified the recovery methods.
Big Joe I	September 9, 1959	Suborbital	1,300	13	7 airplanes 3 helicopters	Reentry glow, SOFAR, electronic	Ship	Planned for 1,831 nautical miles but resulted in an undershoot with landing at 1,300 nautical miles—about halfway between two destroyers. No tracking information is available; but on the basis of visual sightings of reentry by three destroyers and confirmation of the landing point by a SOFAR bomb fix (T+2 hr), search aircraft located the spacecraft after acquiring beacon contact (T+3 hr) and directed a destroyer in for the retrieval operation (T+8 hr).

Table 16-I.—Summary of Recovery Operations for Project Mercury—Continued

Flight	Launch date	Description	Range, nautical miles	Recovery forces [a]		Location method	Retrieval by	Remarks
				Ships	Airplanes and helicopters			
MA-1	July 29, 1960	Suborbital (unmanned)	4.85	8	5 airplanes 3 helicopters	Visual and electronic	Salvage ship	Flight-vehicle structural failure shortly after launch. Salvage operations recovered most of spacecraft components.
MR-1	November 21, 1960	Suborbital (unmanned)	0	8	6 airplanes 3 helicopters	Visual		Launch-vehicle shut down immediately after lift-off. No recovery required.
MR-1A	December 19, 1960	Suborbital (unmanned)	204	8	4 airplanes 4 helicopters	Visual	Helicopter	Recovered by helicopter which was operating from landing ship, dock.
MR-2	January 3, 1961	Suborbital (chimpanzee)	363	8	6 airplanes 5 helicopters	Electronic	Helicopter	Retrieved by helicopter which was operating from a landing ship, dock, although a destroyer was on the scene. A contingency recovery operation (overshoot) with damaged spacecraft near sinking at time of retrieval.
MA-2	February 21, 1961	Suborbital (unmanned)	1, 244	8	14 airplanes 5 helicopters	Electronic	Helicopter	Successful suborbital flight. Helicopter retrieval and return to landing ship, dock.
MA-3	April 25, 1961	Orbital (unmanned)	0. 25	15	12 airplanes 7 helicopters	Visual	Helicopter	Guidance system failure, destructed by RSO resulting in spacecraft landing off-shore near Cape Canaveral. Launch-site helicopters successfully retrieved spacecraft.

MR-3	May 5, 1961	Suborbital (manned)	263	8	7 airplanes 7 helicopters	Visual	Helicopter	First manned mission. Spacecraft and astronaut retrieved by carrier-based helicopter less than 11 minutes after landing.
MR-4	July 21, 1961	Suborbital (manned)	262	8	7 airplanes 7 helicopters	Visual	Helicopter	Second manned mission. Spacecraft hatch prematurely opened and astronaut escaped into water. Helicopter hooked onto spacecraft but could not retrieve it. Astronaut was recovered by another helicopter and returned to carrier.
MA-4	September 13, 1961	Orbital (unmanned)	1 orbital pass	9	34 airplanes 6 helicopters	Visual	Ship	Planned one orbital-pass mission. Retrieval by destroyer after being located by aircraft in nominal landing area.
MA-5	November 29, 1961	Orbital (chimpanzee)	2 orbital passes	18	49 airplanes 9 helicopters	Electronic	Ship	Planned three orbital-pass mission terminated in planned landing area at end of two passes. Spacecraft and occupant (chimpanzee) successfully recovered by destroyer following aircraft location.
MA-6	February 20, 1962	Orbital (manned)	3 orbital passes	24	49 airplanes 14 helicopters	Visual	Ship	First manned orbital mission. Spacecraft landing in the prime recovery area at the end of third orbital pass. Nearby destroyer retrieved the spacecraft and astronaut.

[a] These figures do not include nonoperating contingency or backup aircraft.

Table 16–I.—Summary of Recovery Operations for Project Mercury—Concluded

Flight	Launch date	Description	Range, nautical miles	Recovery forces [a]		Location method	Retrieval by	Remarks
				Ships	Airplanes and helicopters			
MA-7	May 24, 1962	Orbital (manned)	3 orbital passes	20	49 airplanes 14 helicopters	Electronic	Helicopter (astronaut) Ship (spacecraft)	Planned three orbital-pass mission terminated in a landing 250 miles downrange of the planned landing point. A contingency recovery operation included pararescue deployment approximately on hour after landing. Astronaut recovery by helicopter and spacecraft retrieval by destroyer.
MA-8	October 3, 1962	Orbital (manned)	6 orbital passes	26	69 airplanes 14 helicopters	Visual	Ship	Planned six orbital-pass mission. Landing within sight of prime recovery carrier. Spacecraft provided with auxiliary flotation collar installed by helicopter-deployed swimmer teams. Spacecraft and astronaut retrieved by carrier.
MA-9	May 15, 1963	Orbital (manned)	22 orbital passes	[b] 26	110 airplanes 14 helicopters	Visual	Ship	Planned twenty-two orbital-pass mission. Landing within sight of prime recovery carrier. Spacecraft was provided with auxiliary flotation collar installed by helicopter-deployed swimmer teams. Spacecraft and astronaut retrieved by carrier.

[a] These figures do not include nonoperating contingency or backup aircraft.

[b] This number does not include 2 ships in the Middle East.

MA–9 Recovery Operations

A brief description of the recovery plan and operations for the MA–9 mission will serve as a typical example of the Project Mercury recovery, based on the philosophy and techniques previously described.

Prior to the MA–9 launch, all recovery forces were reported to be on station and ready. After insertion of the astronaut into the spacecraft, a pad-emergency egress team was standing by to assist the astronaut in the event he had to leave the spacecraft for some emergency that did not require activation of the launch escape system. This team included medical personnel, spacecraft specialists, and fire fighters in special vehicles.

Special recovery teams were located in the launch site abort landing area to provide rapid access to the spacecraft for landings resulting from possible aborts utilizing the launch escape system during the late countdown and early phase of powered flight. Because of the variations in the type of terrain and proximity to the ocean in the launch site area, these teams utilized helicopters and amphibious vehicles. Small craft operated in the Banana River, and standing by offshore were several salvage ships. Winds at the launch site were measured and abort landing positions were computed and plotted. These plots were used to evaluate possible landing hazards prior to committing the spacecraft to a launch and to optimize the positioning of these recovery forces.

Areas A through F, the pre-orbital abort landing areas stretching across the Atlantic Ocean and shown in figure 16–4, supported all probable landings in the event an abort was initiated at any time during powered flight. Landings in Areas A and B would result from an abort at velocities up to about 24,000 feet per second, and Areas C, D, E, and F would support aborts at higher velocities where programed use of the retrorockets would provide for selection of the landing area.

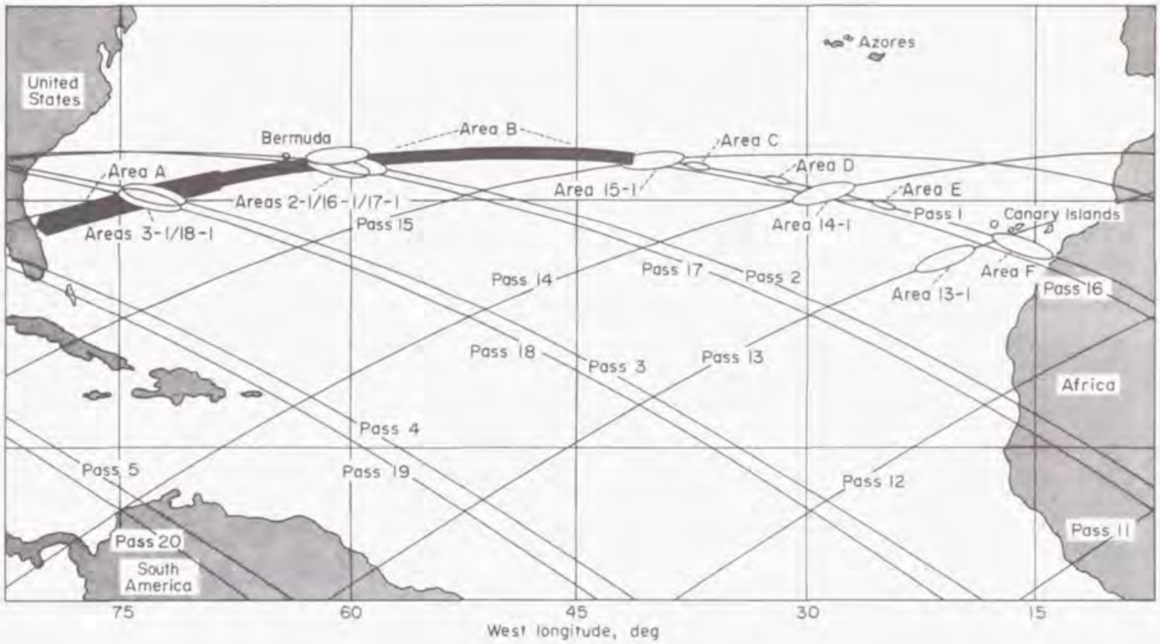
Also shown in figure 16–4 are the numbered landing areas. These locations are planned landing areas or areas in which the spacecraft could have landed if the flight had been terminated prior to the planned end of the mission. The planned landing areas were spaced so that the spacecraft would pass over one of them approximately every 100 minutes or about once per orbital pass.

Recovery forces were deployed within these landing areas so that location and assistance could be provided within a period of from 3 to 9 hours after spacecraft landing. This period, denoted as the recovery "access time," was a function of the planned deployment of recovery forces in a given area and varied according to the probability of a spacecraft landing within that area. Selection of landing areas at spacecraft ground track intersections permitted certain recovery units to move from one area to another during the flight and thereby provide support in several landing areas.

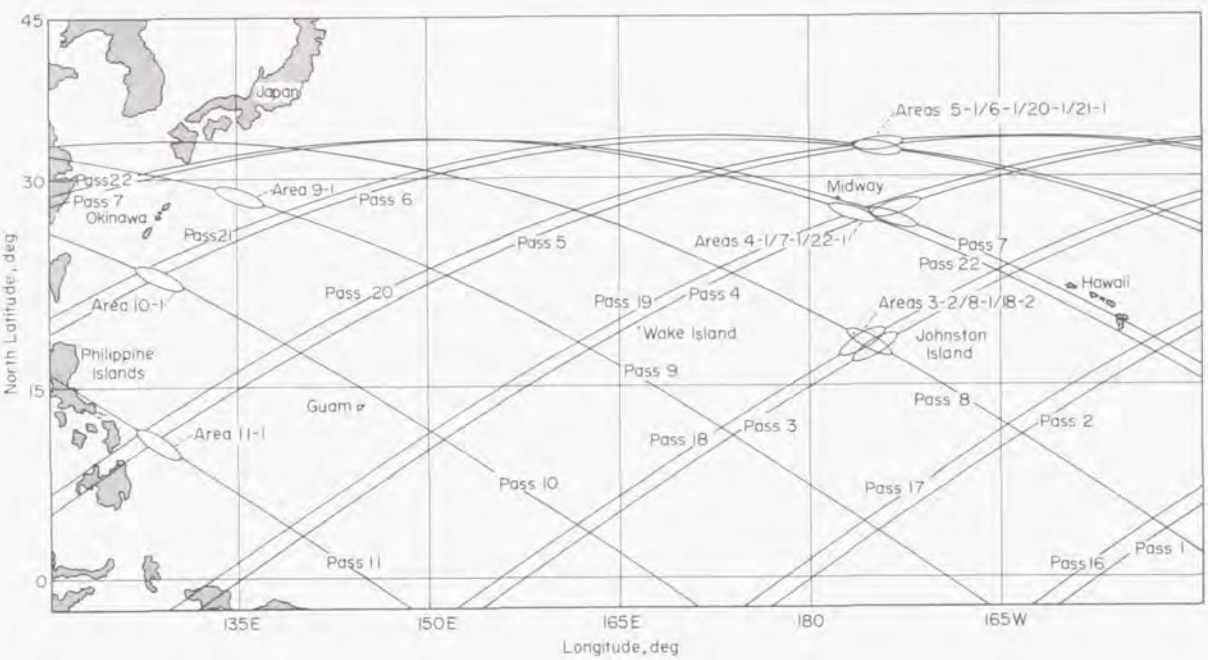
Throughout the mission, flight progress was continuously monitored, and periodically during the mission, decisions based on spacecraft and astronaut conditions were made to continue the flight. Obviously, a higher probability of landing is associated with the landing areas immediately following these decision points. Landing Areas 2–1 and 17–1 in the Atlantic and Area 7–1 in the Pacific were such areas and were referred to as "go—no–go" areas. Area 22–1, the Primary Planned Landing Area for a nominal flight, was located in the Pacific about 70 nautical miles southeast of Midway Island and adjacent to Area 7–1. Since the probabilities of landing in these two areas, 2–1/17–1 in the Atlantic and 7–1/22–1 in the Pacific. were considered to be higher than for other planned areas, recovery-support helicopters operating from aircraft carriers were provided for a more rapid access to the spacecraft and astronaut after landing.

A total of 23 ships and 44 aircraft were employed in supporting the planned water landing areas designated for the MA–9 mission, of which 12 ships and 26 aircraft were in the Atlantic planned landing areas, and 11 ships and 18 aircraft were in the Pacific planned landing areas. Additional search aircraft were available as backups to these aircraft on station.

A total of 66 contingency recovery aircraft and associated personnel were on alert status at staging bases around the world to provide support in the event a landing should occur at any place along the ground track. These aircraft were equipped to locate the spacecraft and to provide emergency on-scene assistance if required. A typical support unit at a stag-



(a) Atlantic Ocean



(b) Pacific Ocean

FIGURE 16-4.—MA-9 planned landing areas.

FIGURE 16-5.—MA-9 staging locations for contingency recovery.

ing base consisted of 2 or 3 long-range aircraft with pararescue personnel. The location of contingency recovery units for the MA-9 mission is shown in figure 16-5. All recovery forces, including those in the planned landing area and those supporting contingency landings, were linked by communications with the Recovery Control Center located within the Mercury Control Center at Cape Canaveral.

The location and retrieval of Astronaut Cooper and his spacecraft were straight forward. The spacecraft of the MA-9 mission landed approximately 4½ miles from the recovery aircraft carrier, the *USS Kearsarge*, positioned in the center of Area 22-1. The *USS Kearsarge* had radar contact with the decending spacecraft, and carrier personnel visually sighted the spacecraft as it descended on its main parachute.

Helicopters launched from the carrier prior to spacecraft landing were in excellent position to deploy swimmers who immediately installed the auxiliary flotation collar around the spacecraft. As the carrier approached the spacecraft a motor whaleboat carried a retrieving line to the spacecraft (fig. 16-6). The spacecraft was lifted clear of the water and placed on the carrier deck. The explosive-actuated hatch was then released, and medical personnel began their initial examination of the astronaut.

Following a debriefing and rest period aboard the carrier, the astronaut and his spacecraft were airlifted to Cape Canaveral from Honolulu, Hawaii.

FIGURE 16-6.—Motor whale boat carrying retrieving line to MA-9 spacecraft.

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17. ASTRONAUT PERFORMANCE

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Summary

As flight experience was gained, confidence in the Mercury mission and particularly in the pilot's capabilities increased, which resulted in the pilot playing an increased role in establishing the configuration and in the operation of the spacecraft. As a result (1) improvements were made in preparing the crews for flight, (2) ground-flight coordination was improved, (3) mission rules became more definite, (4) more functions were delegated to the pilot, (5) many systems modifications were made to increase the pilot's systems management capabilities, (6) operating procedures were simplified, (7) flight activities became more flexible, (8) inflight activity priorities were more clearly defined, and (9) pilot workload became better distributed. The benefits of this experience were manifested during the MA–9 mission where the success of the flight was directly attributable to the performance of the pilot.

Mercury flight experience has shown that man's performance in a spacecraft environment is very similar to his performance in an aircraft environment. This fact will enable manned spacecraft designers to utilize several decades of aircraft design and operational experience in the formulation of man-machine relationships for Gemini and Apollo.

Overall results of the Mercury program verify that the pilot, given adequate controls and displays, and sufficient monitoring instrumentation, is a reliable and flexible system of the entire spacecraft and launch vehicle and enhances the success of the mission. In addition, with the proper equipment, he can greatly benefit the experimental effort.

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Introduction

This paper is the summary report on the pilot's ability to operate the Mercury space vehicle and to accomplish experiments as well as make scientific observations. The main topics to be discussed are attitude control of the vehicle and overall management of spacecraft systems because of their importance during Mercury and future space missions, and because it generally in these areas that the most objective and valid data were obtained. The results obtained from each Mercury flight are summarized with particular elaboration upon the MA–9 results since the results of prior flights have been reported in references 1 to 5. Topics are discussed chronologically with examples from each flight when applicable. This approach should illustrate the trend in operational philosophy throughout the program concerning the increased role of the pilot.

Attitude Determination

Throughout the program a great deal of effort was applied toward investigating the relative value of the Mercury spacecraft's controls and displays for various maneuvers and for vehicle orientation. The results of these investigations, as well as brief description of the different controls and displays, are summarized. Figure 17–1 illustrates the display and control systems that were available in the spacecraft.

The attitude displays available in the Mercury spacecraft were a centerline window, a periscope, and an attitude and attitude-rate indicating instrument (fig. 17–1). The centerline window, located directly in front and almost level with the pilot's head, was trapezoidal

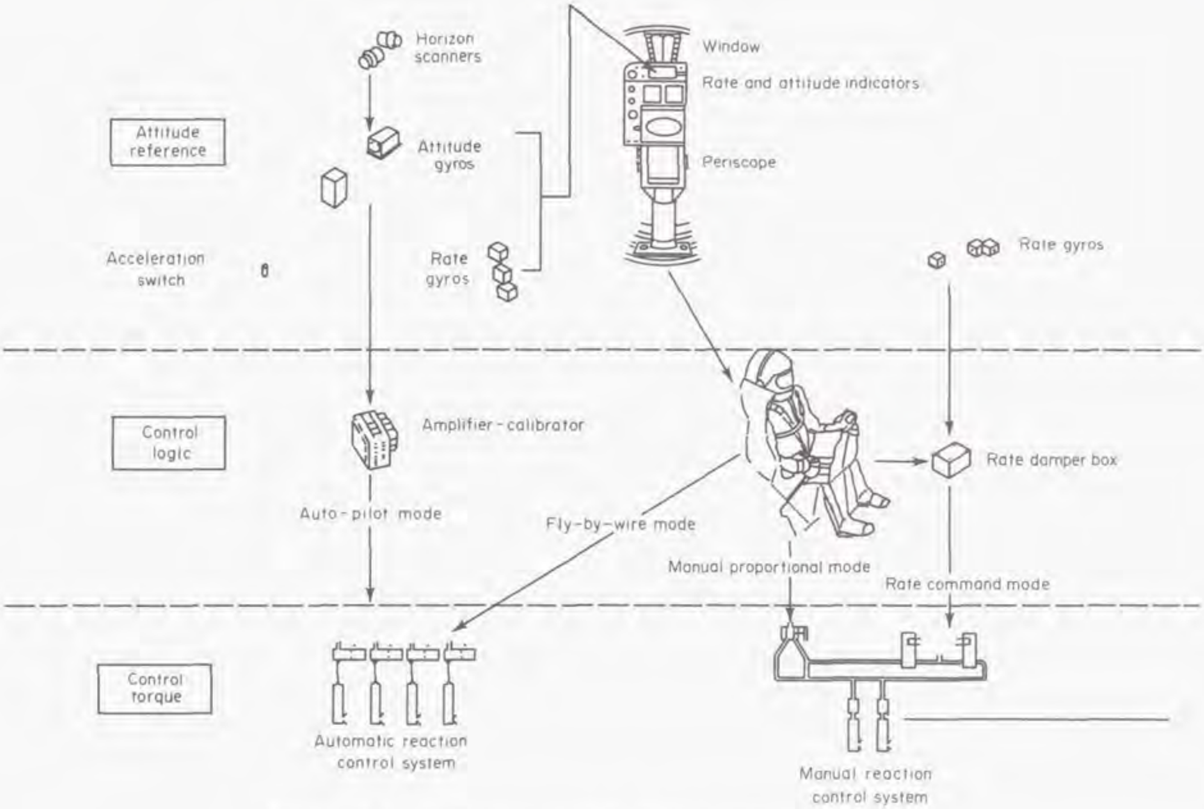


FIGURE 17-1.—Mercury spacecraft display and control systems.

in shape. The viewing limits, with the head restrained, were 33° vertically, 22° laterally at the bottom, and 54° laterally at the top. The periscope, located at the bottom of the center instrument console, was oriented to the earth's nadir when the spacecraft was at a pitch attitude of −14°. The field of view through the periscope was 172°. The attitude and attitude-rate indicating instrument, located at the top of the center instrument console, consisted of six needles, one for each attitude, and one dial which displayed attitude rates. (See fig. 17-2.)

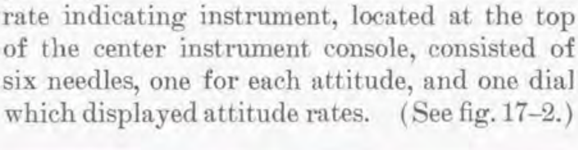


FIGURE 17-2.—Mercury rate and attitude indicators.

The attitude indicators were referenced to the gyros which, in turn, were slaved to the horizon scanners during normal operation.

The relative value of each display system was dependent upon the task to be accomplished. Generally, the window and periscope were both adequate for spacecraft orientation during daylight conditions, whereas only the window was an adequate external display system under reduced lighting conditions. For example, the periscope was the best display for acquisition of the earth horizon and for realinement of the gyros to the true earth-referenced spacecraft attitudes because of its wide field of view. However, in obtaining this wide field of view it was necessary to reduce the image, which resulted in a high attenuation of available light and caused the periscope to be ineffective during the night period. The periscope was removed for the MA-9 flight.

The attitude indicators were used primarily during those periods when the pilot's attention was required in the cockpit, when external references were lacking, and when establishing proper rates and attitudes prior to engaging the automatic system. The indicators were also preferred for controlling the spacecraft attitude during the firing of the retrorockets because the pilots had been trained much more thoroughly in this method than in using an external visual-display system. Although the attitude indicator system provided good references for such operations as those described above, they also had several shortcomings. Attitude maneuvers beyond a very narrow operating corridor had a great effect upon the accuracy of the system. This problem was reduced as a result of modifications to the later Mercury spacecraft attitude-control systems; however, because of the basic characteristics of the gyros and of the attitude repeater stop limits, it remained a nonversatile system.

In summary, the window was the most versatile and reliable of the three display systems. The periscope disadvantages outweighed its advantages, and the attitude and attitude-rate indicators were a good display system within rather narrow operating limits.

Controls

The Mercury spacecraft had four basic attitude-control modes which could be used singly or in various combinations. These control modes were: automatic stabilization and control system (ASCS), manual proportional (MP), fly-by-wire (FBW), and rate stabilization control system (RSCS). Each of these modes was used and evaluated extensively throughout the early Mercury flights, and as a result, their relative value and efficiency for various attitude-control maneuvers became evident.

The ASCS was capable of controlling spacecraft attitude and rates, or both, in all three axes by using information from the attitude and rate gyros. Four automatic modes of operation were available: a reentry mode, an orientation mode, a retrograde attitude hold mode, and an orbit mode. The reentry mode positioned the spacecraft to the proper reentry attitude, inserted the roll rate, and damped the reentry oscillations. The orientation mode was designed to position the spacecraft to any specifically commanded attitude to within $\pm 1°$. The retrograde attitude hold mode utilized the high torque thrusters to maintain the spacecraft to within $\pm 1°$ and $\pm \frac{1}{2}°$/sec of retrofire attitude. The orbit mode was designed to control the spacecraft at the retrofire attitude to within approximately $\pm 8°$. The purpose of the first three control modes is self-explanatory, and their relative value compared with the manual control system is discussed in a subsequent section of this paper. The orbit mode of operation, however, requires a brief discussion at this point. This mode was designed to control the spacecraft within rather broad limits for long periods of time and with economical fuel usage. While in orbit mode, the pilot could devote his attention to other systems, perform experiments, make observations, or relax. During the MA-9 flight this mode was used extensively for conducting various experiments. In addition, the MA-9 pilot utilized a modified orbit mode of operation by manually positioning the Y-Z plane of the spacecraft parallel to the ecliptic plane and then manually realining the attitude gyros to this new reference plane. This action resulted in automatic control of the spacecraft in the desired plane and allowed the pilot to complete the dim-light photographic experiment, the results of which are reported in paper 12.

Of the three manual control systems, FBW proved to be the most versatile. In the initial design, the 1-pound thrusters were actuated at approximately 25 percent of full control-stick travel, whereas the 24-pound thrusters were actuated at approximately 75 percent of full control-stick travel. In order to prevent inadvertent actuation of the high thrusters, a modification was made on the later spacecraft by which the pilot could, by throwing a switch, lock out the high thrusters. Generally, the pilots preferred this control mode during orbit because precise attitude maneuvers and control, or both, could be accomplished with minimum fuel usage.

The MP system was not used extensively during the Mercury flights except in the MA-9 mission. Earlier mission results indicated that neither fine attitude control nor fuel economy could be obtained with this system during orbit because of the minimum thrust levels that could be obtained and the rather long thrust-response lag characteristics that existed in this system. During the MA-9 mission the pilot demonstrated that by making very rapid hand-controller motions, the MP system would produce thrust impulses of a much lower level than expected. Results of this mission indicated that the pilot was able to exercise precise attitude control with fuel consumption rates similar to those of the FBW 1-pound thrusters.

The RSCS was used primarily for the reentry phase of the flight. It was normally not used for orbital maneuvers because fine attitude control was difficult to maintain and required an excessive amount of control fuel. The RSCS was removed from the spacecraft for the MA-9 flight.

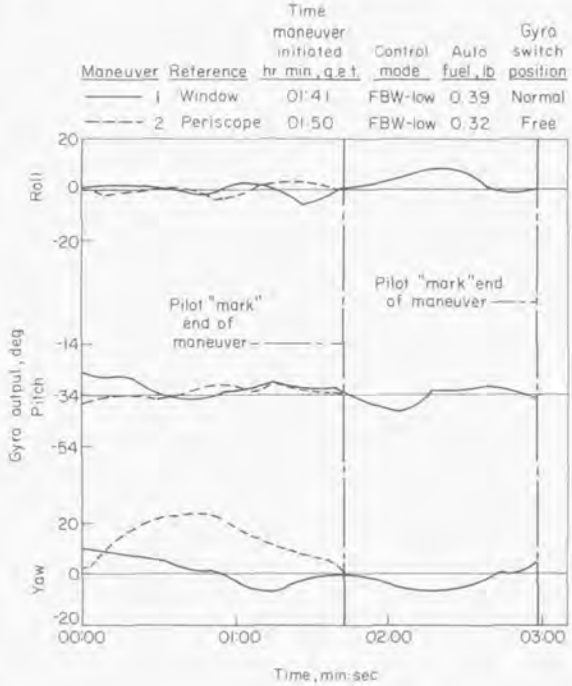
All the various manual control systems were controlled by the pilot by using the three-axis hand controller. This proved to be an adequate controller for manipulation of the manual control systems.

Yaw Determination

Throughout the Mercury program, investigations were made to determine the pilots' abilities to orient the spacecraft in yaw by use of external reference information. Although pitch and roll reference was not considered difficult as long as a view of the earth's horizon was available, as expected, yaw determination was more difficult. Inflight information was considered necessary to evaluate how accurately and how long it would require the pilot to orient the vehicle, particularly when good external references were lacking.

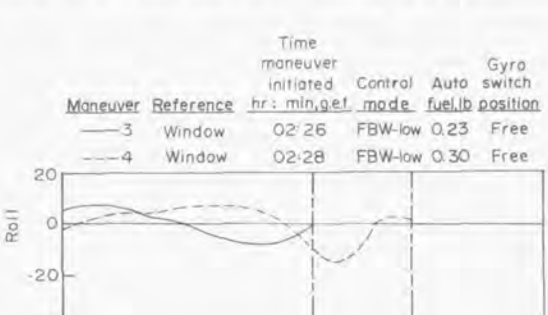
The results from the MA-6 and MA-7 flights indicated that yaw determination during day or moonlit night conditions was not difficult but took more time than did determinations for pitch and roll. Yaw orientation at night with no moon required even more time, and accuracy was somewhat reduced. Both the MA-6 and MA-7 pilots reported that yaw determination by using the window was improved as the vehicle was pitched toward the nadir point. However, since the horizon is not in view to the pilot beyond a pitch-down attitude of approximately 45°, this method makes it difficult to distinguish between yaw and roll errors.

The results of the first two orbital flights suggested that a thorough analysis of yaw determination areas was desirable. A series of yaw maneuvers were planned and accomplished during the MA-8 mission which provided quantitative information on the use of the window and periscope as independent references for determining yaw during both day and night phases of the orbit. (See ref. 5.) The results of these maneuvers are shown in figures 17-3(a) and 17-3(b) and include the attitude variation in all three axes, fuel, time required, and the sole



(a) Day.

FIGURE 17-3.—Yaw maneuvers during MA-8 mission.



(b) Night.

FIGURE 17-3.—Concluded.

reference used. At the termination of each maneuver the pilot "marked" it on the onboard tape recorder.

As can be seen by these figures, the pilot was successful in determining yaw under both day and moonlit night conditions by using the view through the window as a sole reference. Furthermore, these maneuvers were accomplished at a pitch attitude of $-34°$, which made the horizon available for good pitch and roll reference. The day yaw maneuver in which the view through the periscope was used was completed within the same accuracy and time period as were the yaw maneuvers in which the view through the window was used. The pilot did not attempt a night yaw maneuver using the periscope because he found that it was ineffective even under moonlit night conditions. The pilot stated that he could have alined the spacecraft much more quickly than these maneuvers indicated if urgency had been a more important consideration than the conservation of fuel.

Since the information obtained from the first three orbital missions was quite conclusive, the periscope was removed from the MA-9 spacecraft, and no specific investigation concerning yaw determination was planned for the MA-9 flight. However, it should be noted that in preparing for retrofire, the MA-9 pilot performed a very critical and precise yaw alinement at night by using stars and ground references only.

The MA-9 pilot reported that yaw determination in daylight was quite easy even when only a small portion of the earth horizon was in view ($-20°$ to $-25°$, pitch attitude). He felt he could accurately aline the spacecraft directly toward or away from the direction of motion over the ground within 1°. At the 90° yaw position he believed his accuracy might be degraded to $\pm 10°$. The pilot used several cues to determine yaw attitudes and rates during daylight, such as the "streaming by" of terrain features, and cloud patterns, or both, the convergence point of these flow lines, and the tracking of terrestrial objects or cloud prominences across the window.

The pilot reported that yaw-attitude determination at night was not difficult but it usually required more time. If he was well dark-adapted and the moon was illuminating the earth, he used the motion of terrestrial features and cloud features. Occasionally, lighted cities provided good yaw reference even without moonlight. When these references were not available, he was required to use identifiable stars and constellations. This was more complicated and usually took more time because the restricted field of view through the spacecraft window made identification of the constellations more difficult.

A convenient method of yaw determination was noted by the MA-9 pilot after observing the relative motion of the so-called fireflies seen by all of the pilots of previous orbital missions. These luminous particles, which appeared to emanate from the thrusters, were observed to move outward from the spacecraft and then to recede back along the spacecraft's trajectory in the manner of a contrail, remaining visible for several seconds. The pilot believed that by positioning the spacecraft relative to the motion of these particles, an accurate determination of the 0° yaw position could be achieved.

Gyro Realinement

The realinement of the attitude gyros to the spacecraft's attitude was an important function because it directly affected the usability of the entire ASCS and Mercury attitude indicating systems. The two important objectives in accomplishing this maneuver were maximum accuracy of alinement and minimum fuel expenditure. There were several variables which directly affected these objectives, such as the control and display systems used, the external conditions (day-night), the external references available, and the time available. Time was particularly important because the spacecraft could be alined accurately and with low fuel usage even during worst conditions, providing ample time was available to complete the maneuver.

One important systems modification which significantly affected the capability and ease of realining the gyros to the spacecraft attitude was changing the gyro caging position to $-34°$ in pitch. All but the MA-9 spacecraft's gyros caged to the zero position in all three axes. With the spacecraft in this position, the earth horizon was not available through the window. Although the total realinement maneuver was quite complex in the earlier missions, the MA-9 realinement maneuver was relatively simple and consisted of orienting the spacecraft to the retroattitude position by using the horizon and caging and uncaging the gyros (fig. 17–4). As an example, the amount of fuel used by the MA-9 pilot in accomplishing this maneuver was only approximately 25 percent of the average amount required for the maneuver during the previous Mercury missions.

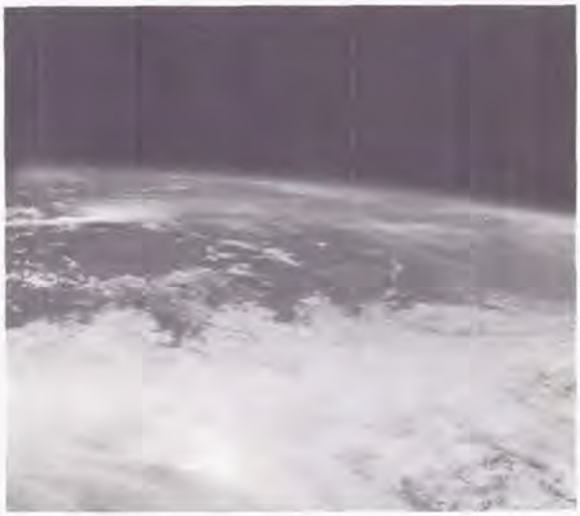


FIGURE 17–4.—Horizon view at retroattitude.

Attitude Control

Turnaround Maneuvers

During the suborbital flights and the first oribital flight the spacecraft was turned around to the retroattitude position by the ASCS, whereas the turnaround maneuvers after orbital insertion for the subsequent orbital missions were accomplished manually as shown in table 17–I. The reasons behind this change warrant a brief discussion.

Table 17–I.—Summary of Turnaround Maneuvers

Flight	Control system	Fuel, lb	Time, min:sec
MR–3	ASCS	4.0	0:30
MR–4	ASCS	4.0	0:35
MA–6	ASCS	5.8	0:38
MA–7	FBW (high and low).	1.6	0:30
MA–8	FBW-low	0.3	1:10
MA–9	FBW-low	0.2	1:40

ASCS—Automatic stabilization and control system.
FBW—Fly-by-wire.

At the very beginning of Mercury Project, it was not known how well the pilot would be able to function in a space environment. This contributed to the Mercury spacecraft being designed so that most of the inflight functions would be automatic with the man being used as a backup system. As flight experience was gained, confidence was increased in the spacecraft, mission operations, and particularly in the man's capabilities. As a result the pilot was permitted more latitude and given more responsibilities as far as inflight activities, such as the turnaround maneuver, were concerned. A second important factor was that fuel conservation became more important during the longer duration missions. Early flight results indicated that an automatic turnaround maneuver would require between 4 and 6 pounds of control fuel. Results on the Mercury procedures trainers, which simulated quite accurately fuel usages for the various control modes, indicated that the pilot could, after practice, perform the maneuver within the same time period required by the ASCS and with a significant savings in fuel.

On this basis, it was decided that the MA–7 pilot would perform the turnaround maneuver, by using FBW, and complete it within approximately the same time normally required by the ASCS. As can be seen by table 17–I, the MA–7 turnaround required only 1.6 pounds of fuel as compared with the 5.8 pounds of fuel required for the MA–6 automatic turnaround. This fuel conservation verified that subsequent flight turnarounds should be conducted manually.

During the MA–8 flight it was planned that if the flight were proceeding smoothly, the turnaround maneuver would be executed at a leisurely pace at a yaw rate of 3°/sec to 4°/sec with the pilot relying solely on the rate and attitude indicators and using only the FBW 1-pound thrusters to conserve fuel. A secondary objective was to confirm that the pilot could perform the maneuver as precisely in a space-flight environment as he could in trainers on the ground.

The pilot performed the maneuver identically as it had been practiced on the procedures trainer. Figure 17–5 shows the flight gyro attitudes with a background envelope of five turnaround maneuvers accomplished on the

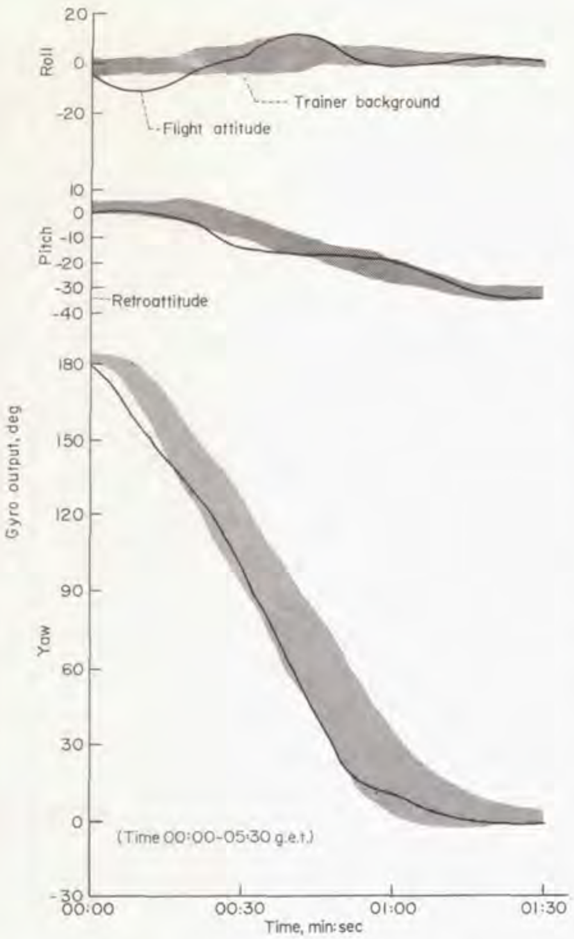


FIGURE 17-5.—Turnaround maneuver, MA-8 mission.

procedures trainers. The pilot executed the maneuver smoothly and with precision, using 0.3 pound of control fuel, which is less than 10 percent of the control fuel normally required by ASCS. As a result of this flight it was clearly established that a leisurely executed manual turnaround, providing the flight was proceeding smoothly, was the most efficient maneuver.

The MA-9 pilot accomplished the turnaround maneuver in a manner similar to that of the MA-8 pilot except that it was not intended to be completed in as precise a fashion as the MA-8 maneuver. He used FBW-low, to conserve fuel, but he elected to observe and photograph the launch vehicle rather than position the vehicle directly to the proper retroattitude position. The pilot had been informed that he had a good insertion, that all systems were functioning properly, and therefore that it was not imperative for the spacecraft to be pitched down to retroattitude. The MA-9 turnaround maneuver required only 0.2 pound of control fuel.

Retrofire

Control of the spacecraft attitude during the firing of the retrorockets was perhaps the most critical and exacting function of either the pilot or the ASCS. Therefore, a great deal of the astronaut's attitude control training on the various fixed and dynamic trainers was devoted to the determination of the relative value of the different control-display configurations and in perfecting the pilot's capability to use these various configurations effectively in accomplishing this maneuver.

The summary of the planned and actual control-display systems used for controlling the spacecraft during the retrofire maneuver of the manned Mercury flights and resultant fuel usages is shown in table 17-II. Of particular note is the fact that only one (MA-8) of the four orbital flight retrofire events was accomplished as planned. The amount of fuel used agrees quite well with the trainer results; that is, in terms of fuel savings there are no significant advantages in selecting any particular control mode.

During the orbital flights it was planned to use the ASCS to control the spacecraft during the retrofire event because it was designed to maintain attitude within very tight limits of $\pm 1°$ and because a manual retrofire did not represent a significant saving in fuel. However, because of systems failures or anomalies affecting the ASCS only the retrofire maneuver of the third orbital flight (MA-8) was accomplished solely by the ASCS.

The MA-6 pilot decided to backup the ASCS by using the MP control system. With this particular set of control modes 11.6 pounds of control fuel were used during the maneuver.

Because of a problem with the ASCS, the MA-7 pilot controlled the spacecraft during retrofire by using both FBW and MP, again resulting in a rather high fuel usage. Because of an error in the pitch indicator the pilot was required to cross-check between the view out the window and his instruments.

The MA-8 spacecraft was controlled by the ASCS during the retrofire event within $\pm 1°$ in

Table 17-II.—Summary of Retrofire Maneuvers

Flight	Control system		Display	Fuel, lb	Landing error, nautical miles
	Planned	Actual			
MR-3	MP	MP	Instruments	4.	
MR-4	MP	MP	Instruments	3.6	
MA-6	ASCS	[1] ASCS, MP	Instruments	11.6	−40
MA-7	ASCS	[1] FBW, MP	Instruments and window	7.0	+250
MA-8	ASCS	ASCS		3.8	−4
MA-9	ASCS	MP	Instruments and window	3.2	−1

[1] Double authority
MP—Manual proportional
ASCS—Automatic stabilization and control system
FBW—Fly-by-wire

all axes. The pilot had selected MP as a backup but it was not required.

As a result of the loss of ASCS power, the MA-9 pilot was required to initiate the retrofire event manually and to control the spacecraft during retrofire by using the rate gyro indicators (the attitude indicators were non-operational) and the view of the earth through the window as rate and attitude references, respectively. The pilot, realizing that he would be conducting the retrofire maneuver shortly after sunrise of the final daylight phase, oriented and maintained the spacecraft very close to the proper retroattitude throughout the last night period by using stars and clouds as references. The pilot was well prepared for retrofire, having completed well in advance the storage and preretrosequence checklists.

During the retrofire maneuver, the pilot used MP and cross-checked between his rate indicators and the view through the window. Because of a high contrast between the relative brightness of his interior and exterior references, the pilot experienced difficulty in adapting his vision while shifting from one reference to the other. Consequently, he had to shade his eyes with his left hand when attempting to view his rate indicators. In spite of this problem and the fact that he did not have the opportunity to practice retrofire maneuvers with this combination of attitude references, except much earlier in his training program on the air-lubricated free-attitude (ALFA) trainer, the pilot was able to maintain excellent control of his spacecraft with this combination of attitude references, as evidenced by the nominal reentry trajectory and accuracy in landing position.

Figure 17-6 shows the spacecraft's attitude rates and attitudes, which were calculated from an integration of the spacecraft rates during the retrofire period. The calculated attitudes and the initial attitude of the spacecraft at the

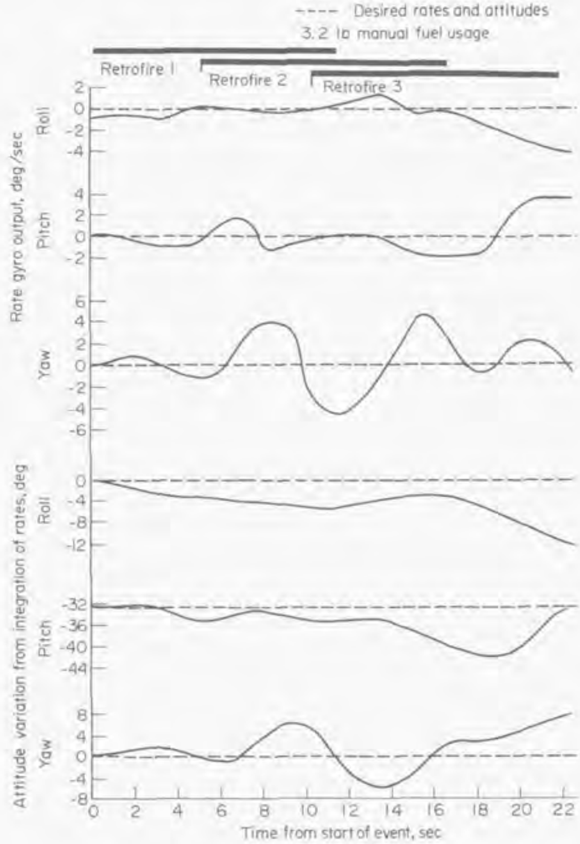


FIGURE 17-6.—MA-9 retrofire maneuver.

beginning of the retrofire were further verified by reentry trajectory computations. The pilot controlled rates extremely well particularly in pitch which is the most critical axis. Rate control was maintained within $\pm 2°$/sec in pitch and roll and within $\pm 5°$/ sec in yaw throughout the first 19 seconds of the 22-second retrofire period. A maximum misalinement torque of approximately 40 to 50 foot-pounds appears to have occurred in left yaw when the number two retrorocket fired. This value represents approximately 40 percent of the MP control capability.

The pilot maintained good control of spacecraft attitudes, with a maximum deviation of $-12°$ in roll at the completion of the maneuver. Deviations in pitch and yaw attitude were negligible as far as the reentry trajectory and landing accuracy are concerned. The maximum pitch deviation was 9°, which occurred very late in the retrofire period; and the maximum yaw attitude deviation was 5°. The pilot purposely maintained the pitch attitude at the nominal $-32°$ position or slightly lower, a direction of deviation which least affects the reentry trajectory.

Reentry

During the reentry the ASCS or the pilot, by means of one of the manual control modes, was required to initiate and maintain a roll rate of approximately 10°/sec and to damp the oscillations in the pitch and yaw axes. Since the frequency and damping of the oscillations varies considerably during the reentry phase, with frequency increasing until maximum dynamic pressure, and damping decreasing after the maximum dynamic-pressure period, the control task requires a considerable amount of pilot skill and technique.

The preferred control systems for this task were either the auxiliary damping (ASCS) or the rate command mode. Rate command, although highly effective in controlling the oscillations, usually consumed a large amount of fuel, as can be seen in the case of the MA–8 reentry shown in table 17–III. The MP control mode had a significant response lag and tail-off in thrust, which made it very difficult to damp effectively. The FBW was not completely adequate for effective control because it was limited to the selection of two discrete thrust levels.

All of the manned Mercury flight reentries except MR–3 were planned to be controlled by the auxiliary damping or rate command control modes. Furthermore, these two control modes were used entirely or in part for each Mercury flight reentry with the exception of the MA–9 reentry. The rate command system had been removed from the MA–9 spacecraft and the auxiliary damping system was inoperative because of the loss of ASCS power.

The MA–9 pilot decided to control the reentry by using FBW, but when he checked the system just prior to 0.05g, he was not satisfied with the way it was operating and elected to use both MP and FBW. During the early portion of the reentry he was able to damp the small and rather slow oscillations by using the FBW 1-pound thrusters and the MP control

Table 17–III.—Reentry Control

Mission	Control mode		Fuel, lb
	Planned	Actual	
MR–3	MP	MP, switched to Aux. damp.	6.5
MR–4	RSCS	RSCS	6.0
MA–6	Aux. damp.	(MP and FBW)[1] switched to Aux. damp.	8.6
MA–7	Aux. damp.	Aux. damp.	4.6 to fuel depletion
MA–8	RSCS	RSCS	10.0
MA–9	Aux. damp.	(FBW and MP)[1]	5.2

[1] Dual authority
MP—Manual proportional
RSCS—Rate stabilization and command system
Aux. damp.—Auxiliary damping part of automatic (ASCS) system
FBW—Fly-by-wire

mode. At approximately 1 minute and 30 seconds prior to peak reentry deceleration, the pilot inadvertently actuated the FBW-high yaw thruster. This actuation resulted in almost 49 pounds of control thrust and added to the amplitude of the oscillations. However, the pilot maintained positive control of the oscillations through drogue parachute deployment. The pilot had no other difficulties in controlling the reentry oscillations except during maximum deceleration for a brief period in which he was unable to manipulate the control handle properly because the g-forces pulled his arm away from the control handle and into a trough on the arm rest.

The maximum frequency of oscillations occurred at peak deceleration with a period on the order of 0.9 second. Maximum rates were approximately $\pm 15°$/sec with a maximum amplitude of approximately $\pm 10°$ in pitch and yaw which occurred after peak deceleration. The pilot reported that he believed he needed dual-authority control to be effective after the peak deceleration point.

Systems Management

As flight experience was gained and as the successive flights increased in length and complexity, it was necessary to make many modifications and improvements in the controls, displays, and monitoring instrumentation so that the pilot could more effectively manage and assess the status of the spacecraft systems. Increased onboard monitoring capability was particularly important during the MA–9 flight because of the long time periods during which the spacecraft was not within communication contact with the various ground stations. A second advantage of onboard monitoring instrumentation was that it was often more reliable than telemetered data, and, if discrepancies did occur between ground and flight information, the actual status could be better determined with the onboard instrumentation. Finally, as mission duration increased the management of consumables, such as fuel and electrical power, became more critical.

Figure 17–7, which compares the MR–3 and MA–9 spacecraft instrument panels, illustrates the numerous changes in the Mercury panel configuration. These changes primarily resulted from the increased knowledge about the spacecraft systems and their operations as well as the mission requirements. One of the major modifications was to the attitude control system and its controls in order to maximize the capabilities of the system and also to simplify the control system management requirement.

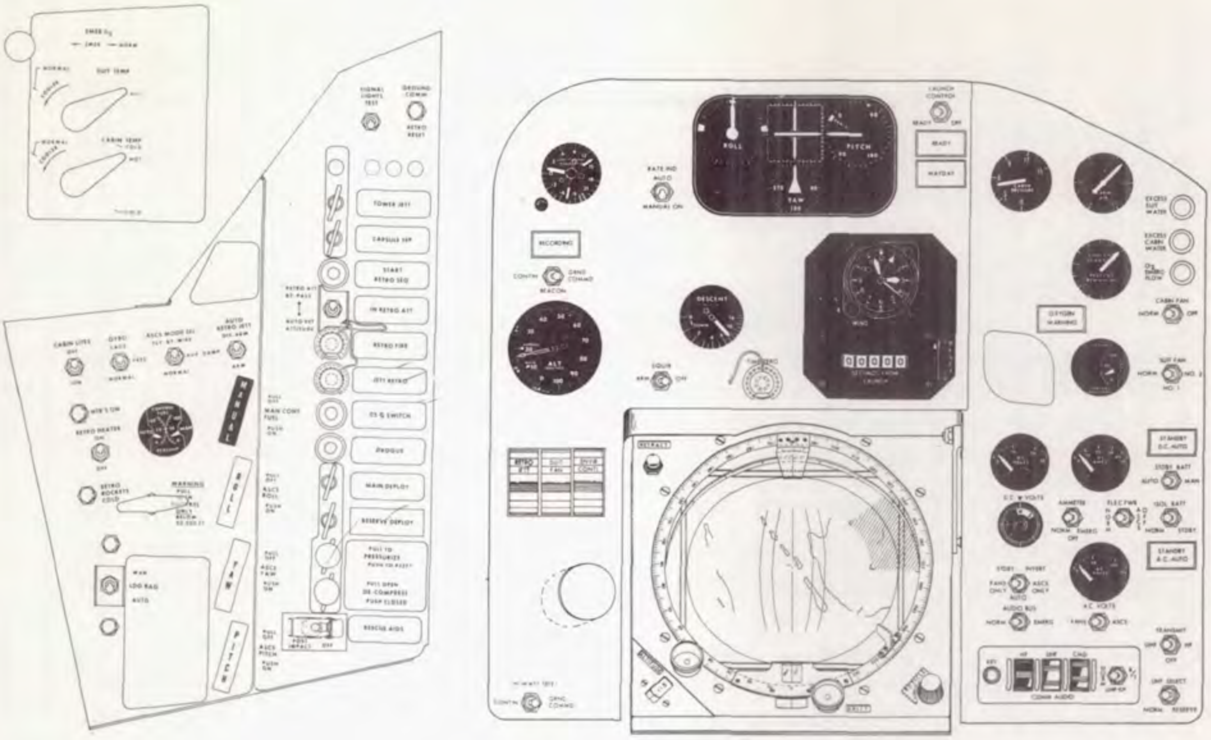
Control-Mode Switching

A major pilot function during all of the Mercury missions, but particularly during the MA–9 flight, was control-mode usage and switching which had a direct effect upon control-fuel expenditure and the success of the entire mission. Table 17–IV shows control-mode usage and switching during the MA–9 flight. In general, the control system was used almost exactly as planned until the 0.05g relay prematurely latched in and the ASCS power was subsequently lost. After this point, the pilot used FBW and MP, or both, since these were the only available systems.

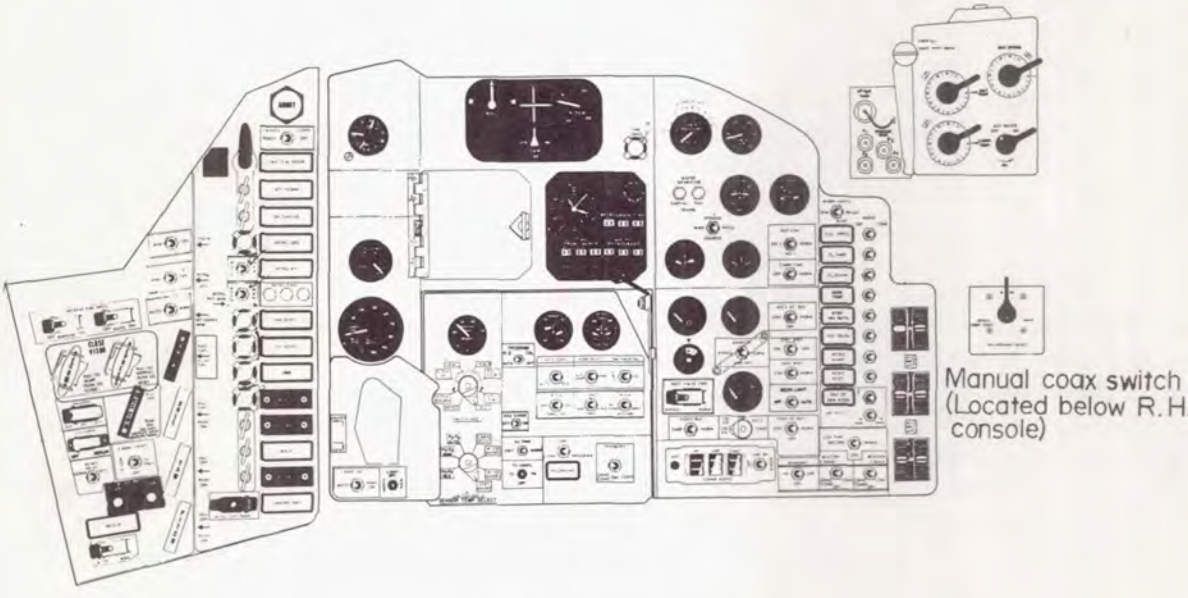
The pilot was very successful in switching from the manual control modes to the ASCS. The orientation high-thruster mode was never

Table 17–IV.—MA–9 Control Mode Usage

Control mode configuration	Percentage time used in rank order	Maximum time used at any one time, hr:min	Frequency used
Drift	43	13:01	2
Drift and MP	26	8:44	1
ASCS orbit	13	1:20	7
Drift and FBW-low	13	3:11	1
FBW-low (gyros uncaged)	2	0:11	8
ASCS reentry	2	0:37	1
MP (gyros uncaged)	1	0:04	5



(a) MR–3 configuration.



(b) MA–9 configuration.

FIGURE 17–7.—Spacecraft instrument panels.

inadvertently actuated throughout the entire flight. The maximum excursions, during the eight times the spacecraft was manually alined to retroattitude and control switched over to the ASCS, were 5° in attitude and $\pm\frac{1}{2}$°/sec in rate. The pilot did not at any time inadvertently use double authority during the mission. Double authority was used purposely for the reentry.

The MA–9 pilot's success in control mode utilization can be attributed primarily to two areas: simplification of the control mode switching operations, which reduced the chances of inadvertent use of orientation mode or inadvertent dual authority, and a very thorough understanding of the operational characteristics of the entire attitude-control system.

Pilot Reliability

Throughout the Mercury flights there were several minor and a few major systems failures. In order to illustrate the value of the pilot as a backup and/or primary system indispensable to the Mercury space flights, a brief review of the failures which occurred in the spacecraft's attitude-control system during the four orbital flights and the effect that these failures would have had on mission success had the spacecraft been unmanned is warranted.

At approximately 1 hour 30 minutes after lift-off of the MA–6 flight, the 1-pound left yaw thruster malfunctioned. After repeated switching between the ASCS and FBW control modes, the thruster began to function properly. However, almost immediately thereafter the right yaw 1-pound thruster malfunctioned and continued to be inoperable for the rest of the flight. Although mission safety was not jeopardized, this malfunction would have required an early termination of the flight because, had the pilot not been on board, the spacecraft would have repeatedly dropped into the ASCS orientation high-thruster mode, and a premature fuel depletion would have resulted.

The pitch horizon scanner malfunctioned throughout the MA–7 flight. At retrofire, the pitch horizon scanner read approximately −16°, whereas trajectory computations based on radar tracking data yielded a pitch attitude of −36.5°. This discrepancy was verified by the pilot who reported that the ASCS orientation mode caused the vehicle to pitch down below the −34° position to such an extent that the earth's horizon was no longer visible through the window. As a result the pilot had to place the attitude permission switch to the "bypass" position and initiate and control the retrofire event manually. Without the pilot the retrofire could not have been initiated from the proper attitude.

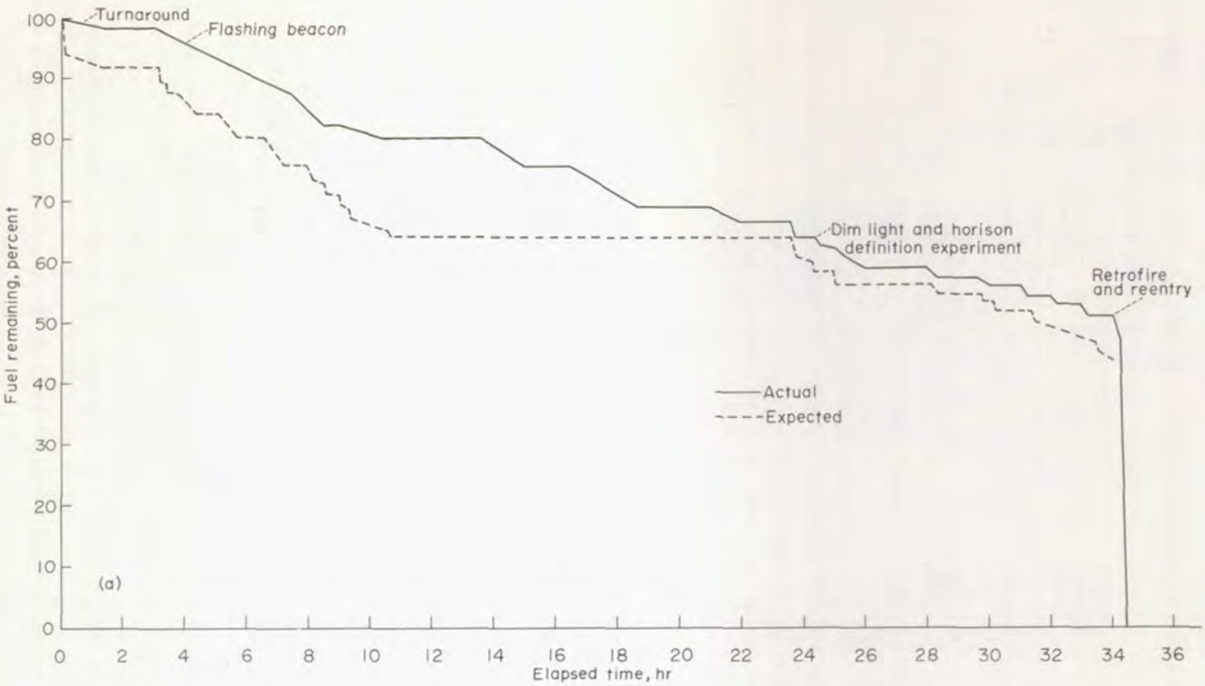
During the MA–9 flight, the amplifier calibrator locked into the 0.05g configuration, which resulted in putting the ASCS into the reentry mode of operation. Shortly thereafter, all ASCS power was lost, and the pilot was required to perform manually all subsequent functions, such as retrofire initiation, retrofire attitude control, and damping of reentry rate oscillations.

In summary, without the man, only the MA–8 flight would have progressed normally; the MA–6 mission would have had to be terminated early; and the MA–9 spacecraft would not have reentered successfully.

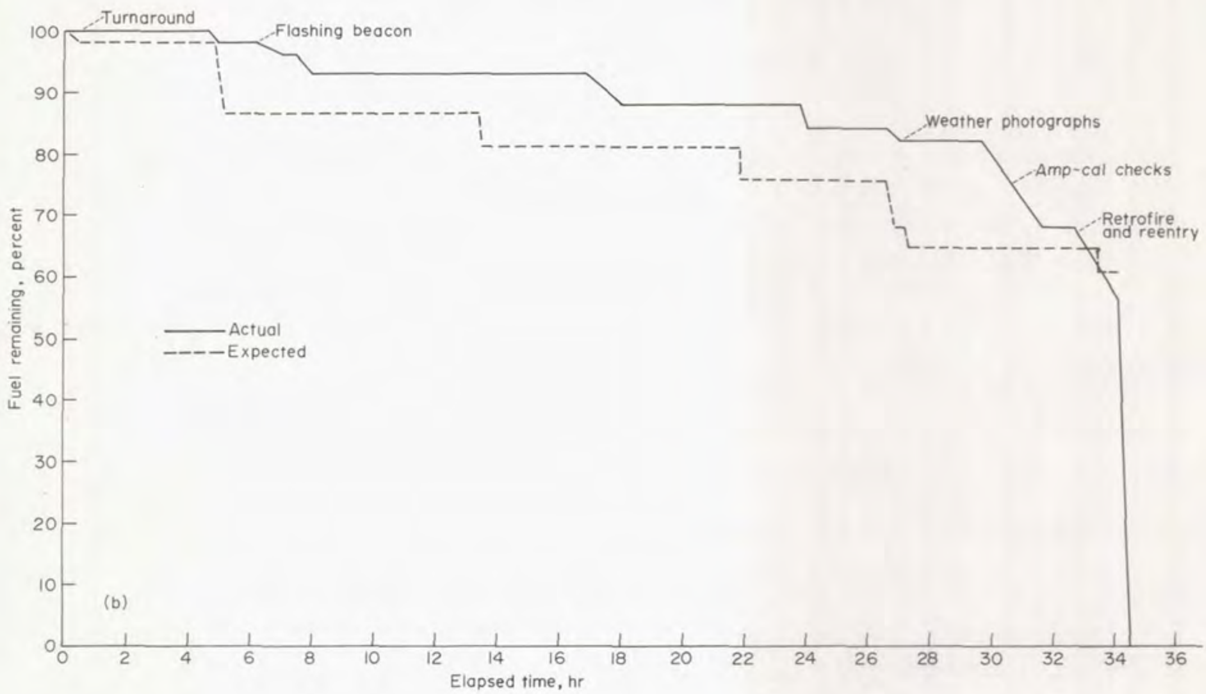
Management of Consumables

An important function of the pilot was to monitor and conserve to the extent possible the various consumables, including attitude-control fuel, electrical power, oxygen, water, and the onboard recorder tape. The first two items were extremely critical to the success of the mission since mismanagement or a malfunction affecting either of these quantities could cause an early mission termination or a loss of the spacecraft.

. Attitude-control fuel was the prime consumable quantity over which the pilot had both monitoring and control capability. The normal premission procedure was to establish both predicted and minimum fuel-consumption levels that were expected and required for a successful mission. After lift-off, the management of the control fuel to meet the mission requirements was the sole responsibility of the pilot. It was found that for both the Redstone missions and the first two manned orbital missions the fuel quantities required were within the system capabilities; however, during the later two missions the longer duration required that particular attention be paid to this parameter. In most cases, particularly during MA–9, the pilot demonstrated an ability to perform the required maneuvers by using less than the expected amount of fuel and to stay well below the predicted and minimum fuel consumption levels as illustrated in figures 17–8(a) and 17–8(b).



(a) Automatic system.



(b) Manual system.

FIGURE 17-8.—H_2O_2 fuel usage.

Electrical power capacity was ample for the shorter duration missions, such as the MA–6 and MA–7 flights. However, monitoring of this quantity was still of importance since a malfunction, if major, could jeopardize flight safety. It was only during the final two missions that electrical power conservation became a concern with respect to full completion of the mission. During the last two missions the electrical power source was not sufficient to allow the use of all electrical equipment throughout the mission and still have an adequate reserve. Consequently, the flight plan included periods of drifting flight in order to conserve power. Thus, during both these missions, it was very important that the pilot monitor and control closely this consumable quantity.

Inflight Activities

Flight Plan

The activities of the pilot on each Mercury mission included requests and requirements from medical, engineering, and scientific areas. In order to obtain the maximum amount of information from each mission, it was necessary to schedule all the activities of the pilot and to assign a priority system in the event of overlap between activities.

The type of activities with which the pilot was involved varied from mission to mission, but generally they included normal systems monitoring and control, spacecraft attitude control, systems checkout, air-ground coordination, medical, and experimental. Activities related to mission reliability such as spacecraft control were given top priority. Second priority activities were those investigations which were intended to improve the spacecraft and its mission capabilities in general. Third priority was given to the experimental and other operational activities that were not directly related to the mission safety. Once all of the flight activities had been determined, they were formulated into a flight plan that was designed to meet all of the objectives of the mission.

The period of weightlessness of the manned Mercury-Redstone flights was too short to allow many activities. The flight plan for these two missions concentrated primarily upon the overall operational requirements, and during the weightless period emphasis was placed upon an evaluation of the various spacecraft attitude-control systems. Starting with the MA–6 mission, all conditions during orbital flight had to be considered. The launch, retrofire, and reentry procedures were similar to those of the Mercury-Redstone missions; however, the orbital period required detailed scheduling. Spacecraft systems checkouts were scheduled following insertion and at the end of each orbital pass. Activities related to mission control and mission-orientated information, such as medical, control-display analyses, and experimental activities, were scheduled so that they would not interfere with basic operational tasks. Results of each mission were analyzed and the knowledge gained was applied to the subsequent missions. The following are the general areas where improvements were made based on the previous mission experience. First, pilots were allowed more time for each specific activity. The first orbital pass was reserved for systems checkout, and time was allowed for the pilot to become orientated to his new environment. More time was allotted for monitoring systems, and the air-to-ground communications were improved and simplified so that they would require a minimum of the pilot's time. Second, the spacecraft systems were analyzed in more detail and the pilots were thoroughly briefed on their characteristics. The spacecraft configuration and activity schedule were also finalized at an earlier date than had been true on previous missions and this allowed the pilot valuable additional time to train and become more familiar with the flight activity schedule.

The sum total of all these improvements was reflected in the MA–9 mission plan. At only one period did the pilot feel rushed; however, even in this case he was able to complete the scheduled activity. Two additional factors which contributed greatly to the improved flight activity schedule of the MA–9 mission were that activities were scheduled at any of several different points in the mission so that the pilot could conduct the activity at the most convenient time and that the increased mission duration allowed a reduction in the frequency of activities.

Communications

Air-to-ground communications procedures were continually being improved throughout the Mercury program in an attempt to determine the best set of procedures which would be simple for the pilot and yet insure proper information flow.

The MA–6 pilot was requested to report a large quantity of information to the various ground stations. Over each ground station, he reported the fuel and oxygen quantities, the control mode, and the general status. In addition, approximately twice during each orbital pass, he was required to report to a ground station all the switch positions and gage readings on the instrument panel. In addition many communication attempts were required to establish contact with each station, primarily because the stations would attempt communications contact prior to the expected acquisition time. These premature attempts resulted in many additional transmissions in an attempt to make two-way communications contact.

Several changes were made in communications procedures prior to the MA–7 flight. The requirement for reporting all the switch and gage readings was deleted and the initial transmission from the ground was not begun until the expected time of acquisition. The MA–8 pilot reported only control mode and status. In addition, many intermediate transmissions were eliminated because the pilot transmitted specific information at given stations, which reduced the number of requests initiated from ground stations. The net effect of all these changes was to decrease the amount of the pilot's time required for this activity and thus permit more time for other activities.

The MA–9 communications procedures represented the application of all the previous experience and included several major improvements. Ground stations did not attempt communications with the spacecraft until after they had received the spacecraft telemetry signals and had evaluated the data. This procedure insured that the spacecraft and ground station were in good communications range. In addition the MA–9 pilot reported only go–no–go status to each station and read out fuel and oxygen quantities once per orbital pass. The sleep period, during which communication silence was maintained, also greatly decreased the total air-to-ground communications. One communications problem that did occur during the MA–9 flight was an interruption due to ground station communications while the pilot was conducting the dim-light experiment.

Conclusions

Conclusions concerning the performance of the pilot during the Mercury program and the implications for future manned space programs are:

(1) The pilot during Mercury flights was a reliable and flexible part of the system, and therefore enhanced mission success.

(2) The three-axis hand controller proved to be adequate for spacecraft control.

(3) Although the Mercury training equipment was generally adequate, good external displays would have provided valuable additional training.

(4) Spacecraft systems modifications should be finalized as early as possible to permit earlier flight-plan finalization and to allow more time for the pilot to practice the various inflight tasks.

(5) There was no significant effect upon pilot's operating capabilities resulting from his being subjected to the space environment for up to 34 hours.

(6) Throughout the Mercury Project there was a trend toward design and operational concepts similar to those for flight-test aircraft. This indicates that the decades of aircraft experience will be very useful in designing systems, selecting and training astronauts, and mission planning.

(7) It is advantageous from a reliability and systems simplicity standpoint to make maximum use of the pilot's capabilities in spacecraft operations. Early design should take manual operation into consideration in order to achieve a most effective and efficient overall system. Those functions that are determined to be beyond man's capability or are of a monotonous or repetitious nature should be designed for automatic operations.

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IV

MISSION RESULTS

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18. AEROMEDICAL OBSERVATIONS

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Summary

The results of physiologic measurements and medical studies of Astronaut Cooper made prior to, during, and following his flight as pilot of the spacecraft of the MA–9 mission are presented in this paper. The pilot was in excellent health and in a complete state of mental and physical fitness for his mission on launch morning. The data revealed that all physiologic parameters measured in flight remained within the envelope of normal variability developed for this pilot through extensive monitoring of these same parameters under dynamic circumstances during his participation in training activities as a Mercury astronaut.

Astronaut Cooper withstood the stresses of the flight situation with no evidence of degradation of his functional integrity as a pilot. He slept as part of the planned mission activities during his flight and reported that sleep was subjectively normal. Postflight examination of Astronaut Cooper revealed that he had developed dehydration. He exhibited an orthostatic hypotension accompanied by an accelerated pulse response in the postflight examinations. The pulse and blood pressure responses returned to normal while the pilot was sleeping between 9 hours and 19 hours after landing. A reversal of the ratio between neutrophiles and lymphocytes was noted in the peripheral blood at an examination accomplished 4 days after the mission. This lymphocytosis persisted for 2 weeks and subsided spontaneously by June 14, 1963. With respect to all other studies, the medical status of the pilot was found essentially unchanged between the preflight and postflight examinations.

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Introduction

This paper presents the specific results of medical studies of Astronaut Cooper's responses during and after his MA–9 mission in the dual context of a detailed report of the final Mercury mission and an effective summary in its own right of the medical findings from Project Mercury. The results of the MA–9 mission are an effective summary of the entire program because every observation which was made on pilots during the earlier missions was repeated and qualitatively reconfirmed in the final flight.

At the same time, the medical-data collection program for the last flight was developed on the foundation of knowledge gained from each of the preceding manned space missions. The suitability and the limitations of the Mercury spacecraft environment to meet the requirements of human physiology were better understood with each succeeding flight. Thus, the final flight was approached with a better understanding of the likelihood of a given physiologic response occurring after exposure to the known stresses of a mission profile than had been previously possible. The opportunity for making valid medical observations during the MA–9 mission was further enhanced by the duration of the mission, as well as by the length of participation of Astronaut Cooper in the Mercury program, which provided an invaluable fund of baseline data prior to his actual flight.

Preflight Observation

Data were evaluated from very thorough medical studies of the pilot, Astronaut L. Gordon Cooper, Jr., conducted immediately prior to his selection for astronaut training in 1959 and from annual examinations since that date. Medical examinations were also conducted both before and after six preflight spacecraft checkout tests and a session in the Cape Canaveral procedures trainer, all of which required the pilot to wear the full-pressure space suit. Special examinations to assess the pilot's fitness for flight were conducted 11 and 3 days before launch. The latter examination conducted on May 12, 1963, designated the "Comprehensive Medical Evaluation," was conducted by specialists in internal medicine, ophthalmology, neuropsychiatry, radiology, and aviation medicine. The NASA flight surgeon who had examined the pilot for most of the preflight activities conducted the final preflight medical examination on launch morning. The preflight aeromedical procedures and examination are listed in table 18-I.

Table 18-I.—Pilot Preflight Activities

[Selected activities for which medical study or support was performed]

Date	Activity	Medical study or support
January 5	Altitude-chamber spacecraft checkout.	Physical examination before and after Background data (biosensors)
March 22-23	Hangar flight simulation	Physical examination before and after Background data (biosensors) Low residue diet (3 days) and flight food (2 days)
April 23	Flight simulation no. 1	Physical examination Background data (biosensors) Timed urine collection
May 4	T-10 day physical examination.	Physical examination, 45 minutes
May 7	Mission simulation (procedures trainer).	Physical examination before and after Background data (biosensors) Timed urine collection
May 8	Launch simulation	Physical examination before and after Background data (biosensors) Timed urine collection Begin controlled diet Blood specimen, 50 cc
May 10	Flight simulation no. 3	Physical examination before and after Timed urine collection Background data (biosensors)
May 11		Begin low residue diet
May 12	T-2 day physical examination	Comprehensive medical examination, 2½ hours Blood (30 cc) and urine specimen
May 14	Countdown (flight canceled)	Physical examination before and after Timed urine collection Blood specimen, 30 cc
May 15	Flight countdown	Physical examination Aeromedical countdown Awaken 2:51 a.m. e.s.t. Launch 8:40 a.m. e.s.t.

In addition to examinations by physicians, baseline clinical evaluations included an audiogram, an electrocardiogram, a chest X-ray, and laboratory studies of blood and urine. The results of these evaluations are found in tables 18-II to 18-V. For the 3 months prior to the flight, the pilot continued in excellent health with no significant abnormalities. In the month prior to flight, he maintained his physical fitness by daily distance running and calisthenics.

Close supervision of the pilot's food intake began 7 days before the planned flight with special preparation of a normal balanced diet. In order to reduce the need for defecation during the mission, a low-residue diet was followed for 4 days before the launch (ref. 1). This diet was well tolerated, although the pilot did mention that appetite satisfaction was short-lived following the low-residue meals.

Table 18-II.—Pertinent Excerpts From Clinical Examination

	Preflight, May 15, 1963; 3:55 to 4:11 a.m. e.s.t.	Postflight (*U.S.S. Kearsarge*) May 16, 1963, 7:15 to 7:45 p.m. e.s.t.
Temperature (oral), °F	97.4	99.4
Heart rate, beats/min	76	86
Respiration rate, breaths/min	16	16
Blood pressure, left arm, mm Hg	108/76 supine 122/82 standing	90/80 supine
Nude weight (bladder empty), lb	147	139¼
Comments	Alert, cooperative, 2+ erythema at BPMS microphone tape site.	Fatigued and sweating. See text.

Table 18-III.—Complete Blood Count

[All times are in e.s.t.]

	Sept 4, 1959	Mar 4, 1963; 1:40 p.m.	May 12, 1963; 5:00 p.m.	May 16, 1963; 8:55 p.m.	May 17, 1963; 9:00 p.m.	May 20, 1963; 11:00 a.m.	May 31, 1963; 3:00 p.m.	June 14, 1963
Hematocrit, percent	46	44	43	49	43	43	43	43
Hemoglobin, grams/100 ml	14.8	14.3	15.0	16.5	14.0	14.7	14.3	14.2
Red blood cells, millions/mm^3	5.09	-----	4.79	4.80	4.83	4.50	-----	-----
Platelets/mm^3	-----	284,000	314,000	-----	-----	230,000	-----	-----
White blood cells/mm^3	5,850	6,800	6,500	9,200	5,650	6,000	7,700	5,100
Differential blood count:								
Neutrophiles, percent	69	50	60	75	49	35	38	49
Lymphocytes, percent	29	46	36	20	42	58	61	47
Monocytes, percent	1	2	3	5	5	5	1	2
Eosinophiles, percent	0	2	1	0	3	2	0	1
Basophiles, percent	1	0	0	0	1	0	0	1

Table 18-IV.—Comparison of Typical Preflight and Postflight Urine Values

	Preflight	Postflight
Date, 1963	May 12	May 20
Source	Random sample	Random sample
Specific gravity	1.018	1.019
pH	6.0	6.0
Albumen, sugar, acetone, and bile	Negative	Negative
Microscopic	Few WBC, no RBC, small amounts of amorphous phosphates and mucus, and one hyaline cast.	One to 2 WBC/HPF, no RBC, no casts, moderate amount of amorphous phosphates.

Table 18-V.—Urine Analysis

Date	Time	Total volume, cc	Specific gravity	Na, mEq/l	K, mEq/l	Ca, mEq/l	Cl, mEq/l	PO_4, mg%	Creatinine, mg%	Comments
Mar. 20, 1963	7:30 a.m. to 9:26 a.m.	184	1. 012	141	55	4. 15	161	26. 7	85	Low residue diet.
Mar. 20, 1963	9:26 a.m. to 12:59 p.m.	260	1. 013	180	49	16. 3	207	42. 2	110	
Mar. 20, 1963	12:59 p.m. to 4:45 p.m.	420	1. 014	129	40	10. 1	159	56. 6	86	
Mar. 20, 1963	4:45 p.m. to 9:10 p.m.	330	1. 015	125	38	8. 7	111	73	111	
Mar. 21, 1963	9:10 p.m. to 1:00 a.m.	340	1. 012	137	17	7. 5	100	58. 3	102	
Mar. 21, 1963	1:00 a.m. to 7:52 a.m.	830	1. 005	79	14	5. 0	79	31. 4	62	
Mar. 21, 1963	7:52 a.m. to 12:46 p.m.	470	1. 011	143	42	10. 3	174	26. 6	94	
Mar. 21, 1963	12:46 p.m. to 5:28 p.m.	286	1. 017	179	54	16. 85	210	74. 3	125	
Mar. 21, 1963	5:28 p.m. to 11:35 p.m.	600	1. 015	189	41	7. 6	178	48	105	
Mar. 22, 1963	11:35 p.m. to 3:26 a.m.	210	1. 015	239	31	10. 6	163	54	----	
Mar. 22, 1963	3:26 a.m. to 5:36 a.m.	110	1. 018	216	34	25. 5	165	55	----	
Mar. 22, 1963	5:36 a.m. to 10:47 a.m.	255	1. 018	154	38	21. 3	142	54	134	
Mar. 22, 1963	10:47 a.m. to 6:35 p.m.	300	1. 020	116	47	20. 85	86	135	152	Before hangar simulated flight.
Mar. 23, 1963	6:35 p.m. to 1:20 a.m.	360	1. 023	131	51	18. 9	119	75. 4	142	During hangar simulated flight.
Apr. 23, 1963	6:00 a.m. to 6:50 a.m.	32	------	196	58	7. 75	158	146	144	Simulated flight no. 1 (before).
Apr. 23, 1963	6:50 a.m. to 12:35 p.m.	394	1. 020	226	85	3. 04	220	70. 8	106	Simulated flight no. 1 (during).
Apr. 23, 1963	12:35 p.m. to 5:08 p.m.	122	1. 022	195	51	5. 95	187	68. 6	98	Simulated flight no. 1 (after).
Apr. 25, 1963	Unknown to 11:35 a.m.	170	1. 020	192	83	6. 3	212	18. 7	107	Simulated flight no. 2 (before).
Apr. 25, 1963	11:35 a.m. to 4:28 p.m.	134	1. 024	242	40	5. 75	226	35. 4	104	Simulated flight no. 2 (during).
Apr. 25, 1963	4:28 p.m. to 5:55 p.m.	308	1. 018	250	44	3. 40	234	46. 1	107	Simulated flight no. 2 (after).
May 7, 1963	6:30 a.m. to 8:30 a.m.	64	1. 020	115	56	13. 9	198	103	152	Procedures trainer (before).
May 7, 1963	8:30 a.m. to 2:00 p.m.	480	1. 014	124	60	5. 65	146	63. 6	88	Procedures trainer (during).

May 8, 1963	9:15 a.m. to 1:40 p.m.	540	1. 012	137	79	7. 4	166	41. 6	74	Launch simulation (during).
May 8, 1963	1:40 p.m. to 6:00 p.m.	360	1. 012	137	53	3. 2	125	43	104	Launch simulation (after).
May 10, 1963	7:30 a.m. to 11:45 a.m.	180	1. 023	148	85	17. 8	176	45. 7	130	Simulated flight no. 3 (before).
May 10, 1963	11:45 a.m. to 2:00 p.m.	170	1. 025	198	72	20. 7	219	76	114	Simulated flight no. 3 (before).
May 10, 1963	2:00 p.m. to 6:30 p.m.	320	1. 023	181	83	13. 4	201	97	115	Simulated flight no. 3 (during).
May 10, 1963	6:30 p.m. to 10:05 p.m.	80	1. 026	200	71	6. 9	165	148	139	Simulated flight no. 3 (after).
May 13, 1963	6:30 p.m. to 9:00 p.m.	440	1. 025	177	54	19. 95	165	128	137	Before canceled flight.
May 14, 1963	9:00 p.m. to 2:50 a.m.	225	1. 024	165	32	10. 0	107	161	152	Before canceled flight.
May 14, 1963	2:50 a.m. to 7:30 a.m.	680	1. 012	120	49	5. 6	128	12. 6	56	Collection device—canceled flight.
May 14, 1963	7:30 a.m. to 12:30 p.m.	315	1. 015	98	50	5. 85	109	34	104	After canceled flight.
May 15, 1963	10:00 p.m. to 2:52 a.m.	178	1. 028	112	34	23. 4	73	214	162	Preflight.
May 15, 1963	2:52 a.m. to 3:55 a.m.	25	1. 025	98	48	12. 4	89	185	165	Preflight.
May 15, 1963	3:55 a.m. to 7:56 a.m.	177	------	184	68	8. 25	212	33. 8	125	Preflight (pad) bag no. 1.
May 15, 1963	7:56 a.m. to 12:29 p.m.	195	------	213	69	14. 1	236	28. 4	131	Inflight bag no. 2.
May 15, 1963	12:29 p.m. to 10:09 p.m.	314	------	197	56	12. 6	188	130	154	Inflight bag no. 3.
May 16, 1963	10:09 p.m. to 7:15 a.m.	333	------	120	38	17. 7	128	125	169	Inflight bag no. 4.
May 16, 1963	7:15 a.m. to 1:14 p.m.	107	1. 026	137	41	15. 6	150	136	170. 8	Collection device.
May 16, 1963	1:14 p.m. to 9:30 p.m.	70	1. 031	107	96	16. 4	126	240	177	1st voided sample.
May 17, 1963	9:30 p.m. to 1:05 p.m.	475	1. 026	41	62	20. 95	29	149	148	2d voided sample.
May 17, 1963	1:05 p.m. to 9:12 p.m.	315	1. 020	29	54	24. 3	59	68. 5	148	3d voided sample.
May 18, 1963	9:12 p.m. to 12:00 p.m.	605	1. 023	29	70	17. 4	41	114	139	4th voided sample.
May 20, 1963	8:00 a.m. to 10:15 a.m.	----	1. 019	125	92	15. 2	150	68	110	4 days after recovery (physical exam Patrick AFB).

The results of the final prelaunch examination revealed a healthy pilot who was ready for the mission. Two minor discrepancies were local skin erythema at the biosensor sites and moderate erythema, edema, and tenderness of the skin over the right sacral prominence. He frequently demonstrates a skin reaction around the sensors for 24 to 36 hours after application, despite the use of microporous surgical tape for fastening these sensors. It should be noted that these sensors were in place for 7 hours during the canceled launch on the preceding day. The skin findings over the sacrum are frequently present following prolonged periods of 4 or more hours on his back in the couch.

On the night before the postponed launch of May 14, 1963, the pilot slept well for about 2 hours and then dozed restlessly for another 3½ hours. However, on the night before the successful launch, he slept well for 6 hours. Although he did become sleepy during periods of relative inactivity, such as the period spent in the transfer van, he felt adequately rested on launch morning. At no time was a drug administered to induce sleep.

The sources of detailed preflight physiologic data are outlined in tables 18–VI to 18–IX. These sources include dynamic tests for evaluation of general physical condition, Mercury-Atlas three-orbital pass simulations, and Mercury-Atlas acceleration profiles conducted at the U.S. Naval Aviation Medical Acceleration Laboratory (AMAL) in Johnsville, Pa., and various spacecraft checkout procedures required during the final stages of preparation for flight.

The procedures which were monitored resulted in the largest number of total hours of observation yet available for any one astronaut. This extensive monitoring was possible as a result of his activity as the MA–8 backup pilot and of his participation in three altitude-chamber spacecraft-checkout procedures, including the longest such test conducted at Cape Canaveral.

The pilot-safety monitoring and data-gathering biosensor system for this mission consisted of two sets of electrocardiographic (ECG) leads, the impedance pneumograph, an oral temperature thermistor, and the blood-pressure measuring system (BPMS). The details of operation of the biosensor system have been described in references 1 to 3. Because of the increased duration of the MA–9 flight, a change was made from continuous rectal to intermittent oral body temperature measurement. The basic thermistor was retained. The thermistor and its lead wires remained within the suit. The sensor was attached to the right ear muff inside the helmet where it was readily accessible. The sensor and its location are illustrated in figures 18–1 and 18–2. It thereby provided an indication of suit-outlet temperature whenever an oral temperature was not being taken. When oral temperature was desired, the pilot placed the small thermistor under his tongue for about 5 minutes. Preflight body temperatures were all within the normal range. The remainder of the biosensor system was the same as that used for the MA–8 mission (ref. 1).

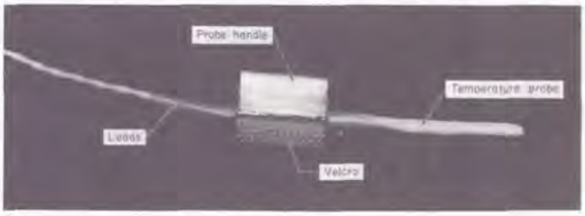

FIGURE 18–1.—Oral temperature probe.

FIGURE 18–2.—Installation of oral temperature probe in helmet.

Preflight biosensor preparation included careful calibration of the system so that accurate, repeatable determinations were assured. Adjustments were required to compensate for individual variations. This requirement was especially true for the blood-pressure measuring system. The clinical blood-pressure mean

Table 18–VI.—Detailed Preflight Heart-Rate and Respiration-Rate Data

[Flight simulation numbers 1 and 3, launch simulation, launch countdown (canceled), and launch countdown were performed on the launch pad]

Date	Procedure	Duration of observation, hr : min	Mean		Heart rate				Respiration rate			
			Heart rate, beats/min	Respiration rate, breaths/min	Number of values	±2 standard deviations, beats/min	Range, beats/min		Number of values	±2 standard deviations, breaths/min	Range, breaths/min	
							Minimum	Maximum			Minimum	Maximum
February 1959.	Lovelace Clinic exercise tolerance test.	[a]0:14	----	----	([b])	------	---	185	([b])	------	---	---
Sept. 28, 1961, and Mar. 28, 1963.	Mercury-Atlas Centrifuge dynamic simulations.	4:18	83	([b])	177	57 to 109	58	151	([b])	------	---	---
Apr. 13, 1962	Altitude-chamber spacecraft checkout.	10:29	79	18	161	54 to 104	60	129	117	11 to 25	12	28
July 23, 1962	Altitude-chamber spacecraft checkout.	7:33	64	19	111	49 to 79	46	92	111	14 to 24	13	26
Jan. 5, 1963	Altitude-chamber spacecraft checkout.	6:17	74	17	20, 000	56 to 92	56	102	123	10 to 24	10	26
Mar. 23, 1963	Hangar flight simulation	2:00	64	19	4, 254	51 to 77	55	106	44	8 to 30	13	41
Apr. 23, 1963	Flight simulation No. 1	3:40	71	19	75	56 to 86	51	92	75	14 to 24	13	28
May 7, 1963	Mission simulation (procedures trainer).	5:22	71	([b])	103	50 to 92	50	102	([b])	------	---	---
May 8, 1963	Launch simulation	4:48	72	20	17, 232	54 to 90	52	107	94	13 to 27	11	28
May 10, 1963	Flight simulation No. 3	3:30	62	19	67	39 to 85	48	96	67	13 to 25	10	26
May 14, 1963	Launch countdown (canceled).	5:41	71	20	19, 666	53 to 89	47	132	96	14 to 26	14	30
May 15, 1963	Launch countdown	2:31	73	16	9, 010	48 to 98	51	104	50	10 to 22	10	24

[a] Duration determined by the maximum heart rate.

[b] Not recorded.

Table 18–VII.—Summary of Heart-Rate and Respiration-Rate Data

Preflight

Date	Procedure	Duration of observation, hr:min	Overall mean		Range of mean rates		Range of ±2 standard deviations	
			Heart rate, beats/min	Respiration rate, breaths/min	Heart rate, beats/min	Respiration rate, breaths/min	Heart rate, beats/min	Respiration rate, breaths/min
September 1961 to May 15, 1963.	Centrifuge simulations and checkout procedures.	56:23	72	19	62 to 83	16 to 20	39 to 104	8 to 30

Inflight

Date	Procedure	Duration of observation, hr: min	Mean		Heart rate			Respiration rate		
			Heart rate, beats/min	Respiration rate, breaths/min	Number of values	±2 standard deviations, beats/min	Range, beats/min	Number of values	±2 standard deviations, breaths/min	Range, breaths/min
May 15 and May 16, 1963.	Orbital flight	34:16	89	15	76,174	62 to 116	55 to 180	151	5 to 25	6 to 28
Postflight										
May 16 and May 17, 1963.	Physical examinations.	([a])	77	16	4	72 to 82	56 to 88	1	([b])	

[a] Not determined, not time critical.
[b] Not applicable.

Table 18-VIII.—Detailed Preflight Blood-Pressure Data

Date	Procedure	Duration, hr:min	Mean blood pressure, mm Hg	Systole		Diastole		Mean pulse pressure, mm Hg
				Number of values	Range, mm Hg	Number of values	Range, mm Hg	
Preflight, clinical								
February 1959	Lovelace Clinic exercise tolerance test	00:14	[a] 174/86					
March 1959	Aeronautical Systems Division dynamic tests:							
	Cold pressor	[b]	105/74	13	100 to 112	13	70 to 82	31
	Tilt	[b]	109/75	30	92 to 138	30	68 to 88	34
	Treadmill	[b]	134/87	18	110 to 156	18	80 to 100	47
September 1959	Lackland USAF Hospital physical examination.	[b]	113/70	4	110 to 116	4	68 to 72	42
April 1962	Physical examinations	[b]	100/80	5	88 to 108	5	72 to 88	20
July 1962	Special BPMS test	[b]	116/78	58	102 to 124	58	64 to 84	39
July 23, 1962	Physical examinations	[b]	103/79	16	98 to 106	16	73 to 82	25
March 12, 1963	Physical examinations	[b]	108/72	4	98 to 118	4	68 to 78	37
Apr. 23, 1963 to May 15, 1963	Physical examinations during final preflight checkout period.	[b]	115/78	8	105 to 120	8	72 to 82	37
Preflight, blood pressure measuring system								
Sept. 12, 1961	Mercury-Atlas centrifuge dynamic simulation.	2:23	114/85	12	103 to 144	12	66 to 98	29
Apr. 13, 1962	Altitude-chamber spacecraft checkout	10:29	134/91	10	128 to 148	10	70 to 124	43
July 10 and July 23, 1962	BPMS calibration	3:00	110/79	73	96 to 128	69	63 to 88	31
July 23, 1962	Altitude-chamber spacecraft checkout	7:33	94/71	8	79 to 111	8	61 to 79	23
Jan. 3, 1963	BPMS calibration	1:00	108/80	14	99 to 116	14	73 to 87	28
Jan. 5, 1963	Altitude-chamber spacecraft checkout	6:17	112/83	12	99 to 122	12	77 to 89	29
Mar. 22 and Mar. 23, 1963	Hangar flight simulation	2:05	94/71	5	89 to 107	5	65 to 81	23
Apr. 23, 1963	Flight simulation No. 1	3:40	114/91	6	104 to 123	6	81 to 99	23
May 8, 1963	Launch simulation	4:48	106/82	12	101 to 123	12	71 to 91	24
May 10, 1963	Flight simulation No. 3	3:30	110/90	2	107 to 112	2	89 to 91	20
May 14, 1963	Launch countdown (canceled)	5:41	120/82	8	117 to 127	8	77 to 89	38
May 15, 1963	Launch countdown	2:31	110/82	4	107 to 119	4	73 to 89	28

[a] Value at test endpoint, other values not available.

[b] Not determined, not time critical.

Table 18-IX.—Summary of Blood Pressure Data

Date	Procedure	Duration, hr:min	Mean blood pressure, mm Hg	Systole			Diastole			Mean pulse pressure, mm Hg
				Number of values	±2 standard deviation, mm Hg	Range, mm Hg	Number of values	±2 standard deviation, mm Hg	Range, mm Hg	
Preflight, clinical										
February 1959 to May 15, 1963	Crew selection examination, special tests and preflight examinations.	([a])	113/79	95	99 to 127	88 to 124	95	69 to 89	64 to 88	34
Preflight, blood pressure measuring system										
September 1961 to May 15, 1963	Centrifuge simulations and preflight test procedures.	56:09	112/79	160	86 to 138	79 to 148	160	58 to 90	61 to 124	33
Inflight, blood pressure measuring system										
May 15 and May 16, 1963	Orbital flight	34:16	119/81	12	([b])	109 to 131	12	([b])	73 to 89	38
Postflight, clinical										
May 16 and May 17, 1963	Postflight physical examinations.	([a])	91/66	16	75 to 107	86 to 100	16	55 to 77	52 to 82	25

[a] Not determined, not time critical.
[b] Not applicable.

values, shown in table 18–IX, are of particular interest and indicate that the correlation between these readings and those taken with the BPMS is valid. The stability of these calibrations was rechecked on several occasions before flight. All systems operated properly during the final preflight-preparation period.

The preflight biosensor data are presented in tables 18–VI to 18–IX. The analysis methods used were both manual and automatic.

All respiration minute rates were obtained by manual reduction; 30-second counts made from the continuous direct-recorded analog signal, with sampling intervals either every 3 or every 4 minutes. Heart rates from many of the records were determined in the same manner. Those sets can be readily identified by the relatively low number of values used. The automatic analysis utilizes a general-purpose computer to determine the intervals between all the R waves of the ECG complex in the record, and the reported values were computed from these determinations. The automatically reduced rates are readily identified by the large number of values. The validity of both of these methods has been substantiated by repeated cross-correlation of results during the two years of development of the analysis program. Although the data analysis format was arbitrarily selected, the results are fully reproducible and appear to be adequate for the present medical requirements. All blood-pressure measurements on record were incorporated in the tables.

A highly significant aspect of the preflight data is the rather wide range of values recorded, particularly heart rates, which have modified the understanding of expected or so called "normal" responses. This wide variation is a common phenomenon among healthy individuals in dynamic situations, and clearly indicates the need for the use of extreme caution in attributing changes observed in flight to weightlessness or other factors peculiar to the flight environment.

The ECG from the preflight observation period was scanned repeatedly by numerous observers. The collective opinions were that marked normal sinus arrhythmia was present with frequent occurrences of a wandering cardiac pacemaker. At times, sinus node suppression was sufficient to allow activation by the atrio-ventricular (A–V) node with escape and fusion beats. This occurrence was identified by both biphasic and negative P waves of decreased amplitude, and on occasion by changes in the ventricular complexes. Numerous such beats were noted during the countdown of the postponed launch, and one brief episode of nodal rhythm occurred during this period. This finding was considered acceptable as a normal variant in this pilot only by virtue of the extensive preflight monitoring which had shown nodal rhythm to be an incidental occurrence. These data are illustrated in figure 18–3. There was sinus bradycardia, which, at times, was followed by a sinus-generated beat and, at other times, was followed by an A–V nodal-generated escape beat. Other infrequent rhythm alterations were premature atrial and ventricular beats. The preflight data were collected in order to establish the baseline physiological responses of the MA–9 astronaut specifically using the flight biomedical instrumentation.

FLIGHT OBSERVATIONS

Inflight biomedical monitoring spanned a time interval of 34 hours, 16 minutes, and 43 seconds on this flight. Continuous onboard recording included the first 1 hour and 35 minutes and the last 10 hours and 45 minutes of flight time until bioplug disconnect. Flight data were programed to be intermittently recorded for 1 minute of every 10 minutes between 1 hour and 39 minutes elapsed time and 23 hours and 32 minutes elapsed time. Recording of physiological data through the mid-portion of the flight was erratic and did not follow original plans because of a malfunction of the tape-recorder programer which occurred at approximately 12:00:00 ground elapsed time (g.e.t.) and continued throughout the flight. However, sufficient data points were obtained for confident extrapolation of trends of physiologic values during this portion of the flight by the astronaut's voice contacts with the ground, his use of the vox-record actuation of the tape recorder, or his turning the tape recorder temporarily to continuous to document certain inflight experiments. Data during the final portion of the flight, from 24:00:00 g.e.t. until landing, were obtained because the failed programer was over-

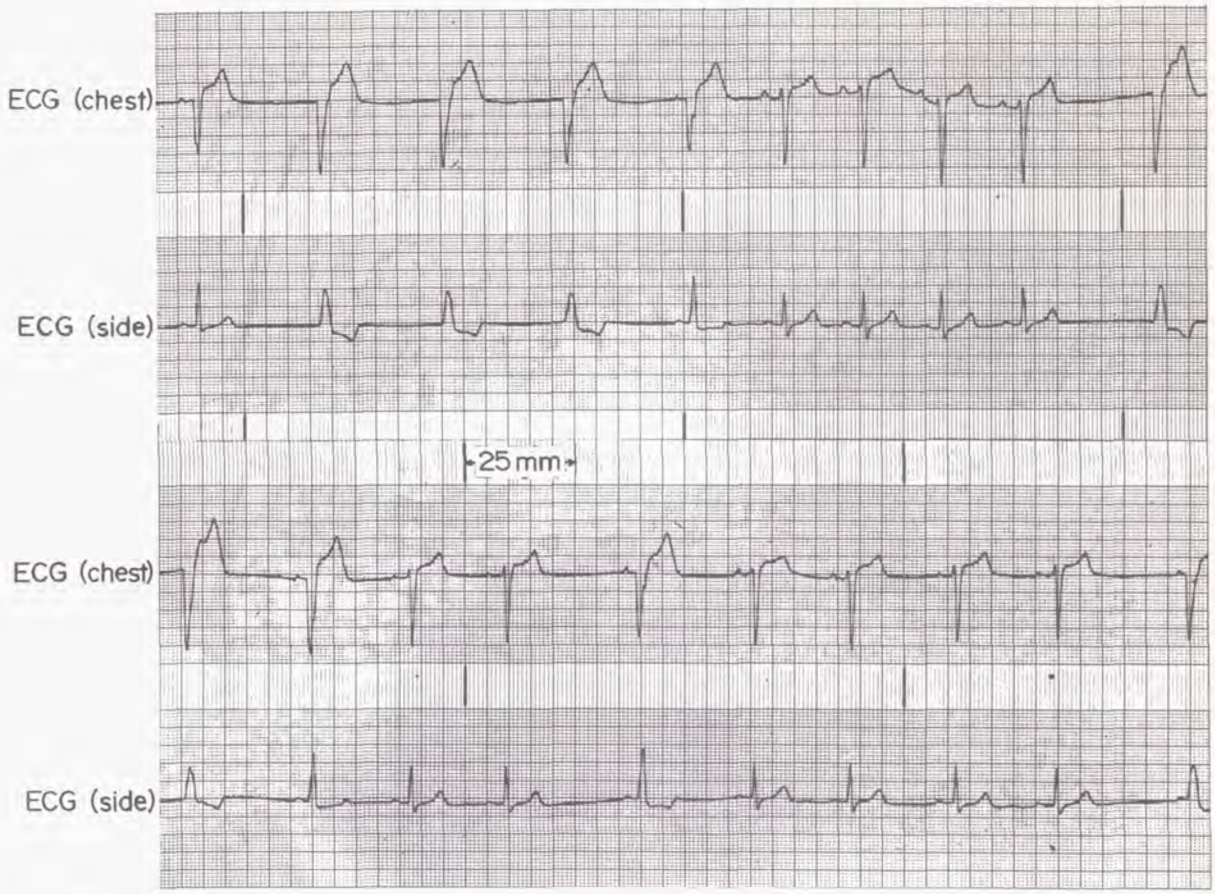

FIGURE 18-3.—MA-9. May 14, 1963, 07:42:00 e.s.t. Sample record illustrating nodal beats occurring during canceled launch countdown. Recorder speed 25 mm/sec.

ridden by the astronaut's selection of continuous recorder operation. During the period when the astronaut was resting quietly or was asleep, essentially no medical data were obtained on the onboard recorder; consequently mean heart-rate values for the entire duration of the flight are probably biased on the high side of a true mean. Data from the onboard recorder have been supplemented by data obtained during network station passes throughout the mission, and an exceptionally valuable short period of recording was obtained onboard the carrier during egress of the astronaut. The inflight responses are summarized in tables 18-VII and 18-IX. Heart-rate response, including mean rates, was obtained through a computer reduction of the inflight data from the onboard tape recorder.

Respiration rates were obtained by the manual reduction of 30-second periods every 3 minutes during the period of continous recording and from 30-second averages taken at all other short intervals when data were available from the onboard tape recorder. Blood pressures were obtained according to the flight plan with only very minor variations. These values were with few exceptions not recorded on the onboard recorder since the astronaut was generally quiet while sending the blood pressure, and therefore the tape recorder was not operating. However, the values were received at ground stations in every instance and read in real time by medical monitors. The readings were subsequently verified by postflight analysis of the tracking-site data. Body temperature was sampled intermittently during the flight with an oral thermistor, which the pilot placed under his tongue on four of the five planned occasions. One additional oral temperature was requested and obtained during the flight. Body temperatures obtained in flight and listed in table 18-X were all within an acceptable range.

Table 18-X.—Oral Temperatures Obtained in Flight

Ground elapsed time, hr : min : sec	Oral temperature, °F
1:10:00	98.5
6:00:00	100.0
10:25:00	100.0
12:25:00	99.0
23:50:00	98.0

The overall mean heart rate recorded during the period when the inflight recorder was operative was 89 beats per minute, and the overall respiratory rate recorded from available data was 19 breaths per minute. The significant events of powered flight showed corresponding increases in heart rate and respiratory rate, as has been the case in all manned Mercury flights. The pilot's heart rate at booster-engine cut-off (BECO) was 147 beats per minute; at launch-escape-rocket ignition, 154 beats per minute; and at sustainer-engine cut-off (SECO), 144 beats per minute. Within 2 minutes after SECO, the heart rate subsided to about 110 beats per minute and then gradually declined over the next 13 minutes to rates of 80 to 100 beats per minute for the remainder of the first orbital pass. Respiratory rate was 28 breaths per minute at BECO, between 25 and 30 breaths per minute through SECO, and then declined to rates of 18 to 20 breaths per minute within the first 15 minutes of weightless flight.

Heart rate remained stable around 80 beats per minute throughout the first 8 hours in space except during periods when the astronaut announced on the tape that he was undergoing some specific exertion such as emptying the condensate tank or removing equipment from the equipment kit. During these intervals, rates would increase to values from 100 beats per minute to as high as 130 beats per minute for very short times.

At 8:25:00 g.e.t., the pilot specifically mentioned struggling with his writing desk. At this time, his heart rate rose to 96 beats per minute and then promptly settled back to its resting rate of about 80. The longer period of observation and the opportunity which this flight afforded to correlate pilot activities with heart and respiratory rates permit a tentative appraisal of the effect on these rates of exertion under equally cramped circumstances at 1g. There does not appear to be a significant difference in terms of heart-rate and respiratory-rate response in the two situations. This impression was further borne out in the two planned exercise periods in which there was similarity between the response to exercise in orbital flight and the response to exercise in preflight practice sessions, as shown in table 18–XI.

When the flashing light was deployed at about 3:26:00 g.e.t. his heart rate rose to a sharp peak of 134 beats per minute and then promptly declined to 95 beats per minute while the pilot was maneuvering the spacecraft in an attempt to sight the flashing light.

The respiratory rate sensor malfunctioned during the flight. The failure was subsequently traced to a separation of the lead wire from the electrode, which was attached to the left lower chest. The first sign of respiration-sensor failure ocurred at 7:08:00 g.e.t.; and throughout the remainder of the flight, the respiratory-rate recording was intermittent. Sometimes, the trace appeared to be a faithful replica of the pilot's breathing, but at other times it was entirely unreliable or without apparent relationship to respiration. The respiratory rates during the last portion of the flight are tentative rates based on the appearance of the pneumograph waveform during periods when evidence available indicated it was following changes in thoracic volume. Typical signals of properly operating biosensors are illustrated in figure 18–4.

During the sleeping period, heart rates recorded on passes over tracking stations were generally as low as 50 and averaged between 55 and 60 beats per minute. However, when the pilot awoke and announced anything which was recorded on the onboard recorder, his heart rate immediately rose to about 80 which is the same value as during his working period earlier in the flight. After about 23:32:00 g.e.t. and for the remainder of the normal orbital flight, the astronaut's mean heart rate rose to a value of about 100 beats per minute. His first indication of a spacecraft system malfunction occurred at about 23:59:00 g.e.t. when he noticed that the 0.05g relay light had come on. Heart rate at this time rose sharply to 148 beats per minute and then rapidly declined to the low of

Table 18-XI.—Summary of Calibrated Work

Prework					Work		Postwork				
Heart rate, beats/min		Blood pressure, mm Hg			Heart rate, beats/min		Heart rate, beats/min		Blood pressure, mm Hg		
Mean	Range	Mean	Range		Mean	Range	Mean	Range	Mean	Range	
			Systolic	Diastolic						Systolic	Diastolic
Preflight, 5 calibrated work periods											
74	60 to 100	104/81	89 to 113	77 to 85	115	91 to 160	85	61 to 120	111/79	89 to 137	71 to 89
Flight, 2 calibrated work periods											
89	80 to 105	117/77	117	77	131	120 to 145	106	124/95	90 to 130	119 to 129	89

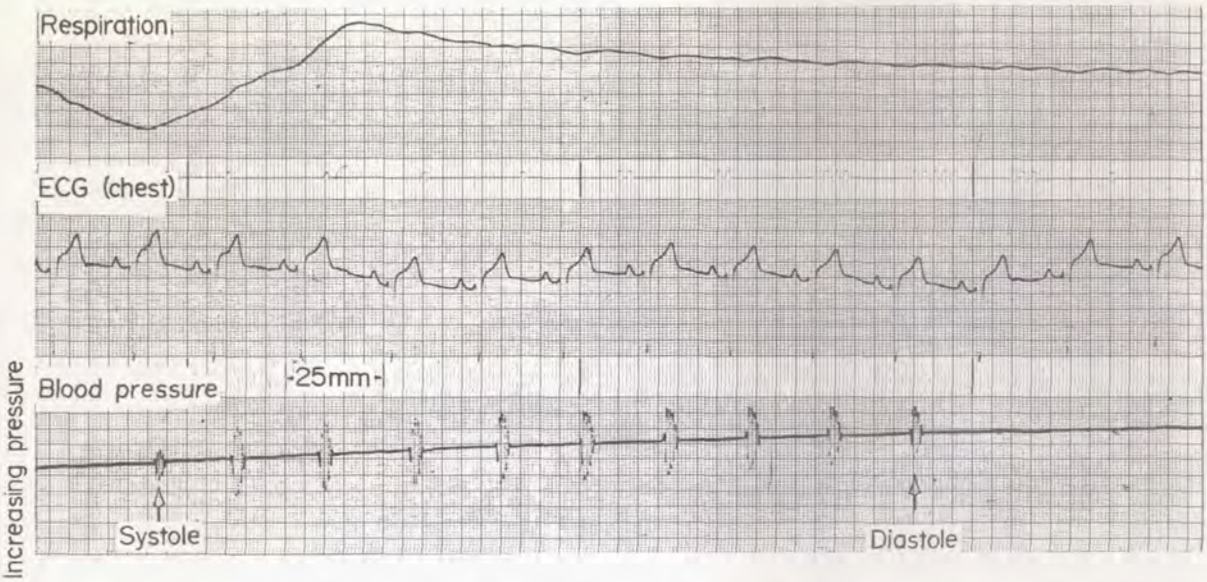

FIGURE 18-4.—MA-9. 12:29:52. Sample of typical biosensor data received at a range station. Blood pressure 117/3 mm Hg. (Recorder speed 25 mm/sec.)

60 beats per minute and stabilized at a rate of around 100 beats per minute. After a preliminary analysis of the nature of the malfunction indicated by this 0.05g light, the pilot's heart rate varied, with a peak of 142 beats per minute while he was engaged in checking his ASCS system at approximately 30:08:00 g.e.t. Again, the heart rate declined rapidly to its resting level of approximately 100 beats per minute.

At about 32:41:00 g.e.t., the pilot was advised to take 5 mg of dextro amphetamine orally which he did very shortly after receiving the advice. His heart rate rose gradually beginning at 33 hours elapsed time, with rather marked swings in rate between levels as high as 140 beats per minute and lows of about 80 beats per minute throughout the remainder of the flight. A significant change in heart rate occurred at retrofire when the heart rate rose to 166 beats per minute for no longer than 20 seconds.

The heart rate during reentry varied between 120 and 140 beats per minute until drogue parachute deployment when it spiked to 184 beats per minute. It then gradually declined to 164 beats per minute when bioplug disconnect was accomplished subsequent to main parachute deployment.

The changes in heart rate throughout this flight seem to fall readily into two categories. Moderate increases in rate with gradual return to the normal resting rate were seen in response to physical exertion. The peak heart rate noted during the flight generally corresponded to levels which have been seen following an equivalent amount of exertion under 1g. A sharper rise of heart rate to high levels in excess of 140 beats per minute was seen as a response when the astronaut was evidently emotionally alerted to a highly significant change in his environmental situation.

The ECG intervals were well within normal physiologic limits during the major portion of this flight. The A–V nodal beats noted during the prelaunch period were rarely seen during the 34½ hours of flight monitoring. A careful review of all flight records revealed that data from both leads of ECG showed periodic changes in the character of the P wave and the P–R interval, which are consistent with a wandering pacemaker. There were frequent prolonged sinus pauses during the flight which generally are associated with deep inspiration by the pilot, and in the great majority of instances a sinus beat, rather than a ventricular escape, followed the pause. One period in which this rule did not hold was during the sleeping time as the astronaut was passing over the Rose Knot Victor tracking ship. At 17:10:00 and 18:45:00 g.e.t., the medical monitor reported a nodal rhythm which was verified during the postflight examination of the records. Figure

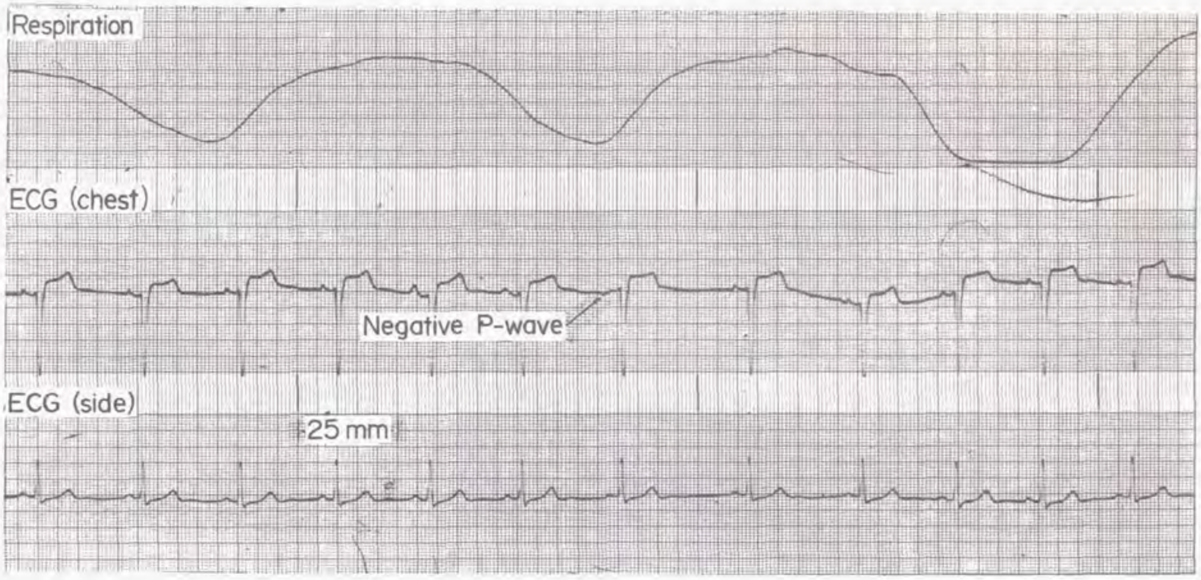

FIGURE 18-5.—MA-19. 16:11:30. Sample of biosensor record at a range station illustrating one of the frequent occurrences of sinus arrhythmia with wandering of the cardiac pacemaker. In this sample, the negative P wave suggests inverse depolarization from the atrioventricular node. Similar changes were observed before flight. (Recorder speed 25 mm/sec.)

18-5 illustrates this variation. Late in the flight, the sternal ECG lead became rather noisy with a marked fluctuation of the baseline. This fluctuation appeared at times to be synchronous with respiration and at other times to bear little or no relationship to respiratory movements. At this period in the flight, sinus arrhythmia was somewhat more pronounced that it had been early in the flight. A recurrent finding on the record consisted of a simultaneous disruption of the sternal ECG recording with a sharp negative impulse on the relatively insensitive respiratory channel and a sinus pause showing on the side-to-side ECG lead. It is believed that this characteristic pattern resulted from either a habitual deep sighing breath taken by the pilot or perhaps a repeated stretching motion made in an attempt to relieve his cramped position.

Blood pressures did not vary remarkably during the flight from preflight values, as shown in table 18-IX.

Postflight analysis of the film badges worn by the astronaut revealed a total radiation dose well below a level of medical concern. (See paper 12 for a report on the radiation measurement.)

With regard to symptoms related to the flight experience, the pilot repeated the observations of each of his predecessors that the g-forces are readily tolerated and that the sensation of weightlessness is an entirely pleasant experience to which he adapted readily. Astronaut Cooper noticed that his perspective within the spacecraft cabin was altered during the first few minutes of weightless flight. Specifically, he observed that after SECO and during the first 20 minutes or so of weightlessness he felt that the equipment kit located near his right arm was rotated 90°. A similar phenomenon of orientation was reported by the MA-7 pilot. See reference 2. This was not a troublesome illusion to the pilot and gradually vanished as he became accustomed to the altered sensory cues of orbital flight.

The astronaut stated that he did not feel particularly hungry during most of the flight and ate primarily because it had been scheduled. However, later in the flight he did feel hungry on one occasion and after eating felt better. Because of problems with the food containers and water nozzle during flight, he was unable to reconstitute properly the freeze-dehydrated food and could only eat one-third of a package of beef pot roast. Therefore, he subsisted on bite-sized cubed food and bite-sized peanut butter "sandwiches." He avoided the bite-sized beef sandwiches, since they had crumbled in their package. His caloric intake during the flight was only 696 calories of the 2,369 calories available to him at launch. He rapidly tired of the cubed "snack-type" foods and this contributed to his low caloric intake. Typical samples of the food types carried aboard from the MA-9 flight are shown in figure 18-6.

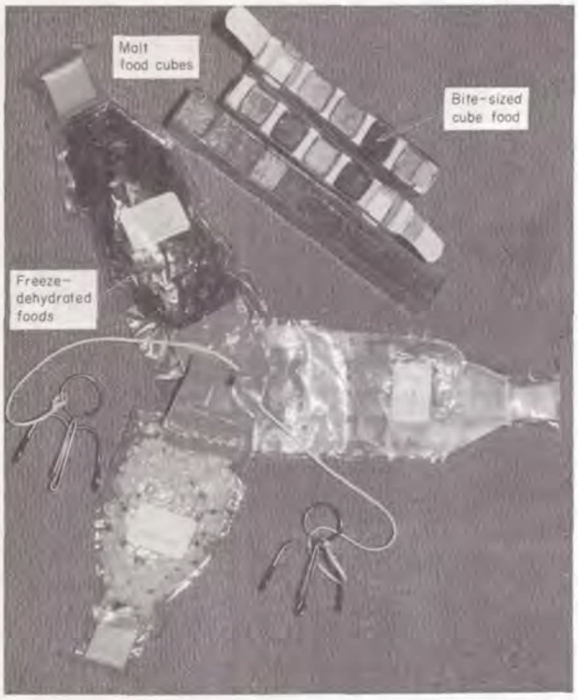

FIGURE 18-6.—Types of food used during MA-9 flight.

The astronaut's water intake was also limited. When the condensate transfer system would no longer permit fluid storage in the 3.86-pound-capacity main condensate bag during the flight he was forced to put condensate water into one of the drinking-water tanks before he had consumed all of its contents. Normal operational procedures required the exclusion of condensate water as a drinking-water source. He began drinking small amounts from his survival-kit water supply, as planned, but he wished to conserve this supply as much as possible. He was not really thirsty until during the last orbital pass, but he was so busy at that point that he did not take time to drink. Because condensate water was placed into the drinking-water tank in which an unknown amount of drinking water remained, it is impossible to make a precise statement as to his water intake during flight, but he did consume more than 1,500 cc.

He urinated without difficulty several times during flight and stated that bladder sensations were normal. The urine collection and transfer system worked well, and separate urine samples were obtained at four different times during the flight. It required, however, a considerable amount of time and effort to transfer the urine to the storage bags manually.

The astronaut had a very good sleep the night prior to launch and was as rested as possible. He found, even early in the flight, that when he had no tasks to perform and the spacecraft was oriented such that the earth was not in view from the window, he easily dozed off for brief naps. This dozing did not occur during times when there were tasks to perform or items to see through the window. During the period designated for sleep, he slept only in a series of naps lasting no more than 1 hour each. His total sleep time was about 4½ hours. He awoke from these 30- to 60-minute naps feeling alert and rested, but 30 to 45 minutes later he would again doze off. He stated that if there had been another person along to monitor the systems, particularly the environmental control system, he could have slept for much longer periods, but still "no more than 4 to 6 hours in a day." Table 18-XII lists estimated inflight sleep periods.

He had a brief period of confusion the first time or two that he awoke in that he did not realize exactly where he was. However, it took him only a very few seconds to become completely awake and oriented. He reported that this brief period of confusion did not occur later in the flight. The pilot stated that he slept "perhaps a little more soundly" than on earth. He did dream, but he did not remember the contents of the dreams. This is consistent with his past experience.

He felt that being strapped into the seat made little difference in his sleep, but he definitely had the feeling he was sleeping sitting up. He noted when he awoke that his arms were floating out in front of him, and because of his concern that he might inadvertently trip a critical switch during sleep, he folded his hands and hooked his thumbs under the helmet restraint cables. He was never startled or alarmed to awaken and see his hands floating in front of his faceplate.

Table 18-XII.—Inflight Sleep Periods

[Other unrecorded naps occurred]

Time, g.e.t.	Estimated duration, min	Source
02:10:15 to 02:14:00	4	Onboard tape.
05:40:00 to 05:45:00	5	Astronaut record.
13:50:00 to 14:46:00	56	Onboard tape.
14:20:00 to 14:47:00	27	Astronaut record.
15:11:00	([a])	Onboard tape.
15:20:00 to 16:05:00	45	Astronaut record.
16:28:11	([a])	Onboard tape.
16:50:00 to 17:50:00	60	Astronaut record.
08:20:00 to 18:25:00	5	Astronaut record.
18:40:00 to 19:27:00	47	Astronaut record.
19:38:39	([a])	Onboard tape.
21:22:44	([a])	Onboard tape.
27:26:08	([a])	Onboard tape.
Total sleep recorded: 4 hours and 9 minutes.		

[a] Short naps, duration not determined.

The oral temperature probe was easily handled by the pilot. It was necessary to use a small hand mirror to check its position on the right ear muff to be sure it was not extending beyond the helmet, but at no time did it interfere with closing the faceplate.

The only real discomfort experienced during the flight was associated with the pressure suit being pulled tightly across the pilot's knees. By the sixth or seventh orbital pass, his knees were becoming quite uncomfortable. He alleviated this discomfort somewhat by periodically sliding his feet up past the normal foot position into the tower area of the spacecraft. This action permitted the straightening of his legs to relieve most of the pressure and also allowed him to pull on the legs of the suit to gain a little slack around his knees.

The astronaut took 5 mg of dextro-amphetamine sulfate approximately 1 hour 20 minutes prior to retrofire on advice of the MCC surgeon. He stated that within 20 minutes he felt much more alert and confident and seemed to be "more on top of things." He had less tendency to drop off to sleep for the remainder of the flight. There was no apparent degradation in the pilot's performance following this medication. The pilot stated that the drug, as far as he could tell, had the same effects as test doses taken prior to flight.

During the last two orbital passes, the carbon-dioxide partial-pressure (PCO_2) gage was noted to indicate a rise in the amount of carbon dioxide in the suit. The astronaut actuated the emergency oxygen flow rate for 30 seconds. It did not seem to change the pilot's onboard reading noticeably, although telemetry signals indicated a slight drop. At this time the pilot closed his faceplate and felt that his respirations were deeper and more rapid. This change in respiration could not be confirmed by postflight examination of respiration and heart rate recordings. Although he felt more comfortable with the faceplate open, he kept it closed during the final orbital pass and the reentry as planned. The PCO_2 gage indicated about 5 mm Hg at reentry. This concentration is not enough to cause symptoms of hypercapnia on the ground, and there was no apparent interference with the pilot's normal responses.

Postflight Observations

The spacecraft landed in the water about 4.5 miles from the recovery ship, the *USS Kearsarge*, and was placed on deck approximately 40 minutes later. In order to gain medical data as early as possible, the NASA flight surgeon aboard the recovery ship was equipped with an 8-foot extension cord for the biomedical cable. Immediately after the hatch was opened, this cord was attached to the astronaut's biosensor plug and blood pressure fitting and connected to the spacecraft onboard recorder to record blood pressures and ECG before, during, and after egress. This system was extremely effective in deriving egress data.

The astronaut was then taken to the ship's sick bay where a comprehensive medical examination and preliminary debriefing were performed. The remainder of the debriefing was conducted by the NASA flight surgeon in the admiral's inport cabin. The astronaut spent 48 hours on board the ship. Details of his activities during this 48-hour period are shown in table 18–XIII.

Table 18–XIII.—Pilot Postflight Activities

Date, 1963	Time, local Midway [a]	Activity
May 16	12:25 p.m.	Landing.
	12:55 p.m.	Spacecraft on deck.
	1:09 p.m.	Blood pressure, recumbent in spacecraft.
	1:12 p.m.	Egress and blood pressure standing.
	1:15 p.m.	Physical examination begun in recovery ship sick bay.
	1:45 p.m.	First tilt table procedure.
	3:00 p.m.	Examination completed.
	3:30 p.m.	First postflight urination.
	3:42 p.m.	Second tilt table procedure.
	4:10 p.m.	First postflight meal.
	5:45 p.m.	First postflight bowel movement.
	7:11 p.m.	Third tilt table procedure.
	9:30 p.m.	To bed.
May 17	7:00 a.m.	Awakened.
	7:40 a.m.	Fourth tilt table procedure and brief medical examination.
	8:00 a.m.	Breakfast.
	9:00 to 11:00 a.m.	Self-debriefing.
	2:00 to 5:00 p.m.	Technical debriefing.
	7:00 to 9:00 p.m.	Medical debriefing.
May 18	1:00 p.m.	Left recovery ship.
May 20	9:00 a.m. e.s.t.	Comprehensive postflight medical examination at Patrick Air Force Base, Fla.

[a] To convert times to e.s.t., add 6 hours.

The postflight examination began prior to egress from the spacecraft. Approximately 40 minutes after landing, two measurements of the astronaut's blood pressure were recorded while he was still lying in the spacecraft on the deck of the recovery ship. He was then able to egress from the spacecraft without assistance and stand erect on the deck while his blood pressure was again recorded on the onboard tape. Later examination of this 3½ minute record shows that, while he was still in the spacecraft, his blood pressures were 101/65 and 105/87, with a corresponding heart rate of 132 beats per minute. During egress and immediately thereafter while standing upright on the deck, his heart rate rose to 188 beats per minute with atrioventricular dissociation. At that point, another blood pressure recording was attempted and, although the apparatus appeared to cycle normally, no pressure pulses were seen on the recording. His heart then returned to a normal sinus rhythm with a rate of 92 beats per minute at sensor disconnect.

After standing on the deck for approximately a minute, the pilot began to look pale and, although his face was already wet, new beads of perspiration appeared on his forehead.

He swayed slightly and reported symptoms of impending loss of consciousness including lightheadedness, dimming of vision, and tingling of his feet and legs.

The cable was immediately disconnected and, with support at each arm, he began to walk away from the spacecraft. After a few steps, 5 to 10 seconds later, he was able to walk without assistance and to salute the ship's commanding officer. There were no other objective changes of this kind throughout the postflight examination and debriefing period.

The remainder of the physical examination was conducted in the ship's sick bay and was completed within 2 hours after landing. During desuiting it was noted that the astronaut was soaking wet, presumably with perspiration. His hands had the white, wrinkled appearance characteristic of prolonged submersion in water. His feet and socks were dry. He complained of being thirsty and his voice was dry and hoarse. He participated actively in the desuiting and examination but appeared tired and less talkative than usual.

The urine collection device contained 107 cc of urine. When the soaking wet underwear was removed, the lead wire to the lower left of the pneumograph sensor on the chest was seen to be disconnected. It is not known whether it separated prior to this time, although it appears probable that it was loose and was making partial contact, held by the plastic insulation sleeve until the suit was removed. There were some evidences of pressure on the skin at all lateral sensor locations, but no signs of irritation by sensors, or paste. All sensors were securely in place and the electrode paste seemed to have maintained its normal consistency. At the sensor locations on the left lateral chest, there were narrow semicircular marks that looked like very shallow cuts with a sharp blade. These cuts may have been caused by the thin edge of the tape where the rubber sensor disc slightly overlapped it.

There were painful and slightly swollen red areas over each patella caused by the pressure suit having been pulled tightly across the anterior knee when the knee was flexed. Other reddened areas were found over each posterior inferior iliac spine and the posterior spinous process of the fifth lumbar vertebra. There was a diffuse redness over the right lateral iliac area, but none over the left.

Additional findings of note were a bilateral conjunctivitis, which probably resulted from drying of the eyes by the constant oxygen flow and a slight reddening around the left tympanic membrane. The astronaut complained that he had a little trouble clearing his left ear during descent. Both ears "crackled" for 6 to 8 hours after recovery as the oxygen in the middle ear was gradually absorbed and replaced with air. This condition is commonly seen in aviators when they have been breathing 100-percent oxygen.

Tilt table studies were performed at 1, 3, 6½, and 19 hours after landing. At no time did the astronaut have any subjective complaints, nor were objective changes noted except in heart rate and blood pressure. Specifically, there were no unusual color changes in the feet, as had been noted following the MA–8 flight. The results of the tilt table studies are tabulated and discussed under Special Studies.

The medical findings during the initial examination after desuiting are shown in table 18–II and included a blood pressure of 90/80 mm Hg while supine, a heart rate of 86 beats per minute, a respiration rate of 16 breaths per minute, a body weight of 139¼ pounds, and a body temperature of 99.4° F taken orally. Three hours after landing, his urine showed a specific gravity of 1.031, and the hematocrit was 49. These findings, combined with the clinical evaluation, indicate a moderate dehydration. As has been indicated elsewhere, this dehydration resulted from a reduced intake of food and water during the flight. Detailed results of the blood and urine analyses are contained in tables 18–III to 18–V. The reversal of the ratio of lymphocytes to polymorphonuclear leukocytes during the week following the flight, without a significant change in the total count, has not been explained. This ratio has since returned to normal. A clinical electrocardiogram and a chest X-ray completed the initial postflight examination. The chest X-ray showed no changes when compared with that taken before the flight on May 12, 1963. The ECG showed a moderate rightward shift in the QRS and T axes when compared to that of May 12, 1963.

The astronaut slept very soundly for 9½ hours and awoke cheerful and eager to complete the debriefing activites.

A brief examination the following day showed that the conjunctival irritation, the hoarseness of his voice, most of the skin pressure marks, and most of the evidence of dehydration had disappeared. The areas of pressure over the knees were still painful and somewhat more swollen than on the previous day. The sharp semicircular marks were still much in evidence and remained visible for several days.

Table 18–XIV.—Period of Pilot's Weight Changes

During the 3-week period prior to flight, the pilot's maximum weight was 149¼ lb and his minimum weight was 146 lb. His weight on launch morning was 147 lb and his weight on the recovery ship was 139¼ lb.]

Date	Activity	Duration, hr	Weight loss, lb
Preflight			
Jan. 5, 1963	Altitude-chamber spacecraft checkout procedure.	9	3.5
Apr. 23, 1963	Flight simulation	7	2.0
May 8, 1963	Launch simulation	8½	3.0
May 10, 1963	Flight simulation	6	2.0
May 14, 1963	Canceled launch	8	1.3
Flight			
May 15/16, 1963	Orbital flight	34⅓	7.75

Table 18–XIV shows the pilot's weight loss during several preflight activities and the inflight experience. Intake and output records for the first 24 hours after recovery indicate a fluid intake of 3,900 cc and a urine output of 545 cc.

The pilot returned to the launch site on the fourth day following launch and was examined the following morning. The same medical specialists who examined him prior to flight found him to be in excellent health. The only changes noted were the persistent slight erythema and tenderness of both patellae resulting from the pressure areas in the suit, a continued rightward shift in the QRS and T axes of the ECG, and persistence of the previously noted alteration in blood count. The ECG shift had become less apparent, however. The laboratory studies of blood and urine are contained in tables 18–III to 18–V.

The pilot remained in good health and maintained his high morale following this examination. He participated in debriefing sessions and other postflight activities without further medical change.

Special Studies

Tilt Test Evaluation

The medical examination performed immediately after the MA–8 recovery suggested an alteration in the pilot's cardiovascular responses to position changes (ref. 1). In order to obtain more quantitative measurements of these responses, an operational tilt procedure was developed for shipboard use. This procedure utilized a Stokes' Litter with cross-bars added for lifting and stabilization. The modifications permitted a tilt of 70° from the horizontal in 3 to 4 seconds. The individual being tested was comfortably secured in the litter, without circulatory interference, by straps across the knees and the upper chest.

Heart-rate and blood-pressure measurements were taken at least every minute in all tests and were chosen as the primary indicators of altered functions, in conjunction with observation of visible reactions and subjective comments. Operational use called for minute heart rates calculated from 15-second counts of the right radial pulse with clinical blood pressures taken from the left arm. Greater capability in the

Space Medicine Laboratory in Hangar S permitted simultaneous determination of both clinical and BPMS blood pressures and continuous recording of respiration rate and ECG from the biosensor sytem. Minute heart rates were determined from the directly recorded biosensor data by using 12-second counts made every 30 seconds.

Minute respiration rates were determined from 30-second counts made each minute. There were no apparent differences between the clinical and biosensor values.

The procedure was carried out in the following manner. After four sets of similar control values, the individual was tilted for 5 minutes and values were sampled at least every minute. Then the subject was returned to the horizontal position for a recording of at least four more sets of similar values. Thus, the minimum time for the complete test was 13 minutes. In order to superimpose a further cardiovascular stress, a modified Flack Test was used in some of the tilts. This test utilizes a tube with a small orifice through which the individual exhales after a maximum inspiration, producing a constant pulmonary overpressure of 40 mm Hg. The Flack Test lasted 15 seconds and was conducted from 3½ to 4½ minutes after the individual was tilted to the 70° position.

Preflight results were obtained from 11 tilt tests on the flight astronaut from January 5 to May 10, 1963. Flack Tests were performed with four of the tilts. All of these tilts were performed in conjunction with a spacecraft checkout procedure which required at least 2 hours in the spacecraft couch in the semisupine position. The time between the prerun tilts and the procedure varied from 1 to 5 hours because of uncontrollable operational factors. In each case, the postrun tilts were conducted from 5 to 15 minutes after the procedure, and on Jan-

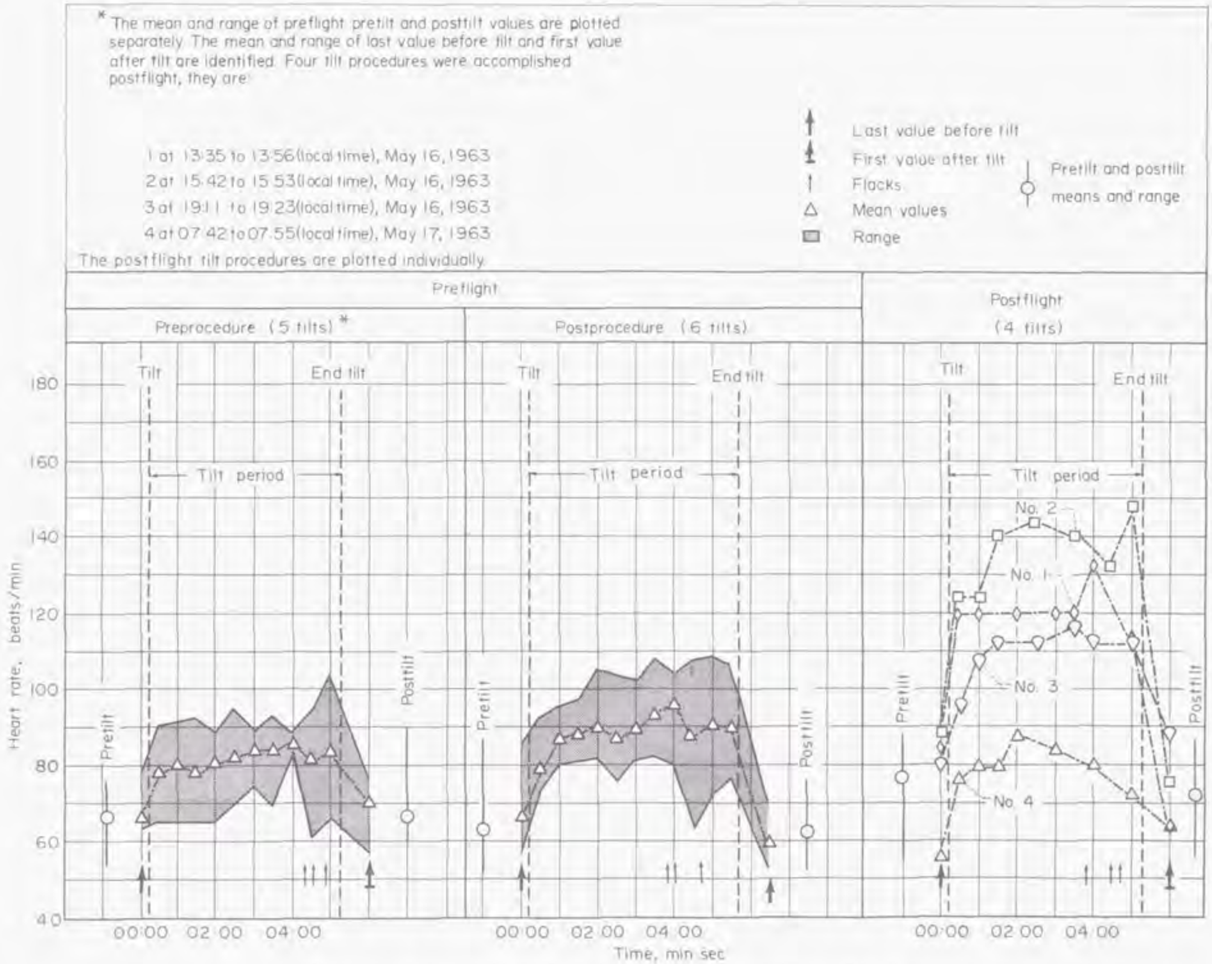

FIGURE 18-7.—Tilt studies—heart rate responses—MA-9.

uary 5, 1963, a second postrun tilt was performed 1 hour after the first.

The heart-rate and blood-pressure values are summarized in table 18–XV and illustrated in figures 18–7 and 18–8. The preflight results fall within the ranges reported in the literature. In the prerun period, most heart rates were between 55 and 80 beats per minute. The tilt produced a rise in heart rate varying from 5 to about 20 beats per minute within 30 seconds. This reading gradually increased during the first 2 minutes to rates of 80 and 90 beats per minute, at which point it stabilized. Posttilt values between 100 and 110 beats per minute occurred after a 6½ hour run, which was more than twice as long as any of the other runs.

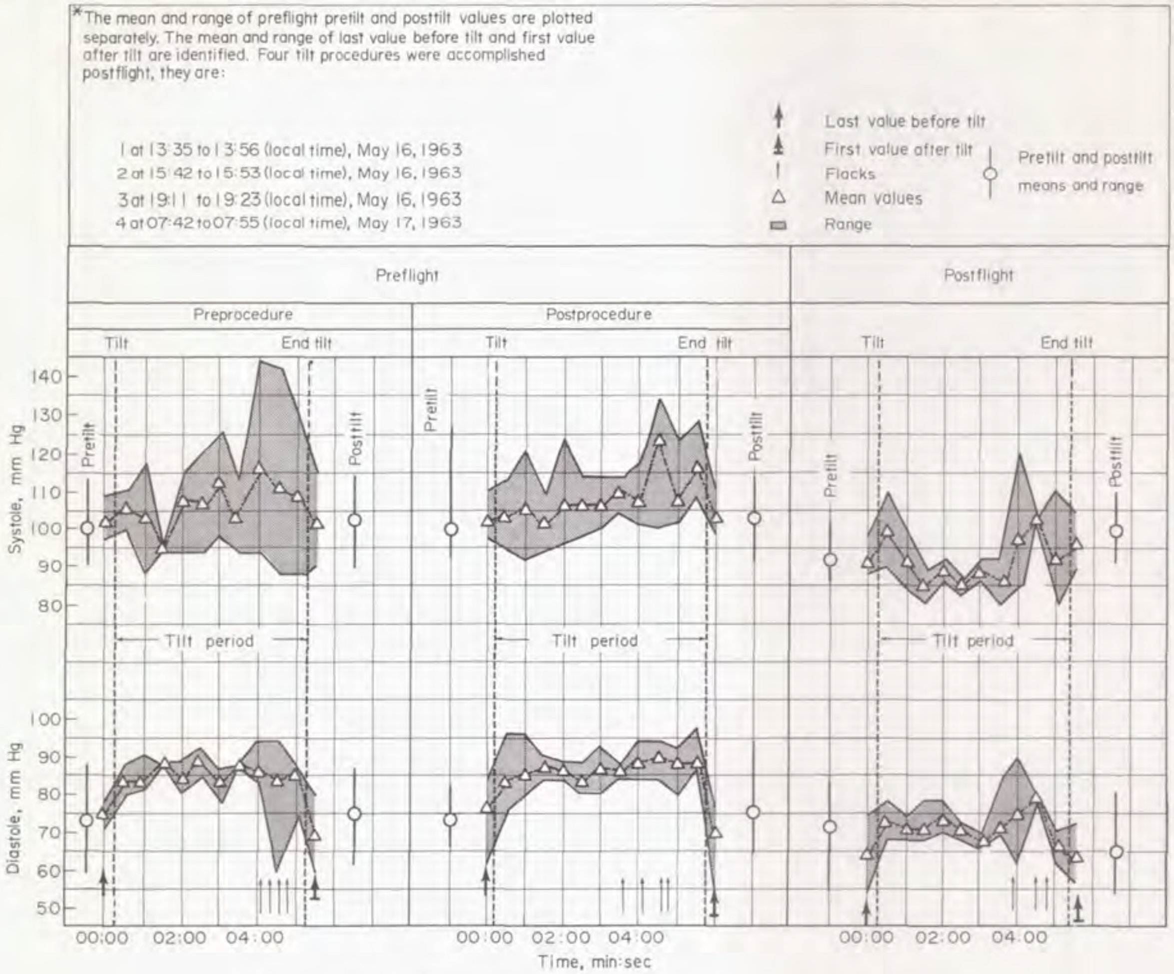

Figure 18–8.—Tilt studies—blood pressure responses—MA–9.

At the beginning of the Flack Test, a bradycardia for 3 or 4 beats usually occurred, followed by an increase in rate to 80 to 90 beats per minute. On several occasions, the maximum observed rates of 110 beats per minute followed a Flack Test. The sudden release of the increased intrathoracic pressure again produced a transient bradycardia followed by an "overshoot" of 10 to 15 beats per minute. Conclusion of the tilt period consistently produced an immediate drop in rate to the pretilt range. Respiration rates were without significant change and are not reported. The increases in diastolic blood pressure were the most remarkable produced by the tilt. The mean increase was 15 mm Hg, but many of the diastolic pressures rose 20 to 30 mm Hg. An initial systolic drop was followed by a compensatory rise. Postrun tilts produced somewhat more striking blood-pressure changes, with narrowing of some pulse pressures to as little at 6 mm Hg. The maximum systolic levels followed Flack Tests, without an associated diastolic change of significance.

Table 18–XV.—Summary of Tilt Studies

Subject	Number of determinations	Pretilt					Tilt					Posttilt				
		Heart rate, beats/min		Blood pressure, mm Hg			Heart rate, beats/min		Blood pressure, mm Hg			Heart rate, beats/min		Blood pressure, mm Hg		
		Mean	Range	Mean	Range		Mean	Range	Mean	Range		Mean	Range	Mean	Range	
					Systolic	Diastolic				Systolic	Diastolic				Systolic	Diastolic
Preflight																
Cooper preprocedure	5	66	53 to 76	100/73	91 to 112	60 to 87	82	60 to 105	100/86	88 to 144	60 to 94	66	60 to 90	102/75	89 to 114	60 to 88
Cooper postprocedure	6	64	51 to 85	99/74	92 to 128	66 to 82	85	72 to 108	105/87	92 to 134	60 to 97	62	52 to 76	102/75	90 to 114	64 to 94
Cooper and Shepard (all preflight tilts)	15	67	55 to 85	100/71	90 to 112	60 to 82	86	60 to 117	107/86	88 to 145	64 to 98	64	52 to 80	103/72	90 to 114	60 to 94
Postflight																
Cooper[a]	3	83	76 to 81	89/64	86 to 90	52 to 82	123	96 to 144	90/73	80 to 110	68 to 84	76	64 to 88	98/69	90 to 106	58 to 80
Cooper[b]	1	58	56 to 60	98/61	96 to 100	60 to 62	80	76 to 88	94/68	86 to 100	64 to 78	60	56 to 64	102/56	96 to 108	54 to 58

[a] Tilts between 1 and 7 hours after landing.
[b] Tilt 18 hours after landing.

The ECG demonstrated expected alteration of the QRS axis secondary to position change. Decrease in size of the QRS was especially prominent in the chest lead as a consequence of R-wave depression. There were sinus pauses with an occasional aberrant complex of ventricular origin. The usual pretilt sinus arrhythmia disappeared with the rate increases. The Flack Test produced dropped beats and occasional premature ventricular contractions during the period after sudden release.

On no occasion could symptoms of near-syncope be detected. Subjectively, all of these tests were exceedingly well-tolerated. Observation of the physical apearance while tilted showed a tendency to bluish mottling of the hands and feet and a tendency to increased filling of the veins of the legs.

Postflight results are shown adjacent to the preflight findings in table 18–XV and figures 18–7 and 18–8. It is readily evident that in the postflight tilt test no. 1 (conducted approximately 1 hour after landing) the mean pretilt heart rates were found to be 11 beats per minute higher than during the preflight controls, and the tilt produced a greater heart rate response than any of the preflight tilts. Most of the values from tilt test no. 1 were 120 beats per minute (maximum 132 beats per minute) and exceeded any of the maximum values obtained during the 11 preflight tilts. A Flack Test was not believed to be indicated in view of the tilt response. Tilt test no. 2, conducted 3 hours after landing and 2 hours after no. 1, began from a higher point and showed an even greater rate response; three of the six values were between 140 and 144 beats per minute. Within 4½ minutes after tilt, the heart rate had declined to 132 beats per minute when the Flack Test produced a jump to 145 beats per minute. The tilt was ended and subsequent rates were similar to the pretilt rates. Tilt test no. 3, conducted 6¾ hours after landing and 3½ hours after no. 2, showed responses very close to the preflight maximums, which are still excessive, but much less so than the previous two tilts. The rates decrease slightly after the Flack Test. Tilt test no. 4, initiated 19 hours after landing and 12½ hours after no. 3, produced responses very near those obtained before flight with a continued slowing of heart rate after the Flack Test. Unfortunately, simultaneous ECG could not be recorded with any of these tilts.

The blood-pressure responses to the postflight tilts were nearly uniform; therefore, only the mean values are shown in figure 18–8. Instead of the preflight systolic drop with prompt compensation and a 15 mm Hg diastolic rise following the tilt, most of the postflight tilts were followed by a systolic drop, a very delayed systolic rise, and little or no change in diastolic levels. Narrowing of pulse pressure to as little as 6 mm Hg was evident in the early postflight tilts. Table 18–XVI presents the postflight blood pressure values during the tilt studies.

The blood pressure responses to the final tilt were nearly normal but still showed a delayed compensation for the systolic drop. No visible objective changes occurred and there were no subjective symptoms.

In summary, the preflight tilt test produced expected cardiovascular compensatory reactions in that they could be demonstrated by heart rate, blood pressure, and ECG data, and all of these tests were well tolerated. The postflight tilt tests demonstrated the presence of moderate orthostatic hypotension, with far greater heart rates required to maintain effective cardiovascular function. Compensation was achieved, however, and the pilot did not develop even near-syncope. Tilt studies of responses after stresses similar to those experienced during flight are not available. Contributing stress factors including heat stress, the effect of prolonged confinement, dehydration, fatigue, and a possible effect of weightlessness per se are thought to be the principal elements responsible for this change. The picture is further clouded by residual effects of the dextro amphetamine.

Calibrated Work

A device for calibrated work consisting of a short plastic handle and expandable bungee cords (see fig. 18–9) was fixed within the spacecraft near the astronaut's feet. A limiting cable ensured repeatability of handle travel, requiring 65 pounds of force for each full extension. At 2:25:00 and again at 7:41:00 g.e.t, the astronaut recorded his blood pressure, pulled the device 30 times in as near 30 seconds as possible, and again recorded his blood pressure. The results of these two work periods were com-

Table 18-XVI.—Blood Pressure Values During Tilt Studies, Postflight

Tilt	Pretilt		Tilt		Posttilt	
	Time	Value	Time	Value	Time	Value
May 16, 1963; No. 1	13:35:00	90/80	13:46:30	90/70	13:52:00	90/70
	13:36:00	90/80	13:46:45	86/70	13:53:00	94/72
	13:37:00	90/82	13:47:30	86/78	13:54:00	96/74
	13:46:00	88/76	13:48:30	86/70	13:55:00	98/78
			13:49:00	84/70	13:56:00	100/80
			13:50:00	84/70		
May 16, 1963; No. 2	15:42:00	86/60	15:44:00	100/70	15:51:00	104/72
	15:43:00	88/62	15:44:30	94/74	15:51:30	104/72
	15:43:15	88/64	15:45:00	84/78	15:52:00	106/74
	15:43:30	88/66	15:46:00	82/72	15:52:30	102/70
			15:47:00	92/84	15:53:00	104/72
			15:48:00	[a]102/80		
			15:50:00	86/60		
May 16, 1963, No. 3	19:11:00	88/52	19:15:00	110/68	19:19:45	92/58
	19:11:30	88/54	19:15:30	84/70	19:20:15	96/60
	19:12:00	90/52	19:16:00	80/68	19:21:00	92/60
	19:13:00	90/54	19:17:00	86/68	19:22:00	94/58
	19:14:00	88/54	19:18:00	80/74	19:23:00	92/58
			19:18:30	[a]120/90		
			19:19:00	80/70		
May 17, 1963; No. 4	07:42:00	96/60	07:45:30	92/78	07:51:00	96/56
	07:43:00	98/60	07:46:00	100/68	07:52:00	100/54
	07:44:00	100/62	07:46:30	88/68	07:53:00	100/56
	07:45:00	98/60	07:47:00	92/70	07:54:00	108/58
			07:48:00	92/66	07:55:00	104/54
			07:49:00	86/64		
			07:50:00	[a]110/64		

[a] Values recorded during Flack Tests.

Figure 18-9.—Exercising device used for calibrated work.

paredwith five such periods performed at normal gravity in the spacecraft and in the procedures trainer.

Subjectively, the astronaut could tell little difference between the work performed under normal gravity and under zero gravity, the effort under zero gravity being, if anything, slightly easier. During flight he felt his postwork breathing was not as labored as it was following control runs, and he thought his heart rate returned to prework values more rapidly. The data, however, do not support this statement.

Analysis of the data does not show any striking differences between the one gravity and zero gravity work periods. Inflight mean heart rates during the calibrated work period are 16 beats per minute higher than preflight, but his inflight mean heart rate before work is 15 beats per minute higher. (Return to prework values was slower following the inflight exercise.) The results are given in table 18–XI and presented graphically in figure 18–10. One preflight heart rate during work was 160 beats per minute. This value occurred at the only time in one of the seven periods in which he worked over 0.7 minute and probably reflects the prolongation of the work period rather than indicating a higher work load. During the 18-second recovery period after the test, the preflight mean heart rate dropped to 11 beats per minute over the preflight value, while during the flight it fell to 17 beats per minute over the prework mean.

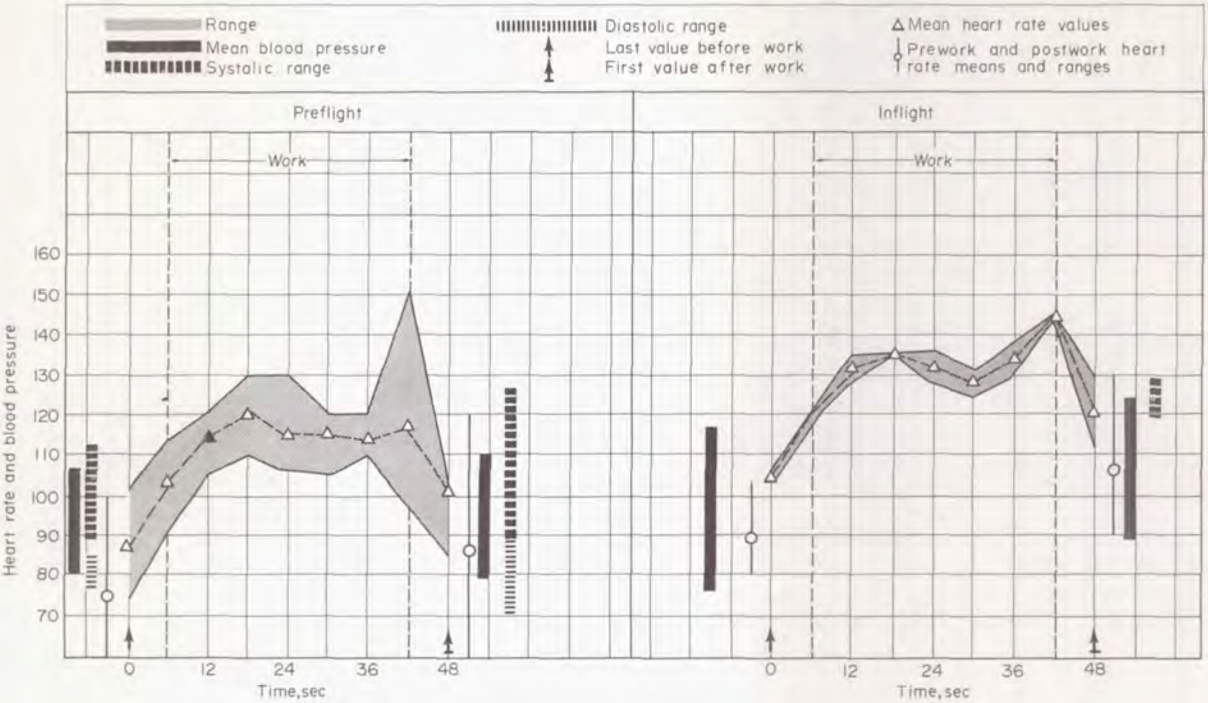

FIGURE 18-10.—Calibrated work—MA-9.

Table 18-XVII.—Blood Chemistries

Determination	Mar. 12, 1963	May 8, 1963	May 12, 1963	May 14, 1963	May 16, 1963; landing +2½ hours	May 17, 1963; landing +24 hours	May 20, 1963
Calcium, mEq/*l*	4. 17	4. 28	4. 60	4. 22	4. 67	4. 56	4. 22
Chloride, mEq/*l*	105	106	100	104	104	102	104
Protein (total), g/100 ml	6. 0	6. 3	6. 0	6. 6	6. 3	6. 2	6. 2
Phosphorus, mg/100 ml	4. 2	3. 5	4. 4	4. 4	4. 5	4. 0	3. 4
Sodium, mEq/*l*	153	151	161	144	153	147	146
Potassium, mEq/*l*	4. 6	4. 6	5. 4	5. 2	5. 2	5. 0	4. 9

Special Clinical Studies

Retinal photography, urine and plasma electrolyte determinations, and plasma enzyme studies comprise special clinical studies. The retinal photographs, taken after the flight for comparison with preflight pictures, show no changes. The results of the urine-electrolyte determinations are presented in table 18-V. The results of the plasma electrolyte determinations appear in table 18-XVII. It should be noted that mineral content of the diet was not provided in equal daily portions during the period of time represented by this table. There was no indication of increased urinary calcium excretion. Sodium and chloride retention shown on May 17 and 18 are consistent with the period of restoration of fluid balance following the dehydration which occurred in flight. All other values are within the normal range for Astronaut Cooper. Enzyme studies have been made in each of the Mercury flights as part of a development program. The clinical significance of the data is still undergoing validation; therefore, interpretation has not been attempted. Consequently, results are not reported in this paper.

Conclusions

On the basis of the total experience obtained during Project Mercury, the following medically significant facts have been derived from the medical operations.

(1) There has been no evidence of significant degradation of pilot function attributable to space flight. A mission of 34 hours in the zero-gravity condition has been well tolerated and all measured physiologic functions remained within anticipated ranges throughout this flight.

(2) Sleep in flight is possible and subjectively normal.

(3) The radiation dose received by the astronauts to date is considered medically insignificant.

(4) There is no evidence of abnormal sensory, psychiatric, or psychological response to an orbital space flight of up to 1½ days.

(5) Following missions of 9 and 34 hours duration, an orthostatic rise in heart rate and fall in blood pressure has been noted and has persisted for between 7 and 19 hours after landing. The changes were of greater magnitude following the 34-hour flight than those following the 9-hour flight; however, all changes disappeared in a similar time interval in both cases. The implications of this hemodynamic response will have to be given very serious consideration as longer missions are undertaken. No other clearly significant changes have been found in comprehensive preflight and postflight physical examinations.

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19. OBSERVATIONS OF SPACE PHENOMENA

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Summary

In the following report are presented the principal scientific observations made by the Mercury astronauts, arranged according to the sequence: daylight, twilight, and night. The first section is principally concerned with the examination of the earth as seen from these heights, although a section is also presented on the sky. In the second section, the appearance of the sun at sunset is discussed, then the twilight atmosphere, and the astronomical phenomena peculiar to the early twilight. In the third section are discussed the new data about the earth as seen at night and the difficulty associated with viewing the moon at the horizon.

Introduction

From the beginning of time, man has looked out upon this world with an active curiosity, cataloging what he saw and eventually developing explanations for why the earth and sky appear as they do. The results of this type of naturalistic activity as they relate to the earth's atmosphere have been summarized by Minnaert (ref. 1), whose work summarizes at least the main lines of all of the knowledge which man had been able to gain from an earthbound position, by use of the unaided eye. With the advent of manned space flight, it is possible for the first time to observe the earth from outside the atmosphere, and so to extend the naked-eye observations which are summarized in Minnaert's work.

This section compiles and summarizes the observations of the Mercury astronauts and the findings from the principal photographic studies conducted during the Mercury flights. These observational and photographic data were limited by a number of operational constraints discussed in paper 12. The position, transmission polarization structure, and field-of-view of the spacecraft window are described in figure 19–1. As can be seen, this window contains two panes of plate glass and two panes of Vycor, the latter set at oblique angles, which increases the problem of light scattering and window reflections from internal lighting during night time observations. The window transmission cuts off sharply at the lower end of the visual spectrum, precluding photography in the ultraviolet region. Transmission in the infrared range permitted photography in this area for the Weather Bureau. Transmission in the visual range is reduced approximately to the same extent that light is attenuated by the atmosphere. The polarization produced by the window was probably of no significance to any of the observations described in this section. The field-of-view was a limiting factor since control fuel conservation restricted the freedom of the pilot to orient his vehicle for making observations. In addition to the viewing limitations indicated in figure 19–1, during the normal launch, the window frequently becomes covered with a film from the exhaust of the escape tower when it is jettisoned, which reduces slightly the light transmission and increases the problem of scattering.

Throughout this portion, an attempt is made to present an integrated picture of the appearance of the earth and sky as viewed from space, together with a physical explanation of the phenomenon observed where sufficient information is available to make hypothesis. In general, most of what has been reported by the astronauts confirms data from other sources, such as recent aircraft, balloon, and sounding rocket studies. If much of the information is not novel, it has helped to fill in the basic outlines

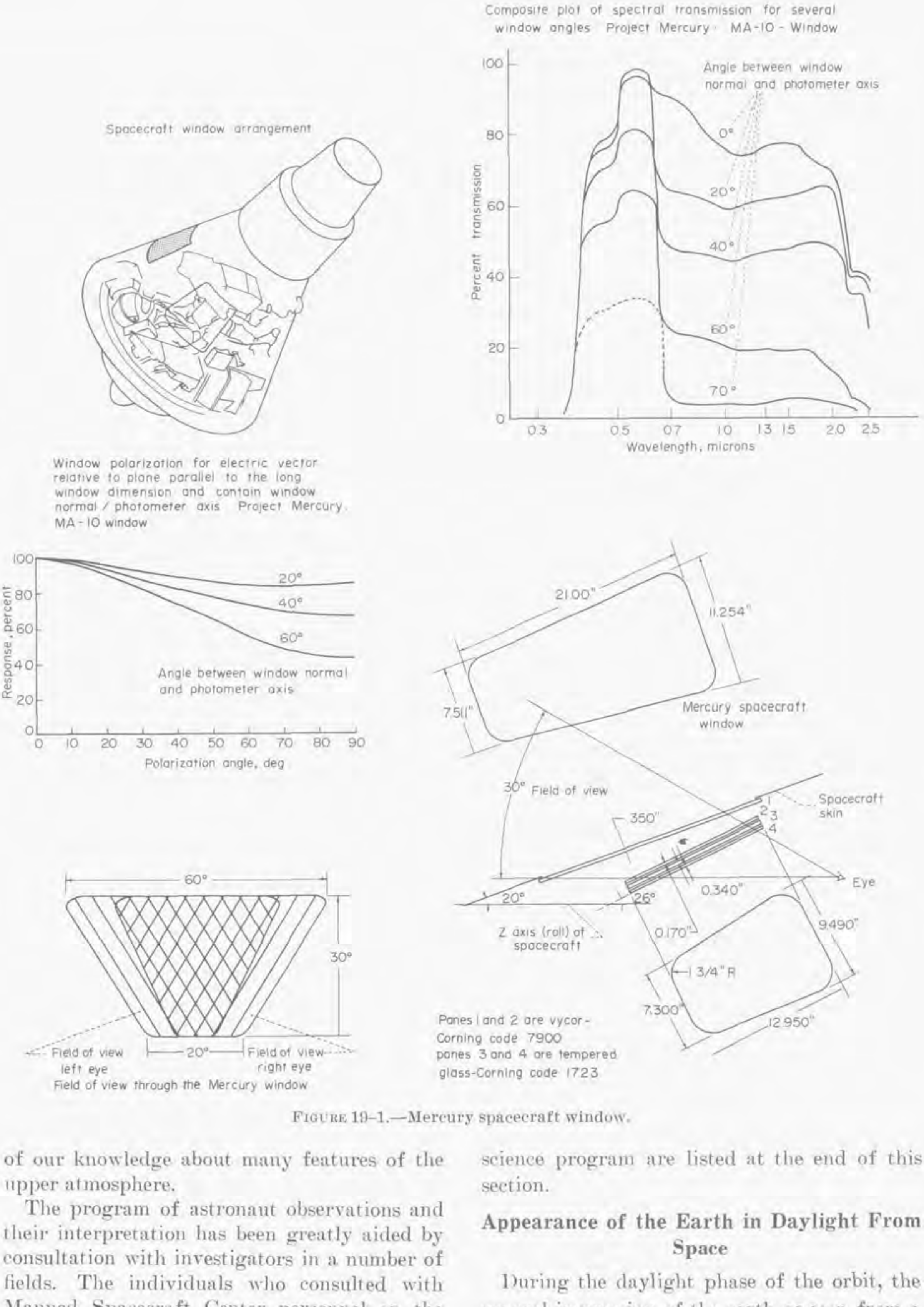

FIGURE 19-1.—Mercury spacecraft window.

of our knowledge about many features of the upper atmosphere.

The program of astronaut observations and their interpretation has been greatly aided by consultation with investigators in a number of fields. The individuals who consulted with Manned Spacecraft Center personnel on the science program are listed at the end of this section.

Appearance of the Earth in Daylight From Space

During the daylight phase of the orbit, the general impression of the earth as seen from a distance of 100 to 150 miles has been characterized by the astronauts as similar to the view from a high-flying jet aircraft. The earth's surface, particularly when viewed obliquely, appears to have a somewhat bluish cast, as would be expected from the longer visual path through the atmosphere. Greens are less readily visible, except when directly below the spacecraft. However, major color variations can be distinguished. The coastlines and rivers are easily visible (fig. 19–2) as are mountain ranges (fig. 19–3).

In the daytime, the clouds are extremely bright and easily visible. The astronauts have reported that, generally, they can determine relative cloud levels, perhaps by noting shadows or the apparent motion of cloud tops relative to the surface. Different types of cloud formations are relatively easily discernible. These may be quite spectacular as when the spiral shape of a hurricane a thousand miles in diameter is clearly seen from above (fig. 19–4).

The day horizon has been described as a light-blue band, shading off into the blackness of the space above the earth. Photographs taken by the astronauts provide some indication of banding in this horizon layer. Such banding has been reported by Astronauts Shepard, Grissom, and Glenn in references 2 to 4, respectively. The banding appears to be related to the layers in the atmosphere. The width of the daytime horizon appears to correspond to the width of the troposphere and to be approximately ½° as viewed from the spacecraft. This is demonstrated in figure 19–5, which shows the moon just above the daylit horizon. The diameter of

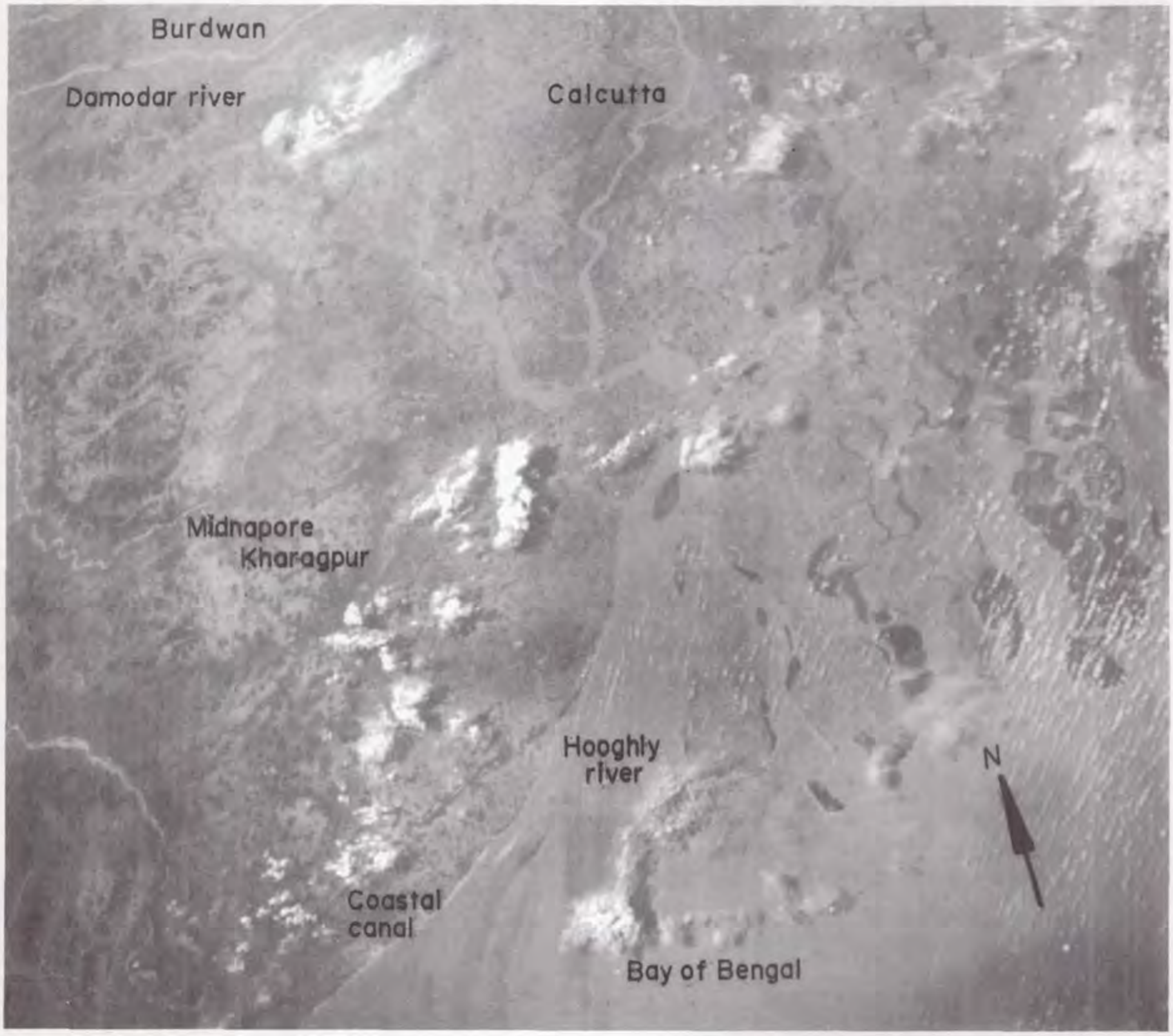

FIGURE 19–2.—Ganges River Basin. MA–9 photograph.

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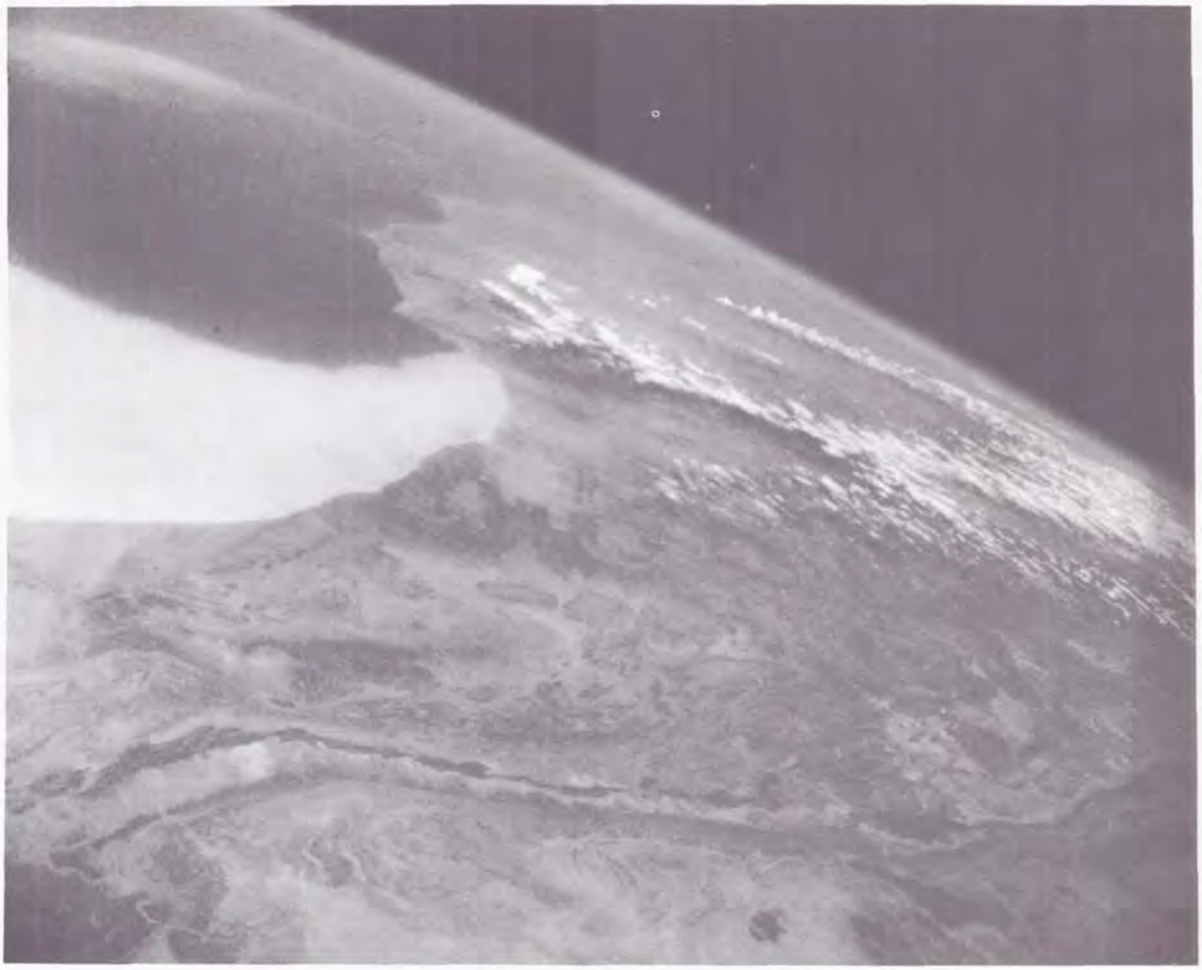


FIGURE 19-3.—Anti-Atlas Mountains in North Africa. MA-4 photograph.

the moon, which is ½°, is approximately equal to the thickness of the daytime horizon as pictured in the photograph.

Visibility of Ground Features

The visibility of small features on the surface of the earth from space is a complex but important problem since ground landmarks offer a potentially very useful navigational reference. To obtain some information on the operational problems of viewing objects on the surface of the earth in addition to that provided by the ground light study reported in the section on experiments, the pilots were asked to report carefully what could be seen from orbit. These observations have been described in the pilot's report made after each manned flight.

One of the major features of interest to Glenn during the MA-6 flight (ref. 4) was the extent of the cloud cover over the earth. The only area that has been consistently clear throughout all the orbital flights is the western African desert shown in figure 19-3 and the southwestern United States. Efforts to observe ground signal lights from the spacecraft were frustrated on three of the four flights by overcast conditions (See paper 12). Astronaut Cooper enjoyed the best visibility conditions of any of the astronauts and yet he estimated the cloud coverage to average 50 percent during his flight.

Even where no cloud coverage is present, visibility may be markedly deteriorated by haze produced by smoke, dust particles, or other aerosols. Thus, for example, Astronaut Cooper noted that, while he could see roads and fields and an airport in the El Centro area, he could not see either Los Angeles or San Diego, though he flew right over them. Figure 19-2, which shows a view of the Ganges River Basin photographed on the MA–9 flight, demonstrates this problem since the city of Calcutta with 2½ million population is almost completely invisible and was not seen by Cooper during the flight. Landmarks can be most clearly seen when viewed directly below the spacecraft. The blue haziness, which is seen in photographs of the daylight horizon (fig. 19–5), illustrates the reduction in visibility produced by the longer path through the atmosphere. The visibility of features farther from the spacecraft is also reduced by the reduction in size because of viewing distance and foreshortening because of the angle-of-view and the earth's curvature.

Moreover, cloud cover may not simply obscure targets. It may also produce cues which lead to misinterpretation of terrain features. An example of this is shown in the photograph in figure 19–3, taken on the MA–4 flight, which shows a low lying cloud over the Atlantic coast of North Africa. The position of the cloud produces an apparent change in the coastline, which could be confusing if such geographical features were to be used for navigation.

Thus, the extent of cloud cover and atmospheric haze in the latitudes in which the Mercury flights have been made reduces the usefulness of landmarks or ground lights for navigation. On the other hand, in areas where the weather is good, relatively small objects may be sighted. However, this is not a result of magnification produced by the difference in refractive index between the atmosphere and the vacuum of space as had been proposed in reference 5. The effect proposed is the same as the magnification of a penny at the bottom of a cup of water—the penny appears to be a little higher than it really is (fig. 19–6). Because of the relatively small difference between the refractive index of the atmosphere and the vacuum,

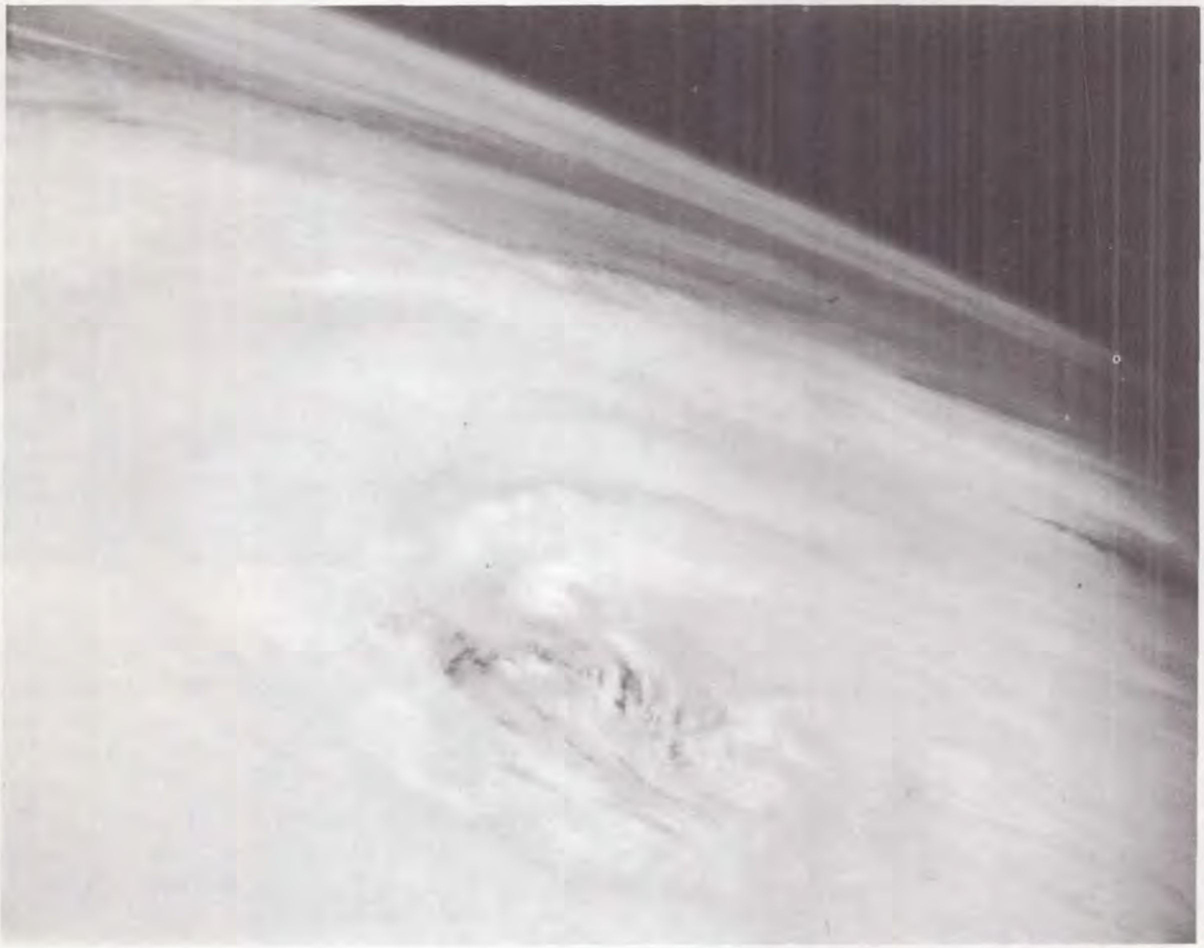


FIGURE 19–4.—Hurricane Debbie. MA–4 photograph.

FIGURE 19-5.—Moon near horizon. MA-5 photograph.

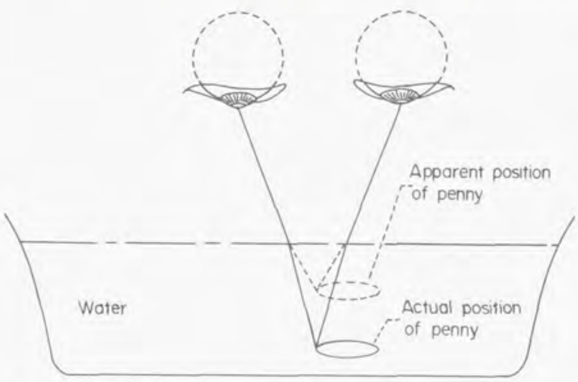


FIGURE 19-6.—Diagram of apparent magnification produced by water.

the effect is much smaller than in water. If the index of refraction is computed and summed for each kilometer of atmosphere up to the altitude of 45 kilometers (where it becomes unity) based on the *U.S. Standard Atmosphere, 1962*, the maximum magnification possible is on the order of only 1.00002, or a rise of 8.5 feet.

The problem of visibility from aircraft has received considerable attention in recent years (ref. 6). This work is too extensive to be reviewed here. However, it is well known that where the dust, smoke, and aerosol content of the atmosphere is low, small objects may be seen for considerable distances if the illumination and the contrast between the object and its background are high. The relationships among illumination, contrast between the object and its background, and the size of the object or angle subtended at the eye is indicated in figure 19-7. These data, taken from the well-known work of Blackwell (ref. 7), illustrate that the smallest object that can just be detected 50 percent of the time is dependent on size contrast and illumination. One minute of arc is often taken as a "rule of thumb" for the practical limit of human visual acuity. However, as can be seen from this figure, this is an oversimplification. Under many combinations of illumination and contrast, the smallest object that can just be seen is 10 times that large, while at other combinations of these factors, objects approximately ½′ of arc can be seen. Where contrast or illumination are very high, even smaller

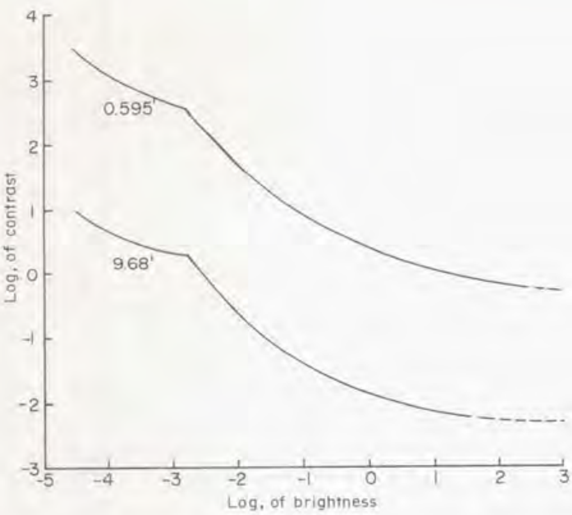


FIGURE 19-7.—Threshold of brightness contrast for 50 percent detection for two stimuli diameters (minutes of arc), after Blackwell (ref. 7. Stimuli brighter than background. Unlimited time of exposure.

objects may be seen. Thus, Zoethout (ref. 8) gives a value of 10″ of arc for the minimum visible white square on a black background. This corresponds to 30 feet at 100 nautical miles.

These general relationships are complicated by several factors. Thus, for point light sources, such as stars, visibility is independent of size and dependent only on the intensity of the stimulus. For line or ribbon objects, the extended length reduces the necessary diameter for detection, thus the width of a line, which can just be detected, may be one-sixth or less than the minimum diameter of a circular object which can just be seen. This is illustrated in figure 19-8 which shows an infrared photograph taken by a Viking rocket over the southwestern United States (ref. 9). This photograph was taken at a height of 150 miles. From the type of film, the characteristics of the camera lens, the exposure length, and the extent of enlargement, the resolution can be calculated to be 500 feet (ref. 10). Yet roads running across the desert, whose width must be on the order of 50 feet or less, can be clearly seen.

There have been several reports by the astronauts of sightings of small objects on the daylight side of the orbit. These observations have primarily been confined to the area of the southwestern desert of the United States between El Centro, California, and El Paso, Texas. In this region, cities, cultivated fields, roads, airports, and railroads have been reported by all four of the pilots who flew orbital flights. These observations have all been made at close to perigee altitude (86 to 90 nautical miles) between 8:00 and 12:00 a.m., local time, under excellent visibility conditions. Astronaut Cooper, who enjoyed unusually good weather conditions, also reported identifying the cities of Dallas and Houston, in Texas, and from the pattern of lakes and wooded areas, the region around Clear Lake where the new Manned Spacecraft Center is being built. In addition, the astronaut made a number of observations in the mountainous and plateau regions of India and Tibet. There he reported what appeared to be individual buildings in Tibetan villages. Some of these observations were apparently aided by trails of smoke from the chimneys of the buildings. In addition, he reported he was able to see roads on one of which he saw a trail of dust. At the intersection of the dust trail and the road, he saw a spot which he felt might be a vehicle (See paper 20). These observations over Tibet were made from an altitude of 88 nautical miles at approximately 7:30 a.m., local time. The weather conditions were clear with good visibility. Atmospheric attenuation was further reduced by the altitude of the Tibetan plateau which at this point is approximately 16,000 feet.

It should be recognized that all these observations were greatly facilitated by the context in which the observation was made. To be reported, objects must be perceived. Previous training and experience have a marked effect on what an individual will report in any situation. Experience generally increases the likelihood that a small object near visual threshold will be detected, although it may work in the opposite direction as when an unusual angle of lighting or shadow changes the appearance of an object to the point that it goes unrecognized. Such experience and training can also lead to the accurate identification of objects that would otherwise not be recognized. This procedure is much like that of interpretation of a photograph where a set of vehicle treadmarks, running into a forest area, indicate the possible presence of a vehicle among the trees.

Astronaut Glenn described a situation in which he saw a road crossing a river. Each of these could be recognized because they were extended, ribbon-type objects. At the point

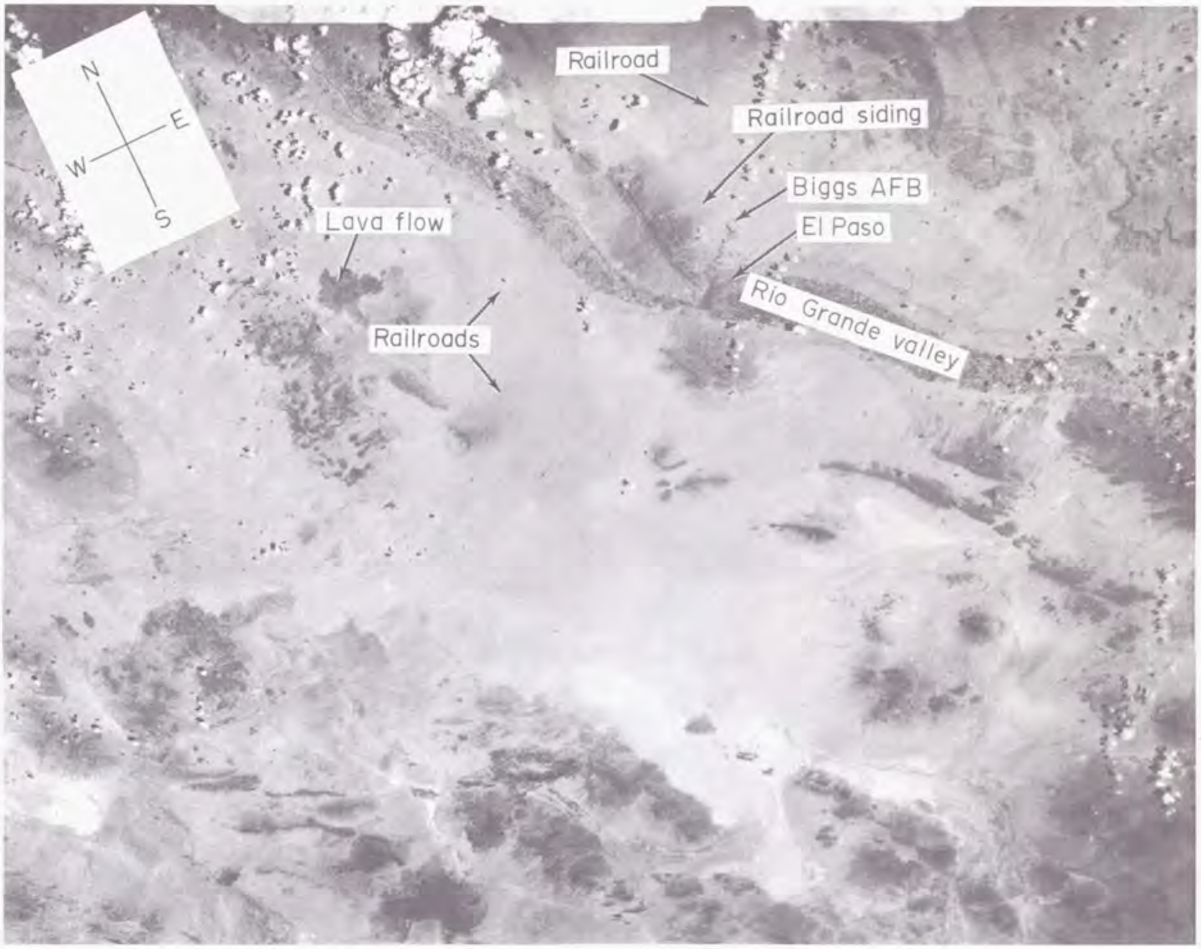


FIGURE 19-8.—Viking photograph of El Paso, Texas, area.

where they crossed, he said that he felt he could almost see the bridge, though he recognized that it was too small to be seen.

Since the actual objects which were being viewed at these points cannot be verified, it is not possible to determine the accuracy of these observations. However, from knowledge of the factors which affect visibility under these conditions, there appears to be no reason to suspect that these identifications were not generally accurate. All the astronauts have normal, or better, distance visual acuity. Astronaut Cooper in particular has an acuity, as measured during a recent annual physical, of 20/12, which is significantly better than 20/20 which is the normal standard of good acuity. All the observations were made under high levels of illumination, excellent visibility conditions, and with the aid of many contextual cues. Thus, there appears to be no need for postulation of either improved visibility resulting from weightless conditions or unexpected atmospheric magnification effects to account for the observations made to date. Despite the impressive nature of these observations, the important feature to be kept in mind is that they are scattered and involve viewing under essentially optimal conditions. As pointed out earlier, the large amounts of haze and cloud cover make ground observations difficult and somewhat unreliable.

Terrain Photography

As with the problem of direct viewing, it is not possible to put a lower limit on the physiographic and geologic detail which can be delineated on space photographs without an extensive study. However, a rough idea of the useful resolution can be gained by examination of some of the Mercury pictures listed in table

Table 19–I.—Summary of Potential Usefulness of Mercury Earth Photographs

Flight	Area covered	Film type	Approximate number useful pictures	Potential uses and remarks
MR–1	AMR	70 mm, black and white	168 total	Meteorology
MR–2	AMR, Florida, Bahamas	70, mm, color	30 useful	Meteorology and topography; good quality
MR–3	AMR	70 mm, color	50 feet exposed	Meteorology; relatively poor quality
MA–4	Atlantic Ocean, North Africa	70 mm, color	About 350 usable photographs	Meteorology, topography, and geology; excellent quality
MA–5	Florida, West Coast, Mexico, Ocean areas	70 mm, color	80 feet probably about 5 to 10 usable terrain photographs	Meteorology, topography; fair quality
MA–6	Florida, North Africa	35 mm, color	38 usable pictures, about 5 or 6 terrain photographs	Meteorology, topography, geology; good quality
MA–7	West Africa	35 mm, color	200 pictures, 4 or 5 terrain photographs	Meteorology, topography
MA–8	Mexico, South America	70 mm	14 color photographs	Fair to poor quality; meteorology; quality of terrain pictures poor
MA–9	Tibet, South east and South Central Asia, Africa, Middle East	70 mm	30 photographs	Meteorology, topography, geology; excellent

19–I. This table summarizes the general purpose photographs taken on manned and unmanned Mercury flights.

The MA–4 photographs of North Africa are of considerable interest because they are among the best color pictures showing unobscured terrain. The Anti-Atlas Mountains are especially striking (fig. 19–3) in the amount of geologic detail which can be seen. The folded structure of the mountains is obvious, and many individual plunging folds can be traced. A linear feature suggestive of the Zemmour fault (ref. 11) can be seen intersecting the coast south of Agadir but not identified with any certainty.

Many of the MA–9 photographs show abundant topographic and geologic detail. Figure 19–9, taken over the Tibetan plateau, is particularly useful because of the favorable camera angle. A geologic sketch prepared from this photograph is shown in fig. 19–10. A number of structures of possible economic interest are indicated in the sketch. For example, the domes and anticlines represent potential oil-bearing areas, and intersections of some of the lineaments might be the loci of mineral deposits.

It is interesting to note that manmade features (excepting large areas of cultivation) are generally very difficult to identify on the color photographs. As already noted, figure 19–2 shows the area of Calcutta but the city itself cannot be recognized.

The scientific value of the Mercury terrain photographs depends on several characteristics in which they differ from conventional aerial

FIGURE 19-9.—Photograph of Tibetan Plateau. MA-9 photograph.

photography. The most obvious of these is the tremendous aerial coverage provided by each picture taken from orbital altitude. This is illustrated by comparison of the 1:800,000 scale of figure 19-9, taken on the MA-9 flight, with the 1:20,000 or 1:40,000 scales of conventional air photos. The area covered increases with approximately the inverse square of the scale, and is so much greater in pictures taken from space as to be virtually a qualitative difference. This great coverage permits continuity of observation which may lead to discovery of large geologic features unnoticed on conventional photographs, such as the very long lineaments illustrated in figure 19-10. It should also be mentioned that the synoptic nature of space photography is valuable in meteorological and oceanographic applications.

Another characteristic of space photographs is the fact that they show the earth, subject to limitations of visibility and resolution, as it is. Stereoscopic vision is possible with even roughly oriented photographs if there is overlap. In addition, subtle tonal differences covering large areas can be detected. Both of these properties are essential for geological interpretation and

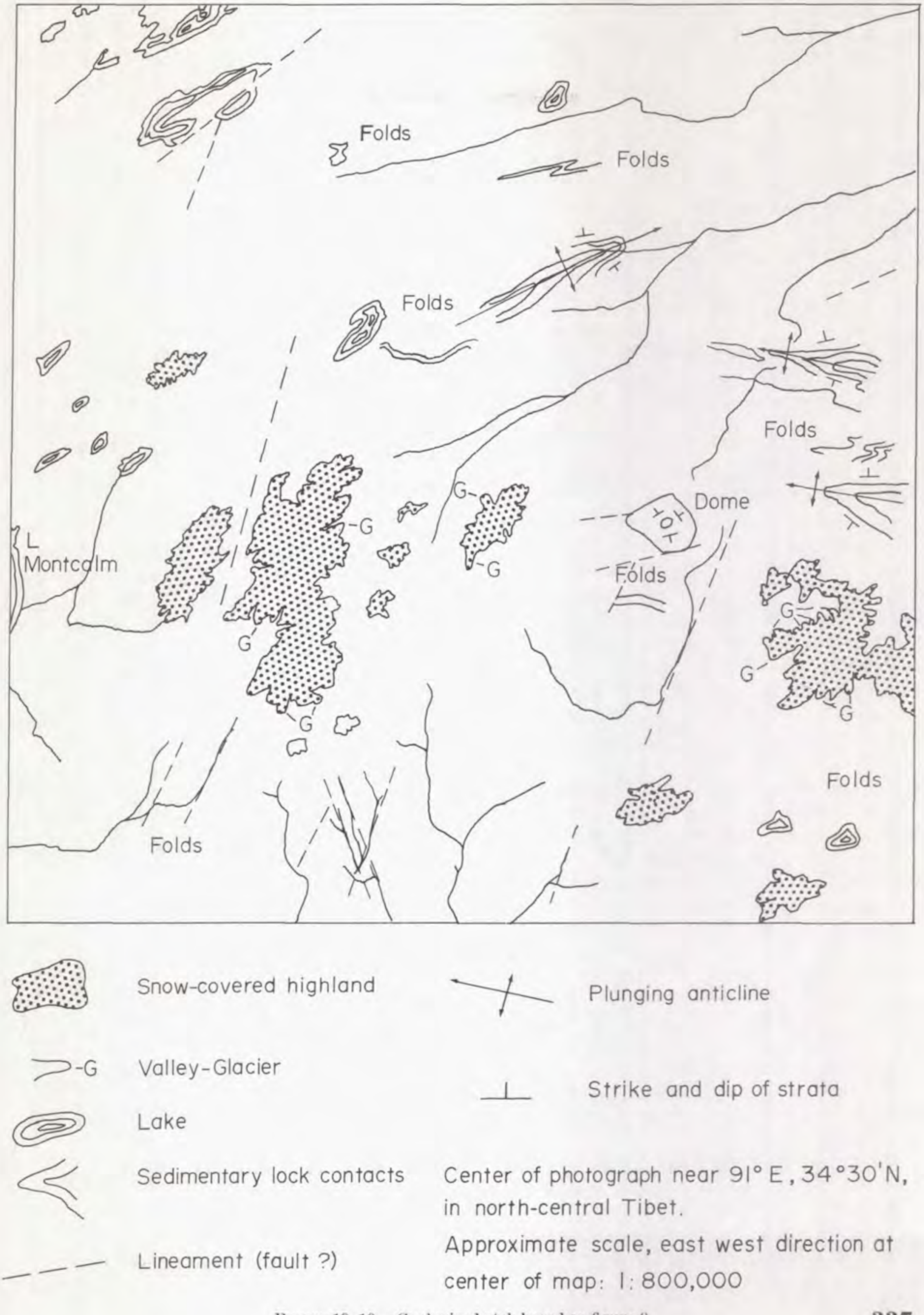


FIGURE 19-10.—Geologic sketch based on figure 9.

cannot, in general, be provided by mosaics of conventional aerial photographs. This strongly suggests the unique scientific value of terrain photographs from orbital altitudes, not only for unexplored areas such as Tibet, but also for areas previously covered by conventional photography.

In sumary, photographs of the earth from orbiting spacecraft are potentially valuable for (1) geologic reconnaissance, (2) topographic mapping, (3) forest mapping, (4) icepack and iceberg monitoring, (5) supplemental weather observations, and (6) mapping of near-surface ocean currents. In addition, experience in interpreting such photographs will prove useful in interpreting similar photographs of the planets when they become available.

Meteorological Information From Mercury Flights

Each astronaut has devoted part of his spaceflight program to visual and photographic observations of value to meteorology (ref. 12). Since high photographic contrast is needed in pictures from weather satellites to aid in distinguishing coastlines and patterns of thin clouds, two photographic studies were initiated to study cloud, land, and water contrast as a function of wavelength. These studies have been described in paper 12.

Astronaut Schirra took a series of 13 black and white photographs of the earth through six color filters in the visible spectral region from 3700 Å to 7200 Å to record some of the spectral reflectance characteristic of clouds, land, and water areas when viewed from outside the atmosphere. In general, the results from this study showed that, as would be expected, photographic contrast increases with increasing wavelength in the visible spectrum.

It might be concluded that the optimum wavelengths for viewing the earth would be in the near infrared spectrum where scattering from atmospheric particles is relatively low. That this is not quite true was demonstrated in a second study conducted by Astronaut Cooper. In this study, three areas of the infrared spectrum were isolated by use of filters and infrared film.

Water has a very low reflectance in the near infrared, while clouds and land have a high reflectance. Therefore, in this second study, coastlines and cloud patterns over water were easily discernible. Unfortunately, however, clouds were more difficult to see over land in the near infrared because of the high reflectivity of both clouds and areas covered with green vegetation containing chlorophyll.

These two studies show, then, that the spectral sensitivity of television camera systems for weather satellites should probably be restricted to the region from about 5000 to 7500 Å as a compromise between the adverse effects of scattering by molecules and aerosols at shorter visible wavelengths and the low contrast effects of clouds over land areas at near infrared wavelengths.

Many of the black and white pictures taken by Astronaut Schirra show a bright band on the earth's horizon. The bright band is approximately 16 kilometers thick, which agrees with the expected thickness of the tropical troposphere. Large light scatterers in the troposphere, such as dust and water droplets, produce this bright band at the earth's limb. The thermal stability of the stratosphere severely limits the convective transport of aerosols to higher levels, so that there is very little scattered light coming from the stratosphere. The apparent brightness of the tropospheric layer varies from picture to picture, suggesting that there are changes in the size or concentration of scatterers over different geographic areas. Changes in brightness in the same picture from one filter to another demonstrate the wave length dependence of the scattering of sunlight: more light is scattered at the shorter wave lengths. However, within an individual picture, both geographical and wave length effects may appear.

The pictures obtained with photographic film contains more meteorological information than do the low resolution pictures from present weather satellite television pictures. Because of the greater resolution and lower altitude the cloud types and patterns can be seen in greater detail in the Mercury photographs. If a meteorologist can see the smaller cloud forms and their orientation, then he may have important clues to the direction of the wind, the wind shear, and possibly a rough estimate of the wind speed in the lower levels of the atmosphere. Photographs from Mercury flights have been useful in cloud studies to help interpret the meteorological information in Tiros pictures.

Several Mercury astronauts have seen lightning in thunderstorms at night, appearing, as Astronaut Glenn described it, "like balls of cotton illuminated from within." Astronaut Cooper observed that each lightning flash was accompanied by static on his high frequency and ultrahigh frequency radio receivers. This observation confirms the findings of a recent research study conducted for the Weather Bureau, which concluded that high frequency energy radiated from a lightning stroke can propagate and be detected and located on a worldwide basis by means of a lightning (or sferics) detector carried on a satellite. Efforts are underway now to develop such an instrument and our confidence that it will work is much higher because of Astronaut Cooper's alert observation.

Cloud systems were visible at night with partial moonlight or none, indicating that low-light level television cameras on weather satellites may photograph cloud cover at night successfully. Photographs of clouds over snow are being studied to seek ways of discriminating one from the other in television pictures. Cooper reported he could detect the difference between snow and clouds. He also reported that smoke trails gave an indication of surface wind direction.

Daylight Sky

To date, none of the astronauts has reported seeing stars on the daylight side when the sun or the illuminated earth's surface was within the field of view. Nor was the flashing light released from the MA-9 spacecraft seen by Astronaut Cooper during the daytime, though the possibility that he was looking in the wrong direction cannot be ruled out (See paper 12). However, some of the astronauts have reported observations of a few bright stars or planets at twilight, but their level of dark adaptation and the degree of cabin lighting are uncertain factors to be considered. There is, of course, no difficulty in seeing the moon (fig. 19-5) since it is even visible from the surface of the earth in daylight.

When the sun and the illuminated earth's surface is not within the field of view, it is possible to look into space and maintain dark adaptation. Under these conditions, Astronaut Cooper reported that the dayside sky appeared less dark than the night sky, and the threshold of star visibility correspondingly raised by as much as two magnitudes. Two hypotheses suggest themselves to account for this observation. The more probable one is that this results from a high altitude dayglow possibly that of the atomic emission at 6300 Å.

A second less likely hypothesis is that the sky appears less dark during the daytime as a result of scattering due to small solid particles. The argument against this proposal is as follows. If the glow were due to small solid particles, they would have to be at a level low enough so that the sun could not reach them during the night; otherwise, this glow would be apparent from the ground all night long. Since astronomical twilight is defined by saying that at the end of astronomical twilight the zenith has reached full night-time darkness, it is clear that at this time, the dust particles, if any, must be out of the sunlight. It is known that astronomical twilight occurs when the sun is 18° below the horizon; and it is a matter of simple trigonometry to show that at this time an object more than about 350 kilometers high would still be in the sunlight. Hence, if there is a layer of dust particles, they must be below 350 kilometers.

Now, Astronaut Cooper reports that the dayglow as he saw it drowned the light of stars fainter than about the fourth magnitude. This is about the same thing that happens on a night of full moon; the fifth and sixth magnitude stars become very difficult or impossible to see. Hence, the brightness of the sky as Astronaut Cooper saw it was more or less like the brightness of the sky on a night of full moon. We know that from the ground the sky causes a loss of about 30 percent in the light reaching the earth; and, thus, we may think of it as if there were small particles covering about one-third of the sky. Above the spacecraft, the sky is so much reduced in scattering power that it scatters only as much light from the sun as the whole atmosphere scatters from the moon. Since the full moon is about 400,000 times fainter than the sun, it follows that the amount of scattering material must be such as to cover about 0.3 of 1/400,000 of the sky, or roughly, one millionth. By the usual laws of optics, this means that in a column one square centimeter in cross-sectional area and 350 kilometers in length, there must be enough matter to cover one millionth of a square centimeter.

It will be shown that this is too much matter. The most efficient size of particle for producing scattered light is about 1 micron in diameter; smaller particles perform the electrical equivalent of bobbing up and down on the light waves without disturbing them, and larger ones simply block the light. A 1-micron particle blocks about 10^{-8} square centimeters; hence about 100 such particles are needed in the above-mentioned column. Since the volume of the column is 35 cubic meters, the density is about 3 particles per cubic meter.

A spacecraft moving at 8,000 meters per second will then encounter 24,000 such particles per second per square meter. Actually, however, micrometeorite counters, which are adequately sensitive for these very small particles, show between 1/100 and 1 particle per second per square meter outside of showers. Rates of thousands of particles per square meter per second are never observed (ref. 15). Hence the layer cannot consist of micron-size particles. Neither can it consist of particles of other sizes, because the counts are even lower for these. There is approximately the same amount of mass in each logarithmic increase in size; and the other sizes are less efficient. The hypothesis of a dust layer thus fails by a factor which can be conservatively estimated as 10,000.

Appearance of the Earth at Sunset and Twilight

The spacecraft window attentuates the average light intensity in the visible range to about the same extent as the atmosphere. It does not, however, produce the same color change. To the astronauts, the sun appears white; they describe it as having the color of an arc light, rather than the yellowish color seen from the earth. As the sun approaches the horizon, a band of orange light spreads from below the sun around the horizon. Above this orange band can be seen the hazy blue layer similar to that of the daytime sky. As the sun comes closer to the horizon, a white layer appears above the orange band. The orange, white, and blue layers are quite distinct, particularly the border between the white and blue layers. Some astronauts have been able to report on layers which do not appear in photographs. The orange, white, and blue layers, however, show up very clearly in the photographs of the setting sun and of the orbital twilight which follows.

As the sun approaches the horizon, the terminator passes below the spacecraft and moves off toward the horizon so that, at sunset, the earth directly below the spacecraft is dark. All that can be seen is the band of light in the west, stretching perhaps as much as 180° around the horizon.

The sun, of course, sets much more rapidly for the astronaut than for the observer on the ground. Since the sun moves for the ground observers at approximately 15° an hour, neglecting the effects of atmospheric refraction, it takes the sun, which is ½° in width, 2 minutes to set from the time it first touches the horizon to the time when it completely disappears. In contrast, for the orbital vehicle, the sun moves at 4° per minute so that, once again neglecting the effects of refraction, it sets in 7½ seconds. Once the sun has set, the glow along the western horizon gradually fades but remains visible for apparently about the astronomical twilight period or until the sun is 18° below the horizon, which is approximately 4½ minutes at orbital velocity.

Solar Flattening Effect

Just prior to sunset, calculations show that the effects of terrestrial refraction should be to give the sun a football-shaped appearance. The phenomenon lasts such a brief time and is so extremely difficult to observe because of the problem of glare that only the visual report from Astronaut Carpenter (ref. 16) conclusively confirms it. It is, however, plainly visible on photographs, obtained by both Carpenter and Glenn (fig. 19–11), and matches the theoretical shape (ref. 17). The significant point here is not that the path of the ray through the atmosphere is different from the path as seen from the ground. Actually, the distance between the observer and the refractive layer causes the entire atmospheric effect to be compressed in such a way that it results in a completely different phenomenon.

Twilight Bands

During twilight, three atmospheric layers at least are distinguishable (fig. 19–11). As illustrated in figure 19–12 at the top of the atmos-

FIGURE 19-11.—Sunset photograph. MA-7 photograph.

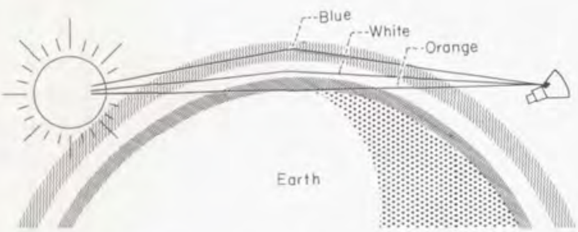


FIGURE 19-12.—Proposed explanation for horizon bands, seen at twilight from space.

phere, the light of the sun is scattered in the ordinary way (Rayleigh scattering) by atoms and molecules of the upper atmosphere. This layer is blue for the well-known reason that Rayleigh scattering varies as the minus fourth power of the wavelength and, therefore, effects the shorter blue wavelengths much more than the longer wavelengths. Lower in the atmosphere the scattering approaches saturation in all wavelengths, and so we have a white layer because there is enough atmosphere to scatter even the red light. Close to the horizon the brightness of more distant atmospheric layers exceeds that of the layers at which we are looking. As a consequence, we see, not the light which has been scattered by the atmosphere but that which has come through it either from the sun itself or from bright layers. As a result, this layer appears red, since the beam which reaches us has lost blue light.

Volz and Goody have studied the colors of twilight as seen from the ground (ref. 18). They find that in the rare cases when there are no storms between the observer and the sun, the twilight colors change slowly and continuously. Discontinuous changes occur when the contribution to the sky which should be made by some distant region is blocked by a storm. In the same way, if there were no storms along the line of sight as seen from the spacecraft, it would be reasonable to anticipate that the colors of the twilight horizon band would melt uniformly into each other. In general, however, just as the storms interrupt the orderly time sequence of colors as seen from the ground, so also they may interrupt the orderly spatial display of colors as seen from space in the twilight horizon band. In addition, the variation between troposphere and stratosphere may play a part in producing these lines.

In addition to these bands, which can be seen on photographs taken at twilight by Astronauts Glenn and Carpenter, Astronaut Schirra noted further detail in the area in and below the Rayleigh scattering level. He observed the planet Mercury setting through this region and reported a dark-blue band, a light-blue band, and then a dark-blue band near the earth's surface. These observations are still being analyzed; however, there is some indication that the Chappus absorption bands of ozone may play a role in producing the central blue band (ref. 19). Copper confirmed these observations of Schirra by describing the appearance of the blue banding and by examining a sketch prepared from Schirra's report.

Luminous Particles

On numerous occasions, when the sun was above the horizon, small luminous particles drifting generally backward along the spacecraft line of motion at relative velocities of a few meters per second were observed by the astronauts. Carpenter demonstrated by rapping on the hatch that such particles could be produced from the spacecraft itself. Given the very close coincidence in orbit velocity, which is implied by the small relative velocity, it is considered highly probable that all such particles originate from the spacecraft. From the remark of Glenn that the particles seemed to be about as luminous as fireflies, it is possible to estimate that the sizes of those seen by him are of the order of one millimeter (refs. 20 and 21). Some of them may have been bits of debris. The majority, however, appear to be ice crystals probably formed from the steam which is released by the life-support system.

Astronaut Cooper (paper 20) reported seeing particles emerging from the attitude jet nozzles. He was observing them under especially favorable circumstances, namely at a time when the sun was up but the window faced away both from the sun and from the earth, so that he had a black sky against which to see them. Furthermore, he was dark-adapted. Under these circumstances he could see objects as faint as the fourth magnitude, as compared with an estimated −9 magnitude for the objects seen by Glenn (refs. 20 and 21). They must thus have been as much as 100,000 times fainter, corresponding to the difference of 13 magnitudes. Thus, their diameters may have been as small as 25 microns. For such small particles, it is extremely difficult to be sure of the origin. Given the high temperature of the jet exhaust (approximately 1,300° F.), ice crystals would not be expected. Furthermore, most of the material leaving the nozzles should be moving at supersonic velocities if the jets are to be effective in moving mass of the spacecraft. However, Glenn reported seeing a small "V" of steam each time he activated the pitch down thruster (ref. 4). Such steam, under more favorable viewing conditions might appear as individual particles. It appears possible that some of the material in the periphery of the jet exhaust may be moving relatively slowly and cooling rapidly upon leaving the nozzle producing minute droplets or crystals which can be viewed under very favorable conditions. It is possible that these particles are tiny fragments of the catalyst eroded by the hydrogen peroxide blast. In any case, particles coming from the jets were not seen by Glenn, Carpenter, or Schirra, probably because the latter were observing them under less favorable circumstances. Cooper had the enormous advantage that his cabin lights could be completely extinguished and his window covered for extended periods of time to assist him in becoming fully dark-adapted.

Dim-Light Phenomena

At the time of the beginning of the orbital flight program, it was realized that the most promising field for nighttime observations was the study of extended dim objects, especially immediately after sundown or before sunrise. At all times, the astronaut is above a major portion of the airglow layer; and this means a major reduction in the background illumination. Near the time of twilight, the astronaut has the further advantage over the ground observer that his sky is without twilight except for the band along the horizon. Since the majority of comets are found by ground observers in twilight, the astronauts were urged to keep an eye out for them at this time. It should be noted that a new comet was discovered at the eclipse of July 20, 1963 (ref. 22). It was hoped that the astronaut would observe the no-man's land between the zodiacal light, which can be observed from the ground only at distances of 30° or more from the sun, and the outer corona, which is invisible at distances from the sun more than about 3° (ref. 23). This gap has been partially bridged by airplane flights, but more data are still needed.

Astronaut Cooper reported that at about 20 seconds after sunset, he saw a whitish arch extending some 15° or so out from the sun. Approximately 1 minute after sunset, Cooper successfully observed the zodiacal light as a faint band concentrated along the ecliptic. The failure of previous astronauts to see it was presumably because of lights in the cabin which could not be extinguished. As part of an experiment developed by Ney and his associates a series of photographs were taken of the zodiacal light, but these were unsuccessful because of the problems described in paper 12.

Appearance of Earth and Sky at Night

Once the orbital twilight has faded, the visibility of the earth depends upon the phase of the moon. Even with no moon, the earth's horizon is visible to the dark-adapted eye.

According to Cooper, the earth's surface is somewhat darker than the space above it, which is filled not only with the visible stars, but also has a diffuse light produced by the countless stars, which cannot be individually resolved by the eye and by dim light phenomena, such as airglow and zodiacal light. With the aid of starlight, zodiacal light, and airglow, clouds and coastlines are just visible to the dark-adapted eye. With moonlight reflected on the earth, the horizon is still clearly defined, but in this case, the earth is brighter than the background of space. With moonlight, the clouds can be seen rather clearly and their motion is distinct enough to provide a cue to the direction of motion of the spacecraft. Lights from cities can be distinguished, even through thin clouds. Thus the lights of Shanghai shining through the clouds were used by Cooper to help aline his vehicle in yaw on the last night pass prior to retrofire.

The night sky appears quite black with the stars as well defined points of light which do not twinkle. Lights upon the earth do twinkle when viewed from above, according to Cooper.

Comparison of visual estimates of angles near the horizon with the corresponding measurements shows that the so-called "moon illusion" continues to exist in space; that is, objects near the horizon seem to be larger than their true angular dimensions (ref. 21). The fact is interesting, since it shows that this illusion is not related to any sensation of gravity, but is a consequence in some way of the visual perception of the location of the horizon.

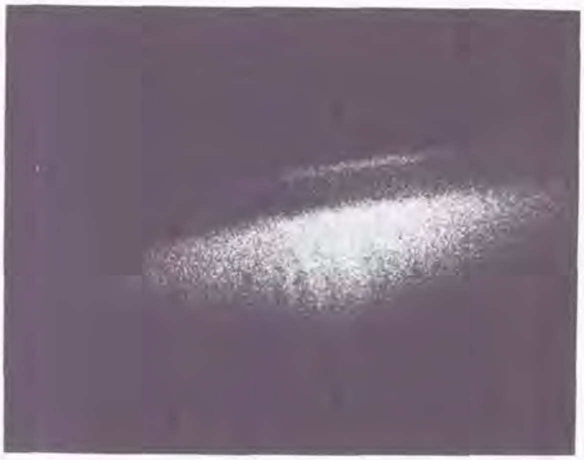
The Nightglow

Around the horizon, all the astronauts report that they saw a band of light, which appeared to them to be centered at a height of some 6° to 10° above the visible horizon. Astronaut Glenn describes it as "tan to buff"; similar descriptions were given by the others. The nature of the band was made clear by Astronaut Carpenter who employed a filter which passed only the 5577 Å line of the neutral oxygen atom (refs. 21 and 24). Through the filter, the band continued to be visible although all other details of the horizon had vanished. It was thus clear that the band resulted from the phenomenon of nightglow; that is, the emission of light by gases of the high atmosphere. In this emission, the line 5577 plays an important part; it constitutes about 1/6 of the total, according to Tousey and his associates. Carpenter reported that the light seen through the filter seemed to be about the same as that without; this remark should, however, be understood as an indication of order of magnitude rather than as a precise measurement, for which neither time nor instruments were available.

Carpenter also provided a rough estimate of the brightness, indicating that it was comparable with that of a bank of clouds near the horizon illuminated by the quarter moon, or about 30 kilorayleighs, according to later computations. This figure happens to agree closely with rocket measurements (ref. 25).

The height of the nightglow layer was also measured on the MA-7 flight. Carpenter observed the passage of the second magnitude star Gamma Ursae Majoris through the nightglow layer. He timed its entrance into the layer, its passage through the level of maximum brightness, and its emergence. From this information, it has been possible to calculate the height of the nightglow layer, by using the standard formulas for the dip of the horizon. A value of 91 kilometers was found; the close agreement with rocket measurements is probably to be expected, since the method is capable of considerable precision.

On the MA-9 flight, a camera with a f/0.8 lens of 3.8 cm focal length using Ansco H 529 color film was carried to photograph the nightglow (see paper 12). A total of 15 usable exposures were made. Some of these were degraded by roll of the spacecraft during the exposure, but a number of them show the nightglow layer as a thin line a few degrees above the horizon as can be seen in figure 19-13(a). The results of this study are summarized in table 19-II.



(a) Nightglow photograph number 29 (MA-9) (Unretouched).

FIGURE 19-13.—Nightglow photography.

supported by the densitometry of the photographs taken by Astronaut Cooper.

Table 19-II shows the altitudes of the spacecraft as a function of time and the measured angles that the airglow layer has with respect to the observable earth's limb. It also shows the inferred heights of the airglow layer, and these heights vary from somewhat in excess of 100 kilometers down to something just under 80 kilometers. The average height as determined from all the pictures is 88 kilometers, and the thickness of the layer is 24 kilometers. There is an indication (figs. 19-13 (a), (b), and (c)) that the earlier photographs of the airglow layer show it higher above the horizon as determined by lightning flashes on the horizon than the later pictures, in which the earth's limb is illuminated by the quarter moon. This could be true latitude effect, and, if it were, would indicate that the airglow layer has a higher altitude at high latitudes—the highest latitude in this case being about 27° S. where the layer is about 108 kilometers as measured from the lightning horizon references. The lowest altitude of the airglow layer is near 17° and is about 78 kilometers.

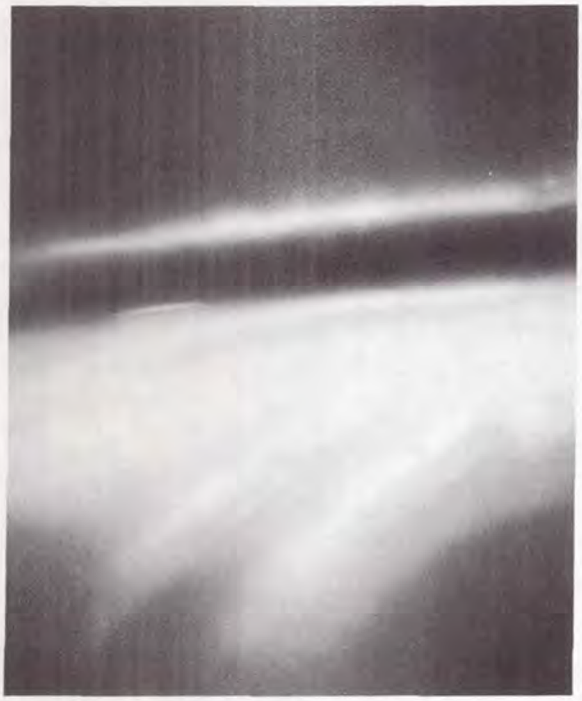
Table 19-II.—MA-9—Nightglow Photographs Used for Geometrical Measurements
[From Gillett, Huch, and Ney, U. of Minn.]

Picture No.	Time, G.m.t.	Angle between earth's limb and nightglow line, deg	Height of spacecraft above earth, km	Height of center of nightglow band, km	Latitude at which nightglow is observed	Angular width at half intensity of nightglow band, deg	Normal exposure time, sec
22	1342:50	3.62	241	111	27° S.	0.66	30
23	1343:10	3.26	240	105	26.5° S.	.69	10
25	1346:20	3.00	232	97	23° S.	.88	30
27	1349:30	2.26	220	75	18° S.	.71	120
28	1350:20	2.40	218	78	17° S.	.89	30
29	1350:40	2.41	217	77	16.5° S.	.87	10
31	1355:00	2.66	202	81	8° S.	.78	30
32	1355:10	2.65	202	81	8° S.	.78	10
35	1401:40	3.20	181	87	8° N.	.92	10
Average		2.86		88		0.80	

The color of the nightglow band, as determined from the photographs, is greenish with respect to the bluish-white illumination of the earth. It is not, however, the same green as a pure 5577 Å line since, as noted above, the light of the 5577 Å line is diluted with other radiations.

On some of the photographs, the atmospheric clouds and haze near the horizon can be seen, illuminated by the moon, then at last quarter (fig. 19-13(b)). As remarked by Carpenter (ref. 24), the brightness of the nightglow layer is comparable with that of the clouds illuminated by the quarter moon; this conclusion is

The width of the nightglow band at the half-intensity points was measured from the films as between 0.66° and 0.92°. By comparison, the distance from the center of the nightglow layer to the bottom was measured by Carpenter and his coworkers (ref. 24) as 0.34°; he did not measure the entry of the star into the layer. Carpenter's half width is in good agreement with the photographed total width; both indicate that the nightglow layer is considerably narrower than the space between itself and the horizon. Table 19–III summarizes and compares the data from the MA–7 and MA–9 flights.



(b) Artist sketch based on nightglow photograph number 29 (MA–9).
FIGURE 19–13.—Continued.

Astronaut Schirra observed on one occasion on the night side, while over the eastern portion of the Indian Ocean and probably while looking in a northerly or northeasterly direction, a large luminous patch which he described as a brownish smog-appearing patch. He saw stars above and below this patch which he felt was higher and thicker (wider) than the "normal" nightglow. On the average, this higher patch or layer did not seem to be as bright as the "normal" nightglow layer. Some stars could be seen near the feathered edges of the layer, but he was not certain he could see any stars in the central denser portion (nor is it likely that, at the short period of observation, there was a rich and bright star field in the background). It is tempting to conclude that this phenomenon may have been a view of a

(c) Artist sketch based on nightglow photograph number 22 (MA–9).
FIGURE 19–13.—Concluded.

tropical 6300 Å atomic oxygen emission, first reported by Barbier and his associates (ref. 14). It is believed that the arc observed by Schirra is similar to that observed at Tamanrasset, Algeria, and Maui, Hawaii. On one occasion, Cooper noticed and immediately reported a patch, similar to that described by Schirra, above the "ordinary" nightglow layer while over South America. It had been predicted that there might be visual concomitants of the South Atlantic magnitude anomaly; however neither of these observations were in the correct geographical location to be related to this phenomenon.

Acknowledgments.—In addition to the individuals specifically referred to in the text of this section, the following scientists assisted in the development of the Mercury inflight research program as consultants, or members of the "Ad Hoc Committee on Scientific Experiments," or the "Panel on Inflight Scientific Experiments" of the NASA Office of Space Sciences: Jocelyn R. Gill, Ph. D., NASA Headquarters; Gordon C. Augason, NASA Ames Research Center; Maurice Dubin, NASA Goddard Space Flight Center; Frederick R. Gracely, NASA Headquarters; John E. Naugle,

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Table 19-III.—Comparison of MA-7 and MA-9 Nightglow Observations

Type of measurement	Carpenter et al.	Cooper photographs
Color	At least partly 5577	Whitish green.
Brightness	Like a cloudbank under a quarter moon; 30 kilorayleighs.	Same.
Height	91 km	88 km.
Width	0.68°	0.66° to 0.89°

Ph. D., NASA Headquarters; Freeman H. Quimby, Ph. D., NASA Headquarters; George P. Tennyson, NASA Headquarters; Ernest J. Ott, NASA Headquarters; Albert Boggess, III, Ph. D., NASA Goddard Space Flight Center; George Swenson, Ph. D., U. of Illinois; Franklin Roach, National Bureau of Standards; Edward P. Ney, Ph. D., U. of Minnesota; Leslie Meredith, Ph. D., NASA Goddard Space Flight Center; and Dale W. Jenkins, Ph. D., NASA Headquarters.

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20. ASTRONAUT'S SUMMARY FLIGHT REPORT

By L. Gordon Cooper, Jr., *Astronaut, NASA Manned Spacecraft Center*

Summary

The MA-9 flight marked the conclusion to the United States' first manned space-flight program. From their initiation into the program in 1959, the seven Mercury astronauts participated as a specialist team, and their combined experiences, both in space and on the ground, constitute a valuable contribution to the nation's manned space-flight capability. The launch checkout activities constitute one of the most valuable portions of this experience, and the MA-9 flight demonstrated once again how critical this period is both to the preparation of the spacecraft and the pilot. The sensations and experiences of the flight were generally similar to those reported by the pilots of previous flights with the exception that better dark adaptation was obtained and therefore more dim light phenomena could be seen. During the MA-9 flight, the zodiacal light and what may have been the daytime airglow were observed for the first time. While some new observations were made on phenomena such as the airglow and space particles, the appearance of the earth features and weather patterns generally seemed to be similar to the description of the previous pilots. As on previous flights, several photographic studies were conducted and the results of these exercises have proved to be valuable. A series of new experiments and evaluations of Mercury systems were conducted, with generally good results. The mission appeared to be relatively routine until a malfunction in the control system late in the flight made it necessary to control attitude manually during retrofire and reentry. The flight of *Faith 7* concluded after some 34 hours in space with a landing within 4½ miles of the primary recovery ship, the *USS Kearsarge*, in the Pacific Ocean.

Introduction

When the seven of us came together as a group for the first time at Langley Field, Virginia, in April of 1959, neither we, any of the newly created NASA Space Task Group, nor anyone in the country knew what our exact roles as Project Mercury Astronauts would entail. We were unsure how we should train for space flights, how we would become familiar with the spacecraft and its many systems, or even how the pilot would be integrated into these systems. We were all starting from scratch, from the ground floor in manned space flight.

Looking back now on more than 4 years of concentrated training, detailed study of spacecraft systems, attending countless hundreds of coordination and planning meetings, participating in hundreds of hours of hardware development and checkout, we can all recognize that in some cases there would have been more efficient ways of doing things. However, considering the limited knowledge in this space business in the spring of 1959, I consider it remarkable that Project Mercury ran so close to its originally planned time schedule. Few programs in the history of airplane development ever ran as close, and no airplane program ever had so many unknowns staring the test operations team in the face.

By correlating all that we have learned in the last 4 years and properly applying it to future manned space programs, we should be able to increase the efficiency of our next program. This application of experience will be important because taking the step from the successful missions of Project Mercury to manned interplanetary flights involves many stumbling blocks and unknowns. These uncertainties must be uncovered and solved in a logical manner.

Back in 1959, the pilot was one of the real unknowns in space flight. No one could really say for certain how a pilot would react or how well he could perform in a space environment. Partially for this reason and because unmanned flights were scheduled as part of the development program, the Mercury spacecraft was designed to perform the mission automatically. Manual controls for spacecraft control and systems management were included primarily as backups to the automatic program. From the start of the program we encouraged the concept of the pilot being a primary part of the overall system. Throughout the manned flight phase, this concept has become more and more of a reality.

While we adopted the team concept during most of our space-flight training, we were required to be at so many places and cover so many areas that each man was assigned a specialty area to monitor closely and brief the others on periodically.

"Faith 7" was the name I selected for the spacecraft which performed so well for me until the electrical problem late in flight. I chose this name as being symbolic of my firm belief in the entire Mercury team, in the spacecraft which had performed so well before, and in God. The "7," of course, as in the names used by the others before me is representative of the original astronaut team. This flight report will present a discussion of my entire flight experience, but I shall attempt to summarize the inflight sensations and observations of the other astronauts and relate their experiences to my own. Beginning with the prelaunch activities which are so necessary to preparing for the mission and concluding with my landing in the Pacific after 34 hours of weightlessness, I shall try to discuss the many experiments and systems operation in which each of us took part.

Preflight And Launch

Spacecraft Readiness and Checkout

The period from the time the spacecraft arrived at Cape Canaveral until the time it was mated with the launch vehicle was the period where the pilot and his backup became completely familiar with the spacecraft and all its various systems (fig. 20–1). We learned all the individual idiosyncrasies of each system. We also became familiar with many of the members of the launch crew and learned whom to call on for expert advice on each system. It was also during this period that we had an opportunity to discuss the coming flight with team members who had flown before (fig. 20–2) and take advantage of their experiences.

The preflight phase was used to incorporate certain modifications into the spacecraft and

FIGURE 20–1.—Astronauts Cooper and Shepard discuss MA–9 camera during prelaunch activities.

FIGURE 20–2.—Astronauts Glenn and Cooper discuss items of the pilot's personal equipment during the MA–9 prelaunch period.

to add some pieces of equipment necessary to meet operational requirements. Because of the limited usable cockpit space and the even more limited center-of-gravity travel and gross weight of the Mercury spacecraft, these configuration changes were always a soul-searching problem. Regardless of how they were accomplished, additions often resulted in some type of compromise to the pilot's comfort, freedom of movement, and/or operational smoothness.

The natural tendency was for everyone to want to improve on existing equipment and to add worthwhile experiments that could be fitted in. Space flight is so expensive that no one wants to waste a single second of orbital time. However, we all discovered that the entire flight is compromised when all equipment, all experiments, and all the flight plan detail are not frozen early enough to check out each piece of equipment and allow everyone, particularly the pilot, to become thoroughly familiar with all procedures.

On all our flights the cockpits have been cluttered to the point where the space remaining for the astronaut and the equipment with which he must work is very limited and inefficiently arranged. In most cases getting some of the equipment located and moved about provided more exercise than did the special onboard exercise device. Stowage of equipment is a very real problem that too often is not given enough consideration.

As the flights lengthened, a detailed flight plan and abbreviated checklists for experiments and operational procedures became a real necessity. It is impossible for a pilot to remember all the details of times, amounts, and so forth, of the many experiments and tests to be conducted. Proper formats and storage for these items had to be developed during the preflight preparation periods.

Integrated Checkout

Faith 7 passed all the spacecraft tests in fine shape and was taken to the launch complex to be mated with the Atlas 130D launch vehicle. At this time, a buildup of integrated launch vehicle and spacecraft tests, system by system, was initiated and proceeded until the program was culminated in a fully integrated simulated flight from countdown to recovery with all systems operating. This series of tests was felt by all of us to be a necessity not only to check out all the systems, but to train the launch crew, the pilots, and the personnel of the worldwide network.

Countdown

I believe that we can very readily shorten the time that the pilot is in the spacecraft prior to launch. I was busy enough with the countdown activities that time did not drag, but I did have time to take a short nap during this period. It seems to me that to conserve the pilot's energy it would be desirable to accomplish more of these checks with the backup pilot prior to insertion. Of course, you do need a few minutes to shift around and get settled, see that the equipment is located properly, before you are prepared for the flight.

Most of the countdowns in Mercury went fairly smoothly as a result of the practice that the launch crews had acquired on simulated flight tests. The first attempt to launch MA-9 on May 14 was delayed for a diesel engine that would not operate to drive the gantry back. Then it had to be postponed because a critical radar set became inoperative. I was in the cockpit for some 6 hours before we scrubbed on that first day. I was quite tired but felt ready to recycle for another count the following day.

The countdown on May 15, 1963, went almost perfectly. Everything was really in a "go" status and I think everyone felt that we were going to have a good launch. And it was!

I had thought that I would become a bit more tense as the count neared minus 1 or 2 minutes, but found that I have been more tense for the kick-off when playing football than I was for the launch on May 15. I felt that I was very well trained and was ready to fly a good flight.

Powered Flight

It is a wonderful feeling when the engines light and you have lifted off. The long period of preparation is over, and at last you are ready to settle down to your work.

The acceleration is not disconcerting or degrading at the levels encountered in the Mercury flights. In fact, it gives one somewhat the same feeling as that of adding full throttle on a fast car, or a racing boat, or a fighter airplane. The pilot can easily monitor several of the more critical parameters, including his attitudes, throughout the entire launch phase. The task that he is given to do should be uncluttered with minor details if possible, but he is fully capable of functioning as an intricate part of the system throughout the entire launch. I was surprised at how many things I could keep track of and feel that I had plenty of time to do the exact item planned.

On previous flights, it had been noted that vibration encountered in the region of maximum dynamic pressure was feeding through the couch to the helmet and causing slight blurring of vision. We found that this could be eliminated by adequate padding between the helmet and the couch. I had approximately 3/4 inch of foam rubber between my helmet and the couch and experienced no blurring of vision.

Booster engine cutoff (BECO) is very distinctive, by the decrease in both the acceleration and the noise. It was just as I had expected it to be from talking to the others.

John Glenn and Scott Carpenter had discussed with Wally Schirra and me how they had encountered some springboard effect from the guidance while in the latter phases of the sustainer flight. Wally Schirra experienced very little or none of this effect. I had an almost perfect sustainer trajectory with almost no guidance corrections at all, so it was an exceptionally smooth and almost perfect insertion.

Sustainer engine cutoff (SECO) is also quite distinctive, in the same manner as BECO. This is followed by the noise of clamp rings and posigrade rockets. The spacecraft is in orbit.

Orbital Flight

Insertion

We had all run many full launch profiles on the centrifuge, so I felt very well prepared for all the powered flight, but there is some difference between the transition from positive acceleration on a centrifuge back to 1-g and the transition from positive acceleration on the flight to zero-g. I felt somewhat strange for the first few minutes. The view out of the window is a tremendous distraction as the spacecraft yaws around and the earth and the booster come into full view for the first time. We all noted a strong desire to concentrate on the tremendous view out of the window. Atlas 130D was only about 200 yards away from me. It was certainly beautiful. I could read the lettering on the sides and could see various details of the sustainer. It was a very bright silver in color, with a frosty white band around the center portion of it. It was still wisping vapor from the aft end. It was yawed approximately 15° to 20° to its left. I had it in sight for a total of approximately 8 minutes. The front end was slowly turning in counterclockwise rotation.

Despite these distractions, the many hours of training took over and we all proceeded to do our tasks as scheduled. After a few minutes I readily adapted to the new environment and felt completely at ease. Weightlessness is extremely comfortable. After a pilot has once experienced weightlessness in space flight, he should almost immediately adapt to this condition when exposed to it again. We all even tended to forget we were weightless.

I agree with Scott Carpenter that the cockpit did seem to be somewhat differently located in respect to myself upon insertion into orbit. You move up forward in the seat, regardless of how tight your straps are cinched. The equipment storage kit on the right seems to be at a different angle to you than it is when you are on the launch pad. I did feel very distinctly that I was sitting upright. Most of the time I felt as if I were lightly floating. A couple of times I felt almost as if I were hanging upside down because of the feeling of floating into the shoulder straps. Because the spacecraft was weightless, equipment stayed where it was whenever I let go of it. Nevertheless, every time I "dropped" something, I had the tendency to grab below it, expecting it to fall.

You really need to have a low workload on the first pass in order to collect your senses, to acclimatize yourself to this new situation, and to organize the flight activities. I felt that I was not on top of the situation as completely as I would like to be right after insertion. Although I was thinking about all the items to be done and of how to do them, I did not feel completely at home. I felt that I was in a strange environment and was not at my best, until perhaps halfway through the pass. By the end of the first pass, I was feeling really adjusted to my new surroundings.

One indication of my adjustment to the surroundings was that I encountered no difficulty in being able to sleep. When you are completely powered down and drifting, it is a relaxed, calm, floating feeling. In fact, you have difficulty not sleeping. I found that I was cat-napping and dozing off frequently. Sleep seems to be very sound. I woke up one time from about an hour's nap with no idea where I was and it took me several seconds to orient myself to where I was and what I was doing. I noticed this again after one other fairly long period of sleep. You sleep completely relaxed and very, very soundly to the point that you have trouble regrouping yourself for a second or two when you come out of it. However, I noted that I was always able to awaken prior to having a task to do. I did not encounter any type of the so-called "break-off phenomena." Although this flight was very enjoyable, a thing of delight, it still is a strange environment to a human being and you have every desire to get back to earth at the planned time.

Comments on Systems Operation

The automatic control is rather sloppy due to the wide limit cycle it operates within. It is no problem as soon as you get accustomed to it. I found that Grissom's and Schirra's description of the manual proportional flight control system was very accurate. It is a rather sluggish system until you learn to use short blips. The fly-by-wire low is much more precise with the crispness of control produced by the firing of the 1-pound thrusters.

I found that orienting the spacecraft after drifting flight was quite easy on the day side and not too difficult on the night side, although orientation on the night side takes more time unless there is moonlight or broken clouds or land masses below. Stars and star patterns are more difficult to recognize because of the limited view through the window. You can slowly drift until you find a star pattern that is recognizable and from this you can pick up a zero yaw star. If you have moonlight, or any broken cloud masses or land masses, you can pick up zero yaw very readily if you turn all the lights off in order to become dark adapted and pitch down to approximately $-20°$.

Speed is very apparent when flying over clear or broken-cloud areas. However, if there is a solid cloud deck underneath you and no other motion cues are available, you have a very slow, floating feeling.

When I was drifting, the changing view out the window was not at all disconcerting, and the random orientation caused me no concern. In fact, it is a very relaxed way to travel. I might mention an item here on the natural dynamics of the spacecraft. When rates were near zero, and the spacecraft was powered down, I never observed any rate greater than 1°/sec about any one axis. Generally, if there were a rate about one axis as great as this, there were no rates about the other two axes. These rates would switch from axis to axis and more than likely only two axes would have any rate at all, and these rates would be between ¼°/sec and ½°/sec, at the most. Frequently, for long periods of time, the spacecraft would have absolutely no rates at all and would be almost completely motionless. The one axis that appeared to have more predominate rates than the others was the roll axis; and the rate, almost invariably, was to the left, approximately ½°/sec.

Although my suit temperature was satisfactory, like Wally Schirra I had to adjust the water flow continually to attempt to hold temperature in limit. The condensate pump that was added just prior to launch failed; so that the condensate tank filled up and the suit was very moist all the time.

The valve on the drinking water container was leaky, and I was unable to place water into the plastic freeze-dehydrated food containers. Therefore, I ate only the bite size foods.

Visual Sightings

During the day, the earth has a predominately bluish cast. I found that green showed up very little. Water looked very blue, and heavy forest areas looked blue-green. The only really distinctive green showed up in the high Tibetan area. Some of the high lakes were a bright emerald green and looked like those found in a copper-sulphate mining area. The browns of the Arabian desert showed up quite distinctly, but the Sahara was not quite so brown. If you are looking straight down on things, the color is truer than if you are looking at an angle.

I could detect individual houses and streets in the low-humidity and cloudless areas such as the Himalaya mountain area, the Tibetan plain, and the southwestern desert area of the U.S. I saw several individual houses with smoke coming from the chimneys in the high country around the Himalayas. The wind was apparently quite brisk and out of the south. I could see fields, roads, streams, lakes. I saw what I took to be a vehicle along a road in the Himalaya area and in the Arizona-West Texas area. I could first see the dust blowing off the road, then could see the road clearly, and when the light was right, an object that was probably a vehicle.

I saw a steam locomotive by seeing the smoke first; then I noted the object moving along what was apparently a track. This was in northern India. I also saw the wake of a boat in a large river in the Burma-India area.

At times during the day, the pattern of the sun coming through the window was hot on my suit. I could also feel heat on the inside of the window right through my glove. Like Scott, I never tired of looking at the sunsets. As the sun begins to get down towards the horizon, it is very well defined, quite difficult to look at, and not diffused as when you look at it through the atmosphere. It is a very bright white; almost the bluish white color of an arc lamp. As it begins to impinge on the horizon line, it undergoes a spreading, or flattening effect. The sky begins to get quite dark and gives the impression of deep blackness. This light spreading out from the sun is a bright orange color which moves out under a narrow band of bright blue that is always visible throughout the daylight period. As the sun sets farther, it is replaced by a bright gold-orange band which extends out for some distance on either side, defining the horizon even more clearly. The sun goes below the horizon rapidly, and the orange band still persists but gets considerably fainter as the black sky bounded by dark blue bands follows it on down. You do see a glow after the sun has set, although it is not ray-like. I could still tell exactly where the sun had set a number of seconds afterward.

At night I could see lightning. Sometimes five or six different cumulus buildups were visible at once. I could not see the lightning directly, but the whole cumulus mass of clouds would light up. From space, ground lights twinkle, whereas stars do not. I could not distinguish features on the moon. It was a partial moon at night, but it appeared full when it was setting in the daytime. It was quite bright at night, but on the day side it was a lightish blue color.

I immediately saw the airglow layer, which all the orbital pilots have seen, in which the stars appear to fade as they pass through it and then reappear below it before disappearing behind the horizon. The earth has a sharp horizon even at night. At the time, the layer appeared to be about 12° to 13° high. It was, of course, actually lower than this as discussed in paper 19.

At two different times, I saw a faint glow just after sunset or prior to sunrise; it was somewhat cone shaped, and I believe it was the faint glow of zodiacal light. It was not exactly perpendicular to the horizon. I had a feeling that this was just a glow off the sun. It was not as bright as the Milky Way. Another night phenomenon that I noticed occurred when I was over South America looking east or northeast. It appeared to be the lower edge of a cloud ceiling on an overcast day. It did not appear to have an upper edge. It was not distinct and did not last long, but it was higher than I was, was not well defined, and was not in the vicinity of the horizon. It was a good sized area, very indistinct in shape. It had a faint glow with a reddish brown cast. It seemed to be quite extensive, very faint, and contrasted as a lighter area in the night sky. It may have been the same high airglow layer that Wally reported.

When there is no moon, the earth is darker than the sky; there is a difference in the two blacks. In general, there was more light from the sky; the sky is a shining black as compared with a dull black appearance of the earth. There is a distinct line at the horizon and the earth is the darker.

I saw the lights of Perth, Australia, and a bright orange light from the British oil refinery to the south of the city. If there is moonlight, then cloud layers and ground features can be seen. The moonlight was bright enough to detect motion of the ground. On several occasions I could see light from cities on the ground through the clouds. On the last night pass, I used the light of Shanghai glowing through the clouds to help me line up in yaw for retrofire.

At times I could see the glow from every one of the thrusters. I saw a tremendous amount of John Glenn's fireflies regardless of my attitude. They appeared to come out from the spacecraft and go back along the flight path. I could see some of them for as long as 30 or 40 seconds. I could see them coming directly out of the pitchdown thruster when it was activated. I had the feeling that the direction of their motion back along the orbital path was distinct enough that they could be used as a rough yaw reference.

The first indication I got of the sun coming up behind me was the lighting of the clouds from underneath. I noted the clouds getting lighter and lighter, and I could still see the stars. Suddenly, my window would get into the oblique sunlight and appear to frost over just as an aircraft canopy does. This was the result of a greasy coating on the inside of the outer pane, which completely occluded my vision under these lighting conditions.

Experiments

Since MA-9 was so much longer than previous flights, I had ample time to conduct numerous experiments. The first orbital flight had very few experiments. As the experimental program increased and the flights lengthened, the number of experiments carried on board increased. In addition to the experiments all of us have tried to make as careful observations as possible. We have been told that these observations of new phenomena can provide some of the most valuable data on features such as the spectacular colors in sunrises and sunsets, zodiacal light, airglow, space particles, stars on the day side, and various distinct earth features (see paper 19).

Photography.—All the orbital flight pilots have carried along a hand-held camera of some type for color photographs of interesting phenomena. These have all yielded some good photos of the earth from a new vantage point.

Several photographic programs were carried out during the orbital flight program. Scott Carpenter took horizon definition pictures for MIT, and Wally Schirra made an evaluation of several different filters for the Weather Bureau. These two studies were extended on my flight. In addition, I attempted to get dim light photographs as well as movies (see paper 12).

Ground light experiment.—The ground light experiment was attempted on all the orbital flights. However, weather precluded John, Scott, and Wally from seeing it. I was fortunate enough to have excellent weather and saw the ground light as scheduled. The lights from the town of Bloemfontein, S. Africa, were more distinctive than the signal light and helped me to locate it.

Flashing light experiment.—On the MA-9 flight, we tried a new experiment designed to provide information that would help us on future rendezvous missions. A 5.75-inch-diameter sphere with two xenon-gas discharge lamps which strobed at approximately one flash per second was ejected from the spacecraft into its own orbit. In this orbit, it moved back and forth relative to the spacecraft so that it would appear at different distances.

At 3:25:00 I went to fly-by-wire low, slowly pitched up to the $-20°$ mark on the window, deployed the flashing beacon, and there was a loud "cloomp" as the squib fired and it departed. I then caged the gyros and powered down the ASCS a-c bus. I never did see the beacon on that first night after it was ejected. However, I was having some difficulty finding my 180° yaw and the spacecraft may not have been properly alined for making the observation. I tried unsuccessfully to observe the flashing beacon early on the day side also.

On the second night side after deploying the flashing beacon, shortly after going into the night side, I spotted the little rascal. It was quite visible and appeared to be only 8 to 10 miles away. I deliberately moved off target, waited until 5:40:00 and eased back to 180° yaw and saw the light again, at which time it appeared to be around 12 to 14 miles away and still quite visible.

On the third night side after deploying the flashing light, I had no anticipation of seeing it at all; but at 6:56:00 ground elapsed time (g.e.t.) there it was, blinking away. It was very faint and appeared to be at a distance of about 16 to 17 miles. I would say it was approximately the brightness of a fifth-magnitude star, whereas on the second night side after deployment it had appeared to be about that of a second-magnitude star.

Systems Difficulties Encountered Towards the End of the Flight

Partial pressure of oxygen in the cabin slowly dropped throughout the flight to about 3.5 psia. I was worried that the network might get concerned about this on the next to the last pass. Also, the partial pressure of CO_2 in the suit circuit had gradually increased to a reading of 3.5 mm Hg. I suspected the gage and went to emergency rate flow and did not get any apparent decrease in this reading. However, I did not stay on emergency rate flow very long. I recognized that my breathing was more rapid and deep. The PCO_2 gage indicated that we were up over 5 on the gage setting just prior to retrofire. However, I could have gone on emergency O_2 flow and accepted slightly higher suit temperatures because of the fans shutting down, which reduces suit circuit flow.

On the 19th orbital pass, I had been switching the warning light control switch to the "off" position in order to darken completely the interior of the spacecraft and thus become dark adapted. When I returned the switch from the "off" to "dim" position, the 0.05g green light illuminated. I immediately turned off the ASCS 0.05g switch fuse and the emergency 0.05g fuse. Thereafter, we made three checks to verify that the ASCS 0.05g relay functions were operative. Since the amp-cal was now latched into the reentry mode, the attitude gyros were no longer operational.

The 250 v-amp main inverter failed to operate on the 21st pass. At about 33 : 03 : 00 g.e.t. the automatic changeover light for the standby inverter came on. I had noticed two small fluctuations in the ammeter just previous to this time and had gone through an electrical check; everything appeared normal. The temperature on the 250 v-amp inverter was about 115° F. The temperature on the fans inverter was about 125° F, and the standby inverter was about 95° F. At this point the light came on and I checked the inverters. The 250 v-amp inverter was still reading about 115° F on temperature, but it was indicating 140 volts on the ASCS a-c bus voltage. I then turned it off. At that time I selected the slug position (manual selection of the standby inverter for the ASCS) and found that the standby inverter would not start. I put the switch back to the "off" position of ASCS a-c power and elected to make a purely manual, or fly-by-wire, retrofire and reentry.

Analysis of these malfunctions illustrated that the entire Mercury network had developed an operational concept of teamwork that culminated in an almost perfect example of cooperation between the ground and the spacecraft on the MA–9 flight. Almost everyone followed the prestated ground rules exactly, and the radio discipline was excellent.

Retrofire

All of us believed that we could control attitude manually during retrofire. However, the flight plans call for autopilot control. Nevertheless, because of failures of one type or another, Wally's was the only flight in which only the autopilot controlled attitude during retrofire. John had trouble with a low-torque thruster and elected to assist the autopilot with the manual proportional system. Scott had a problem with the horizon scanner and controlled during retrofire with the fly-by-wire and manual proportional systems. I had a malfunction associated with one of the control relays which eliminated my autopilot as well as my attitude indicators. Therefore I had to initiate retrofire, use window view for attitude reference, and control the spacecraft with the manual proportional system. This was no problem, though I did have some difficulty reading the rate indicators due to the large variation in illumination between the inside and outside of the spacecraft. This disparity in illumination became a problem because I had to shift back and forth for attitude reference outside and readings of the rate indicators inside. In order to be ready for retrofire which had to occur just after first light, I oriented the spacecraft to the retrofire attitude on the night side. Night orientation is no problem, but it does take considerably longer, because yaw determination is more difficult than on the day side.

As with the others, there was no doubt in my mind when the retrorockets fired. They produce a good solid thump which you can see and hear. However, our sensations at the time they fired were different. John Glenn felt like he had reversed direction and was going "back toward Hawaii." Scott Carpenter felt that he came to a standstill. Wally Schirra and I did not feel that the motion of the spacecraft changed.

Reentry

After retrofire, there is a period of several minutes prior to the start of reentry (0.05g). As you approach 0.05g, the spacecraft control becomes sluggish and feels as though it wants to start reentry.

As in the retrofire case, all of us knew that we could reenter on manual control. However, the flight plans generally called for autopilot control during reentry. Nevertheless anomalies of system function resulted in partial manual control in all but Wally's flight. I used manual proportional control on MA–9 since I had lost the ASCS and standby inverters during the 20th orbital pass. The reentry worked out very successfully and showed again that the pilot can accomplish this control task very adequately.

I found that the oscillations of the spacecraft were not difficult to damp until I descended to an altitude of approximately 95,000 feet. At this point, the amplitude of spacecraft motions increased as they normally do and it took a substantial increase of control inputs to keep within comfortable limits. The oscillation became more severe at approximately 50,000 feet, but I deployed the drogue parachute at 42,000 feet, as planned, and the spacecraft was quickly stabilized.

The g-forces are more sustained on reentry than on launch but are still easily tolerable.

During reentry there was no uncomfortable increase in cabin temperature. If the pilot is performing a manual reentry, he will be perspiring profusely when landing, but mostly because of the work load rather than the increased temperature.

Landing And Recovery

Landing at a rate of 30 fps with the landing bag down is a good solid jolt, but certainly tolerable. In fact, one does not really have to be in an ideal position and braced tightly to be able to take this momentary shock in good shape.

There have been varied opinions among the pilots of all the Mercury space flights as to the sensations encountered upon landing in water. When the spacecraft rolls over and goes under the water, there is a natural tendency to wonder if it will sink or float and whether it will right itself. One item we stressed in training was that of preparing during the descent on the parachute to evacuate the spacecraft immediately after landing in the event it starts to sink. If the pilot knows that the recovery forces are in the immediate area, this first period on the water is considerably more relaxed and enjoyable.

By the time the landing occurs, the pilot is perspiring profusely. The air from the snorkels is quite cooling, but the cabin is fairly warm and humid.

FIGURE 20–3.—Astronaut Cooper climbs out of *Faith 7* after the 34 hour MA–9 flight.

FIGURE 20–4.—Astronaut Cooper stands on the deck of the *USS Kearsarge* immediately after egressing from *Faith 7*.

Almost the full gamut of recovery procedures were used in the course of the Mercury program. The recovery procedure is greatly simpified if the spacecraft lands near a recovery ship. In this case, the spacecraft can be lifted out of the water directly onto the deck. However, all the procedures would be simplified even more if land landings were made.

When I first stepped from the spacecraft on board the *USS Kearsarge* I felt fine (figs. 20–3 and 20–4). As I stood still waiting on a blood pressure check, I began to feel dizzy. I mentioned this to the doctors, who then started moving me along. As soon as I took two or three steps, I immediately began to feel clear-headed once more, and at no time did I become dizzy again.

Concluding Remarks

After my recovery in the Pacific, the aeromedical specialists conducted their prescribed tests designed to glean as much from my flight as possible. Upon my return to the launch site, a series of formal debriefings covering every aspect of my space flight experience were begun. In these debriefings, I found it useful to refer to my previous training, and that of my six colleagues, in describing my sensations and observations. In the 4 years since we were first initiated into Project Mercury, a great deal has been accomplished and a great deal has been learned. Many of the anxieties and misgivings of space flight have been relieved. Although relatively brief, our early training was intensive and complete, and its effectiveness has been proven, we believe, by our ability to participate actively in the operation of the spacecraft. Al Shepard's flight was our first manned launch, and this initial experience in getting the spacecraft, launch vehicle, and the man ready at the same time was valuable. As a result of losing Gus Grissom's spacecraft, our landing and recovery procedures were promptly changed. In John Glenn's flight, a serious control system malfunction and a somewhat frightening but erroneous signal that the heat shield had been released caused some concern among us on the ground, but John's manual retrofire and reentry completed his mission successfully. Scott had a problem in the control system also, but his manual retrofire, although not quite as precise as he would have liked, brought the *Aurora 7* spacecraft home. Wally Schirra, after bringing his suit temperature under control, completed a "textbook" six-pass mission and landed just under 5 miles from the *USS Kearsarge*.

As I think back over my mission, which actually began right after Wally's flight, it has been an exciting experience indeed. The specific training for my 1-day mission, the many engineering reviews of the changes required for the *Faith 7* spacecraft, the physical conditioning, and even the low-residue diet were all memorable parts of the prelaunch preparation. The initial experience of prolonged weightlessness and the magnificent view of the earth takes a while to get used to just as it did for all the orbital pilots, but once I was accustomed to the new surroundings, events and activities proceeded as scheduled. In fact, until that infamous moment in the 19th orbital pass, it seemed like another Wally Schirra "textbook" flight. Only three more passes stood between me and a routine landing off the bow of the *USS Kearsarge*. When I received the first indication that the sequencing system had malfunctioned a number of interesting experiments and systems evaluations had been completed, with just a few more to go. Then, with the sudden electrical anomaly and the sequence of events which followed, I knew I had a job ahead of me. Unlike Scott's case, however, I had sufficient time to contemplate a plan of action and collaborate with the flight-control personnel on the ground. Their valuable assistance was instrumental in the completion of my successful retrofire, reentry, and landing.

Now that Mercury is over and we stand at the threshold of more ambitious programs, the lessons each of us have learned will be constant tools with which to accept and accomodate new developments. Mercury has been only a beginning for the seven of us. The job at hand is to work to meet our new challenge in space with the same enthusiasm that everyone exhibited throughout this program.

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APPENDIXES

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APPENDIX A

TYPICAL DOCUMENTS PREPARED FOR MERCURY

This appendix contains a listing of the types of documents prepared for use in the control and reporting of Project Mercury. Most of these documents are not available for general distribution.

Type of document	*Estimated number of different volumes of each type*	*Prepared by—*	*Remarks*
1. Mission Rules	8	MSC	
2. Technical Information Summary	14	MSC	
3. Flight Plan	4	MSC	
4. Mission Directive	17	MSC	All issued as working papers.
5. Data Acquisition Plan	13	MSC	
6. Instrument Calibrations	23	MSC	
7. Recovery Documents	27		
a. Recovery Operations			
b. Recovery Requirements			
c. General Information			
d. Recovery Procedures			
e. Operations Plan for Recovery Team.			
8. Postlaunch Reports	21	MSC	Issued as working papers prior to MR–1 (7 issues).
9. Working Papers	134	MSC	Includes Items 5 and 9.
10. Technical Memorandums	2	MSC	
11. Miscellaneous	61		Includes items (a) through (d).
a. Schedule and Cost Analysis	1		
b. Descriptive Synopsis of Project Mercury.	1		
c. Articles for journals	23		
d. Conference papers	30		
e. Operational Requirements	3		
12. Documentary Film	26	MSC	
13. Quarterly Reports	20	MSC	
14. Flight Controller Handbook–1	14	MSC	
15. Flight Controller Handbook–2	6	MSC	
16. Consolidated Remote Site Report	6	MSC	
17. Mercury-Redstone Monthly Status Report	12	MSFC	
18. Master Operational Schedule	4	MSFC	
19. Complete Firing Test Report (5 parts)	4	MSFC	
20. Operations Procedures	2	GSFC	
21. Network Countdown	5	GSFC	
22. Communications Operations Procedure	2	GSFC	

Type of document	Estimated number of different volumes of each type	Prepared by—	Remarks
23. Network Performance Report	3	GSFC	
24. Network Operation Directive	1	GSFC	
25. Test Requests, covering such items as: vibration, shock, heating, systems tests, destruction tests, accoustical tests, Project Orbit, functional tests.	1, 125	Contractors	
26. Drawings (spacecraft)	>1, 800 (3, 200 pages)	McDonnell Aircraft Corp.	Does not include revisions.
27. Formal Report Releases	200	McDonnell Aircraft Corp.	Includes items (a) through (e).
a. Spacecraft configuration	20	----------	For each spacecraft.
b. Failure Summary Report	41		
c. Full Scale Simulated Mission Test.	25		
d. Contractor Furnished Equipment Status Report.	1	----------	Periodically revised.
e. Other	128		
28. Service Engineering Department Reports ((SEDR).	444	McDonnell Aircraft Corp.	Separate SEDR's were generally issued for each system and test for each spacecraft.
29. Miscellaneous:			
a. Contracts (formal)	85	MSC	
b. Contract change proposals	390	McDonnell Aircraft Corp.	
30. Detailed Test Objectives	9	Aerospace Corp.	
31. Operations Requirements	3	Air Force Missile Test Center	
32. Operations Directive	2	Convair/	
33. Flight-Test Reports	9	Astronautics	

APPENDIX B

NASA CENTERS AND OTHER GOVERNMENT AGENCIES

This appendix contains a list of government agencies that supported Project Mercury.

NASA Headquarters, Washington, D.C., and the following NASA Centers participated in Project Mercury:

- Ames Research Center, Moffett Field, Calif.
- Flight Research Center, Edwards, Calif.
- Goddard Space Flight Center, Greenbelt, Md.
- Langley Research Center, Langley Station, Hampton, Va.
- Launch Operations Center, Cocoa Beach, Fla.
- Lewis Research Center, Cleveland, Ohio
- Manned Spacecraft Center, Houston, Tex.
- Marshall Space Flight Center, Huntsville, Ala.
- Wallops Station, Wallops Island, Va.

Department of Defense, Washington, D.C.:

- Space Systems Division, U.S. Air Force, Los Angeles, Calif.
- U.S. Navy, 5th Naval District Headquarters, Norfolk, Va.
- Arnold Engineering Development Center, Arnold Air Force Station, Tenn.
- El Centro Naval Parachute Test Facility, El Centro, Calif.
- Naval Air Development Center, Johnsville, Pa.
- Wright Air Development Center, Wright-Patterson Air Force Base, Ohio
- Air Force Missile Development Center, Holloman Air Force Base, N. Mex.
- Naval Ordnance Test Station, Pensacola, Calif.
- Pensacola Naval Air Station, Pensacola, Fla.
- Air Proving Ground Center, Eglin Air Force Base, Fla.
- Army Ballistic Missile Agency, Redstone Arsenal, Ala.
- U.S. Army Transportation Command, Ft. Eustis, Newport News, Va.
- U.S. Marine Corps Air Station, Cherry Point, N.C.
- Military Air Transport Sciences, Dover, Del.
- White Sands Missile Test Center, White Sands, N. Mex.
- Pacific Missile Range, Point Mugu, Calif.
- Naval Air Station, Corpus Christi, Tex.
- Atlantic Missile Range, Cape Canaveral, Fla.

State Department, Washington, D.C.

Weather Bureau, Washington, D.C.

Aeronautic Chart and Information Center, St. Louis, Mo.

Public Health Service, Washington, D.C.

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APPENDIX C

PRIME CONTRACTORS

This appendix contains a list of the prime contractors for Project Mercury.

- Aerospace Corp., El Segundo, Calif.
- Chrysler Corporation, Highland Park, Mich.
- General Dynamics/Astronautics, San Diego, Calif.
- General Electric Co., Schenectady, N.Y.
- Burroughs Corp., Detroit, Mich.
- The B. F. Goodrich Co., Akron, Ohio
- McDonnell Aircraft Corporation, St. Louis, Mo.
- North American Aviation, Inc., El Segundo, Calif.
- Pan American World Airways, Inc., Guided Missiles Range Division, Patrick Air Force Base, Fla.
- Philco Corporation, Philadelphia, Pa.
- Thiokol Chemical Corporation, Bristol, Pa.
- Western Electric Company, Inc., New York, N.Y.

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APPENDIX D

SUBCONTRACTORS AND VENDORS

This appendix contains a list of Project Mercury spacecraft subcontractors and vendors that had contracts totaling more than $25,000:

AiResearch Manufacturing Co., Los Angeles, Calif.
Airwork Corp., Miami, Fla.
American Welding and Manufacturing Co., Warren, Ohio
Ampex Corp., Redwood City, Calif.
Applied Electronics Corp., Metuchen, N.J.
Arnoux Corp., Los Angeles, Calif.
Atlantic Research Corp., Arcadia, Calif.
Barnes Engineering Co., Stamford, Conn.
Beckman and Whitley, Inc., San Carlos, Calif.
Beckman Instruments, Inc., Berkeley Div., Fullerton, Calif.
Bell Aerosystems Co., Div. of Bell Aerospace, Buffalo, N.Y.
The Bendix Corporation, Utica Division, Utica, N.Y.
Bohanan Manufacturing Co., Falcon Field, Mesa, Ariz.
Brush Beryllium Co., Cleveland, Ohio
Burton Manufacturing Co., North Ridge, Calif.
CTL Division of Studebaker-Packard Corp., Cincinnati, Ohio
Cannon Electric Co., Salem, Mass.
Cannon-Muskegon Corp., Muskegon, Mich.
Carlton Forge Works, Paramount, Calif.
Collins Radio Co., Chicago, Ill.
The Connecticut Hard Rubber Co., New Haven, Conn.
Consolidated Electrodynamics Corp., Pasadena, Calif.
Consolidated Vacuum Corp., Rochester, N.Y.
Corning Glass Works, Chicago, Ill.
Crucible Steel Co. of America, Pittsburgh, Pa.
Custom Printing Company, Ferguson, Mo.
DeHavilland Aircraft of Canada Ltd., Downsview, Ont.
Dit-MCO, Inc., Kansas City, Mo.
Donner Division, Systron-Donner Corp., Concord, Calif.
Dorsett Electronics Laboratories, Inc., Norman, Okla.
Dynamic Research, Inc., Los Angeles, Calif.
The Eagle-Picher Co., St. Louis, Mo.
Electro-Mechanical Research, Inc., Sarasota, Fla., and Princeton, N.J.
Electronic Associates, Inc., New York, N.Y.
Electronic Wholesalers, Inc., Melbourne, Fla.
Emerson Electric Manufacturing Co., St. Louis, Mo.
Endenco Corporation, Los Angeles, Calif.
F. M. C. Corp., Buffalo, N.Y.
Fairchild Camera and Instrument Corp., Cable Division, Joplin, Mo.
Filtors, Inc., E. Northport LI., N.Y.
General Devices, Inc., Princeton, N.J.
Gulton Industries, Metuchen, N.J.
Harris Manufacturing Co., St. Louis, Mo.
Haynes Stellite Co., Chicago, Ill.
Hurletron, Inc., Control Products Division, Wheaton, Ill.
Interelectronics Corp., New York, N.Y.
Johns Manville Sales Corp., Chicago, Ill.
Walter Kidde and Co., Inc., Chicago, Ill.
Kollsman Instrument Co., Elmhurst, N.Y.
Leach Corp., San Marino, Calif.
Linde Co., Chicago, Ill.
Lockheed Propulsion Co., Redlands, Calif.
J. A. Maurer, Inc., Long Island City, N.Y.
D. B. Milliken Co., Arcadia, Calif.
M. B. Electronics, Div. of Textron Electronics, New Haven, Conn.
Minneapolis-Honeywell Regulator Co., Boston Division, Boston, Mass.

Minneapolis-Honeywell Regulator Co., Aeronautical Division, Minneapolis, Minn. (2 locations)
Missouri Metal Shaping Co., Overland, Mo.
National Car Rental, Sarasota, Fla.
National Water Lift Co., Kalamazoo, Mich.
Olin-Mathieson Chemical Corp., Winchester Western Div., Eastern Alton, Ill., and Baltimore, Md.
The Perkin-Elmer Corp., Norwalk, Conn.
Radioplane, Division of Northrop, Van Nuys, Calif.
Raymond Engineering Laboratory, Middleton, Conn.
Rock County National Bank, Janesville, Wis.
Schmelig Construction Co., St. Louis, Mo.
Selb Manufacturing Co., St. Louis, Mo.
Southwest Truck Body Co., St. Louis, Mo.
Tarco, Inc., Santa Monica, Calif.
Teleflex, Inc., Philadelphia, Pa.
Thiokol Chemical Corp., Elkton Div., New York, N.Y.
Thompson Ramo Wooldridge, Inc., Cleveland, Ohio
Titanium Metals Corp. of America, New York, N.Y.
Unidynamics, A Division of Universal Match Corp., St. Louis, Mo.
United Aerospace Div. of United Electrodynamics, Inc., Pasadena, Calif.
Waltham Precision Instrument Co., Inc., Waltham, Mass.

APPENDIX E

NASA PERSONNEL WHO PARTICIPATED IN PROJECT MERCURY

This appendix contains a listing of NASA personnel that contributed to the Mercury Project and represents the best effort possible to obtain a complete listing; however, it is known that some names are missing, such as people from the Langley Research Center. Those contributors whose names are missing are recognized as a group.

Ackerman, Sylvester J.
Actor, J. Paul
Adams, Robert S.
Adams, Ruth Ann
Adams, Walter I.
Adkins, James E., Jr.
Aiken, Donna S.
Aldrich, Arnold D.
Aldridge, Roy C.
Alexander, James D.
Alexander, Nancy C.
Alexander, W. Carter
Algranti, Annebell
Algranti, Joseph S.
Allaback, Wilber
Allen, Charlie C.
Allen, David J., Jr.
Allen, Elizabeth D.
Allen, Louis D.
Allen, Thomas H., Jr.
Allen, Vera J.
Allison, Howard J.
Anastos, Steve
Anderson, Donald W.
Appel, Margaret C.
Arabian, Donald B.
Arbic, Richard G.
Ard, Elizabeth H.
Armistead, Lucille B.
Armitage, Peter J.
Armstrong, Carol A.
Armstrong, Curtis S.
Armstrong, Dale E.
Armstrong, Geri
Armstrong, Lawrence D.
Armstrong, Stephen
Armstrong, William O.
Arnette, Sandra A.
Arnold, James P.
Arslanian, John G.
Arthur, James S.
Ashe, Gloria Jean
Ashley, Fancine
Askew, Abner N.
Assadourian, Arthur
Atamanchuk, Ivan J.
Atkins, Jones, Jr.
Augerson, William J.
Ault, John W., Jr.
Avery, John J., Jr.
Babola, Robert J.
Bailey, Charles L., Jr.
Bailey, E. Lou
Bailey, Frederick J., Jr.
Bailey, Glenn F.
Bailey, James W.
Bailey, John R.
Bailey, Norman R.
Bailey, Robert J.
Baillie, Richard F.
Baker, Ben R.
Baker, Robert L.
Balinas, Verby Lee
Balisky, Eileen M.
Ball, George D.
Ball, William R.
Ballas, Bebe B.
Banks, Harold H.
Banks, Judith Bower
Barker, Edward S.
Barker, Joseph T.
Barkley, Garland B.
Barnard, Jack
Barnes, Harold F.
Barnes, Lyndon S.
Barnett, James H., Jr.
Barney, Walter F.
Barrow, John M.
Barsky, Jerome
Barton, Ruth A.
Bates, James Richard
Battaglia, Harold F.
Battin, Richard B.
Baum, Herman
Beach, Mary
Beane, Patricia B.
Beatty, Lamarr D.
Beck, Harold D.
Beck, Jeanette H.
Becker, Robert W.
Beckman, David A.
Beddingfield, Samuel T.
Beerman, Rebecca
Beers, Charles A.
Beeson, Willirie M.
Begnaud, Ellis L.
Behuncik, John A.
Bell, Anita S.
Bell, Daniel M.
Bell, John
Bell, Larry E.
Bell, Lawrence Wilson
Bender, David
Bennett, James A.
Bennett, Marvin L.
Benson, Donald D.
Benson, Richard B., Jr.
Bergman, Clayton M.
Bergtholdt, Charles P. I.
Bernardin, Robert M.
Berney, Kathryn C.
Bernstein, Ruth
Berry, Dr. Charles A.
Berry, Ronald Lewis
Bertram, Emil P.
Bias, A. Dell
Biggs, Charles
Billingham, John
Bilodeau, James W.
Bishop, Halley M.
Bivens, Virginia T.
Black, Dugald O.
Black, Thomas
Blackwood, Howard F., Jr.
Blakemore, Thomas L., Jr.
Blance, Lucille

Blanchard, Robert S.
Blanco, J. A.
Bland, William M., Jr.
Blankenbaker, Lloyd
Blanton, Fred B.
Blanton, Lelia M.
Blase, William A.
Blevins, Edwin K.
Blue, Barbara
Blume, Donald D.
Blumentritt, James
Bobik, Joseph M.
Bobo, Leonard F.
Bobola, Robert E.
Bodmer, James E.
Bogart, William M.
Boler, L. Joseph
Bond, Aleck C.
Bond, Arthur C., Jr.
Bone, Eric Dale
Bone, James E.
Bonham, Robert L., Jr.
Booher, Cletis R.
Boozer, Becky
Bopp, Marlin Leroy
Borgman, Elsa M.
Borgman, Richard R.
Boring, James W.
Bostick, Jerry C.
Bostick, Linda T.
Bost, James E.
Boswick, Guy W., Jr.
Bosworth, George L.
Bothmer, Clyde B.
Bott, Barbara E.
Bowen, Maureen E.
Bowman, Melvin D.
Bowman, Robert A.
Boyce, William M.
Boyd, Robert
Boydston, Donald L.
Boykin, Wilbur R.
Boynton, John H.
Bracey, Gerald W.
Bradford, Halley, Jr.
Bradford, William C.
Bradley, Raymond H.
Brady, James T.
Branscomb, Albert L., Jr.
Braquet, Louto J., Jr.
Braslow, Myrtle S.
Braun, Alois, Jr.
Braun, Jane D.
Bray, Donald O.
Bray, Julia F.
Brent, Mary Sue
Brenton, Westley H.
Brewer, Mary H.
Brewer, Gerald W.
Brickel, James R.
Briggs, Thomas
Brigham, Richens E.
Brinkman, John
Britt, Leon E.
Britt, Malcolm V.
Broadwell, James D.
Brock, Eugene H.
Broman, Roseanna A.
Brooks, Laura A.
Brooks, Melvin F.
Brooks, Russell G.
Broome, Douglas R.
Broughton, Thomas G., Jr.
Broussard, Marcus J.
Brown, Beverly P.
Brown, Constance G.
Brown, David
Brown, Doris J.
Brown, James T.
Brown, J. Robert
Brown, Richard L., Sr.
Brown, Shirley A.
Brown, Timothy Murphy
Brown, Woodridge C.
Browne, Robert A.
Brownstein, Herbert
Bruce, David F.
Bruce, D. Jean K.
Bruemmer, Carline M.
Brumberg, Dolores
Brumberg, Paul G.
Brums, Dr. Rudolf H.
Bryan, Catherine C.
Bryan, Comer B., Jr.
Bryan, Doris E.
Bryan, Frank G.
Bryant, George K.
Bryant, John P.
Bryant, William C.
Byrne, Frank
Buck, Ann L.
Buck, Kenneth J.
Buckley, Charles L., Jr.
Buckley, Robert Hunt
Buller, Elmer H.
Bullock, Edward C.
Burbank, LaRue W.
Burbank, Paige
Burge, Betty Shelton
Burgeson, Frances
Burgess, James A.
Burgh, Anabel
Burke, Richard J.
Burkett, James E.
Burton, Mary Shepherd
Burton, Walter G., Jr.
Busch, Arthur M.
Bush, William H., Jr.
Bushong, Wilton E.
Butler, Walter Emmett
Butler, Wilbur E.
Butterworth, Ronald C.
Byer, David L.
Byrnes, Martin A., Jr.
Byrum, Doris
Cagle, Jewel J.
Cain, James L., Jr.
Caldwell, Ernest S.
Call, Dale W.
Callaway, Shirley L.
Calloway, Willis G.
Calonna, Richard
Calvillo, Efren
Camady, John E.
Cameron, Winifred S.
Camp, Howard C.
Campagna, G. Edward
Campbell, Jack A.
Campbell, Janet S.
Campbell, Jewel T.
Campbell, Marianne C.
Campbell, Melvin E.
Cannon, William L.
Canright, Richard B.
Capo, Raymond V.
Capps, Charles H.
Carbaugh, James P.
Carley, Richard R.
Carlson, Robert L.
Carmines, Sidney D.
Carpenter, Edward A.
Carpenter, Malcom S.
Carr, Ronald
Carroll, James B.
Carson, June M.
Carson, Thomas M.
Carter, Dan S., Jr.
Carter, Elmer J., Jr.
Carter, Nancy K.
Carter, Rosemary
Carter, Thomas F., Jr.
Case, Darlene D.
Casey, Francis W., Jr.
Casey, L. O.
Cash, Wanda
Cashion, Kenneth D.
Cason, Barbara L.
Cassels, George A.
Cassetti, Marlowe D.
Catloth, Mary M.
Catron, Dora B.
Catterson, Dr. Duane
Cerven, James C.
Cessac, Robert J.
Chalkley, Lois G.
Chamberlin, James A.
Chambers, Jerome P.
Chambers, Milton
Chambers, Thomas V.
Chandler, Amie F.

Chandler, William
Chandler, William O., Jr.
Chaplick, Robert G.
Chapman, Arthur C.
Chaput, Paul Theodore
Charlesworth, Clifford E.
Charters, Richard E.
Chase, William Raymond
Chauvin, Leo T.
Chauvin, Theodore T.
Cheatham, Donald C.
Chicoine, Ervin L.
Childers, Frank M.
Childs, Dewey L., Jr.
Chilton, Robert G.
Chitwood, Willie N.
Chop, Al
Christman, Laurence M.
Christopher, Kenneth W.
Christopher, Maxwell G.
Claffey, Patricia L.
Clark, Bobbie W.
Clark, Howard E.
Clark, Robert H.
Clark, Stewart
Clarke, J. C.
Clary, Charles D.
Clason, Robert M.
Clay, Russell P.
Clayton, Elden G.
Clayton, Mance S.
Clemence, Raymond R., Jr.
Clemens, Joan
Clements, Henry E.
Clements, James R.
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Clever, Edwin C.
Clickner, Russel E., Jr.
Cline, Jack S.
Clinton, Thomas S.
Coats, Boyd R.
Cochran, Harold W.
Cobb, James B.
Coble, Bill M.
Cockerham, Earl D.
Coe, Frank S., III
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Cofield, John T.
Cohen, Jack
Cohen, Robert
Cohen, William
Cohn, Stanley H.
Cole, Charles W.
Coleman, Donald J.
Coleman, Mary R.
Coler, Charles
Coley, Patsy M.
Colleps, Dorothy
Collier, Frank
Collins, Curtis C.
Collins, Daniel D.
Collins, Dorothy
Collins, Harold G.
Collins, Walter E.
Collner, Joseph D.
Collura, Salvadore J.
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Comer, Howard E., Jr.
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Conley, James O.
Conlon, John W.
Conn, W. Jane
Connelly, Russell
Conner, Alfred L.
Conneway, Fred D.
Conrad, Ralph
Contella, Janice E.
Contella, Milton C.
Conversano, Andrew
Cooke, Arthur M.
Cooper, James
Cooper, LeRoy G., Jr.
Coppedge, Frank O.
Corbett, Bailey L., Jr.
Corbett, Gloria C.
Corbett, Wayne W.
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Corey, Donna
Cormany, Charles A.
Cornelius, Paul T.
Corn, Graydon F.
Correale, James V.
Coston, Charles L.
Cottee, Gatha F.
Cotton, Paul E.
Cour-Palais, Burton G.
Covington, Clarke
Covington, Ozro M.
Cowan, John R.
Cox, Flo
Cox, Roy L.
Cox, William M.
Craighead, Paul T.
Crain, Doris J.
Crain, Josephine C.
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Crane, Luther L.
Craven, John P.
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Creighton, Henry C.
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Crichton, Frank M.
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Critzos, Chris C.
Critzos, O. Constance
Crone, Norman A.
Crow, Frank G.
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Crutcher, Thomas M.
Crowell, James L.
Crunk, Henry G., Jr.
Cumberworth, Gloria E.
Cunningham, Monte T.
Curlee, Harvey L., Jr.
Currie, C. Elsie
Curry, T. Bradley, Jr.
Dabbs, John H.
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Dalke, Edgar A.
Dall, C. E.
Dalton, Danny A.
Daniel, Tom H., Jr.
Daniels, Patricia A.
Dasilva, Anibal J.
Davenport, William H.
Davidson, William L.
Davids, Irving
Davis, Lawrence
Davis, Mary S.
Davis, Walter A.
Dawn, Frederic S.
Day, Joe L.
Day, Richard E.
Davidson, John C.
Davis, Leo P.
Davis, Philip W.
De La Portilla, Martha
De La Rosa, Herman J.
Dealy, Kathleen R.
Deagro, Richard P.
Dean, Kenneth J.
Deans, Philip M.
Deason, William P.
Debus, Dr. Kurt H.
Decamp, Royal D.
Decker, William E.
Deering, Ross E.
Deese, James H.
Deluca, Louis A.
Dement, Marvin Ernest
Deming, James E.
Dennis, William R.
Der Bing, William
Deshields, Shirley R.
Dessens, Charles Wayne
Devine, Robert G.
Devore, Phoncille
Dewell, William G.
Diaz, Rodolfo A.
Dibella, Josephine
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Dickinson, William B.
Dickson, Ernest L.
Dietlein, Lawrence F.
Dills, Judith
Dingman, Reece
Disher, John H.
Dittmer, Dr. Daniel

Divone, Louis V.
Dixon, Ruth H.
Dobbs, John H.
Dobbs, Nancy Lynn
Dodd, Richard P.
Dodson, Joe W.
Donadio, Sullivan C.
Donaway, A. Inez
Donegan, James J., Jr.
Donnelly, Paul C.
D'Onofrio, Gus A.
Dotts, Homer
Dougherty, Raymond
Douglas, William K.
Dowling, Carlise W.
Downs, James E.
Doyle, Eugene L.
Driskill, Billie R.
Driver, Mary H.
Driver, W. B.
Drone, Benjamin R.
Drummond, William E.
Dryden, Dr. Hugh L.
Duck, Kenneth J.
Dudley, Brenda T.
Dudley, Nan Goode
Duggan, Orton L.
Duggins, Alberta D.
Dugoff, Leon
Dukes, Francis B.
Dumay, William Henry
Dungan, Larry J.
Dunning, Robert W.
Dunseith, Lynwood C.
Dupree, B.
Duret, Eugene L.
Durocher, Charlotte
Durrett, William Reuben
Dutton, Richard E.
Dyal, Lawrence E.
Easter, William B.
Eaton, Albert J.
Eckert, Charles J.
Eddington, Chester E.
Eddy, B. Eugene
Edelberg, Robert E.
Edmonds, Eugene
Edmondson, Florence M.
Edmondson, F. William
Edrington, John W., II
Edwards, Elwood S.
Edwards, Kermit A.
Edwards, Marion D., Jr.
Edwards, Thomas M.
Eiband, A. Martin
Eicher, Grace E.
Eickmeier, Alfred B.
Eickmeier, Lester R., Jr.
Eik-Nes, Kristen B. D.
Ekeroot, Stig
Elk, Jimmy R.
Eller, Joseph M.
Ellis, Anna Whiteside
Ellis, Wilbert Edward
Elms, Charles P.
Emily, Jerry
Enders, John H.
Enderson, Laurence W., Jr.
Engel, Jerome N.
Engvall, John L.
Enlow, Roger D.
Ensley, Betty M.
Epperly, James W.
Epperly, Virginia H.
Erb, Bryan R.
Ernull, Robert E.
Ertel, Ivan
Ertl, Emily M.
Erwin, Sue R.
Esenwein, George F.
Evans, Norma M.
Everline, Robert T.
Ewart, David D.
Ezell, Melvin
Faber, Stanley
Fagan, John E.
Faget, Maxime A.
Fahlstrom, Paul G.
Fairchild, John J., Jr.
Falbey, Iola M.
Fannin, Lionel E.
Farley, John S.
Farmer, Norman B.
Farrior, Leona
Faulk, Ryan J., Jr.
Feddersen, William E.
Fellows, Mary E.
Fergerson, Shirley J.
Ferguson, Barbara
Ferguson, Clarence
Ferguson, Gordon M.
Ferguson, Helen L.
Ferguson, Nellie G.
Ferguson, Paul O.
Ferguson, Richard B.
Fernandez, Joseph
Ferrall, Gordon B.
Fielder, Dennis E.
Fields, E. M.
Filipowski, John J.
Filley, Charles C.
Filley, Charles W.
Finn, James E.
Finley, Robert P.
Fiorentino, Kelly A.
Firth, Ruth R.
Fisher Emmitt E.
Fisher, Frankie
Fisher, Jackie L.
Fisher, Lewis R.
Fisher, Vernon E.
Fitch, David C.
Fitzgerald, Evelyn B.
Fitzgerald, Hugh D.
Fitzgerald, James J.
Fitzgerald, Norma B.
Fitzkee, Archie L.
Flanagan, James R.
Fletcher, Calvin B.
Flournoy, Walter
Foley, Helen N.
Folkes, Doris P.
Folkes, William G.
Folwell, Paul A., II
Forquer, Madeline H.
Foster, Galloway B., Jr.
Foster, Mary P.
Foster, Norman G.
Foster, Richard W.
Fout, Blanche H.
Fowler, James W.
Fowler, Joe
Fowler, John F.
Frandsen, Niels P.
Franklin, Arthur E.
Franklin, Darold Bernard
Franklin, George C.
Franklin, Marion R., Jr.
Frank, M. P.
Frasier, Cline W.
Frazier, Jesse C.
Frazier, Thomas W.
Frazier, Violet M.
Freedman, Gilbert M.
Freeman, Gil
Freeman, James R.
French, Burrell O.
French, Harold N.
French, John C.
Frere, John A.
Fridge, Ernest Marion III
Friloux, Henry J., Jr.
Frye, C. Lawrence
Fugler, Bartley A.
Fuller, Carolee Boykin
Fulmer, Otis, Jr.
Funderburg, Paul E.
Fulton, Jeanne S.
Fultz, Bennet M.
Funk, J.
Funkhouser, Robert B.
Gadow, Charles G.
Gaffney, Patrick S.
Galezowski, Stanley H.
Gallagher, Thomas F.
Gallagher, Virginia M.
Galloway, Sarah Helms
Gambill, Ilona G.
Gammon, Frank M.
Gans, Barbara

Gant, William L.
Gantz, B. R.
Garbacz, Michael
Gardner, Benson B.
Gardner, Virgil F., Jr.
Garino, Joe D., Jr.
Garland, Benjamine J.
Garner, Charles W.
Garner, Iris A.
Garrett, Arnold W.
Garrett, Crayton
Garrison, John C., Jr.
Garza, Alfred M.
Gaster, Barbara J.
Gaster, Jeanne
Gatchell, Herbert L.
Gates, Sally D.
Gaughan, David
Geddes, Leslie A.
Geier, Douglas J.
Geier, Robert
Geisler, Phyllis A.
Geller, Samuel
Gerber, David L.
Gerstle, John E., Jr.
Gfeller, Virgil A.
Gibbons, Howard
Gibbons, Jim L.
Gibbons, Thomas F.
Gibson, Pearl C.
Gibson, Thomas F.
Gifford, Burton M.
Giles, June A.
Gilkey, John E.
Gillespie, Ben
Gillespie, Warren
Gill, William L.
Gills, Sidney
Gilruth, Robert R.
Glenn, John H., Jr.
Glenny, Virginia T.
Glover, Kenneth E.
Glynn, Francis I. P.
Goad, John W.
Goldcamp, Thomas F.
Goldenbaum, David M.
Goldsmith, Verl A.
Goldstein, Stan
Gonzalez, Jose L.
Goodman, Jerry R.
Goodson, Adolph
Goodwin, Burney H.
Goodwin, Haskell J.
Goodwin, Mary Ann
Gordon, Bob
Gordon, Donald L.
Gorman, Robert E.
Gorman, T. P.
Goslee, John W.
Gottuso, Vincent J.

Grace, Thomas J.
Grafe, Robert L.
Graffe, Robert T.
Graham, Glenn W.
Graham, John B., Jr.
Graham, Ralph E.
Graham, William
Grames, H. Jack
Grammer, Donald B.
Grana, David C.
Grandfield, Allen L.
Granger, Harold E.
Grant, Charles M., Jr.
Graves, Barry
Gray, Wilbur H.
Green, Don
Green, M. Linda
Green, Robert N.
Greene, L. Annette
Greene, Merton D.
Greenfield, Sarah F.
Greenfield, Terry B.
Greenglass, Bertram
Gregory, Donald T.
Greil, Karl F.
Griffin, Bobby G.
Griffin, Charles H.
Griffin, Oscar F.
Griffin, Wesley W.
Grimes, Walter E.
Griffis, Carl L.
Griffith, Jack A.
Grimbly, Samuel C.
Grimes, Walter E.
Grimwood, Jim
Grissom, Virgil I.
Gross, Bernard D.
Gross, Harry G.
Gross, Stanley A.
Grow, R. Bruce
Grow, Emily H.
Gruene, Dr. Hans F.
Guice, Mildred L.
Guidry, Mark A., Jr.
Gunnersen, Alf S., Jr.
Gundersen, Robert T.
Gurley, John R., Jr.
Guthrie, Alfred E.
Guthrie, George C.
Guy, Judith
Guy, Walter W.
Gwinn, Ralph T.
Habron, Betty H.
Hackworth, Robie
Hagan, Mason
Hager, Mary C.
Hagood, Martin L.
Hairston, Ernest
Hall, Charles J.
Hall, Eldon W.

Hall, Dr. Harvey
Hall, James L.
Hall, John B., Jr.
Hamblett, Edward B., Jr.
Hamby, William H.
Hammack, Jerome B.
Hammer, Louis
Hammersmith, John
Hammock, David M.
Hammond, James P.
Hammond, Joseph W., Jr.
Hampton, Harold D.
Hand, Arthur A.
Haney, Francis J.
Hannigan, James E.
Hansen, Paul
Hardin, Donald W.
Hardin, William G.
Hardwin, William B.
Hargrave, Claude S.
Harper, Richard H.
Harper, Velda B.
Harrelson, Patsy Ann
Harrin, Eziaslav N.
Harrington, Nancy J.
Harrington, Robert D.
Harris, Carl B.
Harris, Emory F.
Harris, Fred A.
Harris, George, Jr.
Harris, Janet E.
Harris, Joe
Harris, John B.
Harris, Russell
Harris, Sylvia
Harrison, Floyd L.
Harrison, Margaret R.
Harrison, Rena B.
Hart, Robert F.
Hartlein, John
Hartung, Jack B.
Harvey, Gordon W.
Hassett, Raymond
Hathcock, Juanita
Hatton, George
Haugew, Kenneth R.
Havenstein, Paul L.
Hawk, Willard E.
Hawkins, George M., Jr.
Hawkins, I. Edna
Hayes, Leroy
Hayes, Leslie E.
Hayes, Neisel M.
Hayes, William C.
Haynes, James F.
Hays, Edward L.
Hays, Robert D.
Hearn, Chase P.
Heathcote, Dennis E., Jr.
Heather, Gerald D.

Heaton, Sydney N.
Heberlig, Jack C.
Heckelmoser, Charles J.
Heetderks, H. Richard
Hegwood, Robert B.
Hegwood, Sarah E.
Hehn, Joseph A.
Heidler, Homer F., Jr.
Heinlein, Marjorie J.
Heiser, Robert F.
Heitman, Erwin W.
Heller, Niles R.
Heller, Robert H.
Helterbran, Irene J.
Henderson, Grady P.
Henderson, Joseph D.
Henderson, Melba S.
Henderson, Sharon
Henderson, Thomas Harder
Hendrickson, Douglas R.
Henry, James P.
Hensley, James B.
Henson, Kirby
Herbert, Frank J.
Herbert, Herbert L.
Herring, Hugh S.
Herring, Robert W., Jr.
Herrman, Dorothy M.
Hershey, Theodore P.
Hessberg, Rufus
Hesson, Robert K.
Hester, Randolph H.
Hettinger, Fredric L.
Hibbs, William C.
Hicks, Claiborne R., Jr.
Hicks, Wilburn
Hiers, Harry K.
Hiers, James R.
Higgins, Rodney F.
Hightower, Libbie L.
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Hill, Elizabeth J.
Hill, Harold H.
Hill, Lawrence E.
Hill, Ralph E.
Hill, Norma L.
Hiller, Mary Jo
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Hinds, James J.
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Hinson, James K.
Hirst, Carolyn W.
Histand, Dorothy B.
Hjornevik, Wesley L.
Hock, Catherine
Hodge, B. Leon
Hodge, John D.
Hoff, Orlo
Hoffman, Ernest E.
Hoffman, John P.
Hoffman, Raphael F.
Hogan, Edward J.
Hogg, Carolyn
Hoggard, Walter C.
Hoisington, Jerry E.
Holden, Joan S.
Holland, John
Hollingsworth, Miles M.
Holloway, Tommy W.
Holman, Richard A.
Holmgren, Herbert L.
Holt, Richard L.
Holt, Talmadge W.
Holt, Thomas E.
Honicker, Candy B.
Hoover, Ida B.
Hoover, Luther L.
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Hopton, Conrad E.
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Horstmann, Robert W.
Horton, Caroline L.
Horton, Elmer A.
Horton, Eugene E., Jr.
Hough, Agnes S.
House, Edward G.
Howard, Carole A.
Howard, Lalah
Howell, Joseph J.
Howerton, John C.
Huffman, Bobby R.
Huffstetler, William J., Jr.
Huggins, Matilda M.
Hughes, Carroll V.
Hughes, Donald F.
Hughes, George H.
Hughes, Helen W.
Hughes, James
Hughes, Virginia B.
Hull, Anne L.
Humphrey, Francis S.
Humphrey, John T.
Humphrey, William R.
Hungall, Robert G.
Hunt, Gerald L.
Hunt, Hal
Hunt, Phyllis S.
Hunt, Shirley A.
Hunter, Daniel S.
Hurlbert, Alma Adams
Huss, Carl R.
Hutchens, Rachel B.
Hutchinson, Neil Barrie
Hux, Lillie R.
Hyle, Charles T.
Idomir, Kenneth
Incerto, Donald J.
Ingalls, Charles W., III
Ingels, Claude
Ireland, Fred H.
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Isley, William C.
Jaap, Fred S.
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Jackson, Bruce G.
Jackson, Carmault B.
Jackson, James
Jackson, Margaret M.
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Jacobsen, Stanley
Jafferis, William
Jakir, N. S.
James, Frances L.
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Janokaitis, John, Jr.
Jarrett, Jaye C.
Jenke, Richard K.
Jenkins, Morris V.
Jenness, Martin D.
Jenness, Phyllis T.
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Johnson, Bryant L.
Johnson, Caldwell C., Jr.
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Johnson, Carol L.
Johnson, Edward T.
Johnson, Edwin Cyril
Johnson, Elizabeth P.
Johnson, Francis, Jr.
Johnson, Harold I.
Johnson, Jane
Johnson, Jeanne
Johnson, John H.
Johnson, Kenneth L.
Johnson, R. E.
Johnson, Robert
Johnson, Suellyn
Johnson, Virginia W.
Johnson, W. Kemble
Johnston, Richard S.
Jollay, James H.
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Jones, Jack A.
Jones, Jeremy B.
Jones, Rosemary
Jones, Sidney C., Jr.
Jones, Z. Vance
Jordan, Adaran B.
Jordan, Carolyn
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Jordan, Sandy

Jorolan, Albert E.
Jow, Josephine
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Kaplet, Ruth P.
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Karberg, Elmer H.
Karick, Francis S.
Kase, Louise E.
Katchmore, Betty R.
Kaufman, Louis L.
Kavanaugh, Walter W.
Keathley, William H.
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Keck, Frank
Keegan, Evelyn P.
Keene, Bernard A.
Keene, Lester F.
Keffer, Clarence O.
Kehl, Robert P., Jr.
Keil, Esther
Keith, Ernest L.
Keller, James A.
Keller, Leonard
Kelley, William A.
Kelly, Ferdinand G.
Kelly, James R.
Kelly, Keith V.
Kelly, William R.
Kempainen, Leona L.
Kendall, Joseph
Kenerly, Barney G.
Kennedy, Daniel C.
Kennedy, E. Frances
Kennedy, Richard C.
Kent, Henri J.
Kent, Thomas, Jr.
Kerns, Carl Wesley
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Kiker, John W.
Kilby, Ann B.
Kilgallen, Raymond F.
Killmer, George F., Jr.
Kinard, Martha Rebecca
Kincaide, Patricia N.
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King, Fred L.
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Kinnaird, Oxley T.
Kinzler, Jack A.
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Kirkpatrick, James C.
Klabosh, Charles
Kleinknecht, Kenneth S.
Kline, Robert T.
Klockmann, Robert K.
Kloetzer, Paul H.
Knapp, Joan R.
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Knell, Kenneth E.
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Knothe, Dr. Adolf H.
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Koons, Wayne E.
Koos, Richard H.
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Koplin, Joyce H.
Kornegay, John H. F.
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Kosmo, Joseph J., Jr.
Koutsandreas, Peter
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Kraft, Christopher C., Jr.
Krambo, Betty Jane
Kramer, Paul Clinton
Kranz, Eugene F.
Krasnican, Milan J.
Krause, Marilyn H.
Kreske, Doris S.
Kreske, Joseph
Krpec, Charles
Krueger, Mary L.
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Kugel, Harold
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Lackey, David J.
Labutka, Joseph R.
Lail, Margaret H.
Lafleur, Walter
Lamache, Andy
Lamay, Harold J.
Lamey, William C.
Lambert, Clarence C.
Lamonte, Robert J.
Lane, James Howard
Langford, John H.
Langosh, Eva K.
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Lautzenheiser, Ernest G.
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Lawrence, Bernard W.
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Lawrence, Thelma
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Layton, Norma
Lea, Robert N.
Leach, Barney H.
Leach, Diane E.
Leatherman, Pattie S.
Leblanc, Curtis
Lechter, Sidney
Ledbetter, Otis W.
Lee, Arc F.
Lee, John B.
Lee, Lewis H.
Lee, Mark T., Jr.
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Leech, Ted B.
Leech, Theodore
Leezer, Robert
Legg, Ruby L.
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Lem, John D., Jr.
Lemay, Harold J.
Lemmon, Carl L.
Lemons, Eddie J.
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Leonard, Pauline O.
Leonard, Sylvia
Leopold, Louis
Leshko, John E.
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Leslie, Claude E.
Lewis, Charles R.
Lewis, James L.
Lewis, John H., Jr.
Lewis, Louise B.
Lewis, Martha Camp
Liccini, Luke L.
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Liddy, Joan M.
Liddell, John J.
Liebau, Charles R.
Lightsey, Alfred E.
Lill, Joseph C.
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Lindeman, James L.
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Lineberry, Edgar C., Jr.
Link, Dr. Mae
Link, Patricia D.
Linn, Daniel
Linn, Kathryn E.
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Lishman, Penny P.
Little, George Watkins
Littlehales, Mary C.

Lizcano, Ester R.
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Lobb, John D., Jr.
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Lockard, Miles L.
Locke, Vandiver
Logan, Harry K.
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Long, James L.
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Loomis, Leonard W.
Lopez, Mary F.
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Lord, Douglas R.
Lord, Harold W.
Lorenzen, Gerald A.
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Lovejoy, William L.
Low, George M.
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Lowe, John B.
Lowe, Joyce T.
Lowe, Nancy C.
Lowman, Dr. Paul D.
Luker, Nephi M.
Lowry, Bryce W.
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Lucas, Dick Manton
Lucas, Majorie Frye
Lucas, Paul V.
Lucas, William A.
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Lunney, Glynn S.
Lusby, George W.
Lutz, Charles C.
Lytle, Carroll D.
MacDougall, George F., Jr.
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Mahone, Mildred A.
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Maloney, Philip R.
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Mann, Everette S.
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Mansberg, Gerald
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Marak, Ralph J.
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Marbach, James R.
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Maronde, Del R.
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Marsh, Louise K.
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Martinkovic, Carol Ann
Martin, Shell E.
Martin, Thomas E.
Martin, Virginia A.
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McCafferty, Riley D.
McCann, Robert R.
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McCutcheon, Ernest P.
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McKay, Scott S., II
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McCollum, Marcia H.
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Moser, Robert E., Jr.
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Odenwalder, Edgar P., Jr.
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Ohnesorge, Thomas E.
Okand, Kazuo Fred
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O'Neill, James E.
Orman, Donald L.
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Ould, Wallace
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Owen, Robert
Owens, Marion C.
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Packham, Leonard E.
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Peake, Robert L.
Pearce, Fred T., Jr.
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Pendley, David D.
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Pennington, John B.
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Peterson, Jean L.
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Peytonel, Milton
Pfau, Robert W.
Pfeiffer, William A.
Phelps, Ellsworth, Jr.
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Phillips, Emmett
Phillips, Franklyn W.
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Phlieger, Graydon A., Jr.
Pickett, Andrew J.
Picos, Marvin N.
Pierce, Bobby J.
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Pinson, Vestor L.
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Plunkett, Robert A.
Pollard, Dr. Richard
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Poole, Richard B.
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Pordon, Ellen
Porten, Rita
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Powell, Alice J.
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Preston, G. Merritt
Preston, Richard K.
Price, Donald F.
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Prim, James W., III
Prince, Robert N.
Prine, Elbert
Privette, James E., III
Proctor, LeRoy, Jr.
Proferes, Constantine Gus
Prothman, Lillian V.
Purser, Paul E.
Quarterman, Wallace L.
Quayle, Howard G.
Quinn, Edith O.
Quinn, Joseph R.
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Rainwater, Wallis C.
Raley, Eldon O.
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Raney, James L.
Rann, John A.
Rapp, Rita M.
Rasberry, James R.
Rasco, Woodrow W.
Rasnick, Thomas W.
Rathburn, Donald Ford
Rayfield, John F.
Razwich, Irene M.
Ream, Harold E.
Reardon, Lester D.
Reaves, Ollie M.
Redfield, Marvin
Reed, Gene A.
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Reed, Lettie B.
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Remson, O. James
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Revels, Antoinette P.
Rexroad, Eva O.
Reyer, Bobby G.
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Richard, Louie Gene
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Rideout, Janet H.
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Riegert, Daniel
Rigell, Ison A.
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Rippstein, Wayland J., Jr.
Risler, Welby T.
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Roach, Jones W.
Roach, Leo O., Jr.
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Robbins, Rosaleigh M.
Roberts, Benjamin H.
Roberts, Eugene
Roberts, Glenn B.
Roberts, John E., Jr.
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Robertson, Duane E.
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Robins, Joyce F.
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Robinson, Glover H.
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Rogers, Charlie E., Jr.
Rogers, Christine M.
Rogers, Ernest R.
Rogers, William F.
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Rose, Rodney G.
Rosen, Milton W.
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Rosenberry, John
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Ross, Mildred C.
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Roth, Carl E.
Roth, Janet S.
Roth, John A.
Rouiller, Charles A., Jr.
Rouse, Carroll R.
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Rowell, Steiner L.
Rudolph, Pauline B.
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Ruff, George E.
Ruggeri, Ann L.
Russell, Howard
Russell, J. B.
Russell, Libreda B.
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Rutland, James M.
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Saecker, Albert J.
Saieg, Richard L.
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Salyer, Walter D.
Salzberg, Irving M.
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Samonski, Joan P.
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Sandige, Carolyn W.
Sandridge, Richard A.
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Saucer, Dr. Rayford T.
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Saunders, Nannie L.
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Sawyer, Diane F.
Sawyer, O. McCoy, Jr.
Sawyer, Ralph S.
Sayers, Robert
Sayler, J. O.
Schaefer, Lola S.
Schaibley, John R.
Scheetz, Carlton F.
Scherer, Harris F., Jr.
Scheuerman, Hugo P.
Scheurmann, Henry
Schiesser, Emil R.
Schiller, Barbara A.
Schirra, Walter M., Jr.
Schisser, Glenna
Schler, Morton
Schlottman, Paul W., Jr.
Schmidt, Richard A.
Schmitt, Arthur L.
Schmitt, Joe W.
Schnarte, Dave
Schneider, Harold
Schnell, Doran E.
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Schoch, Robert H.
Schuiling, Roelof L.
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Schultz, Sandra C.
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Schulze, Joan
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Schwartz, Daniel E.
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Scott, Edwin C.
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Scrivener, Nina O.
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Seals, Marie M.
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Segota, Peter
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Seille, Mary A.
Selby, LeRoy, Jr.
Seligman, Margo S.
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Shankles, Thyra K.
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Sharma, Herman S.
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Shinkle, Frank J.
Shirk, Nancy M.
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Shoaf, Harry C.
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Shrum, Janet A.
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Simmons, Jan
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Simpson, Shirley
Singer, Herbert
Sink, James A.
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Sloan, James E.
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Smead, Wilbur H.
Smith, Alva E.
Smith, Camilla M.
Smith, Charlotte R.
Smith, Dorothy P.
Smith, Earl
Smith, George B.
Smith, Henry A.
Smith, Leona G.
Smith, Norman F.
Smith, Richard F.
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Smith, Wilma
Smitt, Joseph
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Snead, Wilbur H.
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Snyder, Richard G.
Sobel, Donald
Sobik, Joseph M.
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Soulant, Matthew R., Jr.
Southers, Raymond C.
Spann, Robert L.
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Stoffel, Bernard L.
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Stout, William H.
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Strauss, Eugene J.
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Sumner, Kenneth
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Walker, Vivian
Wallace, Hugh O.
Waller, Barbara E.
Wallis, Robert J.
Walliser, Sylvan A.
Walsh, Leo F.
Walters, Ernest E.
Walters, Louise H.
Walters, William H., Jr.
Walton, Thomas S.
Walz, Joseph E.
Wanczyk, Eleanore
Waranch, Myer
Ward, George L.
Ward, Welby G.
Warnock, Charles F.
Warnock, James M.
Warren, Carlos S.
Warren, James W.
Warren, Lawrence
Wasel, Robert A.
Waters, John G.
Watkins, Edith N.
Watkins, Julia R.
Watson, Riley A.
Watt, John D.
Watts, George A.
Waugh, Merle G.
Webb, Dalton D.
Webb, James E.
Webster, George I.
Wedding, Michael A.
Weedon, Jack Sanford
Weinberger, Robert A.
Weinert, Robert
Weining, Roger F.
Welhan, Alex
Wells, James L., Jr.
Welly, Charles E.
West, Edward L.
West, Julian
West, Walter M., Jr.
Westbrook, Samuel S., Jr.
Westerlage, Lois R.
Westervelt, Maurice A.
Weston, Kenneth C.
Westphal, Ralph L.
Wetmore, Warren C.
Wetzel, Waunita D.
Whalen, John E.
Whatley, Billy G.
Wheeler, Andrew E.
Wheeler, William P.
Wheelwright, Charles D.
Whisenant, Elmo R.
Whitaker, Paul R., Jr.
Whitbeck, Philip
White, James R.
White, Robert
White, Ted A.
Whitehurst, Herman D.
Whiteman, Lynn R.
Whiteside, Carl A.
Whiting, Donald F.
Whitney, Ernest G.
Wible, Veronica A.
Wiggins, Judy
Wikstrom, Harold
Wiley, Alfred N., Jr.
Wilfert, Donald F.
Wilhelm, John R.
Wilkerson, Alex.
Wilkes, T. Marshall
Wilkinson, Reuben L.
Willadson, Richard D.
Williams, David C.
Williams, Elburta B.
Williams, Foster T., III

Williams, Grady F.
Williams, Jack H.
Williams, John Joseph
Williams, John T.
Williams, Joseph B.
Williams, Lawrence G.
Williams, Paul F.
Williams, Richard
Williams, Rose T.
Williams, Thomas N.
Williams, Walter C.
Williams, Wiley Edward
Willis, William E., Jr.
Wilson, Almeda P.
Wilson, Anne F.
Wilson, B. M.
Wilson, James M.
Wilson, Terry L.
Wilson, William T.
Windler, Milton L.
Winn, Grace
Winnette, Walter M.
Winterhalter, David L., Sr.
Winters, James G., Jr.
Wirhan, Nelson R.
Wirman, Nelson R.
Wise, John P.
Wisniewski, Richard J.
Witherington, Guy N.
Wobig, Orrin A.
Woldorff, Leon
Wolfe, Gayle N.
Wolfer, M. Ernestine
Wolhart, Walter D.
Wolman, Dr. William W.
Womack, William D.
Womick, Otto
Wood, Bruce M.
Wood, H. W.
Wood, Sandra
Wood, Wilfred
Woodling, Carroll H.
Woodman, Ray S.
Woodruff, James W.
Woodsmall, Charline W.
Woodward, Charles F.
Woodyard, Charles E.
Woods, Donald J.
Woods, Gary J.
Woods, Thomas F.
Woodyard, Jean M.
Worf, Dr. Douglas L.
Workman, Bob
Wright, David S.
Wright, William W.
Wrightsman, Harold E.
Yannotta, Lucille N.
Yarbrough, Alvie E.
Yates, Sandra S.
Yenni, Kenneth R.
Yodzis, Charles W.
Yokum, Charles O.
Yorker, Lloyd O.
Youmans, Henry B.
Youmans, Randall E.
Young, Earl B.
Young, Eugene N.
Young, Kenneth A.
Young, Minerva S.
Young, William J.
Yusken, John W.
Zarcaro, John G.
Zavasky, Raymond L.
Zedekar, Raymond G.
Zeigler, Irene B.
Ziegler, Thomas A.
Zelenevitz, Joyce
Zepp, John P.
Zetler, Albert
Zirnfus, Edward R., Jr.
Zita, Myrtle C.

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APPENDIX F

MA–9 AIR–GROUND VOICE COMMUNICATIONS

The following is a transcript of the MA–9 flight communications derived from both the spacecraft onboard recordings and the Mercury network station recordings to form a single text. It is, therefore, a complete transcript of the air-to-ground and ground-to-air communications during station passes and inflight comments made by the pilot between stations. A few nonflight-related transmissions and an occasional repetitive word or partial sentence were removed by the astronauts and the editors to improve the clarity. Instances of this type are noted by an asterisk at the beginning of the altered transmission. Where a whole transmission has been deleted because of lack of confirmation or nonflight-relationship, the asterisk appears where the transmission was removed. The text is otherwise verbatim.

The format used for presentation is as follows, from left to right: The first column contains the spacecraft elapsed time (c.e.t.) from lift-off in hours, minutes, and seconds at which each communication was initiated. The second column identifies the communicator and the third column contains the text of the communication. The station in communication with the astronaut is designated at the initiation of communications. When no station contact was made for a complete orbital pass the text is headed with the orbital pass number only.

The c.e.t. was reduced from the recording of the spacecraft-clock commutated time segments on both the onboard tape and the network station tapes. These c.e.t. times are accurate to ±0.8 second. Timing of a few communications was not obtained because of either weak noisy signals on the network tapes, or the short sampling of onboard commutated time segments resulting from commutator sampling interruptions when the pilot was recording in the vox-record programed mode and paused longer than ½ second. When timing was not obtained for either of these reasons, the first column contains the notation "unreadable" for that communication.

The communicators are identified as follows:

P—Pilot

CC—Spacecraft communicator at the range station

SY—Systems monitor at the range station

F—Flight director at Mercury Control Center

R1—Pilot of primary recovery helicopter

R2—Pilot of backup recovery helicopter

Stony—Blockhouse communicator at launch complex 14

K—Communicator onboard the *USS Kearsarge*

At various times throughout the flight, the pilot or network station communicator would indicate a precise time, event, or action by the use of a significant word, such as "MARK", or "NOW". The transcript editors also selected a few significant words or events for timing. The timing of these words or events was accomplished by the same process as that used to determine the c.e.t. times for column one and is indicated by the time enclosed in brackets followed by the superscript T.

All temperatures are given in ° F; all cabin and suit pressures are in pounds per square inch, absolute (psia); fuel and coolant quantities are expressed in remaining percent of total nominal capacities; retrosequence times are expressed as ground elapsed time (g.e.t.) in hours, minutes, and seconds.

Within the test, a series of dots is used to designate communications or portions of communications which could not be deciphered. A single dash indicates a pause during a communication. Information contained within unmarked parentheses indicates editorial insertions for clarification.

	Stony	10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0.
00 00 01	CC	Lift-off.
00 00 02	P	Roger. I have a lift-off and the clock is operating.
00 00 05	CC	Roger, clock.
00 00 07	P	Sigma Seven, Faith Seven on the way.
00 00 14	P	Standing by to start the backup clock.
00 00 16	CC	Roger.
00 00 18	CC	3, 2, 1, MARK. [00 00 20][T]
00 00 23	P	Roger. And the backup clock is running.
00 00 25	CC	Roger. You look good here, Gordo.
00 00 27	P	Roger. Feels good, buddy.
00 00 29	CC	Good sport.
00 00 31	P	Thirty seconds, and fuel is go. Oxygen is go. Cabin pressure on the top peg. Altemeter is working.
00 00 38	CC	Roger. You're looking beautiful.
00 00 48	P	What an afterburner!
00 00 51	CC	That's a beauty, and your clock's are in sync.
00 01 01	P	One minute and fuel is go. Oxygen is go. Cabin pressure, 10 psi on schedule. All systems go.
00 01 09	CC	Roger. We have a good go here, and pitch, 50 [degrees].
00 01 29	CC	Still looks go.
00 01 30	P	Roger. One minute 30 seconds. Fuel is go. Oxygen is go. Cabin pressure is 6 psi.
00 01 37	CC	Roger. Pitch 32 [degrees], looks good.
00 01 41	P	Roger. The Sun is coming in the window now.
00 01 46	CC	Roger. Standing by for your BECO.
00 01 50	P	Roger.
00 01 58	P	Running pretty smooth now.
00 01 59	CC	Good show.
00 02 02	P	Two minutes. Standing by on BECO.
00 02 03	CC	Roger. Time out good.
00 02 14	P	Roger. Have BECO.
00 02 15	CC	Roger. Your BECO. Confirm staging.
		*[Undetermined transmission omitted.]
00 02 22	P	And you can feel the staging—waiting on tower.
00 02 27	CC	Very good on BECO time; SECO should be nominal.
00 02 29	P	Roger.
00 02 38	P	And there goes the tower. Does she take off!
00 02 41	CC	Roger. Confirm your tower.
00 02 43	P	Roger. Retrojettison switch to off.
00 02 45	CC	Retrojettison switch off.
00 02 55	P	*Okay. Fuel is go; oxygen is go; cabin pressure sealed at 5.6 [psi] and holding.
00 03 03	CC	Roger. Sealed on 5.6 [psi] and holding. Very good. Pitch −4 [degrees].
00 03 10	P	Roger. I agree on pitch.
00 03 12	CC	You look real pretty here.
00 03 14	P	She felt real pretty.
		*[Nonflight-related transmission omitted.]
00 03 24	P	All electrical is go. Pressure is go. Oxygen is go. Sigma, Faith Seven is all go.
00 03 34	CC	We have a full go here for you, Gordo.
00 03 36	P	Roger.
00 03 38	CC	This is Sigma Seven down here, buddy.
00 03 40	P	That's what I said. Sigma, Faith Seven is go.
00 03 44	CC	Roger, Faith Seven.
00 04 00	P	Four minutes and fuel is still go. Oxygen go. Pressure holding. All systems look good.
00 04 08	CC	Roger. Your pitch indication is −4 [degrees]: we concur.
00 04 11	P	Roger.
00 04 13	CC	Trajectory looks real good, Gordo. I'll give you a mark on 0.8 [V/V_r].
00 04 17	P	Roger.
00 04 32	P	Four plus 30 [seconds]. All systems still go.
00 04 35	CC	Roger. We're still go here. Coming up on 0.8 [V/V_r]. Stand by.
00 04 38	P	Roger.

00 04 40	CC	We have 0.8 V/V_r.
00 04 42	P	Good deal.
00 04 48	CC	You have a real sweet trajectory, Gordo.
00 04 50	P	Excellent.
00 04 58	CC	Go.
00 04 59	P	Roger.
00 05 04	P	Roger. I have SECO, sep cap. Going to aux damp.
00 05 09	CC	Right in there, baby.
00 05 12	P	Have sep cap green. SECO. I'm on aux damp. Going fly–by–wire.
00 05 24	P	Everything is green here.
00 05 30	CC	Seven, we're right smack dab in the middle of the plot.
00 05 34	P	Say again.
00 05 35	CC	Smack dab in the middle of the "go" plot. Beautiful.
00 05 45	CC	Seven. Your turnaround looks beautiful.
00 05 47	P	Roger. She's yawing around very nicely. What a view. Boy, oh boy!
00 05 59	P	And there's the booster.
00 06 03	CC	Real pretty.
00 06 04	P	Boy, oh boy, is it ever close, too.
00 06 08	CC	Fun, isn't it?
00 06 10	P	Yeah.
00 06 18	P	Fly–by–wire is working just like advertised.
00 06 21	CC	*We have good indications on systems here. You did a real good job of it.
00 06 44	P	Booster is still smoking. It looks silver, Wally.
00 06 48	CC	Good.
00 07 06	CC	Hello. Cape Cap Com.
00 07 17	CC	Faith Seven, Cape Cap Com. Seven, Cape Cap Com.
00 07 19	P	I'm in retroattitude or in orbit attitude.
00 07 23	CC	Faith Seven, Cape Cap Com. How do you read?
00 07 25	P	Roger, Cape Cap Com. Faith Seven reading you loud and clear.
00 07 29	CC	Roger. You're on Bermuda relay, and you're coming in real sweet, and everything looks perfect here.
00 07 33	P	Roger. Looks mighty good here. Booster is really in sight.
00 07 37	CC	Very good. What color is she?
00 07 39	P	*Silver. Silvery as can be with a white frosty band right around the middle.
00 07 45	CC	Roger. Understand.
00 07 53	CC	Faith Seven, this is Cape. Your 1–Alpha [contingency recovery area retrosequence] time is nominal.
00 07 57	P	Roger. Thank you.
00 08 05	P	Yaw shows up very well.
00 08 07	CC	Roger. Are you ready to copy [recovery area] 2–1 [retrosequence] time?
00 08 10	P	Negative. Stand by and let me get on auto here.
00 08 35	P	Going to auto control.
00 08 37	CC	Roger. How is she hitting in auto?
00 08 39	P	Roger. No quiver at all on the rates. I'm in auto. She seems to be holding so far.
00 08 45	CC	Very good. Let me know when you're ready for 2–1.
00 08 48	P	Roger.
00 08 51	CC	Pretty nice equipment, isn't it?
00 08 54	P	Very nice.
00 09 00	CC	Faith Seven, Cape. We had a cabin [heat exchanger] dome [temperature] of 65 [degrees] at Bermuda.
00 09 08	P	Roger. I have a cabin dome of 65 [degrees] and a suit dome of about 64 [degrees].
00 09 13	CC	Roger.
00 09 15	P	I'm increasing flow very slightly.
00 09 17	CC	Roger. You're increasing flow slightly.
00 09 23	CC	I'll give you your 2–1 [recovery area retrosequence] time, and you can write it later. It's 01+27+52. Over.
00 09 31	P	Roger. 01 27 52.
00 09 34	CC	Roger. And [contingency recovery area] 1–Alpha [retrosequence time] is nominal. Have a good ride, boy.
00 09 38	P	Thank you, buddy.

00 10 26	P	Roger. My $T_s+314.5$ lights have gone out. Squib switch to off. [A dome-temperature warning tone occurs at 00 11 00][7]
00 12 43	P	And the booster is still following me along at 12 minutes 45 seconds. It's coming down into the bottom of the window. ASCS is working nicely. It is diverging [drifting] off, to the 11 degrees. . . .
00 13 06	P	*Seems to be correcting properly. I have both suit and cabin dome temps on bottom peg. I'm going back to my initial setting. *[Nonflight-related transmission omitted.]

CANARY ISLANDS (FIRST PASS)

00 14 53	CC	Faith Seven. Faith Seven, this is Canary Cap Com. We have T/M solid. We would like a temperature readout, our segment is very low. That's dome temperature, Faith Seven, suit dome.
00 15 07	P	Roger, Canary Cap Com. Faith Seven reading you loud and clear. What temperatures would you like? Over.
00 15 14	CC	I would like a readout of suit [heat exchanger] dome temperature. Over.
00 15 19	P	Roger. My suit dome temp warning light is on. I have gone back to my initial suit setting. My cabin dome was on, and I have gone back to my initial setting on it. Cabin dome temperature is normal, about 52 degrees. Suit dome is still setting down rather low. I think it is coming back up though. Over.
00 15 45	CC	*Roger. Understand. I have a message from the Cape. [Contingency recovery] area 1–Bravo [retrosequence time] is nominal. Your apogee is 144.6 [nautical miles]. You will have no problems with nighttime. Also the Cape would like a blood pressure at this time. They missed it at Bermuda. Over.
00 16 08	P	Roger. Sending you blood pressure now.
00 18 31	P	Canary Cap Com.
00 18 35	CC	This is Canary Cap Com. Have you started your T^s+5 second check? Over.
00 18 39	P	I'm getting ready to start it right now.
00 18 43	CC	Roger.
00 19 47	CC	This is Canary Cap Com. Would you confirm your 16-millimeter camera is off? Over.
00 19 56	P	Roger. 16-millimeter camera is off.
00 19 58	CC	Roger.
00 21 12	CC	This is Canary Cap Com. Could you give us another readout on suit dome temp. We have lost T/M on that segment. Over.
00 21 20	P	Roger. Suit dome temp is slowly coming up here. It's still reading about 40 [degrees], but it's easing back up now.
00 21 31	CC	Roger.
00 21 35	CC	We are having T/M LOS. Could you give us a reading on cabin dome. It's going back down at LOS here.
00 21 44	P	Roger. At 50 [degrees], cabin dome.
00 21 53	CC	Faith Seven, this is Canary Cap Com. Do you read? Over.
00 21 58	P	Roger, Canary, Faith Seven. Still reading you.
00 22 11	CC	Faith Seven, this is Canary Cap Com. Do you read? Over.

KANO (FIRST PASS)

00 22 16	CC	Faith Seven, this is Kano Cap Com. We have T/M solid. We request the suit-dome temperature reading. We have no reading on the ground. Over.
00 22 28	P	Roger, Kano Cap Com. I have about 42 degrees. The suit-dome temp is easing back up now. Over.
00 22 36	CC	Roger. You are 42 degrees.
00 22 39	P	That is affirm.
00 22 44	CC	Kano, Roger.
00 22 49	CC	Faith Seven., this is Kano Cap Com. We have an indication that your TV is still on. Will you confirm? Over.
00 22 58	P	TV is off now.
00 23 01	CC	Kano, Roger.
00 23 09	P	Thank you.
00 23 13	CC	We request a cabin-dome temperature reading. Over.
00 23 21	P	Roger. Cabin-dome temp is bouncing around a little. It now reads 42 [degrees]. I've decreased my setting here slightly on it.
00 23 35	CC	Kano, Roger. We're reading 40 [degrees] on the ground.

00 26 46	CC	Faith Seven. Give us another cabin-dome temperature, please.
00 26 50	P	Roger. Cabin-dome temperature is 54 degrees.
00 26 57	CC	Please give us suit dome.
00 26 58	P	Roger. Suit dome is 40 [degrees]. I have decreased my setting a little more to ease it on up. Over.
00 27 07	CC	*Thank you. What is your present setting?
00 27 10	P	Roger. I am down below my nominal setting now.
00 27 13	CC	Roger.
00 27 43	CC	Faith Seven. We had a roll scanner ignore. Are you orienting the capsule at all? Over.
00 27 49	P	Negative.
00 27 51	CC	Roger.

ZANZIBAR (FIRST PASS)

00 30 47	CC	Faith Seven, Faith Seven, this is Zanzibar Cap Com. How do you read?
00 30 54	P	Roger, Zanzibar. Reading you loud and clear. Faith Seven here.
00 30 57	CC	Faith Seven. Our telemetry on the ground looks like you have a very good capsule at this time. We would like to confirm the suit-dome temperature, however.
00 31 07	P	Roger. The suit-dome temperature is still down low. I'm easing up on it.
00 31 12	CC	We're reading approximately 40 degrees on the ground.
00 31 15	P	Roger. I'm indicating about 42 [degrees] here, and I have decreased my setting. It should be coming up momentarily.
00 31 27	CC	Could you give me auto fuel, manual fuel, and oxygen readings?
00 31 32	P	Roger. Auto is still 101 [percent]. Manual is 102 [percent]. Oxygen is 196 [percent] on primary and 100 [percent] on secondary.
00 31 44	CC	Roger.
00 32 20	CC	Faith Seven, Zanzibar Cap-Com.
00 32 24	P	Go ahead, Zanzibar.
00 32 25	CC	*We just had a report from the Cape. Based on Smithsonian 2, you have approximately 20 over 25 orbits. This gives you approximately three times as much on more conservative estimates.
00 32 45	P	Roger. I understand I have at least 25 then. Is that affirm?
00 32 51	CC	Faith Seven. Zanzibar Cap Com.
00 32 55	P	Go ahead, Zanzibar. Faith Seven.
00 32 58	CC	Have you confirmed your T_s+5 check and that the TV is off?
00 33 03	P	That is affirm. TV is off. I have confirmed my T_s+5 second check.
00 33 10	CC	Roger.
00 33 26	CC	Faith Seven, Zanzibar Cap Com.
00 33 28	P	Go ahead Zanzibar, Faith Seven.
00 33 31	CC	We've had a slight rise on both cabin and suit-dome temperature.
00 33 39	P	Roger. I have a cabin [heat exchanger] dome [temperature] up to 60 [degrees]. Suit [heat exchanger] dome is still about 42 [degrees]. Over.
00 33 45	CC	Cabin-dome 60 [degrees]. Suit-dome temp, 42 [degrees].
00 33 48	P	That's affirm.
00 33 51	CC	Roger. You received that [contingency recovery area] 1–B [retrosequence time] was nominal. Is that correct?
00 33 52	P	Roger. Understand it is nominal.
00 33 56	CC	Okay, do you have anything else for this time for us?
00 34 02	P	Negative. Not this trip, I don't believe.
00 34 05	CC	Please repeat.
00 34 07	P	Negative. Not this time.
00 34 09	CC	Roger. We'll leave you alone then.
00 34 11	P	Roger. Thank you.
00 36 46	CC	Zanzibar Cap Com. Do you read?
00 36 48	P	Roger.
00 36 50	CC	Negative. We had a small problem on T/M on the ground. What is your ASCS bus reading?
00 36 59	P	ASCS bus reading, 121 [volts].
00 37 02	CC	We confirm. We had a small T/M problem.
00 37 05	P	Roger.
00 37 06	CC	Zanzibar, out.
00 37 30	CC	Faith Seven, Zanzibar Cap Com. How about giving me a suit and dome right now? It'll be LOS time.

00 37 36	P	Roger. Suit dome is about 45 degrees. Cabin dome is about 61 degrees.
00 37 43	CC	Roger. Thank you very much. See you next time.
00 37 46	P	Roger. Will do.
00 38 35	P	Okay. I finally have my dome temps—fairly good handle on them. I have about 62 [degrees] on the cabin dome. I have approximately 45 [degrees] on the suit dome. These temperatures have taken a setting of 2.0 [comfort-control-valve setting] on the suit and about 3.8 [comfort control valve setting] on the cabin. I have checked my control systems out. Manual proportional is operational. It is very sloppy compared to fly-by-wire low. The Sun is very hot coming in the window. I have the Sun directly in the window. I have from fairly midway through the launch. Lost it at the top of the trajectory. And then picked it up again when I yawed back around to orbit attitude.
00 39 50	P	My cabin pressure has slowly dropped to the advertised value of 5.2 [psia] and appears to be holding. My suit dome has dropped down again now to about 42 [degrees] and seems to be oscillating about this point area. Body temperature is good, not quite as cool as I would prefer, but good. My suit inlet temperature indicates 60 degrees, however, so the sun is probably the biggest factor heating me up. I have drunk some water.
00 40 56	P	Time for my short status report. My N_2 low pressures, auto is 475 [psi]; manual is about 480 [psi]. B-nut temperatures: retro temp, 60 degrees; pitch down, 85 [degrees]; pitch up, 84 [degrees]; yaw left, 78 [degrees]; yaw right, 89 [degrees]; roll counterclockwise, 90 [degrees]; roll clockwise, 90 [degrees].
00 41 57	P	Peroxide reserve tank temperature, 68 [degrees]; peroxide manual tank temp, 69 [degrees]; peroxide auto fuel tank temp is 72 [degrees].
00 42 30	P	Isolated bus voltage is 28 [volts].
00 43 22	P	*First night side and I have a bright blue band. A thick diffused band of blue color. A bright blue band. The Sun is spread out very widely. It's setting now. And there it goes. A very bright blue band all the way around the earth.
00 44 03	P	Captured another washer. That's my second one.
00 45 16	P	*I believe I have the dome temps somewhat under control now. My face plate is open. Cabin air is indicating 100 degrees. Suit inlet temp is 60 degrees. Dome temperature has stabilized pretty well. There is a very pronounced band—a bright blue band—around the Earth. ASCS is holding attitude very well on this night side. *[Non-flight-related transmission omitted.]
00 47 14	P	Taking my pilot light out, NOW [00 47 15]^{T}—very good.
00 47 43	P	Turning my warning lights off—to dim.
00 47 58	P	And I have the haze layer that Wally was talking about. I can see the stars down in it. But it is—up and around the Earth—to a number of degrees. It is several degrees thick, perhaps 12 to 15 degrees thick. I can see the stars above it, I can see the stars down in it.
00 48 35	P	*I have seen several lightning flashes on the Earth, now. I see them on the Earth, now.
00 49 19	P	*Water squeezers are working.
00 49 53	P	Closing my face plate.
00 50 05	P	And there is Orion, Betelgeuse. What a beautiful night tonight.

MUCHEA (FIRST PASS)

00 51 02	CC	Faith Seven, Faith Seven, Muchea Cap Com. Over.
00 51 06	P	Roger, Muchea Cap Com, Faith Seven.
00 51 10	CC	Roger. Reading you loud and clear.
00 51 11	P	Roger. Likewise here. How are things down there?
00 51 12	CC	Very fine, very fine.
00 51 16	P	Roger.
00 51 21	P	You appear to be having a little lightning and thunderstorms down there.
00 51 26	CC	Looks clear from here.
00 51 29	P	Roger. Back out to the west of you there are some.
00 51 33	CC	Aeromed is standing by for your blood pressure.
00 51 41	P	Roger. Blood pressure coming now.
00 52 01	CC	Faith Seven. How does your cabin dome and suit dome temp look now?
00 52 17	P	Roger. I was waiting until the blood pressure got finished there.
00 52 25	CC	How does your suit and cabin [heat exchanger] dome [temperature] look now?
00 52 26	P	*Roger. My cabin dome and suit dome [temperatures] have been fluctuating somewhat.

00 52 36	CC	Stand by for emergency voice check.
00 52 38	P	Roger.
00 52 45	CC	This is Muchea Cap Com, transmitting on emergency voice for a short count. 1, 2, 3, 4, 5, 5, 4, 3, 2, 1. Do you copy?
00 52 58	P	Roger, Muchea Cap Com. Reading you loud and clear on emergency voice.
00 53 02	CC	Roger.
00 53 07	P	Roger. On these dome temps, I have decreased my setting again, and my cabin dome is running about 48 degrees. My suit dome is back on the bottom, 40 degrees now. I've decreased it; it should be coming back up momentarily.
00 53 25	CC	Roger. Stand by for an astro alarm check.
00 53 31	P	Roger.
00 53 34	CC	Command is on the way. [Command tone occurs at 00 53 35] [T]
00 53 36	P	Roger. I have retro reset light and the tone.
00 53 40	CC	Roger.
00 53 56	CC	*Faith Seven, would you give me a reading on your cabin temperature please.*
00 54 00	P	Roger. Cabin temperature is running 100 degrees.
00 54 04	CC	Roger.
00 54 12	CC	Faith Seven. Perth has their lights on tonight; you might look for them and see if they're visible.
00 54 19	P	Roger.
00 54 21	CC	They should be just slightly off to the right of your flight path.
00 54 27	P	Roger. I'll watch for them.
00 54 28	CC	Roger.
00 55 03	P	Roger. I have the lights of Perth in sight. Loud and clear.
00 55 08	CC	Roger, Faith Seven. People here will be glad to hear that.
00 55 11	P	Roger. Looks good.
00 55 23	P	Looks like the refinery down to the south is burning again too.
00 55 27	CC	*That's affirmative.
00 55 29	P	Roger. I can see that separately.
00 55 32	CC	Cape Flight would like to know how your ASCS is working now after selecting gyro slave.
00 55 37	P	Roger. ASCS appears to be operating as advertised. Over.
00 55 42	CC	Roger.
00 55 52	CC	This is Muchea Cap Com. We have about 1 minute to LOS.
00 55 56	P	Roger.
00 56 47	CC	Faith Seven, Muchea Cap Com. *Could you give us your [comfort] control valve setting?*
00 56 57	P	Roger. I'll give you my heat exchanger dome temps here.
00 57 00	CC	Roger.
00 57 03	P	Roger. I'm reading 52 degrees on cabin dome, and I'm reading 40 degrees on suit. I have decreased suit again, slightly. And it should be coming up again.
00 57 15	CC	Roger.
00 58 45	P	*This haze layer. I'm describing as light in color. It's a white haze, does not appear to have any color at all to it.
01 04 08	P	I now have the suit coolant valve set to 1.5, cabin valve set to launch mark, about 3.6, and cabin [dome temperature] reads 50 degrees, and suit [dome temperature] is coming up slowly, now reads about 45 degrees. Suit inlet temp is about 58 degrees.
01 05 18	P	There is considerable cloud cover over the Earth now. This haze layer is still up above that. I can see a dark hazy sky above the Earth, and then this haze layer appears to be sitting several degrees—it's hard to estimate the number of degrees—above the Earth. The stars are in the background. The stars are above this haze layer, and they're quite clear, of course, above it.
01 06 07	P	Long status report. B-nut temperature: Pitch down is 90 [degrees]; pitch up is 85 [degrees]; Yaw left is 82 [degrees]; yaw right is 95 [degrees]; roll counterclockwise is 92 [degrees]; roll clockwise is 92 [degrees]. Cabin outlet, 40 degrees; 250 inverter, 110 degrees; 150 inverter, 112 degrees; standby inverter, 90 (degrees). Cabin temperature, 102 degrees; suit temp 58 degrees. Heat exchanger dome temps: cabin is now 50 [degrees]; suit is now 46 [degrees].
01 08 04	P	I'm reading 18 amps on current. Main bus reads 24 [volts]; isolated [bus], 28 [volts]; number one battery, 24 [volts]; number two battery, 24 [volts]; number three battery, 24 [volts]; standby [battery] one, 25 [volts]; standby [battery] two, 25 [volts]; isolated [battery], 28 [volts].
01 08 36	P	I'm now opening my face plate to take an oral temp.

CANTON ISLAND (FIRST PASS)

01 10 02	CC	Faith Seven, this is Canton Cap Com. Over.
01 10 14	CC	Faith Seven, we have a valid body temp.
01 10 18	P	Roger. I'll talk to you then. Ha, ha! Faith Seven here, reading you loud and clear.
01 10 24	CC	Roger. Would you give me a readout on your cabin heat exchanger dome temp, please.
01 10 31	P	*Roger, standby 1 second. Roger. Cabin heat exchanger dome temperature is 50 degrees; suit heat exchanger dome temp is 45 degrees; the suit inlet temperature is 58 degrees; and cabin outlet temperature is about 40 degrees.
01 11 03	CC	Understand, 43.
01 11 05	P	40.
01 11 07	CC	40.
01 11 35	CC	Seven, Canton.
01 11 37	P	Go ahead Canton, Faith Seven.
01 11 41	CC	[Recovery] area 2–1 retrosequence time 14 32 03. Over.
01 11 49	P	14 32 03. Roger.
01 11 52	CC	Affirmative.
01 11 54	P	Roger.
01 12 25	CC	Seven, Canton. Your c.e.t. [capsule elapsed] time on the 2–1 retrosequence time is 01 27 50. Over.
01 12 39	P	Roger. 01 27 50. That's on 2–1. Is that affirm?
01 12 45	CC	Affirmative.
01 12 47	P	Roger.
01 13 02	CC	*Seven, Canton. All readouts are in the green.
01 13 06	P	Roger, they all look green here, thank you.
01 18 01	P	*I have transferred the urine from the internal suit bag to the number one bag at this time.
01 19 27	P	Alpha and Beta Centauri.
		*[Non-flight-related transmission omitted.]
01 20 52	P	Sweet little baby.
01 21 15	P	*At this time I now have 1 hour and 21 minutes and I am observing John's fireflies drifting away from me. I can observe them—appear to be departing from the spacecraft and drifting out to the rear. I then can see some of them a considerable distance out to the rear.
01 22 02	P	The Sun is coming up behind me; I'm beginning to get the glow on the clouds.
01 22 22	P	*The fireflies appear to be white, very whitish, almost a green, like real fireflies.
01 23 01	P	The clouds on the Earth below are changing color, are getting quite light.
01 23 54	P	*I am now on the day side; the Sun is not yet quite up and I am observing stars. The Earth is light below me. The sun is still behind me, the sky looks dark above me, and I can see stars very distinctly.
01 24 41	P	I am decreasing cabin dome [comfort control valve setting] now to about 3.4.

GUAYMAS (FIRST PASS)

01 27 13	CC	Faith Seven, Guaymas Cap Com.
01 27 16	P	Roger, Guaymas Cap Com, Faith Seven here.
01 27 19	CC	Hey, Gordo, give me your heat exchanger outlet temperatures please.
01 27 24	P	Roger. I've got 50 [degrees] on the cabin, and 50 [degrees] on the suit.
01 27 31	CC	Roger. Are you comfortable?
01 27 34	P	Roger. Just slightly warmer than absolutely ideal, but well within a very comfortable range. My suit inlet temperature is 58 degrees. Over.
01 27 43	CC	Very good. Everything looks good down here. We give you a go for seven more.
01 27 48	CC	We are giving you a go for seven orbits.
01 27 51	P	Roger, for 30 how many?
01 27 55	CC	As many as you want.
01 27 56	P	Ha, ha! Roger.
01 27 58	CC	And Gemini sends you their regards.
01 28 03	P	Roger. Thank you.
01 28 08	CC	Will you give me a short report?
01 28 12	P	Roger. It's great.
01 28 19	CC	That's good enough.
01 28 22	P	It's pretty hard to describe, but it really is. I've seen the haze layer that Wally talked about, and I've seen John's fireflies, saw the lights of Perth, and it's been quite a full night. Quite impressive. Everything appears very nominal on board here.

01 28 40	CC	How was the sunrise?
01 28 42	P	Quite impressive.
01 28 49	P	Everything seems very nominal on board here.
01 28 53	CC	Excellent.
01 29 11	P	How's the fishing?

CAPE CANAVERAL (SECOND PASS)

01 33 50	CC	Faith Seven, Cape Cap Com.
01 33 52	P	Roger, Cape Cap Com. Faith Seven here.
01 33 55	CC	Roger. You look real good. I'm going to send you a T/M command.
01 33 59	P	Roger.
01 34 05	CC	I will wait for your TV camera.
01 34 08	P	Roger.
01 34 14	CC	Gordo, could you give me a readout on your H_2O_2 pressures, please?
01 34 20	P	Pressure?
01 34 22	CC	Pressure.
01 34 23	P	I have 475 [psi] auto and I have 490 [psi] in manual.
01 34 29	CC	Roger. You're getting kind of chinchy on this fuel up there.
01 34 32	P	Roger. FQI [fuel quantity indicator]: I'm indicating 101 [percent] on auto and 102 [percent] on manual.
01 34 41	CC	You son-of-a-gun, I haven't got anything to talk about.
01 34 42	P	Ha, ha, ha!
01 34 46	CC	How's your H_2O separator lights working?
01 34 51	P	Fine. They're just beating their little hearts out every 10 minutes.
01 35 00	Stony	Faith Seven, this is Stony. Maybe, maybe the FQI is stuck. Why don't you try the hammer?
01 35 07	P	Ha, Ha! I'll save that for later. I'm thinking of using the hammer on the dome temp, however. On the dome temp light.
01 35 20	CC	We're starting to pick a picture up now. You look pretty casual.
01 35 27	P	Oh, I am.
01 35 41	CC	Do you want to do your KK experiment over us please?
01 35 45	P	Roger. Opening the KK clamp.
01 35 52	CC	Roger.
01 36 42	P	Roger. I'm getting ready to power down.
01 36 46	CC	Roger. I would like to have you open up your TV about one stop.
01 36 51	P	Roger. Is that any better? It's already wide open.
01 37 08	CC	Roger. I still see that fly on your nose.
01 37 13	P	Ha, ha, ha!
01 37 17	CC	Okay, Gordo. I guess you can shut your power down.
01 37 19	P	Roger. Going to fly-by-wire low. On fly-by-wire low.
01 37 22	CC	Roger.
01 37 30	P	Going to fly-by-wire low. Going to gyros caged, and they caged just as advertised. And ASCS a–c bus off.
01 37 50	CC	Roger. Checking volts down, and amps down.
01 37 54	P	Roger.
01 38 28	P	*Apparently the heat exchanger dome temps have stabilized pretty well now.
01 38 36	CC	Roger. It takes quite a while to get a grasp on it.
01 38 38	P	Roger.
01 38 43	CC	Before LOS, don't forget your TV camera. We're still reading you very well now.
01 38 50	P	Roger.
01 39 01	CC	The other item to check is your tape recorder on program.
01 39 05	P	Roger. Tape recorder going to program.
01 39 08	CC	You are program.
01 39 10	P	Are you still receiving the TV picture?
01 39 13	CC	That's affirm.
01 39 19	P	Roger. I'll hold. Turning it off for a moment.
01 39 21	CC	Okay.
01 39 30	P	Mode select switches to off.
01 39 33	CC	Roger. Mode, off.
01 39 35	P	Manual fuel is off.

01 39 38	CC	Manual, off.
01 39 44	CC	Frank [Samonski] says you can stop holding your breath any time and use some oxygen if you'd like.
01 39 49	P	Okay. You set such a good example; I've got to equal you here.
01 40 01	CC	Yeah, you son-of-a-gun. I'm still higher and faster, but I have an idea you're gonna go farther.
01 40 09	P	Al, what is my apogee height?
01 40 15	CC	It's about 146 nautical [miles].
01 40 19	P	Roger.
01 40 20	CC	You can kill your TV, Gordo.
01 40 22	P	Roger. TV off.
01 40 24	CC	Roger. And put your C-band to ground command.
01 40 31	P	Roger. C-band's on ground command. S-band's on ground command.
01 40 37	CC	Roger.
01 40 40	P	Recorder on program; I'm leaving telemetry on continuous.
01 40 50	CC	All of our monitors down here are overjoyed. Everything looks beautiful.
01 40 54	P	Very good. Looks mighty good up here, too.
01 41 02	CC	There's LOS on your T/M. Bermuda may have picked up, but I don't think they'll discover anything we haven't.
01 41 09	P	Roger.
01 41 43	CC	Faith Seven. This is Sigma Seven. Do you read?
01 41 46	P	Roger. Sigma Seven, Faith Seven reading you loud and clear.
01 41 49	CC	Roger. We have no messages for you. We'll let you have some quiet time. Have a good ball.
01 41 54	P	Roger. Thank you.
01 42 03	P	Might tell Bob Graham I've found a couple of those items that we were discussing. I can see the smudge layer on the window that Wally was discussing. It looks just like road grease splashed on a car. It also has spreckledy, streakedy, dots on it, smudged in with it. The smudge—the added smudges—run length of the window. Closing my visor now at 01 44 38.

CANARY ISLANDS (SECOND PASS)

01 48 26	CC	Faith Seven, this is Canary Cap Com. We have T/M solid, all systems look green. Over.
01 48 35	P	Roger, Canary Cap Com. I'm turning TV on here for you.
01 48 41	CC	Roger.
01 48 45	P	All systems are green here.
01 48 48	CC	Roger. Your [contingency recovery area] 2–Bravo [retrosequence] time is nominal.
01 48 52	P	Roger. Nominal, thank you.
01 50 19	CC	Faith Seven, this is Canary Cap Com. We're having T/M LOS. Turn off your TV. Over.
01 50 26	P	Tv control to off.
01 50 28	CC	Roger.
01 50 38	P	Drifting now; I was upside down in roll attitude. Just passed over Canaries. Everything appears nominal.
01 51 09	P	I'm now receiving a Z and R cal apparently from program.
01 52 22	P	*Coming in over the coast of Africa. It's very clear here: no clouds, no haze. I'm drifting through an ideal location here. I'll try and snap off the 16 millimeter. Just took a 16-millimeter blurb coming over the Atlas Mountains in Africa. Coming over the coast. It's very dry, very clear over Africa. I'm drifting window down, ideal attitude. I'm now increasing my suit flow by just a hair. I'm opening my visor now. Cabin still appears drier than the suit. Apparently suit is running a little moist, although it doesn't feel it at all. Had six or seven large sips of water from the drinking-water container. I have put a little liquid into this little experimental ball and find that the liquid adheres to the surface just near as good as it should. Try a little bit more later on here.

KANO (SECOND PASS)

01 55 02	CC	Kano, has solid T/M.
01 55 09	P	Roger, Kano, Faith Seven. Everything's nominal here.
01 55 14	CC	Faith Seven, this is Kano Cap Com. Everything looks nominal on the ground. Have a good trip.
01 55 19	P	Roger. Thank you very much.
02 00 36	P	*At 2 hours, recording light is on; so I'll slip something on the tape. All systems appear nominal. My . . . cabin dome temp is 48 degrees; suit dome temp is about 56 degrees. Oxygen is still on the top peg on both systems. So is the fuel. Cabin temp, 98 [degrees]. . . . 2 hours and 3 minutes . . . 2 hours and 4 minutes. MARK [Unreadable].[T] Rate indicators are on, I am drifting at this point; I have left roll rate of about half a degree/sec. I have a pitch down rate of about one-quarter of a degree/sec and a right yaw rate of about one-half of a degree, and relatively constant. They're all considerably different than nominal. I don't feel that it's worth going into all the settings. I think the cabin dome temp is the important thing.

ZANZIBAR (SECOND PASS)

02 05 20	CC	Faith Seven, Zanzibar Cap Com.
02 05 23	P	Roger, Zanzibar. Faith Seven reading you loud and clear.
02 05 26	CC	Reading you loud and clear, also. I have your [contingency recovery area] 2–B [retrosequence] time. It is nominal. Do you need it?
02 05 34	P	Negative, I have it. Understand nominal.
02 05 37	CC	That is affirmative. Would you give me a readout of your cabin heat-exchanger dome temperature?
02 05 45	P	Roger. It is sitting on 40 [degrees]. It has just gone down here; it's bobbing around, and I am decreasing my flow to it.
02 05 54	CC	Roger.
02 06 02	CC	Can you give me fuel and oxygen readouts, please?
02 06 06	P	Roger. I am still indicating 101 percent on auto, 102 percent on manual. I'm reading 196 percent on primary oxygen, and 100 percent on secondary. Over.
02 06 22	CC	Roger.
02 06 28	CC	How do you feel about this heat situation?
02 06 34	P	What, the heat exchanger?
02 06 35	CC	No, how is your comfort?
02 06 38	P	Roger. My comfort is good.
02 06 43	CC	Your comfort is good.
02 06 44	P	That's affirmative.
02 06 54	P	My cabin heat exchanger [dome temperature] is easing back up now to about 42 [degrees]. Slowly coming back up.
02 07 00	CC	Roger.
02 07 02	P	I have about 42 [degrees], and it's coming back up slowly now.
02 07 05	CC	Roger.
02 07 07	P	. . . dome temp.
02 07 08	CC	T/M confirms all your systems go. Your clock is in sync.
02 07 14	P	Roger.
02 07 23	CC	T/M indicates you are getting a rise in your cabin [heat exchanger] dome temperature, also.
02 07 29	P	Roger.
02 09 12	CC	Faith Seven, Zanzibar Cap Com.
02 09 14	P	Roger, Zanzibar. Go ahead.
02 09 16	CC	We've had another increase in cabin heat exchanger dome temperature. It's now 48 degrees on the ground.
02 09 23	P	Roger. I agree.
02 09 25	CC	Roger.
02 09 32	CC	What is your dome setting—the handle setting at the present time?
02 09 42	P	Nominal. I don't feel that it's worth going into all the settings. I think the dome—the cabin [heat exchanger] dome temps are the important things.
02 09 49	CC	Roger. You're getting weak and fading. I'll sign off and see you later.
02 09 53	P	Roger.

02 14 12	P	The time is 02 14 15. People wonder if it's hard to sleep up here. I just drifted off for about 3 or 4 minutes on a quick little nap. Sleep here just like you do anywhere else. Status report. Nitrogen low pressure: auto source, 494 [psi]: manual 490 [psi]. FQI [fuel quantity indicator]; 101 [percent] on auto: 102 [percent] on manual. [B-nut] temps: pitch-down, 95 [degrees]; pitch-up, 85 [degrees]; yaw left, 82 [degrees]; yaw right, 96 [degrees]; roll counterclockwise, 95 [degrees]; roll clockwise, 95 [degrees]; reserve tank, 75 [degrees]; manual tank, 70 [degrees]; auto tank, 78 [degrees]. [Isolated] bus voltage, 28½.
02 21 41	P	I am now drifting on the night side. I have the Moon in sight; I'm upside down; I'm observing lightning flashes from considerable-size thunder storms that are below me. These create static in the radio every time the lightning flashes down there.

MUCHEA (SECOND PASS)

02 24 13	CC	Faith Seven, Muchea Cap Com. Over.
02 24 18	P	Roger, Muchea Cap Com. Faith Seven.
02 24 21	CC	Roger. Reading you loud and clear. Aeromed requests that you give him a mark when you begin your exercise and a mark when you stop your exercise. Over.
02 24 30	P	Roger. Will do.
02 24 34	CC	I have [recovery] area 3–1 retrosequence time, 02 58 05. Do you copy?
02 24 46	P	02 58 05. Is that affirm?
02 24 48	CC	That's affirmative.
02 24 55	P	Roger. I'll be sending a blood pressure in just 1 second.
02 24 58	CC	Roger.
02 25 43	CC	Faith Seven. Systems reports that your suit [heat exchanger] dome temp is decreasing rather rapidly. Would you check that, please?
02 25 51	P	*Roger. I'll just decrease the flow on both cabin and suit here.
02 25 57	CC	Roger. We confirm here.
02 26 08	P	Roger. I'm getting the exerciser now.
02 26 28	P	Starting the exercise.
02 26 55	P	Ending the exercise now.
02 26 57	CC	Roger.
02 27 01	P	Sending blood pressure now.
02 27 03	CC	Roger.
02 27 14	CC	We're reading your cabin heat [exchanger] dome temp at 44 [degrees] now.
02 27 19	P	Roger. I concur. 44 [degrees] on cabin and about 47 [degrees] on suit.
02 27 24	CC	Roger. We concur here.
02 27 44	P	How does your med. like those blood pressures?
02 27 50	CC	Stand by. They report they look very normal.
02 28 01	P	Roger.
02 28 25	CC	Could you give me a cabin air temp reading?
02 28 28	P	Roger. Cabin air temp is 98 degrees.
02 28 31	CC	Roger. 98.
02 28 33	P	Roger.
02 29 24	CC	Do you have the Perth lights in sight?
02 29 30	P	One moment, let me get my cabin lights down.
02 29 42	P	Negative, I'm upside down. I can't see them.
02 29 45	CC	Roger.
02 30 18	CC	We have approximately 1 minute to LOS.
02 30 22	P	Roger.
02 30 25	P	Tell Warren not to get lost out in the outback.
02 30 29	CC	We almost got lost last Sunday.
02 30 31	P	Ha, ha!
02 30 33	?	Astro, most of the boys have joined tennis clubs here.
02 30 36	P	Roger. This is more fun than tennis.

02 34 35	P	Long status report . . . . . temperature: Let's see, first, retro 60 [degrees]; pitch down, 95 [degrees]; pitch up, 82 [degrees]; yaw left, 80 [degrees]; yaw right, 95 [degrees]; roll counterclockwise, 92 [degrees]; roll clockwise, 92 [degrees]; 250 inverter, 102 [degrees]; 150 inverter, 118 [degrees]; standby inverter, 98 [degrees]; cabin temperature, 98 [degrees]; suit inlet temperature, 60 [degrees]. Heat exchanger dome temperatures: cabin 50 [degrees]; suit, 48 [degrees]. Just then decreased flow and is coming back up. Main d-c bus, 24 volts; isolated [bus], 28 [volts]; current, 8 amps. It is 02 36 40. Milky Way is quite distinct. Now looking at the False Cross. Upside down, drifting flight at the moment.
02 39 38	P	*And I have the constellation of Sagittarius in sight. Nunki right there. There's the Moon directly in the top of my window.

CANTON ISLAND (SECOND PASS)

02 43 39	CC	Faith Seven, Canton Cap Com. All systems look green on the ground. We're standing by.
02 43 45	P	Roger, Canton. All systems look green here, thank you.
02 47 39	CC	Faith Seven, Canton.
02 47 41	P	. . . Canton, Faith Seven.
02 47 47	CC	Seven, [contingency recovery area] 3–Alpha [retrosequence time] is nominal.
02 47 50	P	Roger, [contingency recovery area] 3–Alpha [retrosequence time is] nominal, thank you.
02 48 33	P	The time is 02 48 35 NOW [02 48 36]T. Regulated pressure source on fuel, 475 [psi] auto; 490 [psi] on manual. Fuel, FQI 101 percent on auto; 102 percent on manual. Cabin dome temp, 50 [degrees]; suit dome temp, 50 [degrees]; cabin temp, 95 [degrees]; suit inlet temp. 60 [degrees]; cabin pressure holding at 5 psi.* Main bus 24½ [volts]. I'm using 8 amps current.
02 49 53	P	Sunrise—and the sun is behind me, moving to the rear of me, with Saturn along by it. And I'm getting John's fireflies again, coming off the spacecraft. And you could almost aline yaw by the fireflies. They drift away to the rear of the spacecraft along to the rearward of the flight path.
02 50 32	P	Sunrise is coming in.
02 51 38	P	There's a coating of frost on the next to outside layer of window, which I believe, seems to be burning off as the sun hits the window.

HAWAII (SECOND PASS)

02 51 44	CC	Faith Seven, Faith Seven, Hawaii Cap Com. How do you read?
02 51 48	P	Roger, Hawaii Cap Com. Reading you loud clear.
02 51 52	CC	Roger. Everything looks good on the ground. Your suit [heat exchanger] dome [temperature] is 54 degrees. Aloha from Hawaii.
02 52 00	P	Roger. Aloha to you, too. Everything appears to be normal here.
02 52 04	CC	Roger. We're standing by.
02 52 07	P	Roger. Thank you.
02 53 37	P	And after having entered the day side, I've drifted around where I'm looking towards the black sky. I have seen a star again, and I've been observing the fireflies drifting away.
02 58 01	P	I'm in bright daylight now, at 2 hours 58 minutes. I'm upside down. I still have, oh, about ½ degree per second roll rate—very, very, very light—almost ½ degree [1 sec] yaw, and pitch is oscillating between ¼ and ½ [degree/sec], close to the rate of roll.

CALIFORNIA (SECOND PASS)

02 59 55	CC	Faith Seven, Faith Seven, this is California Cap Com.
03 00 00	P	. . .
03 00 01	CC	Faith Seven, Faith Seven. All systems here are green. You look real good here on the ground. Over.
03 00 21	P	. . .
03 00 48	CC	Faith Seven, Faith Seven. This is California, got you here, and you look real good all over on the board. The medics give you a clean bill of health. They would like to know if you just feel comfortable. Over.
03 01 01	P	Roger. I do feel comfortable, very comfortable. In fact, I had a little nap.
03 01 06	CC	Roger. We have a little news here from an old friend of yours, like Major Dick Shankle. Would you like to say hello?

CALIFORNIA (SECOND PASS)—Continued

03 01 14	P	Hello, Dick.
03 01 18	CC	I'll pass that on, Gordo.
03 01 20	P	Roger.
03 01 56	CC	Faith Seven, we see you have powered up your ASCS; and also, I believe you are scheduled for tape recorder, continuous.
03 02 06	P	Roger.
03 02 22	P	Roger. Tape recorder is on continuous.
03 02 25	CC	Roger. Your clocks look real good here, in sync. No problems that we see.
03 02 27	P	I'm on fly-by-wire low.
03 02 30	CC	We see.
03 02 31	P	Roger.
03 02 32	CC	California standing by.
03 02 34	P	Roger. I'm alining the spacecraft, very slowly, to go to auto. Coming in over the coastline now; it's very clear; looks like very good weather down there with clouds standing off shore.
03 02 54	CC	Ha, ha! Roger.
03 02 55	P	I see the islands off shore.
03 03 44	CC	Attitudes look really good on the ground. You must have her alined real good.
03 03 48	P	Roger.
03 04 00	CC	Oh, wait a minute. Your gyros are still caged, aren't they?
03 04 03	P	That's affirm.
03 04 11	SY	Cabin heat exchanger outlet temperature.
03 04 13	CC	Systems requests a cabin outlet heat exchanger temperature.
03 04 19	P	Roger, cabin heat exchanger outlet is about 48 degrees. I've decreased the flow very slightly a few minutes ago and it should be easing on up.
03 04 25	CC	Roger. 48 [degrees] and you've decreased the setting.
03 05 54	P	Okay. I'm just about in attitude here, getting ready to uncage the gyros.
03 07 19	P	I am on auto orbit.

CAPE CANAVERAL (THIRD PASS)

03 07 32	CC	Faith Seven, Cape Cap Com.
03 07 35	P	Roger, Cape Cap Com, Faith Seven.
03 07 38	CC	Roger. Read you loud and a little garbled.
03 07 42	P	Roger.
03 07 44	CC	Like to send you a T/M command, Gordo.
03 07 46	P	Roger. Go ahead.
03 07 54	CC	I have about three requests from you, cabin temperature?
03 07 59	P	Roger. Cabin temp is 92 degrees.
03 08 03	CC	Read 92.
03 08 05	P	Roger.
03 08 07	CC	Have you had any results on your **KK** clamp release?
03 08 11	P	Negative. I could not see any flow at all on it, so I clamped it off as planned.
03 08 18	CC	Roger, would you give us a readout of your cabin dome?
03 08 21	P	Roger. Cabin dome [temperature] is about 46 [degrees]. I have increased the flow slightly on it. Suit is 50 [degrees].
03 08 30	CC	Roger.
03 08 33	P	I mean I have decreased the flow on cabin.
03 08 41	CC	I'd like to give you a time hack, if you will.
03 08 43	P	Roger.
03 08 45	CC	Give you an elapsed time first at 50 seconds, that will be 3 hours, 8 minutes, 50. 2, 1, MARK. (03 08 52)[T]
03 08 53	P	Roger. I'm 1 second fast.
03 09 02	CC	Roger, 1 second fast.
03 09 03	P	I am on auto orbit.
03 09 06	CC	Roger. Getting into attitude. Your attitude looks good here.
03 09 14	P	*Roger. I've got my gyros alined very easily and went on auto; and the auto appears to be a little bit slow to move it into the smaller gates but it's working very nicely.
03 09 30	CC	Good.
03 09 34	P	TV camera coming on now.

03 09 39	CC	I'll give you a G.m.t. hack in a few seconds.
03 09 42	P	Roger.
03 09 43	CC	16 hours and 14 minutes. 2, 1, MARK. (03 09 48)[T]
03 09 54	P	Roger. What was that, 14 minutes?
03 09 56	CC	That's 16 hours, 14 minutes, 00 second.
03 09 59	P	Roger. On my standby clock I am about 10 seconds slow on that.
03 10 11	CC	Is this your G.m.t. clock?
03 10 15	P	Roger. Both of them—no on the wrist watches—both of my wrist watches are together; however, they are a little slow. I have 14 30 NOW. (03 10 31)[T]
03 10 34	CC	Say again, Faith Seven.
03 10 35	P	Never mind I'll catch you later.
03 10 38	CC	Okay.
03 11 01	CC	Faith Seven, Cap Com.
03 11 04	P	Go ahead Cap Com, Faith Seven.
03 11 05	CC	I have [recovery area] 3–2 [retrosequence] time if you're ready to copy.
03 11 09	P	All right, just a moment.
03 11 27	P	Go.
03 11 32	CC	Faith Seven this is Cape Cap Com. We have had four R and Z cals. Request you turn your R and Z cal switch off.
03 11 39	P	Roger.
03 11 49	P	Go ahead on the [recovery area] 3–2 [retrosequence] time.
03 11 59	P	Cape Cap Com. Faith Seven ready to copy 3–2 time.
03 12 29	CC	Faith Seven, Cape Cap Com.
03 12 33	P	Roger Cape, go ahead.
03 12 34	CC	Did you copy my 3–2? I did not read you.
03 12 37	P	Negative, I didn't copy it.
03 12 39	CC	Roger. It's 04 hours + 08 minutes + 10 seconds.
03 12 46	P	Roger. 04 08 10.
03 12 50	CC	That's correct.
03 13 15	CC	Faith Seven. Your scanners and attitudes agree very nicely. Over.
03 13 27	CC	Faith Seven, Cape Cap Com, you can turn TV off.
03 13 32	PC	Roger. I already have it off.
03 13 43	CC	Faith Seven, Cape Cap Com.
03 13 47	P	Go ahead Cape, Faith Seven.
03 13 49	CC	Are your tower sep lights and cap sep lights out?
03 13 52	P	Affirm.
03 13 54	CC	Roger.
03 13 56	P	They went out at 314.5.
03 14 00	CC	Roger. They should have been. We just had a T/M, and we wondered why.
03 14 02	P	Roger.
03 14 03	CC	No problem on these at all.
03 25 06	P	*I am on fly-by wire, have armed the squib, pitching up very, very slowly, and will deploy the flashing light at the —20 degree point. Flashing light is deployed. I'm marking the tape. Deploy light off. Squib is off. Gyros are caged, free to caged. Roger—and ASCS a-c bus off. NOW. [03 26 28][T] Stick is now cold.
03 27 01	CC	. . . Cape Cap Com. Do you read? Over. . . . Do you read? Over. . . .
Unreadable	CC	Faith Seven . . . on relay. Do you read? Over.
Unreadable	CC	Faith Seven . . . do you read?
03 28 15	P	*ASCS inverter, 110 [degrees] when I powered it down. Sitting at 90 degrees yaw right now. It is easy to determine that the angle is very large, so far as telling to a high degree of accuracy, in a short time; but I am yawing around to observe the flashing light on the night side—is very easy to determine that, it is about 90 degrees yaw, now. I'm getting directly away from the Sun now, observing the night side coming on. With the window head on, I can see the demarcation line between the Sun and the light side and the dark side. Light blue above the Earth, and a band of blue above the Earth that fades in the dark side. Observing fireflys taking off now. And there's a very, very distinct demarcation now.
03 37 17	P	At this point I have no way of knowing what my yaw is. Left cabin light only, with the red filter . . .
03 51 29	P	*I still have not observed the flashing light. I have Sagittarius right in the middle of the window. It is directly on my 80 degree yaw . . . .

03 58 33	CC	Faith Seven, Muchea Cap Com.
03 58 37	P	Go ahead, Muchea, Faith Seven.
03 58 39	CC	Roger. Will you confirm that your squib switch is off?
03 58 49	P	Affirm. Squib switch is off.
03 58 52	CC	Roger. Area [contingency recovery] 4–A [retrosequence] time is nominal.
03 59 00	P	Roger. Thank you.
03 59 05	CC	Aeromeds are standing by for your blood pressure.
03 59 08	P	Roger. Sending it now.
03 59 13	CC	Roger.
03 59 16	CC	Did the beacon deploy?
03 59 20	P	Affirmative. I'm still trying to find it out here in the dark.
03 59 25	CC	You haven't seen the light. Is this true?
03 59 28	P	Negative. I still haven't found it. Still looking, though.
03 59 37	CC	Roger.
04 00 34	P	Everything is nominal on this trip, Muchea. I don't believe anything went wrong at all.
04 00 38	CC	Roger. Understand. T/M reports you green here.
04 00 46	P	Roger.
04 00 49	CC	Aeromed the same.
04 00 52	P	Roger. Thank you.
04 01 17	CC	Faith Seven. How do you know that the beacon has deployed?
04 01 22	P	I felt it deploy.
04 01 24	CC	Roger.
04 01 27	P	I don't know which deployed the fastest, me or it.
04 01 28	CC	Ha, ha, ha! Roger.
04 01 51	P	I am directly on my 180 [degree] yaw, and with the Moon in the upper left hand corner of the window.
04 02 00	CC	Say again, Faith Seven.
04 02 02	P	. . . 180 degrees, and still haven't seen it.
04 02 05	CC	Would you say again your attitudes?
04 02 07	P	Roger. I'm zero roll, about −34 degree pitch, and yaw at 180 degrees. Small end forward.
04 02 17	CC	Roger, and you still haven't found the light?
04 02 20	P	Negative, still haven't found it.
04 04 08	CC	Faith Seven, Muchea Cap Com. We're approaching LOS. You found the light yet?
04 04 14	P	Negative. Not yet.
04 05 49	P	I am now yawed 180 degrees, 0 [degrees] roll, I have a very slight roll attitude into the right. The Moon is in the upper left hand corner of the window—the—directly on my 180-degree path; I'm not able to see the flashing light. I am observing the haze layer again that Wally described. At this time I am still looking for the light. I'm observing lightning flashes on the ground, down on Earth that is. Considerable cloud cover. Venus and Jupiter in the left-hand part of the window.
04 15 00	P	I should still be right on track, on the 180-degree yaw. Still no flashing light, and I'm beginning to get the brilliant blue of Sun rising in the East. Bright blue band underneath all this haze layer. I can see the haze layer, and the bright band of light demarcation coming underneath it. Quite distinctive. There's a faint greenish tint to it where there are clouds, apparently.

HAWAII (THIRD PASS)

Unreadable	CC	Faith Seven, Faith Seven, this is Hawaii.
04 16 39	P	Roger, Hawaii. Faith Seven reading you loud and clear. Roger, understand.
Unreadable	CC	Roger. Is your C-band beacon in a continuous position?
Unreadable	P	Negative. I have it on ground command. I'll bring it to continuous, now.
Unreadable	CC	Roger. On my mark will you switch your TV control switch to T/M, and read out your fuel and O_2 quantities?
Unreadable	P	Roger. Will do.
04 17 28	P	Roger. I am just small end forward. 180-degree yaw, approaching sunrise. Over.
Unreadable	CC (CNV)	Faith, Faith Seven, this is Cape Cap Com on Hawaii transfer for check. How do you read me, over?
Unreadable	P	Roger. Reading you loud and clear, Cape Cap Com.
Unreadable	CC (CNC)	Roger, Gordo. Pretty long talk-line here.

Unreadable	P	You're right.
Unreadable	CC	Stand by for my mark. MARK 04 23 35. Switch your TV control switch to T/M.
Unreadable	P	. . . now going over TV transmitter.
Unreadable	CC	Roger.
Unreadable	P	Roger. These small particles drift away from you, small end forward. In this light they appear brilliant white, without green at all in them. They appear to move on out, and around back toward the flight path.
Unreadable	CC	We're standing by for your readout of fuel and O_2.
Unreadable	P	Roger. My auto fuel, I have 96 percent; on manual, I have 102 percent. On oxygen I have 90 percent on primary and 100 percent on secondary.
Unreadable	CC	Roger. We understand. We also have a message from the Cape. It's possible that you only felt the squib blow and not the beacon deploy. Is there any way that you might check this?
04 24 31	P	Not from in here, I don't think.
04 24 34	CC	Roger, you haven't see the beacon at this time.
04 24 37	P	Negative. I still haven't seen the beacon.
04 24 40	CC	Check.
04 24 46	P	There was considerable noise, though, as if something were departing.
04 24 50	CC	Say again, Seven.
04 24 52	P	* There was considerable noise, which sounded like those doors blowing open so I assume the beacon has departed.
04 24 58	CC	Roger, understand.
04 24 06	CC	T/M looks real good on the ground.
04 25 08	P	Roger.

CALIFORNIA (THIRD PASS)

04 33 15	CC	Faith Seven, this is California Cap Com. Over.
04 33 18	P	Roger, California. Faith Seven.
04 33 21	CC	Roger, Faith Seven. Systems and medics are go here.
04 33 26	P	Roger. My date [flight plan] put my telemack to normal [switch position] . . .
04 33 35	CC	Roger. Just, just stand by a second until systems finish marking the meters.
04 33 45	P	. . .
Unreadable	CC	All right, at my mark then would you switch. I'll start a countdown then. 9, 8, 7, 6, 5, 4, 3, 2, 1, MARK.
Unreadable	P	Roger. . . .
Unreadable	CC	Okay. You confirm TV control switch to off?
Unreadable	P	Roger. TV control is off.
04 34 33	CC	We had a slight decrease in the two links on d-c current. Would you give us a readout?
04 34 41	P	Roger. D-c current: the main bus is 24 [volts]; isolated [bus], 28½ [volts].
04 34 50	CC	Roger.
04 35 32	CC	California standing by.
04 35 35	P	Roger.
Unreadable	P	. . . can see all up and down the California coast, here . . . very clear.
04 36 29	CC	Roger.
04 36 43	CC	I seem to have a little discrepancy between c.e.t. and g.e.t. You're 2 seconds fast according to my clock.
04 36 59	P	. . . I'll give you a mark . . . 4 37.
Unreadable	CC	Roger.
Unreadable	P	2, 1, MARK [Unreadable][T]
04 37 04	CC	Right. The ground shows that your readout there is confirmed with ground. However, it is 2 seconds fast from our g.e.t.
Unreadable	P	Roger.

CAPE CANAVERAL (FOURTH PASS)

04 40 04	CC	Faith Seven, Cape Cap Com.
04 40 08	P	Roger, Cape Cap Com. Faith Seven.
04 40 24	P	Roger, Cape Cap Com. Faith Seven here.
04 40 27	CC	Faith Seven. Cape Cap Com. Would you turn on your TV immediately?
04 40 32	P	Roger. Will do.

04 40 38	P	Faith Seven passing just about over Houston now.
04 40 45	CC	And would you program R and Z cal to auto.
04 40 53	P	Roger. TV coming on now. R and Z cal programer coming to auto.
04 41 01	CC	Understand TV on ; R and Z cal to auto.
04 41 13	CC	Seven, from Cape. Could you give us your best coolant valve settings, please.
04 41 22	P	Roger. Stand by 1 minute.
04 41 42	P	Roger. I'm below the nominal on the suit. I'm using about the 1¾ on suit.
04 41 54	CC	That's 1¾ on suit.
04 41 55	P	Roger, and using about 3.0 on the cabin.
04 42 01	CC	Understand 3.2 on the cabin.
04 42 06	CC	Give you [recovery area] 4–1 retro time. 05 43 41.
04 42 14	P	Roger, 43 41.
04 42 16	CC	Roger.
04 42 22	CC	Have you consumed any water up to this point?
04 42 26	P	Roger. I'm also giving the doctors their first space sample. For the Electro-Chancellor System, that is.
04 42 43	CC	Roger. We understand. We may send up another one ; we understand you're full.
04 42 49	P	Roger, who are you sending up with it?
04 42 59	CC	Seven, Cap Com. We'd like a cabin temp, cabin heat exchange outlet temp, and three H_2O_2 tank temps.
04 43 14	P	Roger. Cabin outlet is 42 degrees.
04 43 22	CC	Roger.
04 43 24	P	Peroxide auto tank is 80 degrees. Manual tank is 70 degrees. Reserve tank is 75 degrees. What else do you want?
04 43 40	CC	Like to know about the cabin air.
04 43 44	P	Roger. Cabin air temp is 90 degrees.
04 43 48	CC	Understand, 90 degrees.
04 43 52	CC	Gordo, this is Wally. Did you have anything to eat?
04 43 54	P	Negative, not yet. I'm planning to shortly, here, though.
04 44 02	CC	Roger. For your information, systems' last computations on fuel at Hawaii give 88 [percent] auto, 98 [percent] manual, which is somewhat better than you're indicating on board.
04 44 17	P	Roger. On board I'm indicating 96 and 102.
04 44 38	P	Oh, boy what a beautiful shot of Florida.
04 44 44	CC	Roger. Looks good from here once in awhile too.
04 44 46	P	*Roger. The whole state is clear. I can see just about all of it. It's been a beautiful view coming over Florida.
04 44 55	P	. . . looks very good.
04 45 01	CC	Roger.
04 45 05	P	. . .
04 45 12	CC	Roger, Faith Seven.
04 45 34	CC	Faith Seven, this is Cape Cap Com. We are very impressed with the work you're doing.
04 45 42	P	Thank you.
04 45 47	CC	We lay a pat on the back from Walt Williams.
04 45 52	P	Thank you.
05 05 03	P	Now on 180 [degrees] yaw. I got here on manual proportional control. I'm at last daylight, going into dark. Have been looking for the flashing beacon. 05 05 18 NOW, [05 05 17]^{T} 28, I'm sorry, not 18. That light in sight—it is below me. It is quite a brownish, reddish brown and considerable altitude above the ground. Every time I fire a pitch down thruster, I get a shower of these little fireflies. The light is flashing now. It is the light. It's quite bright, quite discernible . . . 1, 2, 3, 4, 5, 6, 7, rate. It appears to be about—it appears to be about 10 to 12 miles away. I'm keeping it directly in the window. About the order of a second magnitude star, NOW. [05 11 34]^{T}. Light is still in sight, directly in the center of the window. In the background I can make out a lot of cumulus activities, faced of course to the easterly direction at 180 degrees yaw.

05 13 40	P	*The Milky Way is quite distinct. I can see it out the window. The Milky Way is quite distinctive. It's right in the center of the window. Quite noticeable. 05 16 35 NOW. [05 16 35]T Light is still in sight. Moved off from it and then moved back using it for visual—to see if I could pick it up. I am able to pick it up. . . . thunderstorms all in under it at the moment. It is quite distinctive. 05 18 05 NOW. [05 18 05]T Status report: retro temperature, 62 [degrees]; pitch down is 82 [degrees]; pitch up is 72 [degrees]. Yaw left, 75 [degrees]; yaw right, 90 [degrees]. Roll counterclockwise, 92 [degrees], clockwise, 90 [degrees]. Main inverter temp., 98 [degrees]; fans inverter temp., 120 [degrees]; standby inverter, 98 [degrees]. The squeezers are working again as advertised. Okay, the cabin and suit temperature: the cabin air is 90 [degrees]; suit inlet temp. is 61 [degrees]. Heat-exchange dome temperatures: cabin, 56 [degrees]; suit, 56 [degrees]. D-c bus, 24 [volts]; isolated bus, 28 [volts]; and reading 7 amps, current.
05 34 58	P	*5 hours and 34 minutes; now it's 35 minutes MARK. [05 35 10]T Am drifting now. Do have the light in sight at the moment, apparently right on track. I see Antares on up ahead of me, which indicates that I am on the 180-degree drift point. See Corona Australis and, saw Sagittarius with Nunki apparently. 5 hours 39 minutes 30 seconds, MARK. [05 39 31]T
05 39 36	P	Have the little flashing light still in sight, out ahead of me. About the order of a first magnitude star, now. It's not very discernable . . . due to the flashes. However, it can be picked up. It appears like it's around 13—13 to 14 miles.

HAWAII (FOURTH PASS)

05 41 38	?	[Unintelligible, foreign language transmission recorded here.]
05 51 15	P	. . . there.
05 51 44	CC	Hello, this is Hawaii transmitting on air to ground relay. Do you read?
05 58 35	CC	Faith Seven, Faith Seven, Hawaii Cap Com. Over.
05 58 52	P	Roger, Hawaii Cap Com. Faith Seven, here. Over.
05 58 56	CC	Roger. Faith Seven. May we have an oral temperature at this time and also a readout of fuel and O_2 quantities?
05 59 03	P	Roger. . . .
05 59 06	CC	Roger. It looks good down here. Reading 100 [degrees].
05 59 11	P	Roger.
05 59 19	CC	Standing by for a fuel and O_2 quantity.
05 59 24	P	Roger. Auto fuel, 94 percent; manual fuel, 102 percent. Oxygen primary about 89 percent; secondary, 100 percent.
05 59 43	CC	Roger. Are you—are you in drifting flight?
05 59 47	P	That's affirm. I'm in drifting flight.
05 59 50	CC	Roger. Retrosequence time for [contingency recovery] area 5–A is nominal.
05 59 55	P	Roger. 5–A is nominal. Thank you.
06 00 17	CC	Seven. Cape has just advised you have enough time for 92 orbits.
06 00 27	CC	Hawaii, standing by.
06 00 30	P	Roger.
06 00 50	CC	Seven, this is Hawaii. Have you seen the beacon yet?
06 00 54	P	Affirm. I was with the little rascal all night last night.
06 00 58	CC	Roger. Very good.
06 01 01	P	I tracked it the first part of the night, and then went into drifting flight and then picked it up the last part of the night again. Over.
06 01 07	CC	Very good.

CALIFORNIA (FOURTH PASS)

06 05 55	CC	Faith Seven, this is California Cap Com.
06 05 59	P	Roger, California Cap Com. Faith Seven here.
06 06 02	CC	Roger. Systems and aeromedics give you a go here; and I'd like to check position on your C-band switch.
06 06 24	P	Roger. C-band is on continuous. Over.
06 06 28	CC	Read you. That's continuous?
05 06 29	P	That's affirmative.

06 06 39	CC	Would you please change your S—C-band beacon switch to ground command.
06 06 43	P	Roger. Going to ground command.
06 06 48	CC	On your schedule, for a B.P. [blood pressure] over this station.
06 06 52	P	Roger. You ready?
06 06 55	CC	We are. Roger.
06 08 31	CC	Aeromeds said they received the B.P. and would you turn it off.
06 08 35	P	Roger, will do.
06 08 37	CC	Would you give me a reading on your cabin PO_2 pressure?
06 08 42	P	Roger. Partial pressure of oxygen is about 4.4 [psi].
06 08 46	CC	Roger. Thank you.
06 09 35	CC	Five Baker, Five Charlie, and five . . . [contingency recovery area retrosequence times] are nominal.
06 09 40	P	Roger, thank you.
06 10 14	CC	. . . .
06 10 19	P	Roger.
06 10 26	P	Roger, go ahead.
06 10 30	CC	. . . +17 + 09.
06 10 35	P	Roger. 07 17 09.
06 10 38	CC	Affirm.

CAPE CANAVERAL (FIFTH PASS)

06 14 40	CC	Faith Seven, Cape Cap Com. Do you read, over?
06 14 45	P	Roger, Cape Cap Com. Faith Seven, here.
06 14 53	CC	Faith Seven, Cape Cap Com. Over.
06 14 56	P	Roger, Cape Cap Com. Faith Seven, here.
06 15 01	CC	Faith Seven, Cape Cap Com. Over.
06 15 05	P	Roger, Cape Cap Com. Faith Seven reading you loud and clear.
06 15 09	CC	Faith Seven, Cape Cap Com. Over.
06 15 17	P	Roger, Cape. Faith Seven is reading you loud and clear. How me? Over.
06 15 21	CC	Roger, Gordo. Read you same. Assume you have TV on. Are you looking out the window?
06 15 25	P	Affirmative.
06 15 28	CC	Can just see horizon line, sort of interesting.
06 15 38	CC	Gordo, how did the manual control check work out?
06 15 45	P	Worked out fine.
06 15 46	P	Very good. You're looking beautiful on fuel.
06 15 49	CC	Roger.
06 15 50	CC	Environment tells us that you are using about 4-percent oxygen per hour, indicated. Over.
06 15 59	P	Roger. It looks that way here.
06 16 04	CC	Well this is a computation that will show later on. This is as much as you're using. This is 4 percent of your 200 percent.
06 16 10	P	Roger.
06 16 12	CC	We'd like to have a brief rundown on the acquisition of the beacon if you acquired and an idea of about what distance away you would guess that it was.
06 16 22	P	Roger. When last I saw it, in the last orbit, looked like it was about 12 to 13 miles away. I first thought that it looked like it was about 8 or 10 miles away. And at the last it was getting fairly dim, about the order of a fourth or fifth magnitude star.
06 16 43	CC	Roger.
06 16 46	P	When I first . . . looked like a magnitude star.
06 16 51	P	There's Florida, should. . . .
06 16 54	CC	Roger. We're getting a pretty good picture on this, this time.
06 16 56	P	Roger.
06 16 58	CC	I'd say your f stop is ideal.
06 17 09	CC	Gordo, how did you initially acquire the beacon? Did it just come in your field of view?
06 17 14	P	Roger . . . .
06 17 21	CC	Roger, understand.
06 17 23	P	There it was.
06 17 27	CC	That was during the night side of this last orbit. Is that correct?
06 17 37	CC	Faith Seven, Cape Cap Com.
06 17 40	P	Go ahead, Cape.

06 17 41	CC	You acquired it during the night side of this past orbit. Was that correct?
06 17 44	P	It's affirmative. Just at night.
06 17 47	CC	You can see it only at night.
06 17 49	P	I acquired it just as it got dark, right.
06 17 52	CC	Very good.
06 17 53	P	It was just getting dark when I acquired it. It was shining, there was still sunlight and I could see it shining before I could see it flash, so apparently it had some light reflected off of it.
06 18 04	CC	Roger. Understand.
06 18 30	P	Roger. Turning off [TV] camera now.
06 18 39	P	Go ahead, Cape.
06 18 43	P	Go ahead, Cape, Faith Seven.
06 18 52	P	Roger, Cape. Faith Seven reading you loud and clear.
06 25 40	P	At 6 hours and 22 minutes I turned off the cabin coolant and the cabin fan. Now I'm preparing to eat a little bite. The sandwiches that I am looking at here are pretty crumbly, lot of crumbs floating all over in the bag that they're in. I may not open them.
06 32 23	P	*I just had two pieces of Brownie and nut, small cakes, and just now eating bacon. Will drink some water following this.
06 35 15	P	I have just drunk six or seven large sips of water from the McDonnell drinky drink.
06 54 31	P	* And it's 6 hours 54 minutes 37 seconds NOW. [06 54 38].[7] I have the flashing light in sight again—extremely weak, very, very weak. Actually, just barely discernible. I would estimate it to be somewhere in order of 18 to 20 miles away. The Moon is out, and the water is very, very bright, below. It's quite a lovely moonlit night.
07 03 39	P	Right on the flight plan, there's our old friend Delphinus. I am drinking water at 07 08 00, very fine. Took seven or eight large swallows from the McDonnell tank.
Unreadable	CC	. . .
07 18 09	P	*I was just called by CSQ and informed that Cape desired to leave C-band beacon off.
Unreadable	CC	. . .
Unreadable	P	Short report. Nitrogen low pressure: auto, 475 [psi]; manual 4 . . . B-nut: Pitch-down is 80 [degrees]; pitch up, 70 [degrees]. Yaw left is 72 [degrees]; yaw right is 75 [degrees]. Roll counterclockwise is 78 [degrees]; roll clockwise is 75 [degrees]. And auto tank temp., 79 [degrees]; manual tank, 71 [degrees]; reserve tank, 75 [degrees]. Isolated bus voltage, 28.

HAWAII (FIFTH PASS)

Unreadable	CC	Hello Faith Seven. Faith Seven, Hawaii Cap Com. Do you read?
Unreadable	P	Roger, Hawaii Cap Com. Loud and clear.
07 31 50	CC	Roger. Faith Seven, this is Hawaii Cap Com. For your information, all your experiments should be on time; you have two-tenths cloud coverage for the light experiment. Your electrical power usage has been below expected. [Contingency recovery] area 6–A [retrosequence time] is nominal. Stand by to copy [recovery area] 6–1 [retrosequence] time, 08 50 17. Did you copy?
07 32 08	P	08 50 17, for 6–1.
07 32 13	CC	Roger, and 6–Bravo is also nominal. Will you turn your beacons to ground command at this time and give me a readout on your fuel and oxygen quantities, also your peroxide reducer [regulated] pressure, auto and manual? Over.
07 32 34	P	Roger. Say again on the beacon. What do you want on them?
07 32 39	CC	Roger. Will you put your beacons to ground command at this time?
07 32 43	P	Roger. Beacons are on ground command. Peroxide regulated pressure: 475 [psi] on auto; 490 [psi] on manual. . . . O_2 percent on manual; oxygen is 101 percent on primary, and 100 [percent on secondary].
07 33 12	CC	Roger, give me your fuel again please, Gordo.
07 33 15	P	Fuel is auto, 90 [percent], manual, 102 [percent].
07 33 24	CC	Roger. We've copied all. Did you turn your T/M on for CSQ? Over.
07 33 39	P	. . .
07 33 42	CC	Say again, Gordo.
07 33 44	P	Negative, I did not turn my T/M on for CSQ.
07 33 48	CC	Roger. They did report getting a short burst. Will you please leave T/M off for all periods greater than 30 minutes; no contact with ground stations.
07 33 52	P	Roger.

07 34 15	CC	Faith Seven, Hawaii Cap Com. Do you read?
07 34 17	P	Roger, Hawaii.
07 34 19	CC	Roger. I have [recovery area] 7-1 and 8-1 [retrosequence] times. Do you read?
07 34 23	P	Roger. Go.
07 34 25	CC	7-1 is 10 23 33. 8-1 time is 11 56 24. Did you copy?
07 34 37	P	Roger. 7-1 is 10 23 33; 8-1 is 11 56, and what was the second?
07 34 46	CC	24.
07 34 48	P	24, Roger.
07 34 49	CC	Roger. You're looking fine on the ground, Gordo.
07 34 53	P	Roger. Thank you. I saw the flashing beacon again last night.
07 34 58	CC	Roger. I understand you saw it throughout?
07 35 00	P	I saw the flashing beacon again last night.
07 35 04	CC	Roger. Understand.
07 40 22	P	*In auto orbit. I'm pumping the condensate tank out; and will open the KK clamp. Two strokes, both syringes full, third full syringe full, four syringes full, five syringes full.

CALIFORNIA (FIFTH PASS)

07 40 52	CC	Faith Seven, this is California Cap Com.
07 40 55	P	Roger, California. Faith Seven here.
07 40 58	CC	Roger. Faith Seven. Schedule for B.P. [blood pressure], exercise, and a B.P.'s.
07 41 03	P	Okay, you ready?
07 41 04	CC	Roger.
07 41 06	P	Understand.
07 41 09	CC	Same exercise as Muchea is requested by the medics.
07 41 13	P	Roger.
07 41 59	P	Here comes the exercise.
07 42 12	P	Starting exercise now.

GUAYMAS (FIFTH PASS)

07 42 28	CC	Faith Seven, Guaymas Cap Com.
07 42 29	P	Roger, Guaymas.
07 42 32	CC	Roger, Gordo. Have a little information to pass on to you.
07 42 36	P	Roger. Let me get my exerciser stored back in here.
07 42 39	CC	Roger. You through?
07 42 40	P	Blood pressure coming now, Cal.
07 42 53	P	Roger. I'm through with this.
07 42 56	CC	Roger. We would like to remind you to pump out your condensate and turn on your water wick at about 8 hours.
07 43 04	P	Roger.
07 43 06	CC	And would you give us oral temperature over CSQ. Start taking your temperature at about—elapsed time of—at about 08 45.
07 43 18	P	Roger. Over CSQ. Is that affirm?
07 43 20	CC	Roger. We want to get one over CSQ.
07 43 25	P	Roger.
07 43 26	CC	And the Cape would like to remind you to keep your T/M turned off when you're out of contact with stations. They're trying to keep a close track of the power you've used.
07 43 35	P	Roger.
07 43 39	CC	And you can turn off your blood pressure now.
07 43 51	CC	Did you read that, Gordo?
07 43 53	P	Roger.
07 43 58	P	You said turn off the blood pressure. Right?
07 44 00	CC	Roger. And you can power up your ASCS bus anytime.
07 44 03	P	Roger. Stand by.
07 44 14	P	Roger. Powered up. 120 volts.
07 44 19	CC	Roger, we can—you're okay down here.
07 44 26	P	Okay.
07 45 51	CC	Gordo, have you cut anything off? We get—just got a drop in current.
07 45 57	P	Negative.
07 45 58	CC	Roger.
07 46 03	P	I have ASCS a-c bus powered up. It draws more current when it starts, I suppose.
07 46 09	CC	Roger, I guess that's it.

07 59 04	P	*Scanners are not working very rapidly. Spacecraft is yawed to the left very, very, except in yaw is, all right I mean. Correction, is rolled to the left about 10 degrees and the gyros read okay. Here comes some correction in now. They're beginning to correct. And this syringe full is about full. There is a lot of air in it; this is the last one I'll take out.
08 00 47	P	I'll add it on to all the others, I believe that's 5½. Took 10 large swallows of water. And I am now opening the Kenney Kleinknecht clamp.
08 16 09	P	*Peroxide reserve tank is 72 degrees. Peroxide manual tank, 70 degrees; peroxide auto is 78 degrees. Cabin outlet is 66 [degrees]. 250 inverter is 105 [degrees]; 150 inverter is 120 [degrees]; standby inverter is 95 [degrees]. Oxygen, 90 and 100 [percent]. Fuel, 86 and 102 [percent] . . . Here, I have the light in sight, in the top portion of my window. Extinctometer reading I got was—not any good there, blocking out by the top part of the window. . . . I did observe the ground light; it's quite bright.
08 23 25	P	Very recognizable in the little town. A little horseshoe shaped town was quite distinctive; it was right beside it.
Unreadable	P	*Now in auto reentry. Gyros going to slave. I got there in fly-by-wire low to 0, 0, 0 [degrees], selected auto reentry, and have now put the gyros to slave.
08 26 15	P	*Manual pitch plane precession was a little too great, as the gyros are torquing a little bit of negative pitch in here to correct for the pitch torquing . . . overage. The damn desk is unusable; it's too far down on the lap, and it will not lock down. My legs are in the way at zero g. Cannot bring it down to lock down.
08 35 35	P	*There seems to be some difficulty with the number two urine collection bag. It's very difficult to pump more than the 1½ syringes full that I got into it. And I hear a hissing back behind me; so I suspect there is too much pressure on it, and I'm going to cease on this one.
08 44 29	P	Auto reentry. I see when each one of the thrusters fires, the little fireflies come out of the thrusters and drift away to the rear. Some of them impinging on the spacecraft but depart later. The auto reentry [ASCS reentry attitude mode] portion of the auto mode is holding within plus or minus—within a 11½ degree band. That is, is apears to be slightly more sloppy than ASCS orbit. However, this may not be true; ASCS orbit is not very fine control either. But it is controlling it fairly well.

COASTAL SENTRY QUEBEC (SIXTH PASS)

08 52 13	P	. . .
08 52 16	CC	Roger. We're not getting T/M very good here. Do you have T/M on? Over.
08 52 21	P	Roger.
08 52 22	CC	Roger. He has T/M on.
08 52 26	CC	Do you have TV on, Gordo? Over.
08 52 28	P	Negative.
08 52 30	CC	Roger.
08 52 31	P	TV coming on now.
08 52 33	CC	Roger.
08 52 37	CC	Are you ready to copy retro times? Over.
08 52 39	P	Roger. Go.
08 52 41	CC	Roger. [Contingency recovery area] 7–A [retrosequence time] is 09+11+42 and 7–B is 09+40+19. Over.
08 52 56	P	Roger. . . .
08 53 06	CC	This is CSQ. I didn't get your readback on that. Over.
08 53 30	CC	Faith Seven, CSQ. Cape wants a cabin air temp readout, please. Over.
08 54 00	CC	This is CSQ, Faith Seven. We're reading you very weak, barely readable. Repeat cabin air temp please. Over.
09 00 20	P	Now I am getting ready to release the balloon. I have tape on continuous; I'm on fly-by-wire low, going to three zeros. Camera is in place in the mount and really is in the way of the yaw indicators. And I am on three zeros, squib switch to arm, 16 millimeter camera on, going to extend, hold for 5 seconds; 1, 2, 3, 4, 5, off.
09 01 26	P	Squib off. Pitching slowly down, very, very slowly, going down—very slowly. I did not hear the balloon deploy. Perhaps you cannot hear it deploy; I don't know. Easing down ever so slowly. And I don't see the balloon anywhere yet. And I'm doing a rather sloppy job of flying now, trying to look for the balloon.

09 04 21	CC	Hello Faith, Faith Seven. Hawaii Cap Com. Do you read?
09 04 23	P	Roger. Faith Seven here.
09 04 26	CC	Roger. Gordo, reading you 3 by 3. We need a fuel, and oxygen and cabin-air temperature readouts please.
09 04 34	P	Roger. Cabin air, 90 [degrees]; fuel is 86 percent [auto]; 102 percent [manual]. Oxygen is 190 and 100 [percent].
09 04 46	CC	Roger, copied. Are you ready to begin your balloon experiment at this time? Over.
09 04 52	P	I have already tried to deploy the balloon at 9 hours. The balloon did not deploy.
09 05 01	CC	Roger. Understand you tried to deploy the balloon at 9 hours elapsed, and it did not deploy. Is that correct?
09 05 08	P	This is affirm.
09 05 11	CC	Roger. Have you had any food and water yet?
09 05 14	P	Roger. I have had food and water.
09 05 16	CC	Roger. Would you care to comment on the ground-light experiment?
09 05 20	P	Roger. I saw the ground-light experiment.
09 05 24	P	*Would you ask Cape if they would like me to try deploying this balloon again? Over.
09 05 30	CC	Roger. They are monitoring you; you will get an answer from them shortly. What's your control mode, your gyro switch position, and your status?
09 05 40	P	Roger. My status is go, my control mode is fly-by-wire low; gyros are on slave.
09 05 51	CC	And your gyro switch position, please?
09 05 54	P	Gyro switch position is slave. Over.
09 06 01	CC	Roger.
09 06 05	CC	*Faith Seven, Hawaii Cap Com. Cape advises that you try to deploy the balloon again, and would you give us a mark when you throw the switch. Over.
09 06 08	P	Roger.
09 06 17	P	Roger.
09 06 27	P	Roger, 16-mm camera is on.
09 06 33	CC	Roger, Gordo. Is your squib switch on?
09 06 35	P	Not yet. It will be before I try again, though.
09 06 38	CC	Roger. Just give us a countdown.
09 06 41	P	Roger. Squib is coming on NOW. [09 06 44][T]
09 06 45	CC	*Roger. Understand squib switch is on now.
09 06 56	P	5, 4, 3, 2, 1 [09 07 05][T]—no joy.
09 07 06	CC	Roger. Understand the balloon still does not deploy.
09 07 13	P	Squib switch is off.
09 07 16	CC	Roger. Understand squib switch is off. Hawaii standing by.
09 07 57	CC	Faith Seven. Hawaii Cap Com.
09 07 58	P	Go ahead, Hawaii.
09 07 59	CC	Roger. What's your status with respect to cabin temp and suit temp? Do you feel hot?
09 08 06	P	Roger. Cabin temp is 90 [degrees], suit temp is 61 [degrees].
09 08 11	CC	Okay. And you feel okay, not too hot?
09 08 12	P	Roger, feel fine.
09 08 15	CC	Sounds fine, you look fine. Have a good flight.
09 08 17	P	Roger, thank you.
09 10 04	P	*The balloon did not deploy; felt no shock; hear nothing on it. I will go continuous this portion where the balloon normally would have been used, in auto reentry. I will go around in auto orbit mode. Perhaps I can snap a few pictures for the ground people.
09 11 18	P	*. . . Bingo, I shifted into auto, orbit mode. I got no thrusters on the shift—and scanners seem to be holding it relatively close.
09 18 40	P	*What do you know? The Kenney Kleinknecht experiment is putting water in the exhaust tube, so maybe it is working here.
09 21 31	P	Short status report. . . . air outlet, 68 degrees. 250 inverter, 120 [degrees], 150 inverter, 128 [degrees], standby inverter, 102 [degrees]. Reserve peroxide tank, 71 [degrees]; manual peroxide tank, 69 [degrees]; auto peroxide tank, 78 [degrees]. [Retropack] is 61 [degrees]. Pitch down, 52 [degrees]; pitch up, 55 [degrees]. Yaw left, 68 [degrees]; yaw right, 68 [degrees]. Roll counterclockwise, 85 [degrees]; roll clockwise, 82 [degrees]. Regulated low nitrogen pressure, 475 [psi] auto; 490 [psi] manual. Isolated bus 28 volts.

09 27 08	P	. . . going to pump the rest of that urine into the number 2 tank. First . . . sample. I believe it is pumping correctly. The thing about this pumping under zero g is not good, tends to stand in the pipes, and you have to actually forcibly force it through.
09 40 20	P	Radiation experiment on at 09 39.
09 50 25	P	Radiation experiment coming off, NOW. [09 50 29][T]

ZANZIBAR (SIXTH PASS)

10 00 09	P	. . . O_2 primary is 79 percent.
10 00 18	CC	Reconfirm that, please.
10 00 19	P	Roger. Just a hair short of 80 percent. Over.
10 00 24	CC	O_2 primary?
10 00 27	P	O_2 primary. That's coming in at 180 percent. Over.
10 00 33	CC	Affirmative.
10 00 35	P	It's that Frank Samonski gage, and the secondary is 100 percent.
10 00 41	CC	Affirmative.
10 00 47	CC	Faith Seven, this is Zanzibar Cap Com. At this time, you are go for 17 [passes]. You are go for 17.
10 01 00	P	Roger. Thank you, Zanzibar.
10 01 04	CC	MCC advises that they do not want you to jettison your balloon. They are working on an alternate method for releasing the balloon.
10 01 17	P	Roger. Understand. I will not jettison.
10 01 20	CC	Roger.
10 01 29	CC	Faith Seven, Zanzibar Cap Com.
10 01 30	P	Go ahead.
10 01 31	CC	I have new [retrosequence] times for [recovery area] 7–1. Are you ready to copy?
10 01 35	P	Roger. Go.
10 01 37	CC	Your G.m.t. or c.—, do you want G.m or c.?
10 01 42	P	C.e.t.
10 01 47	CC	C.e.t. is 10 23 37 c.e.t. Do you read?
10 02 01	P	Roger. 10 23 37. Understand.
10 02 05	CC	That takes into account the 5-second error in your clock.
10 02 09	P	Roger. Thank you.
10 02 16	CC	Faith Seven, Zanzibar Cap Com. Check your cabin [heat exchanger] dome temperature.
10 02 23	P	Roger. Cabin dome temperature is 70 degrees.
10 02 28	CC	We confirm on the ground.
10 02 29	P	Roger.
10 02 39	CC	Can you give us a PO_2 cabin?
10 02 42	P	Roger. PO_2 cabin is about 4.4 psi.
10 02 51	CC	4.4?
10 02 54	P	Roger.
10 03 31	CC	Faith Seven, Zanzibar Cap Com.
10 03 34	P	Roger. Go.
10 03 37	CC	Everything looks good here.
10 03 39	P	Roger. Thank you very much. Everything looks good here.
10 03 42	CC	Okay, Zanzibar out.
10 03 44	P	Roger.
10 04 07	P	*Putting my visor back now. I've had to keep increasing the suit flow from a [comfort control valve] setting of 1.5 that I have right now to a setting of about 2.7. Dome is about 58 degrees. Inlet temp. is 58 degrees. This increase in the suit water flow is probably required by the cabin going on up. The heat load in the cabin is gradually going on up, using powered up, and having a cabin fan and cabin coolant turned off.
10 18 23	P	At a [comfort control valve] setting of 3 on the heat exchanger.

COASTAL SENTRY QUEBEC (SEVENTH PASS)

10 24 57	CC	Hello, Faith Seven, CSQ Cap Com. Over.
10 25 01	P	Roger, John. Faith Seven here.
10 25 03	CC	Faith Seven, CSQ. Cape advises you could go ahead and power down here, over our site if you like. Over.
10 25 11	P	Roger. Will do. You have any kind of a reproduction device down there?

10 25 16	CC	No, we're not, Gordo. We're not getting a doggone thing on that; don't know what's wrong with it. You are transmitting, is that affirm?
10 25 23	P	Roger.
10 25 25	CC	Nope. We're not getting any TV at the moment.
10 25 28	P	Okay. . . .
10 25 39	CC	Negative. The boys here tell me we're not getting any carrier on it at the moment.
10 25 47	P	Roger.
10 25 59	CC	This is CSQ Cap Com. You're going ahead and powering down, is that affirmative?
10 26 07	P	That is affirm. I'm going to fly-by-wire now. . . .
10 26 10	CC	Roger.
10 26 21	P	Roger. Auto is off.
10 26 24	CC	Roger. Auto off.
10 26 32	P	Gyros are caged.
10 26 34	CC	Roger. Gyros caged.
10 26 40	P	ASCS a-c bus off.
10 26 43	CC	Roger.
10 26 54	P	The highest my 250 inverter got up to was 130 degrees.
10 26 59	CC	Roger. Understand 250 only got up to 130, is that affirm?
10 27 03	P	Roger.
10 27 30	CC	Roger. We're dropping you.
10 27 40	CC	Gordo, the surgeon wants to know if you're sweating any at the moment. Over.
10 27 46	P	Very lightly, not very much.
10 27 49	CC	Roger.
Unreadable	P	*. . . At roughly 10 hours and 27 minutes, brought auto ASCS control to select. Lights are off. Caged the gyros. Have ASCS a-c bus. At the time the 250 inverter was reading 130 degrees, the highest it had been. The cabin was 96 degrees, the highest it has been. The cabin already is coming down; it's 91 degrees, already.

HAWAII (SEVENTH PASS)

10 37 27	CC	Hello Faith Seven, Hawaii Cap Com. Do you read?
10 37 45	CC	Faith Seven, Hawaii Cap Com. How do you read?
10 37 52	P	. . .
10 37 55	CC	Roger, Faith Seven. Reading you 3 by 4. Will you turn your tape recorder to program at this time.
10 38 05	P	Roger. It is on program. Over.
10 38 08	CC	Roger. R and Z cal to auto.
10 38 12	P	R and Z cal is in auto.
10 38 13	CC	And C-band beacon to ground command now.
10 38 17	P	C-band to ground command now.
10 38 19	CC	Roger. We're standing by for a blood pressure and a fuel and oxygen readout.
10 38 24	P	Roger. Fuel, 81 [percent] auto, 101 [percent] manual. Oxygen is 175 percent primary, 100 percent secondary. Cabin temp, 90 degrees. Here comes blood pressure.
10 38 44	CC	Roger. Understand blood pressure is on the air. Say again cabin temp.
10 38 48	P	Cabin temp is 90 degrees.
10 38 51	CC	Roger. Read 90.
10 39 12	CC	Faith Seven, Hawaii Cap Com. Turn your C-band beacon on at this time. Over.
10 39 18	P	Roger. Coming on now.
Unreadable	CC	Roger, your [contingency recovery area] 8-Alpha and 8–Bravo [retrosequence] times are nominal.
10 39 25	P	Roger. 8-Alpha and Bravo are nominal.
10 39 30	CC	T/M is commanded. Stand by.
Unreadable	CC	Roger, Faith Seven, Hawaii Cap Com. Commanding T/M on at this time.
10 39 56	P	I have it on continuous. You want it on ground command?
10 39 59	CC	Negative, that's fine.
10 40 05	P	Okay.
10 40 18	CC	Faith Seven, Hawaii Cap Com. Turn your T/M to ground command.
10 40 23	P	Roger. Going to ground command now.
10 40 29	P	On ground command.
10 40 35	CC	Roger.

10 41 03	?	. . . Cooper, can you come in on emergency frequency. Come up on 11176. Hickam out.
10 41 35	CC	Faith Seven, Hawaii Cap Com. Your mode and gyro switch position please.
10 41 40	P	Roger. Roger. ASCS control on select, mode select off, fly-by-wire thrust select low, pitch torquing on, gyros to cage, and pitch attitude on orbit.
10 41 53	CC	Hawaii. Roger.
10 42 29	CC	T/M commanded on this time. Faith Seven.
10 42 33	P	Roger.
10 43 14	CC	Faith Seven, Hawaii Cap Com. We're receiving R cal at this time. Will you make sure you have your C-band beacon to ground command before AOS. Over.
10 43 24	P	Roger, will do.
10 43 41	P	C-band beacon coming to ground command now.
10 43 44	CC	Roger. Understand C-band, ground command now.
10 49 34	P	Took some pictures out of the window with the remainder of the first roll of film on the 16 mm. The color film camera in the bracket.
10 50 18	P	* Low nitrogen pressure in 475 [psi] auto; 490 [psi] manual. B-nut temps: pitch down, 86 [degrees]; pitch up, 65 [degrees]; yaw left, 66 [degrees]; yaw right, 70 [degrees]; roll counterclockwise, 98 [degrees]; roll clockwise, 92 [degrees]. Auto peroxide tank, 82 [degrees]; manual peroxide tank, 68 [degrees]; reserve peroxide tank, 76 [degrees].
10 51 18	P	Isolated bus, 28 volts, and I am pulling 6 amps, right now.
11 16 18	P	Tape [and radiation] experiment is now on. I'm eating a pot roast or beef. I've had considerable difficulty getting the water in it from this water device on the McDonnell water tank. I spilled water all over my hands and all over the cockpit here trying to get some in it. I have succeeded in getting about half of it dampened and am proceeding to eat.
11 19 20	P	I am washing my face with a damp cloth now. Certainly feels good.
11 22 30	P	[Forcing grunt]. This is ridiculous. Come out of that damned ditty bag—Pandora's locker.
11 28 31	P	Radiation experiment is off. Tape recorder to program.
11 31 00	P	* It is rather a strange feeling to be able to place objects out into the cabin and let go of them and they'll stay in relatively their same position. This is worrisome as well as an odd sensation. Handy sometimes.

ZANZIBAR (EIGHTH PASS)

11 33 07	CC	Faith Seven, Zanzibar Cap Com. I'd like to get a c.e.t. time hack in about 30 seconds.
11 33 15	P	Roger. We have 11 34 30 on my mark. 5, 4, 3, 2, 1, MARK. [11 33 31][T]
11 33 36	P	That's 11 33 30.
11 33 38	CC	Roger.
11 33 49	CC	Faith Seven, Zanzibar Cap Com.
11 33 53	P	Go ahead.
11 33 54	CC	Your clock is now 7 seconds fast—plus 7 seconds.
11 34 01	P	Roger. Understand. Plus 7 seconds.
11 34 06	CC	[Recovery area] 9–1 [retrosequence] time is 13 19 20. 13 19 20.
11 34 21	P	Roger. 13 19 20.
11 34 25	CC	If you have to set your clock, you'll have to add 7 seconds to that.
11 34 30	P	Roger. Understand.
11 34 40	CC	Your T/M looks good on the ground, Faith Seven. Your T/M looks good.
11 34 45	P	Roger. Thank you.
11 34 49	CC	We'd like to have a TRF clock readout from the capsule also, please.
11 34 54	P	Roger. Time to retrograde will be 22 23 20 on my mark. MARK. [11 35 07][T] Retrograde time, 33 58 26.
11 35 15	CC	We concur.
11 35 17	P	Roger.
11 35 57	CC	Faith Seven, Zanzibar Cap Com.
11 36 01	P	Go ahead.
11 36 03	CC	Everything looks real good on the ground. Cape says they have nothing else for you at this time. We'll see you next time around.
11 36 09	P	Roger, Zanzibar. Thank you.

11 49 58	P	* All right on number 2 [photograph]. I've just taken [a picture, number 3] over India. And I'm just coming in over China very shortly. This is on the general purpose film in the Hasselblad.
11 51 21	P	*Photo 3 with the general purpose film. Here come the Himalayas. Number 4 [photograph] of the Himalayas. First three at 1/250, f/11. These are two . . . that last one was 1/250, f/16.

COASTAL SENTRY QUEBEC (EIGHTH PASS)

Unreadable	CC	Faith Seven.
Unreadable	CC	Hello, Faith Seven CSQ Cap Com. Over.
11 55 57	P	Roger. Faith Seven here.
11 55 58	CC	Roger. Reading you loud and clear, Gordo. Is the TV on?
Unreadable	P	Negative. I'll bring it on now. I didn't think it would work.
Unreadable	CC	Roger, go ahead. We didn't pick it up before here. I got your [contingency recovery area] 9-Able and Baker [retrosequence] times for you if you're ready for them.
11 56 13	P	Roger, stand by 1. Roger, go.
11 56 39	CC	Roger. 9–A is 12+18+24 and 9–B is 12+43+05. Over.
Unreadable	P	Roger 12 18 24. 12 43 05.
Unreadable	CC	That's affirmative, and Cape requests at the end of this pass you can turn your R and Z cal switch off so it will be off for the rest period. Over.
Unreadable	P	Roger.
11 56 57	CC	There we go. We're getting a little picture on you here now, if we can get the thing adjusted a little better.
11 57 07	P	Roger. How's that?
11 57 10	CC	We're receiving a carrier on you here but we're not getting very good modulation. Just big light spots going on and off. Over.
11 57 18	P	Roger. Probably not getting too much light. Just 1 second—I should be getting enough Earth shine off of it here to help.
11 57 25	CC	Okay, good. You upside down?
11 57 27	P	Roger.
11 57 37	CC	Is it on you?
11 57 39	P	Roger.
11 57 46	CC	Can you open the lens up a little bit on that. It's not getting enough light here.
11 57 50	P	Okay it's wide open now.
11 57 51	CC	Roger.
11 58 49	CC	You on fly-by-wire, Gordo?
11 58 52	P	Negative. I have everything powered down now.
11 58 56	CC	Roger. Just drifting. Affirm?
11 58 57	P	Roger.
11 58 58	CC	Roger.
11 59 04	P	Full drift with ASCS a-c powered down.
11 59 07	CC	Roger.
11 59 38	CC	You're sure looking good. Everything couldn't be finer on this pass.
11 59 43	P	Roger. Everything looks good here, John.
12 00 09	CC	How's cloud cover? Do you have a pretty good view?
12 00 14	P	Quite a bit of cloud cover right over you here. A little bit earlier there was a pretty good open area.
12 00 23	CC	It should be interesting to look at.
12 00 26	P	Roger.
12 01 07	CC	For your info, Gordo, we're getting good reports from the monitor aircraft for later on, for retro too.
12 01 13	P	Roger. Thank you.
12 01 30	CC	Surgeon would like to know what your cabin temp is now.
12 01 33	P	Roger. Cabin temp is about 87 degrees.
12 01 37	CC	Roger, very good. You're looking fine.
12 05 58	P	*An interesting aspect of this little liquid experiment that I have along is that the liquid remains on it in globules, hanging along the side in round globule form; and the air is trapped within it in globules and does not separate from it.

12 11 40	CC	Faith Seven, Hawaii. Do you read?
12 11 46	P	Roger, Hawaii. Faith Seven reading you loud and clear.
12 11 48	CC	Roger. Reading you loud and clear. Standing by for blood pressure, fuel and oxygen.
12 11 52	P	Roger.
12 12 01	P	Blood pressure coming now.
12 12 03	CC	Roger.
12 12 09	P	Fuel is 81 percent auto; 101 percent manual. Oxygen is just about 170 percent primary, and 100 percent secondary.
12 12 30	CC	Roger, Faith Seven. Say again oxygen secondary.
12 12 33	P	100 percent.
12 12 35	CC	100, roger. Blood pressure off at this time, please. And did you say 101 manual fuel?
12 12 46	P	That's affirmative 101 manual and about 81 automatic.
12 12 51	CC	Roger. That's all we need. You look good on the ground, you're doing a great job.
12 12 57	P	Roger, thank you, Buddy.
12 13 24	CC	Faith Seven, Hawaii. You clock is holding 7-second error.
12 13 28	P	Roger. Thank you.
12 14 08	P	The eighth picture was shot over Hawaii to the south.
12 14 17	CC	Faith Seven, Hawaii. Could you give me suit [heat exchanger] dome temp, please.
12 14 21	P	*Roger. Suit dome temp is about 45 degrees. I increased flow. Got it down a little low, and I'm easing it back now.
12 14 31	CC	Roger. Understand, understand suit dome 45.
12 14 35	P	*That's right.
12 14 48	CC	Faith Seven, Hawaii. What about O_2 partial pressure.
12 14 53	P	Roger. O_2 partial pressure is about 4.2 [psi], cabin.
12 14 57	CC	4.2. Roger.
12 14 58	P	Roger.
12 15 18	P	Roger. Now back to the scribe mark on the suit temperature selector of about 2.7 with the power down.
12 15 31	CC	Faith Seven, Hawaii. Our T/M shows suit dome of about 38 degrees.
12 15 41	P	Roger. I just decreased the setting, just a minute ago, again.
12 15 45	CC	Roger.
12 17 33	P	*Suit dome temp.'s down to about—slightly below 40 degrees. Decreased the setting of the flow twice, and it's on its—should be on its way back up any moment.
12 21 36	P	*Short status report: Hydrogen peroxide and low nitrogen pressure: 475 [psi] auto, 490 [psi] manual. B-nut temps: pitch down, 85 [degrees]; pitch up, 60 [degrees]; yaw left, 55 [degrees]; yaw right, 70 [degrees]; roll counterclockwise, 85 [degrees]; clockwise, 92 [degrees] . . . auto tank, 85 [percent]; manual tank, 68 [percent]; reserve tank, 98 [percent]. Isolated bus voltage, 28 [volts]. Pumping from the condensate tank to the reserve tank, I have a syringe full. Suit circuit seems to be getting varying amounts of water, probably from the condensate tank, or tin can. Coolant water flow seems to vary considerably. I have it clear back down to a setting of 1. Still haven't gotten the heat exchanger dome temperature out of the warning light area. It is now about 45 degrees. Never have been able to put water in these containers, that have water, due to the leaking of this valve in the back of it. I'm unable to put it into the water, into the plastic neck of the container, and get water into it without leaking water all over the cockpit.

ROSE KNOT VICTOR (EIGHTH PASS)

12 26 00	CC	Faith Seven, RKV Cap Com.
12 26 05	P	Hello RKV.
12 26 07	CC	We have aeromed and systems go here.
12 26 18	P	Roger. Say again RKV.
12 26 21	CC	We have aeromed go here, and systems go.
12 26 25	P	Roger, very good. I'll take the temperature probe out now, then.
12 26 30	CC	We've got a long list of capsule readouts that the Cape requires before you go into the
12 26 42	P	rest period.
12 26 43	CC	Roger. Go.

12 26 53	P	Okay, 24 volts main. Just rotate the switch through, Gordo. All positions on your d-c volts. Roger, d-c volts: Main [bus], 24½ [volts], isolated [bus], 28 [volts]; main [battery] one is 25 [volts]; main [battery] two is 25 [volts]; main [battery] three is 25 [volts]; standby [battery] one is 25 [volts]; standby [battery] two is 25 [volts]; isolated [battery], 28½ [volts].
12 27 11	CC	Roger, understand. 150 v-a [inverter] volts?
12 27 17	P	Roger, 150 v-a is still 121 [volts]; fan, 121 [volts].
12 27 24	CC	Fans bus, 121 [volts]?
12 27 26	P	Roger.
12 27 27	CC	Suit-coolant and cabin-coolant control valve settings.
12 27 33	P	Roger. I'm back on 2.5 on the suit. Cabin is still shut down.
12 27 41	CC	Roger. Partial CO_2 and partial O_2.
12 27 45	P	Roger. Partial O_2 cabin is about 4.2 [psi], and suit CO_2 is on the bottom peg, zero.
12 27 55	CC	Roger. Auto and manual fuel pressure?
12 27 59	P	Roger. Auto fuel pressure, 475 [psi]; manual fuel pressure 490 [psi].
12 28 04	CC	Roger. Okay temperatures, just rotated through pitch, and all the way through.
12 28 13	P	Roger. Retro, 62 [degrees]. Pitch down, 75 [degrees]; pitch up, 60 [degrees]. Yaw left, 55 [degrees]; yaw right, 70 [degrees]. Roll counterclockwise, 95 [degrees]; roll clockwise, 93 [degrees].
12 28 37	CC	Roger, H_2O_2 reserve, manual and auto.
12 28 41	P	Roger. Auto peroxide tank is 85 [degrees], manual is 68 [degrees], and reserve is 78 [degrees].
12 28 52	CC	Roger. Cabin heat-exchanger-outlet temperature.
12 28 55	P	Cabin heat-exchanger outlet 72 [degrees]; 250 inverter, 112 [volts]; 150 inverter, about 1—just a second I'll get a light on, I'm getting in the dark—125 [volts].
12 29 13	CC	Roger.
12 29 14	P	Fans inverter about 110 [volts].
12 29 17	CC	Roger.
12 29 23	CC	Okay, that settles this. Can you give me some indication of your tape remaining?
12 29 29	P	Roger. Just a moment. Roger. I have about 75 percent remaining.
12 29 44	CC	Roger. Can you give us a blood pressure?
12 29 50	P	Roger. Coming now.
12 29 56	CC	Okay, the Cape advises that if you desire to turn your T/M to continuous, we'll cut down on the unnecessary communications for the rest of the rest period.
12 30 11	P	Roger.
12 30 31	CC	C.e.t. is showing plus 7, plus 7.
12 30 35	P	Roger. Plus 7.
12 31 12	CC	Seven, RKV. Do you intend to go on a rest period from this site?
12 31 17	P	Roger.
12 31 46	CC	Seven, RKV. Are you sweating any?
12 31 50	P	Negative.
12 31 52	CC	No sweat.
12 32 08	CC	We have you all go on aeromedical and systems. Looks like you can settle down for a long rest.
12 32 14	P	Roger. Thank you.
12 32 36	CC	Seven, RKV. We have LOS.

(NINTH PASS)

13 17 17	P	Photo number 8 being made over Africa, to the north. *(Non-flight-related transmission omitted.)
13 18 47	P	Another being made over Africa.
13 20 32	P	I can see roads, and rivers, and some small towns down here on the ground. Small villages are pronounced. Can almost make out the individual houses.
13 23 30	P	*Now we're in the next series of 12. Over . . . Africa. The first series were started over Africa and across on orbit 9—on across Arabia through India, and that last series of three or four pictures were made right over the Himalayas, and in the India, India-China area.
13 28 39	P	Checking fly-by-wire thrusters, they all work. Fly-by-wire lows, manual proportional, and checking manual thrusters now. Checking yaw, and yaw works, pitch down works, pitch up works, roll left works, roll right works. Manual handle off.

COASTAL SENTRY QUEBEC (NINTH PASS)

13 32 41	P	CSQ Cap Com. Faith Seven.
13 33 18	CC	Hello, Faith Seven, CSQ. Roger. Received you, go ahead with your message.
13 33 24	P	Roger. Just passing over. Everything's nominal here I haven't really started my rest period yet. I had a little tussle with the heat exchanger, with the suit, and I finally got it adjusted.
13 33 38	CC	Roger. Understand, heat exchanger is adjusted now for suit. We are still trying to pick up your TV here. We're not getting a very good picture on it. Over.
13 33 46	P	Roger.
13 33 48	CC	Roger. We had a message out around the range here to keep quiet that you were asleep, and we thought it looked like a typical asleep-type pass on your biosensors here.
13 33 59	P	Roger.
13 34 02	P	Roger. I was busy here just before the pass.
13 34 04	CC	Roger.
13 34 10	CC	Did you say you were asleep just before the pass. Over.
13 34 13	P	Negative. I was busy looking out the window and fiddling with this suit dome temp.
13 34 20	CC	Roger.
13 34 28	P	I've checked my manual and fly-by-wire thrusters and am ready to start my rest period now.
13 34 35	CC	Roger. Understand checked manual fly-by-wire. Ready to start rest period now.
13 34 39	P	Roger.
13 34 42	CC	All right. You will tell everyone to go away and leave you alone now. Okay?
13 34 48	P	Roger.
13 34 52	CC	You're looking real good, Gordo. Everything is going real fine, boy.
13 34 55	P	Roger. Thank you, John.
Unreadable	P	*. . . fourth picture on that second series was made just out from CSQ. Number 6 of second series, taken over at 13 56. Went to sleep at about 13 50. Slept 'til 14 46 quite soundly, slept quite heavily, awoke not realizing where I was—completely, soundly asleep. Picture 8 of second series in the Burma-India area at 14 58 30. Took number 9 over the Himalayas.

TENTH PASS

15 11 35	P	*Standby inverter, 102 [degrees]; 150 inverter, 110 [degrees]; 250 inverter, 102 [degrees]; H_2O_2 auto tank, 85 [degrees]; manual fuel tank, 70 [degrees]. Roll counterclockwise, 78 [degrees]; roll clockwise, 82 [degrees]; yaw right, 65 [degrees]; yaw left, 64 [degrees], pitch up, 58 [degrees]; pitch down, 70 [degrees]. Retro, 67 [degrees]. I put the window cover on 15 14 15 for a period of time and now have awakened.

ELEVENTH PASS

16 28 51	P	*Short status report: Peroxide low pressure regulated: 475 [psi] auto; 490 [psi], manual; clockwise thruster, 72 [degrees]; counterclockwise thruster, 78 [degrees]. Yaw right at 61 [degrees]; yaw left at 60 [degrees]; pitch up is 52 [degrees], pitch down is 58 [degrees]. Retro is 55 [degrees]; auto 85 [degrees]; manual is 70 [degrees]; . . . reserve is 70 [degrees]. Photo series at 16 hours and 40 minutes. Having the problem with the suit exchanger dome temp, . . . down to the freezing mark with a [comfort-control-valve] setting of about 1½. Take a setting of 1 to 1½ and then takes almost turning it off to get it back. It seems to be very inconsistent, in the settings that will take to hold an even heat exchanger dome temperature. Went asleep again and am awake now. Suit temperature is . . . 5.

TWELFTH PASS

18 04 20	P	Photo sequence number 3 made on the Indian coast line at 18 hours and 4 minutes. Next photo made at 18 hours and 5 minutes.
18 14 01	P	*The time is now 18 hours and 14 minutes. Short status report: Nitrogen low pressures: 475 [psi], auto; 490 [psi], manual. Retropack, 71 [degrees]. Pitch down thruster, 58 [degrees]; pitch up, 50 [degrees]. Yaw left, 58 [degrees]; yaw right 52 [degrees]; roll counterclockwise, 72 [degrees]; [roll] clockwise, 70 [degrees]. H_2O_2 auto tank, 82 [degrees]; peroxide manual tank, 72 [degrees]; peroxide reserve. . . . Main bus is 25½ [volts]; isolated bus voltage is 28½ [volts]. [Battery number 1] 25 [volts]; number 2 is 25 [volts]; number 3 is 25 [volts]; standby 1 is 25 [volts]; standby 2 is 25 [volts]; isolated is 28½ [volts]; back to main. Reading 121 volts on the fans. Everything is proceeding along very well. Everything is normal, except for this bothersome heat-exchanger dome temp, and I just can't seem to keep it either from being on the freezing mark or going on over. I vary the settings between . . . and completely off.

COASTAL SENTRY QUEBEC (THIRTEENTH PASS)

19 38 39	P	*Went to sleep again, slept very soundly. And it's time for a short status report: Nitrogen regulated pressure . . . auto, 475 [psi], manual, 490 [psi]. B-nut temps: First, retro temp, 75 degrees. Pitch down thruster, 55 [degrees]; pitch up thruster, 50 [degrees] yaw left, 56 [degrees]; yaw right, 50 [degrees]; Roll counterclockwise, 72 [degrees]. Roll clockwise, 70 [degrees]; Peroxide auto tank, 82 [degrees]; manual tank, 72 [degrees]; reserve tank, 75 [degrees]. Isolated bus voltage, 28.
19 42 15	P	*One comment on these various sleep periods that I've had; nearly everytime that I have awakened, I found that I have been so soundly asleep I don't even know where I am when I awake.
20 23 37	P	*Have a note to be added in for head-shrinkers. Enjoy the full drifting flights most of all, where you have really the feeling of freedom, and you aren't worried about the systems fouling up. You have everything turned off and just drifting along lazily. However, I haven't encountered any of this so called split-off phenomena. Still, note that I am thinking very much about returning to earth at the proper time and safely. Over.

FOURTEENTH PASS

21 00 35	P	Time for another short status report. Auto regulated pressure: 475 [psi], manual, 490 [psi]. Retropack temp, 75 [degrees], pitch down thruster, 51 [degrees]; pitch up, 49 [degrees]; yaw left, 55 [degrees]; yaw right, 50 [degrees]; roll counterclockwise, 72 [degrees]; roll clockwise, 70 [degrees]. Peroxide auto tank, 80 [degrees]; manual tank, 74 [degrees]; reserve tank, 74 [degrees].
21 02 39	P	Darned suit heat-exchanger [comfort-control valve] again. Setting is down to 1¼. One and one-half held it for a while. And now it's gone down to 40 [degrees] on the dome temp. Inlet temp, 62 [degrees].
21 05 16	P	Number 7, sequence 3 was made looking back at Arabia. At 21 05, cabin temp is now 82 degrees; 250 inverter is 95 [degrees]; 150 inverter is 115 [degrees]; a standby inverter is 95 [degrees].

MUCHEA (FOURTEENTH PASS)

		[Extended garbled transmission here. It sounded as though it might have been Spanish.]
21 22 34	P	Hello, Muchea Cap Com. Faith Seven here. Over.
21 22 39	CC	Go ahead, Faith Seven. This is Muchea Cap.
21 22 43	CC	Go ahead, Faith Seven. This is Muchea Cap Com.
21 22 46	P	Roger, Muchea Cap Com. Faith Seven. I'm awake now. Just thought I'd check in with you.
21 22 50	CC	Roger. How was your sleep?
21 22 54	CC	How was your sleep?
21 22 56	P	Very good.
21 22 58	CC	Do you like your coffee white or black?
21 23 02	P	I'll have tea, thank you.
21 23 04	CC	*Roger.
21 23 10	P	In fact, hot black tea would go very well right now.
21 23 14	CC	Roger.
21 23 18	CC	When you get a chance, will you give us your spacecraft status and your status?
21 23 24	P	Roger. Everything is nominal heare. I've had some difficulty with the suit heat-exchanger dome temp, and it's been running with the light on most of the time; but I have it well under control and the suit inlet temp has been running very comfortably.
21 23 45	CC	Very good.
21 23 47	P	My status is excellent.
21 23 50	CC	Roger. Will you give me an auto and manual fuel reading?
21 23 55	P	Roger. Let me get some more lights on here, since I'm in the dark.
21 24 00	P	*Roger. Auto fuel is reading 69 percent and manual 95 percent.
21 24 10	CC	Say again last.
21 24 11	P	Oxygen 150 percent on primary; 100 percent on secondary. The manual fuel is 95 percent.
21 24 23	CC	Roger. I didn't copy your manual fuel.
21 24 25	P	Roger. Manual fuel is 95 percent.
21 24 28	CC	I copied auto at 79.
21 24 32	P	Roger. It's 69, 69.
21 24 35	CC	Roger.

21 24 37	P	Cabin temp is 84 degrees.
21 24 41	CC	Roger.
21 24 55	CC	Stand by, Faith Seven.
21 24 57	P	Roger.
21 25 13	CC	I have [recovery] area 15–1 retrosequence time. Please prepare to copy.
21 25 21	P	Roger. Go.
21 25 24	CC	22 02 13.
21 25 28	P	Roger. 22 02 13.
21 25 31	CC	That's affirmative. Area 15–1.
21 25 43	P	Roger. Got it.
21 25 45	CC	What's your present control mode?
21 25 49	P	I'm in full drift.
21 25 51	CC	Roger.
21 25 59	CC	We have about 1 minute to LOS.
21 26 02	P	Roger.
21 26 39	CC	Hello, Faith Seven, Muchea Cap Com. Do you have anything to report?
21 26 44	P	Negative. I guess not. Everything's fine here.
21 26 47	CC	Roger. Systems report, you go here and aeromed, also.
21 26 51	P	Roger. Thank you.
21 26 53	CC	Roger.
21 36 40	P	*It is 21 36 46 NOW. (21 36 46)[T] I am observing lights of several small cities and scattered areas on the ground. Apparently over the east coast of Australia.
21 46 18	P	*I am viewing to the east now; and I can see very clearly, as I mentioned before, a band of haze layer above the Earth's horizon through which the stars can be seen. Although they're quite faint here and then clear below it. It goes around the earth, approximately the same distance around, just a corona-type thing around the Earth's surface.
21 49 38	P	*I would like to take this time to say a little prayer for all the people, including myself, involved in this launch and this operation. Father, thank You, for the success we have had in flying this flight. Thank You for the privilege of being able to be in this position, to be up in this wondrous place, seeing all these many startling, wondrous things that You've created. Help guide and direct all of us that we may shape our lives to be good, that we may be much better Christians, learn to help one another, to work with one another, rather than to fight. Help us to complete this mission successfully. Help us in our future space endeavors that we may show the world that a democracy really can compete, and still is able to do things in a big way, is able to do research, development, and can conduct various scientific, very technical programs in a completely peaceful environment. Be with all our families. Give them guidance and encouragement, and let them know that everything will be okay. We ask in Thy name. Amen.

CAPE CANAVERAL (FIFTEENTH PASS)

22 03 39	P	Hello, Cape Cap Com. Faith Seven here.
22 03 47	P	Roger, shoot.
22 03 55	CC	The regulated low pressure scores.
22 04 00	P	Roger. I'm reading 475 [psi] auto and 490 [psi] manual.
22 04 10	CC	Could we have an H_2O_2 reading?
22 04 16	P	Roger. That's—say again.
22 04 21	CC	. . . .
22 04 28	P	Just a minute on the . . . .
Unreadable	P	Roger.
Unreadable	CC	Faith, can I have you on H_2O_2 tank temperature?
Unreadable	P	Auto tank is 81 degrees; manual tank is 74 degrees; reserve tank is 74 degrees.
22 06 05	CC	Faith Seven, Cape Cap Com. Over.
22 06 07	P	Cape, Faith Seven.
22 06 09	CC	Roger. Did you use any auto fuel during the sleep period?
22 06 15	P	Negative.[1]
22 06 19	CC	Would you put your R and Z cal to auto?
22 06 22	P	Roger.
22 06 26	CC	We reckoned your fuel to the 69 and 89 (percent). Over.
22 06 32	P	Roger. I read you 69 and 95.

[1] Pilot answer referred to current rest period only.

22 06 38	CC	Roger.
22 06 42	CC	Is your tape recorder on schedule?
22 06 57	CC	We are getting a good picture of you on TV now. Over.
22 07 01	P	Roger. Understand.
22 07 04	CC	Did you transfer any water or urine? Over.
22 07 10	P	Boy, did I ever!
22 07 17	CC	Do you have any air wick observation?
22 07 27	P	Roger. They seem to separate water all right.
22 07 39	CC	Faith Seven, did you make any air wick observation? Over.
22 07 43	P	Affirmative. It does separate water. Over.
Unreadable	P	Did you read me, Cape?
Unreadable	CC	Roger. I read you now. Did you make an air wick observation?
22 08 00	P	Affirmative. It works.
22 08 04	CC	Roger. How is your comfort and humidity level in the suit?
22 08 11	P	Fine.
22 08 12	CC	Very good.
22 08 15	CC	Our surgeon has some goodies. Did you have any dreams?
22 08 20	P	Negative. I slept too soundly to dream.
22 08 24	CC	Roger. We thought you might have had one one time when your suit dome light may have come on.
22 08 33	P	My suit dome light was on a good portion of the time.
22 08 36	CC	Roger. We understand that.
22 08 40	CC	We'd like you to give a body temperature to Canary on your next pass over them coming up. Would you set your oral probe on for that? Over.
22 08 50	P	Roger.
22 08 53	CC	Pass time at Canary is nominal, so about 2 or 3 minutes before would help.
22 09 00	P	Roger.
22 09 09	CC	Would you give us a reading on your coolant-control-valve settings, and what they are now?
22 09 16	P	Roger. Right at the moment I'm reading about 1.8 on suit temp and the cabin is still turned off.
22 09 27	CC	Roger. We concur.
22 09 45	CC	Faith Seven. R and Z cal program switch to off.
22 09 54	P	Roger. Off.
22 09 56	CC	And you can secure TV. We had a pretty fair picture.
22 10 00	P	Roger.
22 10 08	CC	We can see you were drifting and dreaming, can't we?
22 10 11	P	Roger.
22 10 30	CC	Faith Seven, Cape Cap Com.
22 10 32	P	Come in Cape Com, Faith Seven.
22 10 34	CC	I've been asked to relay a message to you from the president of the Republic of El Salvador. I will read: "In the name of the Salvadorian government and people, and in my own right, it gives me pleasure to send you cordial greetings and sincere congratulations on the occasion of your valiant exploit, which constitutes an historic triumph for the free world. Julio Adalberto Rivera, President, El Salvador."
22 11 06	P	Very good, very good.
22 11 07	CC	Roger.
22 12 00	CC	Faith Seven, Cape Cap Com.
22 12 02	P	Go ahead. Cape.
22 12 06	CC	I'll give you c.e.t. hack at 50 mark.
22 12 08	P	Roger.
22 12 09	CC	That was 22 11 50.
22 12 13	P	Roger.
22 12 16	CC	MARK 12 minutes.
22 12 18	P	Roger.
22 12 24	P	. . .
22 12 36	CC	Faith Seven, you're cutting out, it's about LOS. See you next time around boy-san.
22 12 41	P	Roger.

22 18 26	CC	Faith Seven, this is Canary Cap Com. You need not acknowledge this transmission, requesting you turn on your TV and your S-band beacon if you have not already done so.
22 18 40	P	Roger. TV's on.
22 18 49	CC	This is Canary Cap Com. Did you put your—wait a minute, we're getting the body temperature now.
22 19 17	CC	This is Canary Cap Com. Surgeon requests that you hold your body temp probe in your mouth for about 1 more minute.
22 20 01	CC	This is Canary Cap Com. You may take the body temperature probe from your mouth now. Over.
22 20 09	P	Roger. Thank you.
22 20 14	CC	Your [contingency recovery area] 15-Bravo [retrosequence] time is nominal and request a partial O_2 readout, please.
22 20 26	P	Roger. My 15-Bravo is nominal. Cabin partial pressure O_2 is about 4.2 [psi].
22 20 34	CC	Roger. Understand 4.2. I'd like to try to get a c.e.t. clock error here; so I'm going to give you a time hack. I'd like for you to give me the difference in the clocks. On my mark the time will be 22 20 40. MARK. (22 20 57)[T]
22 20 58	P	. . .
22 21 01	CC	Understand 15 seconds.
22 21 05	CC	Roger. . . . .
22 21 07	P	Roger. Understand.
22 21 29	CC	Astro confirms 15. Over.
22 21 35	?	Roger.
22 22 15	CC	This is Canary Cap Com. Could you give me a cabin-pressure readout, please?
22 22 20	P	Roger. Cabin pressure 5.2 [psi].
22 22 23	CC	Roger.
22 23 37	CC	We're getting pretty close to LOS here. Request you turn TV off and the S-band beacon to ground command. Over.
22 23 44	P	Roger. TV off and S-band beacon to ground command.
22 23 47	CC	Roger.

KANO (FIFTEENTH PASS)

22 27 16	CC	Faith Seven, this is Kano Cap Com. We have T/M solid. We would like a cabin (heat-exchanger) dome temperature. That is the only high reading. Over.
22 27 24	P	. . .
22 27 34	CC	Say again.
Unreadable	P	. . .
27 27 44	CC	Roger.
22 27 49	CC	Astro, have you eaten? Over.
22 27 58	CC	Astro, this is Kano Cap Com. Have you eaten? Over.
22 28 03	P	. . . Cabin dome is 72 degrees.
Unreadable	CC	Roger. Have you eaten? Over.

ZANZIBAR (FIFTEENTH PASS)

22 36 27	CC	Faith Seven, Zanzibar Cap Com.
22 36 29	P	Roger, Zanzibar, Faith Seven.
22 36 32	CC	T/M looks good on the ground here. We have no big problems. Like to have fuel and oxygen readings.
22 36 39	P	Roger. . . . fuel, auto . . ., manual 95 percent. Oxygen 150 percent primary, and 100 percent secondary.
22 36 53	CC	Please repeat primary oxygen.
22 36 56	P	150 percent.
22 36 58	CC	Roger. Your [recovery area] 16–1 [retrosequence] time, 23 31 03. 23 31 03.
22 37 12	P	23 31 03.
22 37 16	CC	That is affirmative. That is g.e.t. and does not include your clock error.
22 37 20	P	Roger.
22 37 26	CC	Faith Seven. Have you eaten this morning?
22 37 30	P	Negative. Not yet this morning.
22 37 33	CC	Roger.

22 37 53	CC	Faith Seven. Zanzibar Cap Com. The surgeon would like to know what—how you feel this morning?
22 37 58	P	Fine. Excellent.
22 38 04	CC	Very good.
22 49 25	P	And here comes the short status report again: Nitrogen regulated low pressure: auto, 475 [psi]; manual 490 [psi]. B-nut temperature: pitch down, 50 [degrees] pitch up, 49 [degrees]. Yaw left, 55 [degrees]; yaw right, 51 [degrees]. Roll counterclockwise, 78 [degrees]; roll clockwise, 78 [degrees]. Auto peroxide tank, 80 [degrees]; manual tank, 72 [degrees]; reserve tank, 73 [degrees]. Isolated bus voltage, 28.

MUCHEA (FIFTEENTH PASS)

22 53 25	CC	Faith Seven, Muchea Cap Com.
22 53 27	P	Roger, Muchea Cap Com. Faith Seven.
22 53 30	CC	Are you checking your high thrusters?
22 53 40	CC	Are you checking your high thrusters?
22 53 54	CC	Faith Seven, Muchea Cap Com. Do you copy?
22 53 56	P	Roger, Muchea Cap Com. I am not . . . my thrusters. Over.
22 54 01	CC	Say again last.
22 54 02	P	I am not checking my thrusters. Over.
22 54 05	CC	Roger. We had a partial T/M dropout.
22 54 10	P	Roger.
22 54 16	CC	Have you made any checks on thrusters?
22 54 19	P	Roger. I made a couple of them, three different ones of them. I'm going to bring up my rate indicators shortly and check the rest of them.
22 54 29	CC	Roger.
22 55 03	CC	Systems report T/M looks good and aeromeds report you look good.
22 55 07	P	Roger.
22 55 33	CC	Are you changing the control valve setting on your suit heat exchanger?
22 55 38	P	Roger. Suit dome is on its way down very slowly.
22 55 45	CC	Roger. We concur.
22 55 52	CC	Have you had your breakfast?
22 55 54	P	Negative.
22 57 00	CC	Faith Seven. Could you give me a report on that thruster check? Which thrusters are okay?
22 57 06	P	Roger. I've checked my yaw thrusters both auto and manual. I'm going to ASCS bus and then turn my rate gyros on, and in first-light then check the remainder of my thrusters.
22 57 24	CC	Roger.
22 57 26	P	While alining the spacecraft.
22 57 28	CC	Say again.
22 57 30	P	I will check thrusters while alining spacecraft, while uncaging gyros.
22 57 34	CC	Roger.
22 59 38	CC	We have approximately 1 minute to LOS.
22 59 42	P	Roger.
23 06 51	P	*Just brought the rate indicators to manual on position, and they're indicating about a half of a degree right roll rate, half a degree pitch up rate, and 1 degree left yaw rate. I have now checked my manual proportional thrusters, and they all function correctly and C-band beacon on continuous.

GUAYMAS (FIFTEENTH PASS)

23 31 02	CC	Faith Seven, Guaymas Cap Com.
23 31 07	P	Go ahead, Guaymas Cap Com, Faith Seven.
23 31 09	CC	You sound good, Gordo. Are you going to have time for the ASCS?
23 31 14	P	Roger. The ASCS is powered up. I powered it up about 1 minute ago. Right now, my rate indicators are powered up.
23 31 27	CC	Roger. Tape recorder continuous.
23 31 30	P	Roger. Tape recorder continuous.
23 31 32	CC	How about the C-band?
23 31 35	P	Roger. . . . .

23 31 36	CC	Roger. Are you going to check your thrusters over here?
23 31 44	P	Roger. I've already checked my manual thrusters, and I've checked about half of my fly-by-wires. I'm going to wait 'til daylight and I'll get the rest of my fly-by-wires while I aline the spacecraft.
23 31 59	CC	Roger. You say you're waiting for daylight.
23 32 01	P	Roger. I'm going to aline the spacecraft with the thrusters while getting a check on the rest of them.
23 32 08	CC	Roger.
23 32 21	P	I'll check my fly-by-wires now and aline my spacecraft manually on the manual proportional.
Unreadable	CC	Roger.
23 32 29	P	Checking fly-by-wires now. Man, do those ever throw out the fire at night.
23 32 48	CC	Say again, Gordo. I didn't read that.
23 32 49	P	You can really see the sparks from the thrusters at night.
23 32 53	CC	Ha, ha! Roger.
23 33 13	P	Roger. All fly-by-wire low thrusters work correctly.
23 33 18	CC	Roger.
23 33 29	CC	Could you give me your fuel readings, Gordo?
23 33 33	P	Roger. I have 65 percent auto and 95 percent manual.
23 33 38	CC	Roger.

CAPE CANAVERAL (SIXTEENTH PASS)

23 36 44	CC	Faith Seven, Cape Cap Com. Do you read? Over.
23 36 46	P	Roger, Cape Cap Com, Faith Seven.
23 36 49	CC	Roger. Welcome back, Gordo.
23 36 52	P	Roger. Thank you.
23 36 53	CC	I have a roll angle for you for your dim light study. Over.
23 36 59	P	Roger. Go ahead.
23 37 01	CC	Your angle is 34 degrees at sunset. That is, roll right, 34 degrees.
23 37 08	P	34 degrees. Understand.
23 37 10	CC	Could you give me a reading of your cabin air?
23 37 13	P	Roger. Cabin air temp's about 86 degrees.
23 37 17	CC	Roger, 86. Have you had a good meal today?
23 37 22	P	Fairly good.
23 37 25	CC	Roger.
23 37 27	P	I'm alining the spacecraft now.
23 37 33	CC	Roger. Your attitudes look like you're almost in.
23 37 39	P	It would because the gyros are still caged.
23 37 42	CC	That's interesting.
23 37 44	P	I say they would because the gyros are still caged.
23 37 47	CC	Good deal. You've got real good attitudes on the caged gyros.
23 37 50	P	Roger.
23 37 52	CC	Did you read that I said roll right 34 degrees?
23 37 55	P	Roll right 34 degrees. Roger.
23 38 09	CC	Would you give us some TV, Gordo?
23 38 27	CC	Hello dahr.
23 38 28	P	Hello dahr.
23 39 32	CC	Faith Seven, Cape Cap Com. Would you give us a yell if you get an auto fuel light? Over.
23 39 37	P	Roger.
23 40 57	P	*Caged gyros coming to slave.
23 41 02	CC	Roger.
23 41 20	CC	Our scanners are checking out quite closely, Gordo.
23 41 24	P	Roger.
23 42 36	P	Going to auto.
23 42 46	P	Foiled it again.
23 43 10	CC	Faith Seven, Cape Cap Com.
23 43 12	P	Go ahead, Cape Cap Com, Faith Seven.
23 43 15	CC	Roger. You can kill your TV. Your scanners and attitudes match perfectly at LOS.
23 43 21	P	Roger. Thank you.

23 43 26	P	I'm on auto control.
23 43 28	CC	Roger. Understand on auto control.
23 43 30	P	Roger.
		*[Unconfirmed transmissions omitted.]

CANARY ISLANDS (SIXTEENTH PASS)

23 51 41	CC	Faith Seven, this is Canary Cap Com. We have T/M solid. All systems are green. Do you confirm TV on? Over.
23 51 53	P	Roger. TV is on.
23 53 34	CC	This is Canary Cap Com. Could you send us a blood pressure now, if you please?
23 53 39	P	Roger.
23 53 46	CC	We are receiving blood pressure now.
23 56 22	CC	Faith Seven, would you take a deep breath and hold it, please?
23 56 26	P	Roger.
23 56 31	CC	Okay, exhale, exhale.
23 57 03	CC	Faith Seven, inhale, please.
23 57 50	CC	This is Canary Cap Com, we are coming up on LOS. You may turn off your TV camera, please.
23 57 54	P	Roger.

KANO (SIXTEENTH PASS)

23 58 01	CC	Faith Seven, Kano has T/M solid.
23 58 04	P	Roger, Kano. All systems green here.
23 58 07	CC	I'll give you a check in a minute. Thank you.
23 58 10	P	Roger.
23 58 12	CC	They are all green on the ground.
23 58 14	P	Roger.
23 59 36	CC	Faith Seven, this is Kano Cap Com.
23 59 40	P	Go ahead, Kano.
23 59 41	CC	I thought I'd tell you that [contingency recovery] Area 16–B [retrosequence time] is nominal.
23 59 45	P	16–B is nominal. Roger. Thank you.
24 05 20	CC	Site of Kano will have LOS at 13 08 56.

ZANZIBAR (SIXTEENTH PASS)

24 06 39	P	Hello, Zanzibar, Faith Seven here.
24 06 42	CC	Faith Seven, Zanzibar Cap Com. Go ahead.
24 06 45	P	Roger. First, I have a message for you.
24 06 47	CC	Roger.
24 06 51	P	Hello Africa. This is Astronaut Gordon Cooper, speaking from Faith Seven. I am right now over 100 miles above Africa, speaking to the Zanzibar station. Just a few minutes ago, I passed Addis Ababa. I want to wish success to your leaders there. Good luck to all of you in Africa.
24 07 12	P	Are you ready for a consumable readout now?
24 07 14	CC	Go ahead.
24 07 16	P	Roger. Auto fuel, 63 [percent]; manual, 93 [percent]. Oxygen primary, 145 [percent], secondary 100 [percent].
24 07 29	CC	Confirmed. T/M looks good on the ground here.
24 07 36	P	Roger.
24 07 45	CC	How does it feel on the second day, Gordo?
24 07 48	P	Fine. I may get used to this thing, yet.
24 07 52	CC	Roger.
24 09 17	CC	Faith Seven. Zanzibar Cap Com.
24 09 18	P	Go ahead, Zanzibar.
24 09 20	CC	The surgeon would like to know how deep is your breathing at the present time.
24 09 26	P	Roger. Not very deep.
24 09 28	CC	Roger. Thank you.
24 09 30	P	Here is a full breath.

24 09 34	CC	Please repeat.
24 09 35	P	All right. Now I have a full breath in.
24 09 39	CC	You are taking full breaths. Very good. That's what our recording on the ground shows.
24 09 43	P	Roger.
24 10 18	P	I am now in auto control. Set up for the dim-light experiment. As soon as the Sun approaches the horizon, I will aline with the Sun. Fly-by-wire. Cage and put gyros free. Roll 34 degrees right, cage, gyros free. Back on auto and start taking the pictures.
24 11 03	CC	Faith Seven. Zanzibar Cap Com.
24 11 06	P	Go ahead, Zanzibar.
24 11 08	CC	How much tape do you have remaining on your recorder?
24 11 12	P	About 70 percent.
24 11 14	CC	Roger. Cape advises that you can go onto continuous tape recording.
24 11 20	P	Roger.
24 13 50	CC	Faith Seven. Zanzibar Cap Com.
24 13 52	P	Go ahead, Zanzibar.
24 13 54	CC	Clock readout now shows a +16 seconds. I will give you a mark at 24 13 50.
24 14 02	P	Roger.
24 14 06	CC	1. MARK. (24 14 07) [T]
24 14 10	P	Roger. I was reading 24 14 07 at the time. That's about right—16 seconds.
24 14 22	CC	Roger.
24 14 23	P	Yeah. I was reading just 6, going to 7. That would be right.
24 17 54	P	Okay. The Sun is almost to the horizon. I'm going to fly-by-wire low—yawing over to the left just a little to get to the Sun.
24 19 04	P	I'm perfectly alined. Caging the gyros. Bang, bang. Gyros to free. I'm going to have to get them again. Quite alined in yaw.
24 19 50	P	Boy! This is going to be a doozy, right into the Sun.
24 20 55	P	Okay, gyros caged, to free, 34 degrees right.
24 21 52	P	Gyros caged; gyros free; auto orbit mode; lights off; warning lights off.
24 22 31	P	Here comes 1. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. 1,001. Number 2 exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Third exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Fourth exposure. Trip. 1,001. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 2, 3. Release. 1,001. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Number 3. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Number 4. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.
		Here comes 1. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. 1,001. Number 2 exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Third exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Fourth exposure. Trip. 1,001. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 2, 3. Release. 1,001. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Number 3. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Number 4. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. 10-second series. Trip. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Release. 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 2, 3, 4, 5, 6, 7, 8, 9, 10. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. 30-second exposures. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Trip. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 1, 2, 3. Go ahead, Muchea. 5, 6, 7, 8, 9, 10, 11, 12.

MUCHEA (SIXTEENTH PASS)

24 27 57	P	Roger. Status is green.
24 28 00	CC	Roger. We have it.
24 28 02	P	Dad burn it 21, 22, 23, 24. Roger. Thank you. Roger, I'm busy taking all these picture sequences, counting 1, 2, buckle-my-shoe type thing.
24 28 23	CC	Roger.

24 28 26	P	Ha, ha !, I'm up to 5,244 now. Ha, ha !
24 28 43	P	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, release. 1, 2, 3, 4, 5, 6, 7, 8, 9.
24 29 10	CC	. . . Minus . . . pitch attitude and about a —14 on your horizon scanner pitch output. Would you check this?
24 29 19	P	Roger. I am on gyros free ; auto control ; gyros free : pitch plane torquing on.
24 29 27	CC	Roger.
24 29 28	P	I am pitching around the plane of the ecliptic to take these pictures.
24 29 31	CC	Understand.
24 29 43	P	12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Identifier pictures, two of them. Oops, tripped two accidently. I'm on slave.
24 30 46	P	Faith Seven is now gone to slave and will let the scanners process the spacecraft back around slowly.
24 30 51	CC	Roger. We concur here.
24 31 07	P	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78.
24 31 59	CC	Pitch attitude and horizon scanners.
24 32 01	P	80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, just a minute 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20.
24 32 33	P	Roger. My gyros—it looks like I'm fairly closely on. I can see the actual horizon, and of course, my gyros are being precessed by the scanners back slowly because they were off quite a bit being gyros free and pitch plane precession on.
24 32 50	CC	Roger. . . . You are coming in here now, too.
24 32 54	P	Roger. I wasn't sure the spacecraft would fly this way, but it seems to be doing all right.
24 33 01	CC	Roger.
24 33 07	P	Now for the 30-second exposures. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Roger. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. [223-second break here]
24 37 44	P	13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20. 30-second one coming. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, off.
24 40 54	P	Okay. Third series. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20.
24 42 29	P	30-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. 10-second exposure over. I don't believe the camera tripped right. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.
24 44 56	P	Okay, starting the next series. MARK [24 45 01][T.] 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74. Go ahead, Canton.

CANTON (SIXTEENTH PASS)

24 45 59	CC	Roger. Your [recovery] Area 17–1 [retrosequence] time is 25 04 12. Over.
24 46 08	P	25 04 02?
24 46 12	CC	Negative. 25 04 12.
24 46 16	P	Roger. 25 04 12.
24 46 20	CC	Affirmative.
24 46 28	P	That just about gets it. 30-second one. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.
24 48 51	P	Radiation experiment went on 1 minute ago.

24 49 38	P	Okay, one more series here for you. Starting NOW. (24 49 45)[T] 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, exposure off. 30-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, off.
24 56 06	P	The last series. 1 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, ... 30, 31, (etc.) 40, (etc.) 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, . . . 2, 3, . . . 14, 15, 16, . . . 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60. There is the 2-minute one off. 30-second one started. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second one on. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and a big fat hen and that one's off.
24 58 24	P	And my fuel quantity light came on at 61 percent at 24 58 25.
25 00 25	P	Here comes the sunrise pictures. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. The 1-second one taken and off.
25 01 50	P	The second set of 30 and 1. 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, the 1-second one, and off. And that winds up the zodiacal lights [photography]. May they rest in peace.
		*[Unconfirmed transmission omitted.]

GUAYMAS (SIXTEENTH PASS)

25 03 22	CC	Faith Seven, Guaymas Cap Com.
25 03 25	P	Roger, Guaymas go ahead.
25 03 26	CC	Have you started your photos yet?
25 03 29	P	Man, that's all I have been doing all night long.
25 03 32	CC	Roger, Hasselblad?
25 03 34	P	Roger, I'm just getting them out right now.
25 03 37	CC	Okay, you going to power down first or after?
25 03 40	P	No, I'll power down after I take the first two shots on it. Actually, I'm not going to power down until I finish those shots. I'm going to leave the gyros up to do the shots with.
25 03 49	CC	Okay. Do you want to give me a mark when you take them so I can get your times?
25 03 53	P	Roger.
25 04 18	P	I'm having a little trouble getting things out of Pandora's locker here.
25 04 22	CC	Roger.
25 04 38	P	Oh yeah, you might pass on to the Cape too, my fuel quantity warning light came on at 24 58, 24 hours and 58 minutes.
25 04 50	CC	Roger.
25 04 58	P	At 61 percent.
25 05 04	CC	Roger, Gordo.
25 05 49	P	Okay. I'm getting the first two shots right now.
25 05 53	CC	Roger.
25 06 31	P	Okay, that's the first two shots.
25 06 36	CC	Okay, Gordo.
25 06 52	P	Now, I'm going to fly-by-wire.
25 07 11	P	Yawing around to the 90 degree point on the gyro.
25 07 17	CC	Roger, we read you.
25 08 54	P	Okay, snapping two more pics.
25 09 20	P	Caging the gyros.
25 09 27	P	Get down in proper attitude first here.
25 09 31	CC	Okay.
25 10 19	P	Now it's back to free.
25 11 49	P	Two more pics.

25 12 15	CC	Helloooo up there.
25 12 18	P	Hello down dere.
25 12 22	P	Man, all I do is take pictures, pictures, pictures.
25 12 26	CC	All I do is clean, clean, clean.
25 12 30	P	Ha, ha. Roger.
25 12 38	P	I got all the zodiacal light pics and now I am busily engaged yawing around on the MIT jobbies.
25 12 46	CC	Roger. You have my sympathy.
25 12 51	P	I'm not complaining, ha, ha.
25 12 57	P	I'm at the 270 point now getting the last two pictures in the 30 seconds.
25 13 02	CC	I have 17-Bravo [contingency recovery area retrosequence time] correction, if you can take it.
25 13 07	P	Roger, better hang on just a minute, I'm right—snapping pictures—right at the second.
25 13 13	CC	Okay, standing by.
25 14 12	P	Okay. I can take it now.
25 14 16	CC	Roger. 17-Bravo, 26 14 48.
25 14 25	P	26 14 48.
25 14 28	CC	That is affirmative. We'd like a little Sun gun time if you want to flip it on.
25 14 37	P	Say again.
25 14 39	CC	TV on for a couple of minutes please?
25 14 44	P	Roger, TV coming on.
25 14 56	CC	Gordo, for information only, if you care to use the 6-inch outside, recommending a minimum f stop 16 or 22 with the filter. It's not necessary to do this if you do use it outside; we recommend going this way.
25 15 15	P	At 22 with the filter, is that affirm?
25 15 18	CC	Say again, please.
25 15 21	P	22 with filter.
25 15 24	CC	16, f/16 with filter.
25 15 28	P	Roger.
25 16 05	P	Okay, I'm caging my gyros.
25 16 10	CC	Roger.
25 16 13	P	And they caged correctly.
25 16 17	CC	Good show; it works.
25 16 18	P	Yeah, just like advertised.
25 16 22	CC	How about that.
25 16 28	P	Powering down my ASCS bus.
25 16 37	CC	Roger. Understand ASCS bus is off. Your sure are a miser on the control fuel.
25 16 47	P	You say I'm noisy on the controls.
25 16 51	CC	I say you're miser on the controls.
25 16 57	P	Roger.
25 17 51	CC	. . . 1, 2, 3, 4, 5, do you read?
25 17 54	P	Roger, you are coming in very broken. Over.
25 17 56	CC	. . .

CANARY ISLANDS (SEVENTEENTH PASS)

25 26 01	CC	Faith Seven, this is Canary Cap Com. All systems are green. Do you confirm TV is on? Over.
25 26 11	P	Negative. TV is not on, Canary. I'm busy snapping some pictures.
25 26 24	P	TV coming on now.
25 26 26	CC	Roger.
25 28 46	SY	Faith Seven, Canary systems.
25 28 48	P	Go ahead Canary, Faith Seven.
25 28 51	SY	You're looking real good here, systems-wise. This is our last pass at you. We'll see you back in—back in Houston. Keep up the good work.
25 28 59	P	Roger, will do. Thanks a lot.
25 29 35	CC	This is Canary Cap Com, could you give us a cabin O_2 partial pressure readout, please.
25 29 42	P	Roger. Cabin O_2 partial pressure is about 3.9 [psi].
25 29 47	CC	Roger.
25 29 58	CC	Was that 3.9 or 3.5? Over.
25 30 02	P	About 3.9.

25 30 05	P	Just a tad under 4. I'm going back on my suit. I've had my visor open for a while here.
25 30 11	CC	Roger.
25 30 21	CC	We're having T/M LOS here. Suggest you turn off your TV camera. Over.
25 30 26	P	Roger.

KANO (SEVENTEENTH PASS)

25 32 00	CC	Faith Seven, this is Kano Cap Com. We have T/M solid, and all systems are go.
25 32 06	P	Roger Kano. Thank you.
25 35 28	CC	Faith Seven, this is Kano Cap Com. Your systems are still all green. Goodbye and good luck. Out.
25 35 34	P	Roger. Thank you Kano.

ZANZIBAR (SEVENTEENTH PASS)

25 41 50	CC	Faith Seven, Zanzibar Cap Com.
25 41 56	P	Go ahead, Zanzibar. Faith Seven.
25 41 58	CC	Faith Seven, Zanzibar Cap Com. Your systems look good on the ground.
25 42 05	P	Roger, Zanzibar. They look good up here, too.
25 42 08	CC	Okay. Could I have consumable readouts, please?
25 42 12	P	Roger. Auto. fuel, 60 percent; manual fuel, 91 percent. Oxygen primary, 145 percent; secondary, 100 percent.
25 42 28	CC	Faith Seven, I read you. You are fading.
25 42 34	P	Roger.
25 42 56	CC	Faith Seven, Zanzibar Cap Com. Good luck on your pass.
25 43 01	P	Roger. Thank you.
25 49 33	P	Okay. Short status report: Nitrogen low pressure: auto., 470 [psi]; manual, 490 [psi]. B-nut temperatures: Pitch down, 75 [degrees]; pitch up, 58 [degrees]; yaw left, 70 [degrees]; yaw right, 70 [degrees]; roll counterclockwise, 96 [degrees]; roll clockwise, 95 [degrees]. Peroxide auto tank: . . . 2 [degrees]; peroxide manual tank, 70 [degrees], peroxide reserve tank, 76 [degrees]. 250 inverter, 116 [degrees]; 150 inverter, 128 [degrees]; standby inverter, 108 [degrees]. *[Non-flight-related transmission omitted.]

MUCHEA (SEVENTEENTH PASS)

26 00 54	CC	Faith Seven, Muchea Cap Com.
26 00 57	P	Howdy, Muchea Cap Com. Faith Seven.
26 01 00	CC	We have a systems go and aeromed go.
26 01 49	P	Very good.
26 01 09	CC	Aeromeds are standing by for blood pressure.
26 01 12	P	Roger, coming now. Does he know how to read it?
26 01 20	CC	Roger. They got it now.
26 01 33	CC	I have [recovery] Area 18–1 retrosequence time. Prepared to copy?
26 01 40	P	Roger. Stand by just a second.
26 01 41	CC	Roger.
26 01 47	P	Roger. Go.
26 01 48	CC	Area 18–1 [retrosequence time], 26 34 48.
26 01 56	P	Roger. 26 34 48.
26 01 59	CC	That's affirmative; [contingency recovery area] 18–A [retrosequence time] is 26 58 50.
26 02 10	P	That was [contingency recovery area] 18–A.
26 02 12	CC	Affirmative.
26 02 16	P	*I didn't get the rest of that, 26 what?
26 02 24	CC	26 58 50.
26 02 28	P	Roger. 26 58 50. Roger.
26 02 31	CC	And I have [recovery area] 18–2 [retrosequence time]. 27 43 48.
26 02 38	P	Roger. 27 43 48.
26 02 42	CC	Roger. And these times does—do not include the clock error.
26 02 47	P	Roger. Understand.
26 02 49	CC	That first blood pressure was no good. Would you send another one? It was cut off early.
26 03 03	CC	Roger. We are getting your second blood pressure.
26 03 29	CC	That was a good blood pressure.
26 03 32	P	Roger.

26 03 35	CC	Systems report that your suit dome temp is decreasing slowly.
26 03 41	P	Roger. I'm running it down fairly low. I got it a little bit high.
26 03 45	CC	Roger.
26 03 48	P	It's been running consistently fairly low.
26 03 51	CC	Understand.
26 04 57	CC	Faith Seven. We have a message for you.
26 04 59	P	Roger.
26 05 02	CC	From the Australian Minister of Supply, the Honorable Alan Fairhall: "All Australia following your progress with lively interest. Muchea and Red Lake tracking station staffs and Department of Supply are proud to be associated with this great NASA effort. Happy landings." End message.
26 05 20	P	Roger. Thank you very much.
26 06 55	CC	We have approximately 1 minute to LOS.
26 06 58	P	Roger.
26 07 21	CC	Could you give me a read on your partial O_2?
26 07 26	P	Roger. Cabin partial O_2 is about 3.9 [psi].
26 07 30	CC	3.9 [psi].
26 07 32	P	Roger.

CANTON (SEVENTEENTH PASS)

26 20 17	CC	Faith Seven, this is Canton Cap Com. Standing by.
26 20 22	P	Roger, Canton. I'm all green here.

HAWAII (SEVENTEENTH PASS)

26 27 00	CC	Faith Seven, Hawaii. Do you read?
26 27 04	P	Roger, Hawaii. Faith Seven.
26 27 06	CC	Faith Seven. All systems are green. We are standing by.
26 27 11	P	Roger. Thank you.
26 31 35	P	* And, we are approaching 26 31. We are between Hawaii and California. Very, very low rates. Turning on my manual proportional control. Low rates.
26 32 33	P	I believe it's better to leave it as it is.
26 32 43	P	Now to get the camera out.
26 34 06	P	* And I made the first picture just then between—just off the west coast of the United States. Almost on the west coast.
26 34 49	P	Second one is coming in on the coastline. There are quite a bit of clouds, all different types and patterns. I took one getting in part of the coastline in under the clouds. That's number 2.
26 35 12	P	Snapping all these pics at f/5.6 and 1/125th.

CALIFORNIA (SEVENTEENTH PASS)

26 36 29	CC	Faith Seven, this is California Cap.
26 36 32	P	Roger. California. Faith Seven.
26 36 45	CC	Faith Seven, this is California. We have you all green here on the ground.
26 36 51	P	Roger. Thank you. I'm all green here.
26 36 54	CC	Roger. When you take your photographs, will you turn your tape recorder to continuous?
26 37 00	P	Roger. I have the tape recorder on continuous.
26 37 48	P	Both of those pictures were made looking to—slightly to the south.
26 39 55	P	Looking back to the due west, inland on the desert area. In fact, there's the Salton Sea.
26 40 16	P	*There's the Gulf and Baja California. Next one. There's El Centro area. I can make out individual fields. Smoke from the smokestack down there. There's some roads, houses, a little airstrip. There's a dry lake.

CAPE CANAVERAL (EIGHTEENTH PASS)

26 43 28	P	Faith Seven passing over Dallas.
26 45 56	CC	Faith Seven, this is Cape. Everything is go here. We are standing by.
26 46 01	P	Roger, Cape. Everything go here.
26 46 15	CC	Faith Seven. Would you like a G.m.t. hack? Over.
26 46 21	P	Roger. I would.

26 46 23	CC	All right. On my mark, G.m.t. will be 15 50 30. Stand by, MARK. 15 50 30. (26 46 35)[T]
26 46 40	P	Roger. My G.m.t. clock is 10 seconds fast.
26 46 47	CC	Understand the capsule clock.
26 46 53	P	That's the capsule clock.
26 46 55	CC	Roger.
26 46 59	CC	I have a correction to Diamond Head, retrosequence time. Delta T, 4 minutes 08 seconds for Diamond Head. Over.
26 47 11	P	10 minutes 08 seconds.
26 47 15	CC	. . . 08.
26 47 16	P	4 minutes 08 seconds.
26 47 21	CC	That is correct.
26 47 23	P	Roger.
26 47 28	CC	And if you should be inclined to, use the extra black and white 16-millimeter magazine outside for general photography. Recommending f/16.0 since you have no filter.
Unreadable	P	Roger.
26 47 51	CC	We have no specific requirements for it, however.
26 47 56	P	Roger.
26 53 13	P	Radiation experiment coming on, NOW. [26 53 17][T]. I'm at about, −10 degrees on pitch, roll right about 10 degrees, facing back to the west. Slowly oscillating in a left yaw rate.
26 56 08	P	I'm opening the KK clamp and we'll see what happens here now .
26 57 51	P	*And it appears to be flowing—water out of the tin can.
26 59 00	P	Radiation experiment off.
27 02 26	P	The heat exchange dome temp immediately went down to the freezing point. Closing off KK clamp. I'll have to continue on the original suit circuit.
27 09 15	P	Starting on the second series of the MIT film, just short of Africa. Coastline should be coming in momentarily. Took a shot out over the water of unusual—of good sized cloud buildups.
27 11 25	P	*Now the suit heat exchanger dome temp's starting back up. About thawed out.
27 16 38	P	Okay, short status: Roll clockwise, 85 (degrees), roll counterclockwise, 90 (degrees) ; Yaw right, 68 (degrees) ; yaw left, 75 (degrees) ; Pitch up, 62 (degrees) ; pitch down, 74 (degrees). Retro temp., 75 (degrees). 250 inverter 108 (degrees) ; 150 inverter 124 (degrees) ; standby inverter 108 (degrees). Cabin outlet, 72 (degrees). Auto peroxide tank, 72 (degrees) ; manual peroxide tank, 72 (degrees) ; reserve peroxide tank, 75 (degrees). Correction on that—that auto peroxide tank is 82 (degrees). Isolated bus voltage, 28 volts. Camera going up in the glove box.
27 26 08	P	[Yawn] Man, I dropped off to sleep again for a few minutes there.
27 29 50	P	Now, looks like the 1.5 [comfort-control-valve] setting is holding the suit heat exchange dome temp for the moment. Almost down to the bottom, about 42 degrees.
27 30 47	P	Yo ho ho ho ho ho. [He is singing.]
27 31 51	P	Boy, what a beautiful view from up here. Surprises you every orbit.

MUCHEA (EIGHTEENTH PASS)

27 33 39	CC	Faith Seven, Muchea Cap Com. Over.
27 33 42	P	Roger, Muchea. Faith Seven reading you loud and clear.
27 33 46	CC	Roger. Same. Would you place your telemetry switch in the continuous position please?
27 33 50	P	Roger. Coming continuous NOW.
27 34 15	CC	Roger. We have T/M.
27 34 19	P	Roger.
27 35 11	CC	I have some retrosequence times when you're ready to copy.
27 35 18	P	Roger. Go.
27 35 21	CC	Area 19–A [contingency recovery area] nominal.
27 35 28	P	Roger.
27 35 29	CC	19–B, 28 31 24. Area 19–C, nominal.
27 35 45	P	Roger.
27 35 51	CC	Would you read back area 19–B time?
27 35 53	P	Roger. 28 31 24.
27 35 57	CC	Roger.
27 36 34	CC	Systems here are go and aeromed is go.
27 36 40	P	Roger. Thank you, I'm go from here.

27 37 03	P	Tell Warren to be careful and not get stuck.
27 37 06	CC	Ha, ha. He knows about that.
27 37 12	P	Roger.
27 37 23	CC	Stuck on what?
27 37 26	P	On the outback.
27 37 28	CC	Roger. Acknowledge.
27 37 31	P	Roger.
27 37 57	CC	By the way, we have all joined tennis clubs.
27 38 02	P	Excellent. That's the best thing to do.
27 38 05	CC	Roger.
27 39 57	CC	Faith Seven, Muchea Cap Com. We read a very low suit dome temp.
27 40 02	P	Roger. I'm running it very low. I'm working it back up now.
27 40 17	CC	Say again, Faith Seven.
27 40 19	P	*Roger. I've already made a decrease in setting. It should be coming back up shortly.
27 41 51	P	*The suit dome temp is still acting up. Suit inlet temp is back up to about 68 degrees. The suit dome temp has gone down to about 38 degrees. Have suit coolant almost off now.
27 43 52	P	All right, suit coolant is shut completely off. Now it should come up.
27 50 10	?	. . . read you loud and clear.
27 50 45	P	Some of this fine plumbing they put in this thing. This sad thing on the needle—on the diaphragm fitting has come out so I can't change the needle to any other fitting. I'll have to leave the Kenny Kleinknecht clamp closed. Meantime, I can't pump any more. That container is full and so is the other one.
27 52 24	P	I wish some of you guys who tried to stick in some of this plumbing and—connected here and there, and use it here and there would sit in here awhile and try and use the stuff.
27 55 33	P	Wow! Look at that bright sunshine. Oooo, weee!

HAWAII (EIGHTEENTH PASS)

28 00 28	CC	Faith Seven, Hawaii. Do you read? Over.
28 00 32	P	Roger, Hawaii. Faith Seven reading you aloud and clear.
28 00 35	CC	Read you loud and clear. All systems are green. Standing by for fuel and O_2 readout.
28 00 40	P	Roger. Fuel, 60/90 [percent]. Oxygen, 140/100 [percent].
28 00 55	CC	Say again, O_2 primary, please.
28 00 57	P	140 [percent], one four zero.
28 01 01	CC	Roger. Understand everything is green.
28 01 04	P	Roger. Thank you.
28 01 56	CC	Faith Seven, Hawaii.
28 02 00	P	Go ahead, Hawaii. Faith Seven.
28 02 02	CC	C-band in the continuous position?
28 02 05	P	Roger. It is.
28 02 06	CC	All right.

CALIFORNIA (EIGHTEENTH PASS)

28 08 07	CC	Faith Seven, this is California Cap Com.
28 08 11	P	Roger, California. Faith Seven.
28 08 13	CC	Roger. We have you green clear across the board here.
28 08 18	P	Roger. Good.
28 08 19	CC	California standing by.
28 08 23	P	Roger.
28 13 10	P	Faith Seven passing over Baja California now. See entire Baja California.
28 13 25	CC	Faith Seven. Were you calling California?
28 13 27	P	Negative. I was just commenting that I could see all of Baja California. It's all clear, all up and down.
28 13 38	P	Disregard.
28 13 40	CC	Roger, Faith Seven.
28 16 39	P	Faith Seven passing over Houston, Texas. Have it in sight loud and clear.

CAPE CANAVERAL (NINETEENTH PASS)

28 16 46	CC	Roger, Seven. We read that at the Cape.
28 16 50	P	Roger.
28 17 07	CC	Faith Seven, this is Cape. We would like to see your TV returns, over.
28 17 12	P	Roger. I've got her on.
28 17 40	CC	Faith Seven, this is Cape.
28 17 43	P	Go ahead, Cape.
28 17 45	CC	I have you ATC [Air Traffic Control] clearance. Are you ready to copy?
28 17 49	P	Roger.
28 17 51	CC	"Please pass to Major Cooper, in flight, from Air Force Secretary Zuckert and Chief of Staff General LeMay: 'It is with great pride and enthusiasm that the entire United States Air Force is following the progress of your historic flight—a dramatic contribution to aerospace exploration. God luck, and God speed.' " Over.
28 18 21	P	Roger. Thank you.
28 18 24	CC	That's all right, Colonel.
28 18 37	CC	Faith Seven from Cape. Could you give me a comment on your general comfort, please?
28 18 44	P	* Roger. My general comfort is good, now. I've had a continuing battle with the plumbing in here. I was not able to open the KK clamp due to the fact that—that system is full of water. One of the needles broke off—or the little insert into it broke—and I am unable to transfer any more water out of the condensate tank.
28 19 09	CC	Roger. I gather you are not bothered by it.
28 19 13	P	Negative. I am plenty comfortable. I've had trouble with the suit heat exchanger; keep having to run it up and down and chase it, but it's doing fine.
28 19 23	CC	Looks like you are doing a real good job on that. Apparently you are keeping yourself very comfortable.
28 19 28	P	Roger.
28 19 30	CC	I assume since you've had trouble with this clamp, that it is now in the—rather, since you've had trouble with the condensate transfer, that the clamp is now in the closed position.
28 19 41	P	That's affirmative.
28 19 44	CC	Roger. Good show.
28 19 53	P	Are you getting any TV yet?
28 19 57	CC	I think the light is low inside there, Gordo.
28 20 01	P	I'm outside.
28 20 09	CC	Are you in the Sun?
28 20 10	P	Negative.
28 20 12	CC	I recommend you turn it off.
28 20 14	P	Roger.
28 20 18	CC	Also, how about the little squeezers, have they been beating their hearts out every 10 minutes?
28 20 24	P	Roger. Faithfully, every 10 minutes throughout the whole day and night, every time.
28 20 31	CC	A couple of beady yellow eyes, huh?
28 20 42	P	Ha, ha, Roger. I'm directly over Miami. I'm looking right down on Miami Beach.
28 20 48	CC	. . .
28 21 39	CC	Faith Seven, this is Cape. Would you give us a blood pressure now, please?
28 21 43	P	Roger.
28 31 44	P	Okay, you guys will have had it now . . . another measure . . . .
28 41 31	P	Drink some water.
28 55 34	P	Okay. Radiation experiment coming on now.
28 55 48	P	I'm in full drifting flight, so I'll have random attitudes for it.
28 59 51	P	At 28 59, my 0.05g telelight came on after I turned my warning lights off and back on to dim. Have turned my 0.05g and emergency 0.05g switch fuse off.
29 02 38	P	Radiation measurement is off.
29 24 19	P	For my short status report: Peroxide regulated pressure: auto, 470 [psi]; manual, 490 [psi]. 75 [degrees] pitch down; 60 [degrees] pitch up. Yaw left is 80 [degrees]; yaw right is 65 [degrees]. Roll counterclockwise is 78 [degrees]; roll clockwise is 75 [degrees]. Auto peroxide outlet, 72 [degrees]; manual is 72 [degrees]; reserve, 75 [degrees].

HAWAII (NINETEENTH PASS)

29 28 15	CC	Faith Seven, Hawaii on air-to-ground relay, do you read? Over.
29 28 19	P	Roger, Hawaii. Faith Seven reading you loud and clear.
29 28 29	P	Roger. Faith—Faith Seven is reading you loud and clear, Hawaii.

29 34 07	P	Hawaii Cap Com, Faith Seven.
29 34 09	CC	Go ahead, Seven, this is Hawaii. Read you loud and clear.
29 34 13	P	Roger. Wonder if you would relay to the Cape a little situation I had happen and see what they think on it. While turning my warning lights off and back on to dim, my 0.05g telelight came on in my telelight panel. Now the action that I have taken is, to turn off my 0.05g switch fuse and my emergency 0.05g switch fuse. Would you relay to them, and get their idea on it? Over.
29 34 44	CC	Understand your 0.05g light came on and your turned your 0.05g fuse switch and emergency 0.05g fuse switch off.
29 34 56	P	That's affirmative.
29 34 59	CC	Is that affirmative?
29 35 01	P	Affirmative.
29 35 02	CC	Can we have T/M on?
29 35 06	P	Roger. T/M is on now, have it on ground command.
29 35 10	CC	I have retrosequence time for [contingency recovery] area 20–Alpha, is nominal.
29 35 18	P	Roger. 20–Alpha is nominal. Thank you.
29 35 22	CC	We also pass on to you—turn C-band beacon on, a g.e.t. of 30 58 00.
29 35 33	P	30 58 00.
29 35 37	CC	Roger. Turn off at 31 08 00.
29 35 56	CC	Did you copy, Seven?
29 35 57	P	Negative. I got 30 58 00 on.
29 36 02	CC	Roger. Turn it off 10 minutes later.
29 36 05	P	Roger. Will do.
29 36 19	CC	Seven, this is Hawaii. Was that a red or a green telelight?
29 36 38	CC	Faith Seven, Hawaii. Do you read? Over.
29 36 40	P	Roger. Go ahead, Hawaii. Faith Seven.
29 36 42	CC	Roger. Was your 0.05g light red or green?
29 36 46	P	It was green. Over.
29 36 50	CC	Consumable readout please.
29 36 52	P	Roger. Fuel: 58 [percent] auto.; 90 [percent] manual. Oxygen: 140 [percent] primary; 100 [percent] secondary.
29 37 02	CC	Roger. Understand.
29 37 28	CC	Seven, this is Hawaii Cap Com.
29 37 31	P	Go ahead, Hawaii. Seven.
29 37 37	CC	Faith Seven, Hawaii. Over.
29 37 39	P	Go ahead, Hawaii. Faith Seven.

CALIFORNIA (NINETEENTH PASS)

29 41 32	CC	Faith Seven, Faith Seven. This is California Cap Com.
29 41 35	P	Roger, California Cap Com. Faith Seven here.
29 41 39	CC	Roger. Faith Seven. Our panel looks good. Telemetry does not indicate 0.05g.
29 41 52	P	Roger. It must be a . . . . I just threw a glitch into the light when I was turning my warning lights off and on, then, probably.
29 42 02	CC	There is a little diode in your light test, that failed could cause that light to come on.
29 42 08	P	Roger. Does MCC recommend that I go ahead and put my 0.05 and emergency 0.05g switch fuses back on?
29 42 21	CC	Faith Seven. Leave them off.
29 42 25	P	Roger.

GUAYMAS (NINETEENTH PASS)

29 44 07	P	Go ahead, Guaymas. Faith Seven.
29 44 09	CC	I have some retrosequence times for you, for [recovery area] area 20–1.
29 44 16	P	Roger.
29 44 17	CC	30 53 01.
29 44 22	P	Well, just a minute. Which one is that?
29 44 25	CC	Area 20–1.
29 44 28	P	Roger. 30.
29 44 30	CC	53 01.
29 44 33	P	53 01. Roger.
29 44 34	CC	Roger. And [contingency recovery] areas 20–B, C, and D are nominal.

29 44 42	P	Roger. Understand. Thank you.
29 44 45	CC	Roger. And 20–1 doesn't take in your clock error.
29 44 49	P	Roger. Understand.
29 48 38	CC	Faith Seven. Guaymas Cap Com.
29 48 40	P	Go ahead, Guaymas. Faith Seven.
29 48 42	CC	*Would you go ahead and power up your ASCS bus? We would like to know if you have your amp cal programer.
29 48 50	CC	. . . gyros caged now?
29 48 51	P	Gyros are caged. Fly-by-wire; ASCS coming on normal now.
29 49 25	P	Guaymas, are you still reading me?
29 49 29	CC	Go ahead, Faith Seven.
29 49 32	P	Roger. You still have me on telemetry?
29 49 35	CC	Roger. You look good.
29 49 37	P	Roger. I am supposed to do this HF antenna test, now.
29 49 43	CC	Roger.
29 49 49	P	I will be on HF for a couple of minutes and then back on UHF.
29 50 13	P	This is Faith Seven on high frequency. Capsule elapsed time, 29 50 20. Now for HF antenna test. My attitudes are zero [degrees] in roll; am rolling 90 degrees and repeating.
29 51 37	P	This is Faith Seven on the second portion of the HF antenna test. C.e.t. 29 51 45. Now I am rolled 90 degrees. HF out.
Unreadable	P	Faith Seven is back on UHF.

CAPE CANAVERAL (TWENTIETH PASS)

29 52 26	CC	Faith Seven. This is Cape. How do you read? Over.
29 52 29	P	Roger, Cape. Faith Seven reading you loud and clear.
29 52 32	CC	Roger, Gordo. On this 0.05g business, we are interested in whether or not the amp cal has switched to 0.05g logic. Do you follow?
29 52 43	P	Roger.
29 52 44	CC	* We figured the best way to do it—after gyros have warmed up—is to uncage, initiate a slow rate in any axis, and see if you have attitudes. If you do have attitudes, we feel that the amp cal has not latched at 0.05g. Over.
29 53 01	P	Roger. Assume a slow rate in any axis and see if the attitudes follow. Right?
29 53 09	CC	Right. When you uncage the gyros, you'll have to set up a very slow rate and see if you have attitude indications.
29 53 16	P	Roger.
29 54 04	CC	Seven, from Cape. We may have LOS before you are able to do this. Once you have done it, report to us through some other station, and then power down the ASCS after your test is complete.
29 54 18	P	Roger.
29 55 07	CC	Seven from Cape. Have you uncaged gyros yet?
29 55 10	P	Negative. Not yet.
29 55 14	CC	All right. We may lose you. Advise the next station.
29 55 19	P	Roger.
29 55 21	CC	Try to advise us even if we've had LOS.
29 55 29	P	Roger.
29 57 41	P	Cape. Faith Seven here.
29 58 13	P	Cape Cap Com. This is Faith Seven on high frequency. How do you read on this? Over.
Unreadable	CC	. . .
29 58 28	P	Cape Cap Com. Faith Seven, on high frequency.
Unreadable	CC	. . .
29 59 09	P	Hello, Cape. Faith Seven on high frequency. Over.
Unreadable	CC	. . .

COASTAL SENTRY QUEBEC (TWENTIETH PASS)

30 48 03	CC	Hello, Faith Seven . . .
30 48 13	P	Roger, Faith Seven here. Go ahead.
30 48 16	CC	. . .
30 48 48	P	Faith Seven, here. Go ahead, John, just barely read you.
30 49 02	?	. . .

30 50 36	CC	Hello, Faith Seven. Hello, Faith Seven, this is CSQ Cap Com calling early. If you read me, Gordo, answer on HF. Over.
30 50 58	P	Roger, John. This is Faith Seven. Reading you about 4 by 4. How me?
30 51 05	CC	Hello, Faith Seven. CSQ Cap Com reads you very weak and unreadable. If you can read, give me status of your ASCS check, please. Over.
30 51 17	P	Roger. My amp cal is latched up 0.05g. I do not have ASCS. Over.
30 51 25	CC	Understand you do not have ASCS. Is that affirmed?
30 51 29	P	That is affirm.
30 51 37	CC	Faith Seven, this is CSQ. Can you say again, trouble with your amp cal? I did not receive that part of your transmission. Over.
30 51 45	P	Roger. My 0.05g portion of the logic is latched in on the amp cal, so I do not have attitude indications through the auto pilot any more.
30 52 01	CC	Roger . . . amp cal . . . Gordo, understand the amp cal is not working and the ASCS is inoperative. Was your gyro in the slaved position when you overturned? Over.
30 52 11	P	Say again.
30 52 58	P	This is Faith Seven on UHF. How do you read, CSQ?
30 53 33	CC	Faith Seven, CSQ Cap Com. Do you still receive me? Over.
30 53 37	P	Roger, CSQ. Faith Seven on UHF. How do you read? Over.
30 53 41	CC	Roger. Still reading you, Gordo. Did you have any of your gyros switched to slave during the ASCS check? Over.
30 53 47	P	*Roger. I had them caged, and then I went to slave; and in moving my rates, I did not get any attitudes. Over.
30 53 59	CC	Roger. Understand. No attitudes. Did you go into roll at all? Over.
30 54 03	P	Roger. I tried roll, pitch, and yaw. Over.
30 54 07	CC	Roger. You did not go into automatic roll. Is that affirmative?
30 54 11	P	*I did not power up the ASCS. All I did was turn my ASCS on, powered up my ASCS a-c bus. And when it was warmed up, then uncaged my gyros to the slave position, which should give me attitude.
30 54 30	P	And if . . . .
30 54 32	CC	Repeat that please. We don't have much time. Over.
30 54 34	P	Roger. I do not have attitudes when I go to slave on my gyros. When I uncage my gyros, I do not have attitude indications with the ASCS a-c powered up.
30 54 48	CC	Understand you did not go into actual ASCS. Is that affirmative?
30 54 51	P	Negative. I did not.
30 55 39	CC	Faith Seven. . . . .
30 55 41	P	Roger. Reading you loud and clear.
30 55 44	CC	Roger. I am reading you rather weak. You did not go on ASCS. You powered up, and went to the slave position; got no gyro indication. Is that affirmative?
30 55 58	P	That is affirm, affirm.
30 56 05	CC	Hello, Faith Seven. Be sure your T/M transmitter is on, and C-band beacon is on, for Range Tracker pass. I repeat, make sure C-band beacon is on the T/M is on for the Range Tracker pass.
30 56 21	P	Roger. It's on.
30 56 32	CC	Hello, Faith Seven. This is CSQ Cap Com. . . . on. Acknowledge please. Over.
30 56 44	P	Roger. They are on. Affirm, John.

HAWAII (TWENTIETH PASS)

31 00 30	CC (CNV)	Faith Seven, this is Cape Cap Com. Over. [Loud squeal.]
31 00 33	P	Roger. Go ahead, Cape Cap Com. Faith Seven.
31 00 49	CC (CNV)	Faith Seven, this is Cape Cap Com. Over. [Loud squeal.]
31 00 53	P	Roger. Cape Cap Com, Faith Seven here. Go ahead.
31 00 57	CC (CNV)	Roger Gordo. . . . your amp cal is probably locked up on 0.05g. We are interested in just how much of your amp cal is working.
31 01 08	P	You're not coming through at all, Al.
31 01 11	CC (CNV)	. . .
31 01 14	P	Negative, I'm not reading you.
31 01 17	CC (CNV)	. . .

31 01 23	P	Al, I can't read you. My amp cal is locked up on 0.05g. I do not have attitude indicators. Over.
31 01 33	CC (CNV)	Roger. Roger. Can you read me now?
31 01 37	P	Just barely.
31 01 39	CC (CNV)	Roger. Stand by a few minutes.
31 02 00	CC (CNV)	Hello, Faith Seven. How do you read me now?
31 02 06	P	A little bit better.
31 02 09	CC (CNV)	Faith Seven, I do understand that you do not have attitude indications? . . . do you read?
31 02 20	P	Negative. I'm not able to understand you yet. Over.
31 02 29	CC (CNV)	Okay. Stand by.
31 02 50	CC (CNV)	Seven, from Cape. How do you read?
31 02 51	P	Roger. Reading you better now.
31 03 14	CC (CNV)	Seven, from Cape. How do you read now?
31 03 17	P	Roger. Reading you loud and clear now.
31 03 25	P	Roger, Cape. Reading you loud and clear now.
31 03 28	CC (CNV)	Roger. We're interesting in how much of your amp cal is still available to you.
31 03 42	CC (CNV)	Seven, we would like you to do a how-de-doody test over Hawaii, to find out how much of your amp cal is still available.
31 03 52	P	Roger. Do you say you want me to power up my ASCS?
31 04 12	P	Cape Cap Com, say again. You were cut out on that. Over.
31 04 30	CC	Faith Seven, Hawaii Cap Com. Do you read?
31 04 33	P	A little bit, Scott.
31 05 01	CC	Seven, Faith Seven, Hawaii Cap Com.
31 05 04	P	Roger, Hawaii. Faith Seven.
Unreadable	CC	Go ahead Cape.
31 05 06	F	*We want to use the transfer to your circuit and let Cape Cap Com talk with him this pass.
31 05 14	CC	Roger. You are relaying at this time.
31 05 17	F	Roger. Would you also make sure that your people are prepared to watch for the T/M signal also. After this pass, we would appreciate if you'd play your last pass over again to make sure that you understand what we want in regards to what happened to the 0.05 g light between the time you got acquisition of the . . .
31 05 47	CC	Roger, I copied.
Unreadable	SY	Hawaii command carrier on.
31 07 01	P	Hello, Hawaii. Are you reading Faith Seven now? Over.
31 07 24	CC (CNV)	Faith Seven, this is Cape. Over.
31 07 27	P	Roger, Cape. Faith Seven here.
31 07 37	P	Roger, Cape. Faith Seven here.
31 07 40	P	Roger, Cape. Faith Seven here. Go ahead.
31 07 43	CC (CNV)	. . .
31 07 53	P	You're cutting in and out, I understand you want to find out how much of my amp cal is gone.
31 08 00	CC (CNV)	Affirmative. We would like to have you first switch your ASCS 0.05g fuse switch on and check the 0.05g light.
31 08 11	P	Roger. I'll do that now.
31 08 20	P	Roger. When I have put my ASCS 0.05g switch fuse on, my light comes green. Over.
31 08 28	CC (CNV)	Roger. Turn that fuse switch off and put your emergency 0.05g fuse switch on and check the light, please.
31 08 35	P	Roger.
31 08 40	P	With the ASCS 0.05g switch fuse off and emergency 0.05g switch fuse on, the light is not green. Over.

31 08 50	CC (CNV)	Roger. In the meantime, Hawaii will check T/M. Do not forget that we would like . . . fly-by-wire. . . .
31 09 27	P	You were cutting in and out. I didn't get any of that, over.
31 09 31	CC (CNV)	Okay. We will try it one more time. . . . Over.
31 09 57	P	Roger. To go into auto and check for what?
31 10 00	CC (CNV)	. . . 0.05g.
31 10 08	P	You were cut out.
31 10 11	CC (CNV)	Roger. We would like to have you check for the roll rate which occurs after 0.05g.
31 10 18	P	Roger. Understand.
31 10 21	CC (CNV)	If you get this rate . . . .
31 15 22	P	Retro temp is 80 [degrees]. Pitch down is 70 [degrees]; pitch up is 65 [degrees]. Yaw left, 80 [degrees]; yaw right, 62 [degrees]. Roll counterclockwise, 72 [degrees]; roll clockwise, 68 [degrees]. Auto peroxide tank, 80 [degrees]; manual, 70 [degrees]; reserve, 72 [degrees]. 250 inverter, 101 [degrees]; 150 inverter, 121 [degrees]; standby inverter, 98 [degrees].

CALIFORNIA (TWENTIETH PASS)

31 16 44	CC	Faith Seven, Faith Seven, California Cap Com.
31 16 47	P	Roger, California, Faith Seven. Loud and clear.
31 16 51	CC	Be sure when you check for roll rate that the ASCS 0.05g fuse switch is in the on position.
31 16 59	P	Roger.
31 17 03	CC	. . .
31 17 08	P	*I have both fuse switches in the on position. My ASCS a-c bus is powered. I'm going to gyros slave. Now I understand I'm to go on to auto. Is that affirm?
31 17 26	CC	Say again, Faith Seven.
31 17 28	P	Roger. I have ASCS bus powered. Gyros are slaved, and now I understand that they want me to go into auto and see if I get the roll rate. Over.
31 17 39	CC	This is affirmative, Faith Seven.
31 17 42	P	Roger. Then do I come right back off with it if I get the roll rate? Over.
31 17 46	CC	*This is true. You can stop the capsule with the fly-by-wire.
31 17 50	P	Roger. Going into auto, NOW. [31 17 52] T
31 17 58	P	Roger. I do have the roll rate.

GUAYMAS (TWENTIETH PASS)

31 18 25	CC	Guaymas, Cap Com.
31 18 26	P	Go ahead, Guaymas. Faith Seven.
31 18 29	CC (CAL)	You can turn off the ASCS now.
Unreadable	CC	And turn the 0.05g ASCS fuse switch off and the . . . .
31 18 39	P	Roger. I have my ASCS 0.05g switch fuse off, and I'm powering down the ASCS. Is that affirmative?
31 18 49	CC	Power down your ASCS.
31 18 53	P	Roger. Powering down ASCS.
31 18 56	CC	Cage your gyros.
31 18 57	P	Roger. They are already caged.
31 19 01	CC	Gyros caged. ASCS bus turned off.
31 19 04	P	Roger.
31 19 13	P	*Would you ask the Cape what do I have left now. I have aux damp, fly-by-wire, and manual proportional; is that affirm, for retrofire?
31 19 46	CC (CAL)	. . . Com.
31 19 51	P	Go ahead, Guaymas.
31 19 53	CC (CAL)	. . .

31 20 05	P	Roger. What are they recommending? Do you know?
31 20 11	P	Roger.
31 20 17	CC (CAL)	. . .
31 20 21	P	Roger.
31 20 27	CC (CAL)	. . .
31 20 31	P	Roger. No problem.
31 21 10	CC (CAL)	Gordo. This is your last pass over us.
31 21 15	P	Roger. I'll see you in a couple of days.
31 21 18	CC (CAL)	Roger. You're doing an outstanding job. I'm proud of you.
31 21 19	P	Roger. Thank you, Gus.
31 21 23	CC (CAL)	Your friends in Mexico say adios.
31 21 25	P	Roger. Muchas gracias. Muchas gracias. That's French for thank you.
31 21 37	CC (CAL)	The same.
31 54 25	P	*Okay. Here I am at 31 54 28, now. Slow drift again in the nighttime. Still having trouble with the cabin—with the suit heat-exchanger dome temp; got control of it here, pretty close. Will fool around with it for about another 2 hours and some odd minutes.
31 55 18	P	Everything looks good. I have 53 percent auto [fuel] and about 79 percent manual [fuel].
31 58 20	P	Okay.
32 20 55	P	I'm observing some cities through the clouds at 32 20, 32 21.
32 21 17	P	Seeing out over Laos.

COASTAL SENTRY QUEBEC (TWENTY-FIRST PASS)

32 22 02	P	Roger, CSQ Cap Com. Faith Seven here.
Unreadable	CC	. . .
32 22 18	P	Roger, CSQ Cap Com. Faith Seven reading you.
32 22 23	P	Roger. I read you, John.
32 22 38	CC	Faith Seven, this is CSQ Cap Com. Answer if you read me on HF. Over.
32 23 01	P	Roger, CSQ Cap Com. Faith Seven reading you.
32 23 07	CC	CSQ Cap Com, Roger. We're going to change your clock, Gordo, to keep you from doing it. We have a list to copy here on this retro procedure. Are you ready for clock command? Over.
32 23 16	P	Roger. Go ahead.
32 23 19	CC	Command, on. What we're doing is backing your clock off 1 hour. You'll still be able to use minutes and seconds okay for retro. Over.
32 23 27	P	Okay.
32 23 29	CC	Okay. Here is the list to copy. Over.
32 23 37	P	Roger. Go ahead.
32 23 39	CC	Roger. Also, before we start this, make sure C-band is on for Range Tracker and also T/M. Over.
32 23 46	P	Roger. C-band and T/M are on.
32 23 55	CC	Roger. Okay, are you ready to copy?
32 23 58	P	Roger. Go.
32 24 00	CC	Roger, number 1 is attitude permission bypass.
32 24 09	P	Go.
32 24 11	CC	Attitude permission bypass is number 1. Do you acknowledge?
32 24 14	P	Roger. I got that. Go ahead.
32 24 16	CC	Roger. Retrorocket arm switch, manual.
32 24 21	P	Roger. Got that.
32 24 24	CC	Roger. Fly-by-wire thrust select switch, high and low.
32 24 32	P	Roger. Got it.
32 24 33	CC	Roger. Retrosequence fuse switch, number 2.
32 24 40	P	Roger. Got it.

32 24 43	CC	Roger. Retromanual fuse switch, number 2.
32 24 49	P	Roger.
32 24 51	CC	Roger. ASCS a-c bus switch, on.
32 24 54	P	Roger.
32 24 56	CC	ASCS 0.05g fuse switch, number 1.
32 25 04	P	Roger.
32 25 06	CC	ASCS control switch, select.
32 25 16	P	Roger.
32 25 18	CC	Mode select switch, off.
32 25 25	P	Roger.
32 25 27	CC	Manual handle, push on.
32 25 34	P	Roger.
32 25 37	CC	Roger. That will put you on manual. If you want to go fly-by-wire all you'd have to do is pull the manual handle off and your mode select to fly-by-wire. Roger.
32 25 45	P	That's affirm.
32 25 46	CC	Roger, okay. Squib arm will come on at retrofire minus 5 seconds.
32 25 57	P	Roger.
32 25 59	CC	Roger. And I will count down to retrofire with the Cape so you can hear. Over.
32 26 04	P	Roger, and I'll manually use fire retro then. Is that affirmed?
32 26 09	CC	Roger. The next step is to depress fire retro override; in other words, push the fire button. Over.
32 26 14	P	Roger. Understand.
32 26 16	CC	Roger. Now, if you have no retros, you can use as a backup, the following. If there are no retros, the next procedure would be used as a backup.
32 26 26	P	Okay.
32 26 29	CC	Hold just a second. What does your clock read now? Over.
32 26 34	P	Time to retrograde 01 31 50 now.
32 26 40	CC	Say, your clock setting should read 34 59 52. Over.
32 26 47	P	Negative. It does not.
32 26 50	CC	Roger. Did you copy 34 59 52? Over.
32 26 58	P	Roger. 34 59 52.
32 27 01	CC	Roger. You can set it yourself after leaving station here. I think we should get the rest of this procedure now. Over.
32 27 06	P	Roger.
32 27 09	CC	Roger. If you have no retros, use—if you get no retros—use as backup the following: number 1, retro delay to instant.
32 27 21	P	Roger.
32 27 22	CC	Press retrosequence button.
32 27 24	P	Roger.
32 27 26	CC	Okay. Some additional precautions. The retrojettison will have to be done manually.
32 27 31	P	Roger.
32 27 32	CC	Be sure that you do not arm the retrojettison switch until after the rockets have fired. Over.
32 27 38	P	Roger. Don't worry.
32 27 39	CC	Yeah, I'm with you. You'll probably not get a fire retro telelight, but we should get them okay here on the ground. Over.
32 27 47	P	Roger.
32 27 48	CC	Okay. Hold your retroattitude until jettison retro. Keep rates as low as possible, maintaining visual reference as aid for low rates; and at your nominal 0.05g time, select reentry mode.
32 28 03	P	Roger.
32 28 04	CC	That reentry mode of selection should be at about 34 09 19.
32 28 11	P	Roger.
32 28 14	CC	Okay. You'll come up on ASCS, go on auto with ASCS continuous, switch for your 0.05g, and then your reentry. Over.
32 28 26	P	Roger.
32 28 27	CC	Okay. That's the whole works now. Also go cabin fan normal now and your cabin control valve to 3.0. Over.
32 28 35	P	Roger. I already have it on.
32 28 40	P	What's wrong with reentering on aux damp on the reentry portion.

32 28 46	CC	Say again, Gordo.
32 28 48	P	Never mind, I'm losing you. Let's go UHF.
32 28 51	CC	Roger. Okay, see if you can get that 34 59 52 set up before you leave our telemetry. Over.
32 28 59	P	Roger, will do.
32 29 31	P	Roger. 34 59 52.
32 29 40	CC	Roger, Faith Seven. I have you at 34+59+52. Over.
32 29 45	P	That's affirmative.
32 30 09	CC	Faith Seven, CSQ. If you receive, switch to HF. Over.
32 30 20	P	Roger. Reading you loud and clear now, John.
32 30 23	CC	You came back in loud and clear then. We have your clock setting 34 59 52. That's correct.
32 30 29	P	That is affirmative.
32 30 32	P	That's 1 hour off, right?
32 30 34	CC	Say again, Faith Seven.
32 30 36	P	That's 1 hour beyond, right?
32 30 37	CC	That's correct. When we count down, we'll use minutes and seconds only. Over.
32 30 42	P	Okay.
32 30 45	CC	They'll check you on this—on later in this pass. Over. We should be ready next time around.
32 30 50	P	Roger.
32 31 04	P	Is that next time around or the time after that?
32 31 09	CC	Say again.
32 31 10	P	Roger. That is the next time around, is it not?
32 31 13	CC	That is correct; next time around when we see you, I will be firing.
32 31 17	P	Roger.
32 31 23	CC	What is your attitude? Are you in drift now, Gordo?
32 31 26	P	That's affirmative.

HAWAII (TWENTY-FIRST PASS)

32 40 42	CC	Hello Faith Seven, Faith Seven, Hawaii Cap Com. Do you read?
32 40 46	P	Roger, Hawaii Cap Com, Faith Seven. Loud and clear.
32 40 49	CC	Roger, Faith Seven, Hawaii Cap Com recommend take a green as for go now and go over your stowage checklist now . . . did you copy?
32 41 03	P	Roger. I'm practically all stowed right now.
32 41 09	CC	Say again, Faith Seven.
32 41 11	P	I'm practically completed with my stowage checklist now.
32 41 15	CC	Roger. You understand to take green for go, at this time?
32 41 19	P	To take what?
32 41 21	CC	Green for go. Take green for go at this time.
32 41 25	P	Roger, I understand. A green for go, will do.
32 41 31	CC	Roger. Zanzibar will go over this checklist that you copied from John, and John will help you with the retrofire time. Also do you understand that the time in your clock now is retrofire time +1 hour? You should read at retrofire 01 00 00.
32 41 55	P	Roger. Understand.
32 41 58	CC	Roger. What's your PCO_2 reading please?
32 42 02	P	* Roger, PCO_2 is about 2½ [mm Hg] now.
32 42 19	CC	PCO_2 is 2.5. Is that right?
32 42 21	P	That's affirmative.
32 42 48	CC	Faith Seven, Hawaii Cap Com.
32 42 52	P	Go ahead, Hawaii.
32 42 56	CC	We want the retrofire checklist completed over the Atlantic with the exception of your squib switch which you can get at retrofire—5 sec.
32 43 07	P	Roger. I intend to have it completed before then.
32 43 23	CC	Seven, Hawaii Cap Com. I'm sure you're familiar with the star pattern you'll be using during the retrofire.
32 43 32	P	Roger.
32 44 21	CC	Faith Seven. Hawaii Cap Com. Everything looks good on the ground. You might keep your eye on the PCO_2. What is your visor position?

32 44 29	P	Roger. My visor is open and I'm breathing off the cabin.
32 44 32	CC	Roger.
32 44 34	P	I'm going to emergency rate on my oxygen for a moment just to see if it's the gage, or if it actually is building up a little.
32 44 42	CC	Roger. Understand emergency flow rate at this time? [Tone noted.]
32 45 03	P	Roger. It does not seem to be decreasnig on the gage, so it must be the gage error.
32 45 10	CC	Roger. We're reading an increase on the ground as well.
32 45 23	P	I'm back on normal oxygen rate.
32 45 27	CC	Understand, back on normal.
32 45 30	P	Roger, fans are running.
		[Standby a-c auto warning tone occurs at 33 03 09][T]
33 05 43	P	Well, things are beginning to stack up a little. ASCS inverter is acting up, and my CO_2 is building up in the suit. Partial pressure of O_2 is decreasing in the cabin. Standby inverter won't come on the line. Other than that, things are fine.
	P	All right, I've checked that.

ZANZIBAR (TWENTY-SECOND PASS)

33 33 14	CC	Faith Seven, this is Zanzibar Cap Com. How do you read?
33 33 18	P	Roger, Zanzibar. Faith Seven reading you loud and clear.
33 33 21	CC	Faith Seven, Zanzibar Cap Com. Let's start your checklist here.
33 33 28	P	Roger, go ahead.
33 33 29	CC	One item has been added. Verify visor is closed.
33 33 36	P	*Negative, visor is not closed at the moment; I have a high CO_2 rate in suit.
33 33 47	CC	Item number 1 on the checklist now reads: cage gyro and remain caged throughout reentry.
33 33 58	P	Roger. I have an item for you. My ASCS a-c inverter has failed; so I will be making a manual reentry.
33 34 09	CC	ASCS inverter has failed?
33 34 12	P	That is affirmative.
33 34 14	CC	Roger. Let's continue this checklist now. Attitude permission bypass, bypass position.
33 34 21	P	*Roger. Bypass.
33 34 23	CC	Retrorocket arm switch manual?
33 34 26	P	Roger, on manual.
33 34 28	CC	*Fly-by-wire thrust selector switch, high-low.
33 34 34	P	Roger on high and low.
33 34 36	CC	Retrosequence fuse switch number 2.
33 34 39	P	Number 2.
33 34 42	CC	Retromanual fuse switch number 2.
33 34 46	P	Number 2.
33 34 47	CC	ASCS bus switch on.
33 34 51	P	ASCS a-c bus is off.
33 34 53	CC	Roger. ASCS 0.05g fuse switch to number 1 position.
33 34 59	P	On number 1.
33 35 01	CC	ASCS control switch select.
33 35 04	P	On Select.
33 35 07	CC	Mode select switch off.
33 35 08	P	Mode select off.
33 35 11	CC	Manual handle push on.
33 35 14	P	Manual handle is on.
33 35 16	CC	*Right. Squib arm at retro minus 5 seconds.
33 35 27	P	Roger.
33 35 28	CC	And that will occur in approximately 25 minutes.
33 35 31	P	Roger, I understand.
33 35 35	CC	Have you tried the standby inverter on ASCS bus?
33 35 38	P	Roger, the standby inverter will not start.
33 35 41	CC	The standby inverter will not start.
33 35 43	P	That is affirmative.
33 35 45	CC	Roger. Cape Flight advises you believe your CO_2 partial gauge in the capsule, as this was confirmed over Hawaii.
33 36 05	P	Cape advises what?

33 36 09	CC	We will advise you at this time. You have sufficient oxygen in to continue on emergency rate from now through reentry if required.
33 36 17	P	Ah, Roger. I understand.
33 36 22	CC	Shall we go over the retro backup?
33 36 26	P	Negative. I have that straight. I'll just go to retrofire to instantaneous and punch retrosequence.
33 36 35	CC	That is correct. You have the other additional precautions.
33 36 47	P	Negative. What's that?
33 36 48	CC	Retrojettison must be done manually.
33 36 52	P	Oh, roger, roger. I have those.
33 36 53	CC	Retrojettison switch to arm, after rockets fired.
33 36 58	P	Roger. I have that.
33 37 03	CC	You will probably not get a fire retro telelight.
33 37 06	P	Roger.
33 37 08	CC	Ground should be able to confirm, though.
33 37 11	P	Roger.
33 37 31	CC	Faith Seven, Zanzibar Cap Com.
33 37 34	P	Go ahead Zanzibar, Faith Seven.
33 37 36	CC	*We've had about 3-percent rise on the CO_2 partial. Do you think it is advisable to purge again at this time?
33 37 47	P	Negative. It seems to be holding pretty steady over what it has been.
33 37 51	CC	Roger. We're getting very poor air-ground communications at this time.
33 37 56	P	Roger.
33 38 09	CC	. . . Faith Seven. Zanzibar Cap Com.
33 38 12	P	Go ahead, Zanzibar. Faith Seven.
33 38 14	CC	We would advise the visor be closed prior to retrofire.
33 38 20	P	Roger, it will be.
33 38 35	CC	Faith Seven, Zanzibar Cap Com.
33 38 38	P	Go ahead.
33 38 39	CC	Cape advises closing visor.
33 38 42	P	Roger.
33 38 44	CC	Do you confirm.
33 38 46	P	Roger. Will close visor. Visor is closed and locked.
33 39 02	CC	Roger, visor is closed and locked. Continue to watch that PCO_2 meter and if it rises, go on emergency rate.
33 39 10	P	Roger.

COASTAL SENTRY QUEBEC (TWENTY-SECOND PASS)

33 56 25	P	CSQ Cap Com, Faith Seven. Over.
33 57 03	CC	Hello, Faith Seven, CSQ Cap Com. Over.
33 57 06	P	Roger, CSQ Cap Com. Faith Seven in retroattitude. Checklist complete.
33 57 16	P	Roger, CSQ Cap Com, Faith Seven.
33 57 19	CC	Faith Seven, CSQ Cap Com. Roger. You're sounding good. How's that check test? All complete?
33 57 24	P	Roger. All complete except for squib.
33 57 26	CC	Roger. How's the window attitude? Check okay?
33 57 30	P	Roger. Right on the old gazoo.
33 57 32	CC	That's the way, boy.
33 57 34	CC	*Okay. Our procedure, Gordo. I'll give you the 1-minute hack before retrofire and then I'll give you a 10-second countdown to what would normally be retrosequence. This time there will just be a countdown to a 30-second point and then a 10-second countdown to retrofire and at the 5 point tell you to arm squib.
33 57 53	P	Roger. That's fine.
33 57 54	CC	Roger.
33 57 59	CC	How's your PCO_2 doing?
33 58 02	P	Oh, its coming on up. And my ASCS inverter has failed, few other little odds and ends.
33 58 09	CC	Okay. Roger.
33 58 11	P	*I'll shoot the retros on manual, and I'll reenter on fly-by-wire.
33 58 18	CC	Roger. Okay.

33 58 20	P	I'm looking for a lot of experience on this flight.
33 58 23	CC	You're going to get it.
33 58 26	CC	Okay, we've got the beginning of the 1-minute period and about 25 seconds here.
33 58 31	P	Roger.
33 58 48	CC	Okay. One minute to go on my mark. Stand by.
33 58 54	CC	MARK. [33 58 54]^{T}
33 59 00	CC	Did you get that?
33 59 03	P	Roger. I got it.
33 59 04	CC	Roger. I'll give you a 10-second count here down to the 30-second point.
33 59 08	P	Roger.
33 59 14	CC	10, 9, 8, 7, 6, 5, 4, 3, 2, 1. Thirty [33 59 24]^{T} seconds.
33 59 30	CC	Okay. The next 10-second count will be a countdown to your manual retro. Over.
33 59 35	P	Roger.
33 59 44	CC	10, 9, 8, 7, 6, squib arm. 4, 3, 2, 1, fire [33 59 53]^{T}. Roger. A green one here.
34 00 13	P	Roger. I think I got all three.
34 00 16	CC	Roger. How did your attitude hold, Gordo?
34 00 18	P	Well, pretty fine.
34 00 20	CC	Good show, boy, real fine. Looks like they came off right on the money on time.
34 00 25	P	Roger, I think so.
34 00 28	CC	*Roger. Very good. On the next mark at 60 seconds from that retro, you should jettison retros; and you'll do that one manually, right?
34 00 37	P	Roger.
34 00 40	CC	Got any estimate on your attitude hold, in any axis how far you drifted off on retro? Over.
34 00 45	P	No, I sure don't. I held it relatively close, John, but I couldn't guess.
34 00 52	CC	That's the way to do it. Just too close to tell any error. Good head.
34 00 55	P	Ha, ha. No, I wouldn't say that.
34 00 59	CC	Roger. You can go ahead and jettison retros and time.
34 01 01	P	Roger. Jettisoning retros.
34 01 09	P	And off they came.
34 01 14	CC	We have your signal.
34 01 17	P	Roger.
34 01 18	CC	*Okay. Dealers choice on reentry here, fly-by-wire or manual. I think you said, you're coming back in fly-by-wire?
34 01 28	P	Roger. I think I'll come back in fly-by-wire.
34 01 31	CC	Roger, okay. You can hold retroattitude now for a while here. If you wanted to hold your attitude more close by holding retroattitude until you get a little closer to 0.05g.
34 01 43	CC	Your 0.05g is 34 09 19. Just before you get to that, you can come up to your zero reentry attitude. Over.
34 01 51	P	Roger.
34 01 53	CC	And you can establish roll at that time also.
34 01 56	P	Roger.
34 02 01	P	*What was the time on establishing that?
34 02 06	CC	*34 09 19. That is your 0.05g time.
34 02 11	P	Roger.
34 02 14	CC	Just a little bit before that you could come on up to zero zero.
34 02 20	P	Roger.
34 02 31	CC	Roger. Keep your rates down, keep your rates as near zero as you can.
34 02 36	P	Roger. Will do.
34 02 49	CC	*It's been a real fine flight, Gordo. Real beautiful all the way. Have a cool reentry, will you?
34 02 55	P	Roger, John. Thank you.
34 03 24	CC	Faith Seven, CSQ.
34 03 27	P	Roger, CSQ.
34 03 28	CC	ASCS 0.05g switch fuse to the off position. Over.
34 03 33	P	Roger. 0.05g switch fuse to the off position.
34 03 37	CC	Roger.
34 03 42	P	Roger.

RANGE TRACKING SHIP (TWENTY-SECOND PASS)

34 08 21	CC	Faith Seven, Faith Seven, Faith Seven, this is RTK M and O [Maintenance and Operations]. How copy?
34 08 27	P	Roger, Faith Seven. Reading you loud and clear.
34 08 30	CC	* Roger, RTK here. I have landing area weather for you. Ready to copy?
34 08 34	P	Roger.

HAWAII (TWENTY-SECOND PASS)

34 13 07	CC	Faith Seven, Faith Seven, Hawaii Cap Com. Do you read?
34 13 11	P	Roger.
34 13 13	CC	Faith Seven. What is your status?
34 13 16	P	Roger. Doing fine.
34 13 21	CC	Faith Seven, Hawaii Cap Com. Say your status. Over.
34 13 25	P	Roger. Faith Seven is doing fine. Reentering.
34 13 29	CC	Roger. Is your altimeter off the peg yet? Over.
34 13 33	P	Roger.
34 13 36	CC	Say your altitude; say your altitude.
34 13 38	P	Roger, 95,000 [feet].
34 13 43	CC	Roger. Understand 85. Are you standing by for the drogue at 40,000 [feet]?
34 13 49	P	Roger.
34 13 50	CC	We have tops of cloud in recovery area at about 36,000 feet.
34 13 58	CC	There is a 0.5 cloud coverage at 1,500 feet. 5 to 6 foot waves. Surface wind, 15 knots from 085 degrees. Stand by for your recovery time. Did you copy?
34 14 15	P	Roger, you'll have to wait a minute, I'm just hanging on here now.
34 14 21	CC	Roger, Faith Seven. Say again your last.
34 14 31	P	I got a drogue.
34 14 34	CC	Understand, drogue is out.
34 14 35	P	Roger.
34 14 42	CC	*Think I got a—an oral report of drogue out. Stand by.
34 14 52	CC	Faith Seven, Hawaii Cap Com. Is your drogue out at this time?
34 14 55	P	Roger, drogue is out.
34 14 59	CC	Checklist follows. Snorkel ring at 20,000 feet. Landing-bag switch to auto. Recovery arm switch, manual. Fuel jettison fuse switch, number 1. Fuel cross-feed handle, push on. Roll, yaw, pitch, T-handles push on. Position the T/M switch, your option. ASCS select switch should be off. And give me the status on your fuel dump. Over.
34 15 47	P	Fuel is dumped.[2]
34 15 50	CC	Understand fuel is dumped. Pressure regulator handle should be pulled.
34 16 03	P	Roger. I have a good main.
34 16 07	CC	Say again, Faith Seven.
34 16 09	P	Roger, I have a good main chute.
34 16 11	CC	Good main chute, good show.
34 16 14	P	Roger, landing bag is down and green.
34 16 15	CC	Repeat, please?
34 16 16	P	Landing bag is down and green.
34 16 17	CC	Understand the landing bag is green. What is your rate of descent?
34 16 28	P	About 34 feet per second.
34 16 31	CC	Everything looks good, preparation for impact. Urine transfer shutoff valve closed. Transfer hose, disconnect. Blood pressure hose, disconnect. Aeromed connector, disconnect. Helmet outlet hose, disconnect.
34 16 59	CC	Faith, are you staying with me, Gordo?
34 17 02	P	Roger, I've got my list right here, Scott.
34 17 06	CC	Say again, Gordo.
34 17 11	CC	Roger, helmet should be unlocked and opened.
34 17 19	CC	Temperature probe should be disconnected.
34 17 24	CC	Unfasten your helmet neck-ring seal.
34 17 31	CC	Tighten your straps.
34 17 36	CC	Lock the shoulder reel harness.
34 17 41	CC	Stand by for impact.
34 17 45	P	Roger.

[2] Pilot subsequently informed editor that he meant to say "fuel dump is armed." The rapidity of events at this moment precluded his rendition of a corrective statement to Cap Com.

34 17 47	CC	Are there any recovery aircraft on air-to-ground now?
34 17 52	P	Negative.
34 17 56	CC	This is Hawaii Cap Com. Understand you are in communication with recovery aircraft, is that correct?
34 18 02	P	Negative. Negative, I am not. Over.
34 18 09	CC	We'll stay with you then.
34 18 19	CC	Seven, Hawaii Cap Com. [*USS*] *Kearsarge* has visual contact with you at this time, over.
34 18 25	P	Roger, thank you. That sounds good.
34 18 29	CC	Good show, pal.
34 18 43	CC	Faith Seven, Hawaii Cap Com. Say your altitude.
34 18 47	P	Roger. 4,000 feet.
34 18 49	CC	4,000, your preimpact check is complete. Is that correct?
34 18 53	P	Roger.
34 18 55	CC	Understand preimpact checklist is complete.
34 19 00	P	Roger. Fuel is jettisoned and all T-handles are in.

RECOVERY (TWENTY-SECOND PASS)

34 19 04	R1	Hello Astro. This is 1 Indian Gal. Over.
34 19 07	P	Roger, this is Astro. Go ahead.
34 19 10	R1	Roger, 1 Indian Gal. We are circling you at about 500 feet; you're coming down very nicely. Sea state is about 5- to 8-foot waves, a few white caps. Wind is just perfect for a helo [helicopter] operation. The carrier [*USS Kearsarge*] is about 5 miles away.
34 19 31	P	Roger.
34 19 42	R1	Astro, you are swaying just a little bit, looks like about a 50 or rather, correction, a 30-foot sway. You're coming down very nicely. You are presently about 1,000 feet. The wind is from the southwest at about 12 knots, perhaps 15.
34 20 06	P	Roger, understand.
34 20 14	R1	Astro, 1 Indian Gal. How do you feel? Over.
34 20 17	P	Roger, I'm in fine shape. Excellent.
34 20 22	R1	Thank you Astro. This is Indian Gal. We still are circling you very nicely. You're now steadying up quite nicely, about 400 feet. You are passing my starboard side.
34 20 35	P	Roger.
34 20 36	R1	Have three helos right around you. Got the swimmers with me. They'll be out just about the time you're setting down on the water.
34 20 44	P	Roger.
34 20 47	R1	The carrier is only about 3 miles away. Couldn't be a nicer shot.
34 20 50	P	But I missed that third elevator.
34 20 53	R1	Now you are in the water in good shape.
34 20 57	R1	Your parachute is still with you. Chute has spilled and is in the water.
34 21 09	R1	Collar in the water.
34 21 15	P	Roger.
34 21 23	R1	Your dye markers out now, Astro. Looks nice. I'm coming in now for the swimmers.
34 21 39	R1	Astro, your capsule is on the side. The capsule parachute did not deploy.
34 21 46	P	Roger.
34 21 49	R1	Now your capsule is coming up nicely. It's sitting at about a 30-degree angle on the water.
34 21 55	P	Okay.
34 21 56	R1	You look pretty good.
34 22 02	R1	I'm on top over you, directly overhead. Your capsule is now erected nicely. You're bouncing on the sea. I notice now that the parachute has released. I'm now going to drop the swimmers.
34 22 14	P	Roger. Hold them clear a minute and I'll get the HF antenna up.
34 22 38	K	Astro, from Begonia on *Kearsarge*. How do you read me? Over.
34 22 43	P	Roger, Begonia, Faith Seven. Read you loud and clear. Over.
34 22 47	K	Roger, how you feeling? Over.
34 22 50	P	Fine, couldn't be better.
34 22 52	R1	Astro, all the swimmers are out. The first one is on your capsule now. He's pounding. Do you hear him? Over.
34 22 57	P	Roger, good shape. [Shouting to swimmers.]
34 23 13	P	Hello dahr, how are you? [Shouting to swimmers.]

34 23 17	K	Gordon, this is Begonia. We estimate approximately 45 minutes to have you on deck on *Kearsarge*. Please advise your wishes and any info this subject. Over.
34 23 33	P	I'm okay. I'll wait on the boat. [Shouting to swimmers.]
34 23 37	P	I'm in good shape.
		*[Nonflight-related transmission omitted.]
34 23 45	R1	Astro, this is 1 Indian Gal. Do you hear the swimmers? Over.
34 23 52	P	I just had my helmet off talking to the swimmers.
34 23 54	R1	Roger. I see you don't have smoke. Apparently, you are all right. What is—Begonia desires to know—what your desires about being picked up. Over.
34 24 02	P	Roger. I'd like to come aboard the carrier if they will grant me permission for an Air Force troop.
34 24 06	R1	*Roger. Begonia, this is 1 Indian Gal. Gordon Cooper desires to come on board the carrier if they will let an Air Force Officer aboard. Over.
34 24 18	K	Roger. Permission granted, of course, and I don't know whether he heard me before or not. Estimate about 45 minutes to have him on deck. Over.
34 24 30	R1	*Major, Begonia estimates 45 minutes for your on-deck time. What are your desires? Over.
34 24 37	P	Roger. I'll wait to go on board. Over.
34 24 40	R1	Roger, understand that you desire pickup by Wildcat . . . .
34 24 44	P	Thank you, sir. No, negative. I'll wait and go on board the carrier. Begonia did you read? Over.
34 24 47	R1	Roger. I understand you will be hoisted by the carrier. Begonia did you read? Over.
34 24 53	K	This is Begona. I copy. Out.
34 25 00	K	Indian Gal 1, Begonia. What status on collar? Over.
34 25 05	R1	Roger, collar is about half way around. The swimmers are in the water nicely. The capsule is working well.
34 25 12	K	Roger.
34 25 14	R1	The parachute was a little delayed in deploying. It it now riding very nicely in the water.
34 25 26	?	Roger, Wildcat, Tea Kettle 222. Go . . . .
34 25 31	R1	*They attached the collar just about all the way around. The sea state is the same as the ship.
34 25 39	R1	The collar—the capsule looks like it's riding at about a 20-degree angle. Quite steady in the water.
34 26 13	R2	One from two.
34 26 15	R1	One. Over.
34 26 16	R2	*Roger. Swimmers desire to save chute. Shall I deploy swimmers? Over.
34 26 20	R1	*This is one. Don't deploy swimmers at this time. The boat looks like it will pick up the chute. It is close enough.
34 26 29	R2	Roger.
34 26 30	R1	Wildcat, the collar now looks like it is all the way around the capsule. It's just about to be inflated.
34 26 37	R1	The swimmers are still with it. The chute is still floating next to the capsule. They don't look like they are having any difficulty. Looks like a normal operation.
34 26 49	K	This is Begonia. Roger, out.
34 26 52	R1	*The collar is now inflated fully.
34 26 56	R1	It has picked the capsule up nicely. It is now erect, and the swimmers are making final adjustments.
34 27 06	K	Begonia. Roger, out.
34 27 08	P	Sorry, I missed that third elevator, Begonia.
34 27 12	R1	Begonia, Gordon Cooper says he's sorry he missed the third elevator.
34 27 18	K	I think it's a quite acceptable shot, Major.
34 27 25	P	Thank you.
34 27 33	R1	Begonia, the swimmers are now hanging on to the collar. It is fully inflated; the capsule is upright. The capsule looks like it's riding very nicely in the water, just going up and down slightly on the 5- to 8-foot waves. There are a few white caps around, but they are not breaking over the tower.
34 27 57	R1	Looks like a normal operation, and they are just waiting for him.

34 28 07	K	* This is Begonia. Gordon, are you in communication with the swimmers at this time? Over.
34 28 14	P	I can yell to them through the hatch here.
34 28 18	K	I understand that you can hear them through the hatch. Is that correct?
34 28 21	P	Roger, we can communicate by yelling back and forth, I believe.
34 28 26	K	Roger. Out.
34 28 42	K	Major Cooper, from the USS *Kearsarge*, welcome to the Pacific. Good landing.
34 29 01	R1	*Major, the *Kearsarge* is now making a down base leg. They are going to make a normal 180 approach to you. They are about 2 miles away coming down wind. They will start their turn into your position in about 10 minutes.
34 29 17	P	Roger. Very fine.
34 29 19	P	Hello. How are you doing? I'm fine. Okay. How are you? [Shouting to swimmers.]
34 29 36	K	Major, they estimate your miss at 3,900 yards. Looks like a record.
34 29 43	P	Say again, sir. Say again, I was talking to the swimmers.
34 29 47	K	Roger. You missed by 3,900 yards, very acceptable.
34 29 51	P	Thank you.
34 29 54	P	What? I'll wait on the carrier. What? [To swimmers.]
34 30 05	R1	Two, this is One. Looks like the parachute is sunk now, I don't see it anymore. There is a small drogue chute still . . . upwind of the green dye.
34 30 15	K	Delighted to have you back in the Pacific and congratulations on a wonderful, wonderful ride.
34 30 23	P	What? Yeah, I'll wait on the carrier. [To swimmers.]
34 30 32	K	Gordon, this is Begonia. John Graham will be on this line and be stationed down near the hangar—near the elevator—about the time that we pick you up. Thought I would alert you that he will be on the line to talk to you just before you get out. Over.
34 30 52	P	Roger. Fine.
34 31 00	K	Is there anything we can do in preparation . . . .

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