pounds of oxygen and pressurized to 810 psia. At the beginning of the second revolution, the pressure had dropped from 810 to 450 psia under a heavy electrical load and after purging of both fuel-cell sections. The switch for the tank heater had been placed in the manual "on" position.

Over the Carnarvon tracking station, the pressure was reported to be 330 psia and dropping rapidly. At the Hawaii tracking station, approximately 20 minutes later, the oxygen pressure had fallen to 120 psia. It was determined at the time that the oxygen-supply heater had failed. In order to maintain the oxygen pressure, the spacecraft was powered down to 13 amperes, and by the fourth revolution the oxygen pressure had stabilized at 71.2 psia. This oxygen pressure was well below the minimum specification value for inlet pressure to the dual pressure regulators, and it was not known how long fuel cells would perform under these adverse conditions. The oxygen in the supply bottle was also on the borderline of being a two-phase mixture of liquid and gas, instead of the normal homogeneous fluid mixtures.

The performance of the fuel cells was monitored with special emphasis during the fourth and fifth revolutions to detect any possible degradation before the passing of the last planned landing area for the first 24-hour period. During this time, the orbit capabilities of the reentry batteries were reviewed in order to determine the maximum time that could be spent in orbit if a total fuel-cell failure occurred as a result of starvation of reactant oxygen. The maximum time was calculated to be 13 hours.

At the end of the fifth revolution, the flight crew were advised of a "go" condition for at least 16 revolutions. This decision was based on the following facts:

(1) Reactant-oxygen supply pressure had held steady at 71.2 psia for the fourth and fifth revolutions.

(2) There had been no noticeable voltage degradation.

(3) There had been no delta pressure warning light indications.

(4) Ground-test data indicated that no rapid deterioration of the fuel cells could be expected.

(5) There were 13 hours available on the reentry batteries.

This decision allowed flight-control teams to evaluate the fuel-cell operation for an additional 24 hours. The fuel cell reacted favorably during the next 24 hours, and another "go" decision was made at that time.

Gemini VI–A/VII Premission Planning

On October 28, 1965, 3 days after the first Gemini VI mission was canceled and approximately 6 weeks prior to the Gemini VII launch, the proposed Gemini VI–A/VII mission plan was presented to key flight control personnel for evaluation. From the initial review, the largest area of concern centered in the proper management of telemetry and radar data from two Gemini spacecraft. The ground system was configured to support one Gemini spacecraft and one Agena target vehicle for the Gemini VI mission. The major problem was how to utilize the system to support two Gemini spacecraft simultaneously without compromising mission success or flight-crew safety. Preliminary procedures for optimum data management were prepared and submitted in 3 days with the recommendation to support the Gemini VI–A/VII mission. Final plans and procedures were submitted 1 week later.

Real-time computer programs for the Gemini VI–A/VII missions were made available in five configurations by the Mission Control Center at Houston. Two remote-site computer programs, one for Gemini VII and one for Gemini VI–A, would match these five control center configurations to do the necessary computer processing and data routing. The Flight Director, through his control center staff, directed control center and remote sites of the proper configurations to provide the desired data for review by flight control personnel.

Control Center

The original Gemini VI computer program was operationally available and was used. The Agena portion of this program was bypassed, and certain processors were utilized to provide tracking data of spacecraft 7.

The following basic ground rules were established and followed as closely as practicable:

(1) Two basic computer programs would be utilized in five different configurations.

(2) Both computer programs would be capa-

ble of receiving manual inputs of spacecraft aerodynamic data.

(3) The Gemini VI–A program would contain the weight, reference area, and aerodynamics for spacecraft 6.

(4) The Gemini VII program would be identical to the Gemini VI–A program, with the following exceptions:

(a) It would process only spacecraft 7 telemetry.

(b) The spacecraft characteristics would initially be those of spacecraft 7.

(c) The Agena weight and area would be those of the Gemini VII spacecraft.

(d) The Agena thruster characteristics would reflect the spacecraft 7 aft-firing thrusters only.

Remote Sites

In a manner similar to that for the control center, certain basic guidelines were established and followed by remote-site personnel in the planning and execution of the combined Gemini VI–A/VII missions:

(1) Two remote-site data processor programs were written, one for Gemini VII and one for Gemini VI–A. The original Gemini VI remote-site data processor program was operational and was used. The Agena target vehicle portion of this program was bypassed, and the new Gemini VII program was obtained by recompiling the Gemini VI program with the spacecraft 7 calibration data.

(2) Two mission telemetry-data distribution frames would be provided. These telemetry-data-distribution-frame patchboards would switch and match the required spacecraft telemetry data to the proper flight control console. With these two patchboard arrangements and two remote-site data processor programs, remote tracking stations were capable of monitoring both spacecraft simultaneously.

At certain times the Gemini VII telemetry frequencies to be observed by ground control personnel were changed so that radiofrequency interference would be eliminated during launch preparation activities on Gemini VI–A at Cape Kennedy.

Since both spacecraft contained identical onboard command and telemetry systems, these systems had to be reviewed with the flight crews, and ground rules were established to eliminate any conflicts.

Orbital Activities

Gemini VII—Water in Space Suits

After the power-down of spacecraft 7 at the conclusion of the rendezvous with spacecraft 6, the flight crew reported water draining from their space-suit hoses when disconnecting the suits. At first this was thought to be condensate resulting from the chill-down of the spacecraft during the powered-down period. A cabin temperature survey reflected cabin humidity to be very high, approximately 90 percent. Over the Hawaii tracking station on the 167th revolution, the crew reported water was still draining from the suit hoses, and the onboard suit temperature gage was reading off-scale on the low side. Although this was still thought to be condensate from the chill-down, there was a possibility the suit heat exchanger was flooded due to the water boiler (launch-cooling heat exchanger) being filled to the point that the differential pressure across the suit heat-exchanger plates was not sufficient to transfer water. The water boiler was not thought to be overfilled, since the evaporator pressure light was not on.

The result of the suit heat exchanger being flooded could indicate that the lithium hydroxide canister was being filled with water, which would inhibit its carbon-dioxide absorbing capabilities. Thus, the decision was made to dump the water boiler by boiling the water overboard. This was accomplished by bypassing the coolant around the space radiator and placing the cooling requirements on the water boiler.

Over the *Rose Knot Victor* tracking ship on the 168th revolution, the following procedure was voiced to the crew:

Time from lift-off, hr:min:sec	*Procedure*
268:33:00	Turn primary A pump on, B off; turn secondary A pump on, B off. Orient the spacecraft broadside to the sun. Start 8- to 10-degrees-per-second roll rate; maintain and select broadside orientation. Select radiator to bypass.
268:37:00	Turn evaporator heater on.
268:41:00	Select radiator flow.
268:42:00	Turn evaporator heater off. Turn primary A pump off, B on. Turn secondary A pump off, B on. Stop roll rate.

The above procedure was performed over the *Coastal Sentry Quebec* tracking ship on the 168th revolution. The Gemini VI–A flight crew reported large amounts of water actually vented from the water boiler. Approximately 2 hours later, the Gemini VII flight crew reported that the cabin was warm and dry, indicating that the suit heat exchanger was again operating properly and removing condensation. The development of this inflight test and the associated procedures was beyond the capability of the flight crew in the allowable time period.

Gemini VI–A—Accelerometer Bias Correction

During the first revolution of the Gemini VI–A spacecraft, it was apparent from the telemetry data that the X-axis accelerometer bias had shifted from the prelaunch value. The flight crew also noticed a discrepancy in the X-axis bias correction over the Carnarvon, Australia, tracking station when they performed their normal accelerometer bias check during the first revolution. The decision was made to update a new bias correction value via digital command load to the spacecraft computer over the United States at the end of the first revolution. Since a 24-second height-adjust burn was scheduled just after acquisition of signal over the United States, the bias correction was not uplinked until after completion of the burn. It was decided that the accuracy of the height-adjust burn was not critical enough to warrant updating prior to the burn. After the burn, the X-axis bias was updated as planned, and the value remained constant for the remainder of the mission. Correcting this bias constant made the execution of the remaining translational maneuvers more precise during the rendezvous phase and the remainder of the flight, including retrofire. This function of precisely accounting for the accelerometer bias is beyond the capability of the Gemini crew and must be performed by the flight control team. The requirement to update this constant was recognized by flight control personnel during the Gemini III mission. Requirements and procedures were developed to accomplish this task on the next spacecraft that required it.

Orbit Adjustments

The preflight mission plan called for the Gemini VII flight crew to perform a spacecraft phasing maneuver on the sixth day. This maneuver would provide an optimum Gemini VI–A launch opportunity on the ninth day for a rendezvous at the fourth apogee.

The preflight mission plan was not carried out because of the excellent turnaround progress at the launch site in preparation for the Gemini VI–A launch. To take advantage of this rapid turnaround progress, the decision was made to do a partial phasing maneuver on the third day, which would allow later orbit adjustments to optimize for either an eighth or ninth day launch of the Gemini VI–A flight. A posigrade burn of 12.4 feet per second was requested and accomplished, and subsequent tracking verified a normal spacecraft thruster burn. Again, a real-time mission plan change such as this is an example of the mandatory flexibility inherent in mission control operations. This flexibility permits a rapid response to take advantage of the situation as it unfolds.

Gemini III, V, and VI–A/VII Flight-Controller-Technique Summary

The most significant aspect of the items discussed has been the ability of the flight-control organization to identify the anomalies or requirements, to utilize the collected and available data, and to recommend solutions that enable the flight crew to accomplish the primary mission objectives. Without this extension of the flight-crew systems analysis, it is conceivable that several of the Gemini missions conducted thus far would have been terminated prematurely.

Concluding Remarks

The ability of the flight-control organization and the flight crew to work together as a team has greatly enhanced the success of the flight tests up to this point in the Gemini Program. This interface has been accomplished by numerous training exercises, by mission rules and procedures development, and by participation in system briefings between the flight crew and the flight-control personnel. Through this close relationship has developed the confidence level that must exist between the flight crews and the flight-control teams.

Experience gained from the Gemini Program up to this point is summarized as follows:

(1) During the launch, rendezvous, and reentry phases of a mission, the flight control task is primarily a flight-dynamics real-time problem. During the other mission phases, effective consumables management and flight-plan activities become more dominant.

(2) The orbital mission rules are immediate, short-term, or long-term decisions. Flight-control personnel do not normally participate in immediate decisions, as these are effected by the flight crew. Short-term and long-term decisions allow flight controllers time for data collection, review, analysis, and recommendations to accomplish mission objectives.

(3) Existing flight-vehicle instrumentation schemes are a design trade-off between systems complexity, payload capability, economics, and inflight systems management. Flight control personnel participate in flight-vehicle instrumentation configuration meetings to assure adequate malfunction-detection analysis and consumables management. In some instances, real-time computer operations are required to allow full use of the available data.

(4) During long-duration missions, detailed flight planning is not necessary except for the launch, rendezvous, extravehicular activity, and reentry phases of the flight tests. For extended missions, the remaining flight-plan activities must be arranged in a priority order and integrated into the flight plan at the appropriate times to accomplish the primary and secondary mission objectives.

(5) Experience gained during the testing phase of the program must be available for real-time use. Results of overstress testing are of particular importance in this area.

(6) The spacecraft mission simulator should be utilized primarily for procedural crew interface for launch and critical-mission-phase training, while development of computer-math models of flight vehicles is continued for detailed flight-controller training. This will eliminate a large computer programing effort and interface checkout on the mission simulator and also allow full utilization for flight-crew training.

(7) Communications satellites are effective systems in the accomplishment of manned space-flight operations. During the combined Gemini VI-A/VII missions, the *Coastal Sentry Quebec* tracking ship never lost communications while being supported by the communications satellite, Syncom III. In comparison, frequent loss was encountered over alternate routes during atmospheric transition periods.

(8) Advance planning and the inherent flexibility in both the facilities design and mission-control procedures allow for significant changes in mission objectives close to the launch date, if the basic configuration of the vehicle remains essentially constant.

(9) Flight-control support has been provided during all mission phases. During the Gemini VI-A/VII flight test, the flight-control team monitored and directed the Gemini VII spacecraft in its orbital activities while simultaneously accomplishing:

(a) A rendezvous simulation with the Gemini VI-A spacecraft at Cape Kennedy.

(b) Pad-support activities and the final launch countdown for the Gemini VI-A space vehicle.

(c) Simulations for the first Apollo mission from a different control room in the same control facility.

(10) Success in the proper and effective execution of mission control operations is a function of effective and thorough premission planning.

The basic experience learned thus far in the Gemini Program will be expanded and applied in appropriate areas for the remainder of the Gemini flight tests and for future programs in such a manner that the flight-control organization will continue to accomplish its assigned tasks.

21. GEMINI POSTLANDING SYSTEMS TESTS AND RECOVERY OPERATIONS

By Robert F. Thompson, *Chief, Landing and Recovery Division, NASA Manned Spacecraft Center;* Donald E. Stullken, *Ph. D., NASA Manned Spacecraft Center; and* Peter J. Armitage, *Chief, Operational Evaluation and Test Branch, NASA Manned Spacecraft Center*

Summary

The recovery phase of the Gemini Program is discussed with consideration given to both postlanding systems and operations. The philosophy of systems operational evaluation, development, and validation prior to flight is presented, and the testing performed to support this philosophy is reviewed. The adequacy of this test program has been verified by the satisfactory performance to date, wherein all postlanding systems have performed as expected and wherein there have been no significant failures on actual flight missions.

Overall recovery operational support plans are summarized, and techniques are discussed for locating the spacecraft after landing and providing on-scene assistance and retrieval. The various landing situations encountered to date in the Gemini Program are presented, and the recovery activities reviewed. Landing distances from the recovery ship have varied from 11 to 91 nautical miles, and on-scene assistance times have varied from 12 to 50 minutes. Recovery operational support has been very satisfactory for all landing situations encountered. In addition, the operational flexibility provided by multiple landing areas has proved to be very valuable, in that it allowed the Gemini V mission to continue while a spacecraft electrical-power problem was being evaluated.

Introduction

The recovery phase of the Gemini Program is considered to encompass those activities from spacecraft landing through location and on-scene assistance and retrieval, together with the systems, plans, and procedures required for support during this period.

In the Gemini Program, postlanding systems, operational development, and testing were conducted in keeping with the basic philosophy that, insofar as possible, all systems and procedures would be validated in an operational test environment prior to flight. The systems include both those inherent in the spacecraft and those utilized by the operational support forces. Recovery operations in support of flight missions have been planned in keeping with the basic philosophy that a positive course of action would be preplanned for all possible landing situations, with the level of recovery support deployed into a given recovery area commensurate with the probability of landing in that particular area. Therefore, recovery forces are in position to support many different landing situations for each mission.

Postlanding Systems Testing

Utilizing experience gained in Project Mercury, the philosophy of conducting operational tests on the spacecraft, the spacecraft systems, and the support systems used in the postlanding and recovery mission phases received high emphasis during the periods prior to the first unmanned and the first manned flights. This operational testing supported several requirements: systems development under operational conditions; design verification and qualification; operational technique development; and recovery personnel training. Operational testing was carried out both under controlled test conditions requiring special facilities and also, where possible, under actual operational conditions representing very closely the environment to be expected in the actual mission landing and recovery areas. By this means, it was possible to identify many problem and potential problem areas on both the spacecraft and the spacecraft support systems, making it possible to redesign or change these systems before the flight missions. In potential problem areas where it was decided not to make system changes, the tests served to recognize the problem in sufficient depth to enable adequate operational procedures to be developed for most of the possible recovery situations.

From the spacecraft and spacecraft systems standpoint, the operational tests were carried out in the following basic areas:

(1) Spacecraft water stability (static and dynamic).

(2) Spacecraft structural integrity in the postlanding environment.

(3) Environmental-control-system postlanding testing.

(4) Postlanding electrical power testing.

(5) Spacecraft electronic communications and location-aid testing.

(6) Spacecraft postlanding habitability testing.

(7) Miscellaneous mechanical systems testing, visual location aids, etc.

Spacecraft support-systems and recovery-equipment operational development and testing were accomplished on the following:

(1) The auxiliary flotation device.

(2) The swimming interphone device.

(3) Airborne location receiver systems and tracking beacons.

(4) The survival beacon.

(5) The retrieval crane.

(6) Retrieval handling, and transportation dollies and cradles.

(7) Miscellaneous recovery equipment and line-handling devices.

(8) Launch-site surf retrieval equipment.

Operational techniques were developed for the following:

(1) Flight-crew egress.

(2) Recovery swimmer teams.

(3) Launch-site abort and recovery.

(4) At-sea retrieval.

(5) Postlanding safing and reentry-control-system deactivation.

Water Stability Testing

The Gemini spacecraft is designed to float in a nearly horizontal attitude after landing (fig. 21–1). Because of the small size and the basic circular cross section of the spacecraft, concern was expressed early in the program for the roll-stability characteristics, especially since the roll stability would greatly affect flight-crew egress techniques. There was potential danger of spacecraft flooding and sinking during egress, due to the low freeboard at the hatch-hinge line. Another concern with regard to water stability was in the pitch plane where the spacecraft originally had a nose-down trim attitude, also resulting in low freeboard at the hatch opening. Dynamic conditions, of course, tended to aggravate this condition. The potential hatch flooding problem was recognized early, and the spacecraft design included a sea curtain extending across the low-freeboard part of the hatch opening. This alone, however, was shown to be insufficient, and a combination of changes to the spacecraft configuration and operational techniques resulted from the early water-stability testing and egress-procedure development program. Spacecraft changes included the addition of extra flotation material in the reentry control system section, thus trimming the floating spacecraft to an approximately horizontal attitude in pitch. Initial design integration resulted in a spacecraft configuration that trimmed with an 18° list in the roll direction. This built-in list condition was retained and used to advantage by developing egress techniques in which the crewmembers egress one after the other from the high hatch.

FIGURE 21–1.—Gemini spacecraft postlanding flotation attitude.

Tight control of the postlanding center-of-gravity position was maintained throughout the spacecraft design and buildup phase, and spacecraft preflight measured center-of-gravity data

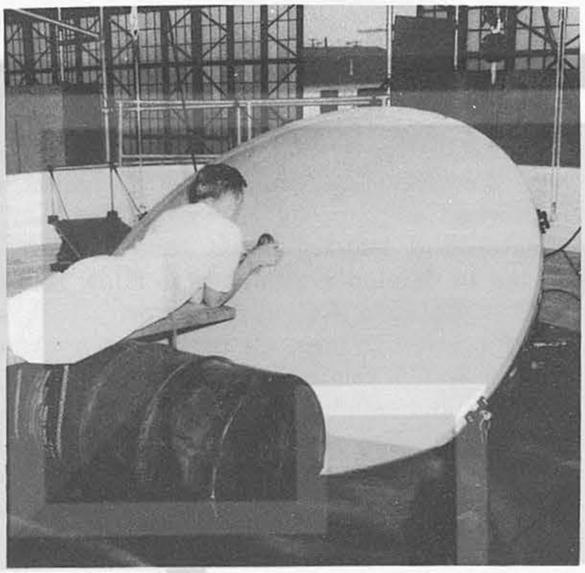


FIGURE 21–2.—Gemini spacecraft during water stability testing.

are checked against the water-stability data to insure satisfactory postlanding performance. Figure 21–2 shows the Gemini spacecraft during static water-stability tests.

Spacecraft At-Sea Testing

Early in the program, it was recognized that the Gemini spacecraft configuration, which called for almost all of the electrical and electronic systems to be packaged outside the pressure compartment, would present some special postlanding problems, since these systems and attendant cabling would be in flooded compartments after a water landing. Thus, the potential shorting and corrosive effects of salt water on all the equipment which was required to function after landing could have a distinct effect on both the safety and comfort of the flight crew and the successful conclusion of the recovery operation. The loss of electrical power to the electronic location beacon, for instance, could preclude, or at least make very difficult, the actual postlanding location of the spacecraft. This is especially the case for a contingency landing where the spacecraft would be in the water for a long period of time, and where the very nature of the contingency makes the location problem more difficult. The water and corrosion proofing of these essential postlanding systems called for stringent regard to detail design on the part of the system subcontractors, as well as close attention by the spacecraft contractor during electrical assembly. In addition, systems validation required realistic operational testing, with the spacecraft and the postlanding systems exactly like the configuration and installation of an actual flight spacecraft.

Gemini spacecraft static article 5 was provided for this testing. For all intents and purposes, this static article represented a flight spacecraft, complete with all systems required to operate in the landing and postlanding phases, and was equipped for manned at-sea testing. Static article 5 was later used for egress training and is still used for this purpose prior to each mission.

This test spacecraft was delivered by the contractor to the Manned Spacecraft Center in late December 1963. At the Manned Spacecraft Center, the spacecraft was extensively instrumented to allow all essential systems parameters to be monitored or recorded while the spacecraft was floating in the at-sea environment. In addition, biomedical instrumentation was installed so that test-subject safety could be determined at all times during manned tests. The instrumentation system called for remote monitoring and recording aboard the Manned Spacecraft Center test ship by the use of a floating cable to the spacecraft (fig. 21–3). For safety reasons, a line capable of lifting the spacecraft was provided as part of the connection from the ship.

In April 1964, static article 5 was placed in the Gulf of Mexico, 30 miles off Galveston, with two test subjects aboard for a postlanding test

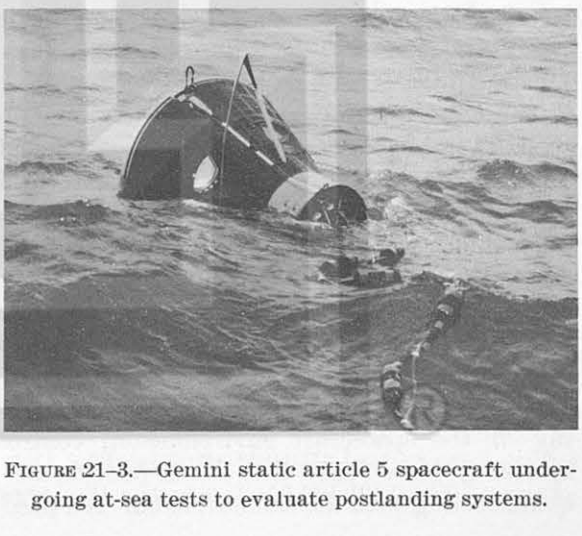


FIGURE 21–3.—Gemini static article 5 spacecraft undergoing at-sea tests to evaluate postlanding systems.

that was scheduled to last up to 36 hours. Wave heights of 5 to 6 feet and winds of 10 to 15 miles per hour existed at the time. These conditions were representative of the open-ocean conditions to be expected in recovery areas. Systems problems were encountered soon after the spacecraft was placed in the water; the first of these was the failure of the high-frequency antenna, which bent due to the wave-induced high rates of spacecraft motion. An abnormally high current drain was encountered in the electrical supply system, and, after approximately 1 hour, one of the two fans supplying air to the space suits failed. Pronounced seasickness of both test subjects was apparent within some 10 minutes after they entered the water, and suit ventilation from the postlanding environmental control system was found to be inadequate to provide crew comfort with suits on and hatches closed. This inadequacy existed even though the water temperature, air temperature, and solar heat load were less than that to be expected in daytime, subtropical recovery areas. The test was terminated after approximately 2 hours, primarily because of crew discomfort and worsening sea conditions.

The posttest systems failure analysis brought to light several areas of shorting in the electrical cabling installation, and corrosion problems on battery straps, electrical connectors, and spacecraft structural areas. The suit-fan failure was found to be caused by sea water entering the snorkel system, and this problem subsequently was solved after many at-sea tests with boilerplate spacecraft incorporating modified snorkel designs. Static article 5 was reworked during a 5-month period and made ready for another at-sea manned test with systems modified as necessary.

The at-sea test was repeated, with two astronauts as test subjects. This time, the test lasted 17 hours, and all spacecraft systems performed to specification except for a few problems of a very minor nature. Crew comfort remained generally inadequate throughout the test, even though the test environmental conditions were again less than to be expected in subtropical recovery areas. With space suits removed, test-subject comfort was improved, but no sequencing of the spacecraft environmental control system could be found that would provide adequate cooling with the hatches closed. All postlanding systems were tested during a test period that included aircraft ranging and homing runs on the ultra-high-frequency location beacon, and tests of the spacecraft high-frequency direction-finding system, using the U.S. Navy and Federal Communications Commission networks.

Subsequent manned at-sea tests were conducted to develop a technique to allow better cabin ventilation for crew comfort. It was found possible to open the high hatch a small amount even in relatively rough sea conditions, and this, in conjunction with suit removal, is the configuration that will be utilized in the event it becomes necessary for the flight crew to remain inside the spacecraft for long periods after a water landing.

Environmental-Water-Tank Tests

In the months just prior to the first manned flight, various degrees of concern existed relative to the ability of the flight crew to sustain the postlanding environment safely. The generally high heat levels to be expected inside the spacecraft cabin after reentry and landing, in conjunction with heat stress placed on the flight crew due to seasickness and possible dehydration, had to be considered in addition to any postflight problems caused by orthostatic hypotension. One of the limitations of operational testing is the difficulty in obtaining simultaneous occurrence at all desired environmental conditions. In order to gain a better feel for systems limitations in providing a habitable postlanding environment, a water-test-tank facility was built to provide for the following controlled environmental conditions:

(1) Air temperature at sea level.

(2) Humidity.

(3) Water temperature.

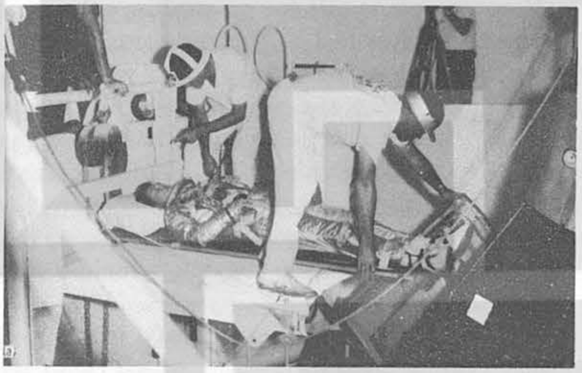
(4) Surface-wind simulation.

(5) Solar heat loading.

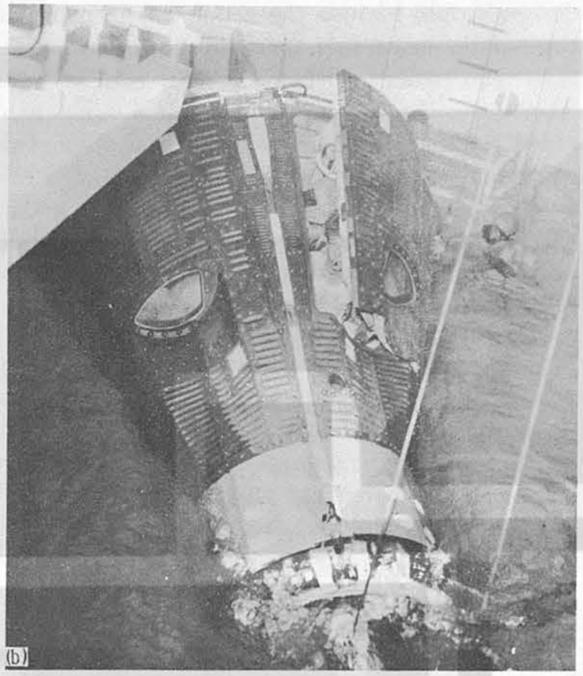
(6) Wave-induced spacecraft motion (by mechanical linkage).

(7) Spacecraft cabin reentry-heat pulse.

It was decided to conduct tests tailored to the actual postlanding environment to be expected in the Atlantic recovery area for the Gemini IV mission, which was the first long-duration flight in this program. In an effort to simulate the preconditioning effects of space flight, bed rest was determined to be the most practical method for the purpose of these tests. Three tests were conducted using the static article 5 spacecraft: the first, using two test subjects without preconditioning; the second, two other subjects who had received 4 days' bed rest preconditioning; and the third, using the original two test subjects with bed rest preconditioning. Figure 21-4(a) shows the suited test subjects being



(*a*) Test subject being placed in spacecraft.
FIGURE 21-4.—Manned postlanding spacecraft habitability tests.



(*b*) Spacecraft during testing in a controlled environment.
FIGURE 21-4.—Concluded.

transferred to the spacecraft inside the test chamber. The transfer is made in this position in order not to compromise the preconditioning effects of horizontal bed rest.

The tests commenced at the simulated time-of-reentry heat pulse and progressed through the spacecraft change-to-landing attitude into an 18-hour postlanding phase, with the test crew egressing into life rafts at the end of the test. Figure 21-4(b) is a photograph taken during the postlanding test period. Biomedical data were taken before, during, and after the tests; and spacecraft systems data were monitored during the test. In general, the tests were considered successful in that the spacecraft system, together with the developed postlanding flight-crew procedures, was shown to be capable of maintaining adequate crew habitability for an acceptable postlanding period in a subtropical recovery environment. Thus, these tests added to the confidence level for postlanding operations on the Gemini IV and subsequent missions.

Retrieval Equipment

An aircraft carrier is used for spacecraft retrieval in the primary landing area, and destroyers are primarily used in abort and secondary landing areas. A carrier has, as basic equipment, a crane capable of lifting weights well in excess of that of the Gemini spacecraft; hence, the carrier retrieval techniques followed closely those previously developed in the Mercury Program. Destroyers could retrieve the Mercury spacecraft with existing boat davits. However, the use of destroyers to retrieve the Gemini spacecraft presented a problem because the existing equipment on this type of ship cannot lift the spacecraft. Trade-off studies were made to determine the desirability and feasibility of providing all destroyers with a special lift capability, compared with use of destroyers only for crew retrieval and with the spacecraft remaining at sea until a ship with an inherent lift capability could arrive. The latter would have meant long delays in spacecraft retrieval time, especially in the abort landing areas. It was concluded that destroyers should be provided with the full capability of spacecraft retrieval, with the design goal of a simple retrieval crane which could be assembled on a destroyer's deck in a minimum of time and with little structural change to the ship. It was also decided at this time that the design should include the capability to retrieve the Apollo spacecraft, thus providing for a future requirement with an overall cost saving. Therefore, the Apollo spacecraft weight provided the main design criteria for all retrieval equipment presently used in the Gemini Program. Two types of lifting crane were designed, manufactured, and operationally tested aboard the NASA test-support vessel in the Gulf of Mexico. Both prototypes were next evaluated aboard a destroyer in the Atlantic, and one prototype, the davit rig, was selected for production manufacture. The davit rig basically consists of a crane capable of lifting 36 000 pounds, which is the Apollo retrieval weight plus 3g. The crane is mounted on the side of the destroyer fantail (fig. 21–5) and is fully power operated, providing spacecraft lift and power rotation of the retrieved spacecraft onto the deck. In addition, the design provides a power-operated holdoff arm which encircles the spacecraft during retrieval, preventing pendulum spacecraft motions due to rough seas. An important feature of the rig is that the entire control operation is accomplished by one man, thus avoiding difficult human coordination problems which are often a problem in rough sea operations. Destroyers have been modified with quickly detachable deck sockets in sufficient numbers to allow for Department of Defense scheduling flexibility in both the Pacific and Atlantic fleets. The entire davit crane can be installed or removed in approximately 4 hours.

FIGURE 21–5.—Retrieval exercise by a destroyer utilizing the davit crane.

To obtain the best techniques, the other supporting retrieval equipment, such as special hooks, lines, dollies, and cradles, was designed and operationally tested in much the same manner as the davit rig.

Auxiliary Flotation Device

Recovery plans call for an auxiliary flotation device to be attached to the spacecraft as soon after landing as feasible. The device is installed by helicopter-deployed swimmer teams in the primary and launch-site landing areas or by pararescue personnel, deployed from fixed-wing aircraft, in other areas. Figure 21–6 shows the device attached to the spacecraft. Basically, the flotation device provides the following:

(1) Flotation to the spacecraft in case of leaks from structural damage, which could result in possible spacecraft loss because of sinking.

(2) A relatively stable work platform for the recovery personnel to provide any required assistance to the flight crew while awaiting retrieval.

The device is designed to be a form-fit to the spacecraft when inflated; thus, little or no relative motion exists between the spacecraft and the device. This provides a damping of spacecraft wave-induced dynamic motions without difficult load-point or fatigue problems. The design incorporates a redundant tube, installed within the external tube, and a second inflation system, as a backup to the primary external flotation tube.

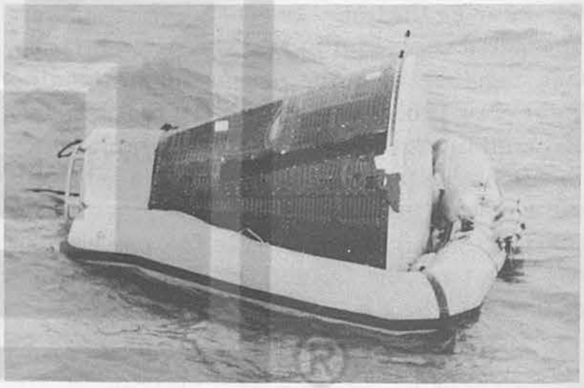


FIGURE 21–6.—Flotation collar installed on the spacecraft.

Development testing, airdrops, operational life tests, and installation techniques were accomplished in actual ocean environments.

Recovery Operations

The primary responsibility of the recovery forces is the rapid location and the safe retrieval of the spacecraft and the flight crew, and the collection, preservation, and return of information relating to the recovery operations, test data, and test hardware. This responsibility begins when the spacecraft and/or flight crew have been boosted relative to the launch pad.

Recovery plans and procedures are provided for all conceivable landing situations. For planning purposes, landing areas have been divided into planned landing areas and contingency landing areas. The planned landing areas are further divided into launch-site landing area, launch-abort (powered flight) landing area, periodic emergency landing area, and the nominal end-of-mission landing area. Any landing outside one of these planned landing areas is considered a contingency landing.

Department of Defense forces support all of these various landing situations. The level of support required is commensurate with the probability of a landing in the area and also with any special problems associated with such a landing.

Recovery Tasks

The various recovery tasks can be divided into three general categories. The first task is that of location. After the spacecraft has landed, the location of this landing may be determined by using tracking information from the Gemini network and then by computing a landing point from this information. Postlanding high-frequency-beacon signals are radiated from the spacecraft and ground-based high-frequency direction-finding stations are alerted for support in the event of a remote-area landing. In addition, the spacecraft is equipped with electronic location-aid beacons which operate in the ultra-high frequency range. This beacon is designed to radiate signals during and after landing. All landing areas are supported by aircraft having special receiver equipment compatible with the spacecraft beacons. Therefore, electronic homing by location aircraft is considered to be the primary means for recovery-force location finding, and considerable attention is given to the equipment and training devoted to this task. Visual location, once this aircraft homing has been accomplished, is assisted in the daytime by the presence of sea dye marker, which is dissipated from the spacecraft after landing, and at night by a flashing light.

Once the spacecraft has been located, the second phase begins, that of on-scene assistance. This on-scene assistance is provided by swimmers deployed either by helicopter or by fixed-wing aircraft. Each of these groups is equipped with the flotation collar which can be rigged on the spacecraft in order to provide for opening the spacecraft and rendering such assistance to the crew as may be needed.

The final phase of the recovery task is the retrieval of the crew and spacecraft and their return to the home base. This is accomplished in the primary landing area by using the inherent capabilities of the aircraft carrier to lift the spacecraft from the water. The crew may remain in the spacecraft for transfer to the recovery ship, or they may be transferred to the ship by helicopter earlier. Other ships, such as oilers and fleet tugs, regularly used in the recovery forces, also have an inherent capability of retrieving the spacecraft. Destroyers, which are also commonly used as recovery ships, do not have such an inherent capability and are fitted with the retrieval rig previously described.

Launch-Site Recovery

The launch-site landing area is that area where a landing would occur following an abort during the late portions of the countdown or during early powered flight. For planning purposes and considering all possible winds, it includes an area approximately 41 miles seaward of Cape Kennedy and 3 miles toward the Banana River from launch complex 19, with its major axis oriented along the launch azimuth (fig. 21–7). However, during the actual mission, the launch-site forces are concentrated on a relatively small corridor within this overall area. The corridor is determined by computing loci of possible abort landing points, utilizing the nominal launch trajectory and measured winds near launch time.

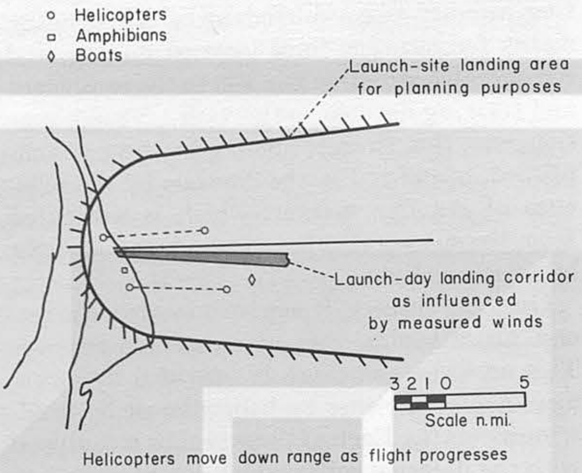


FIGURE 21–7.—Plan view of launch-site recovery area showing a typical force deployment.

Recovery problems in this area are unique and varied. Depending on the time of abort, the following situations can occur:

(1) Abort by seat ejection, followed by a landing on land or in the water just eastward of the launch pad.

(2) Abort by spacecraft, followed by seat ejection prior to landing because of the spacecraft impacting on land or in water too shallow for a safe landing.

(3) Abort by spacecraft, followed by a nominal deep-water landing in the spacecraft.

Decisions following abort in situations (2) and (3) are assisted by a ground observer who uses wind and tracking data in real time. This landing-position observer is prepared to advise the flight crew whether to remain with the spacecraft or to eject, following an abort during this critical time period. Because of the possibility of injury to the flight crew as a result of ejection-seat acceleration, launch-vehicle fire and toxic fumes, and landing in the surf or on obstructions, it is planned for the recovery forces to be capable of rapidly providing medical and other emergency first aid to the flight crew. In order to do this, a number of vehicles having unique capabilities are employed in the launch-site recovery area. The helicopter is the principal means of retrieval of the flight crew in a launch-site abort situation. The recovery forces are deployed in an excellent position to observe aborts in the launch-site area, and this visual observation is considered the primary method of location. However, assistance in location is available, if needed, in the form of information from a computer impact-prediction program. As a further backup, the flight crew's survival beacon is also activated following seat ejection, in order to provide an electronic location aid during parachute descent.

In addition to helicopters, the launch-site recovery force includes special amphibious vehicles and small boats so that all possible landing and recovery situations can be supported. Figure 21–8 shows a launch-site-recovery-force amphibian engaged in a surf recovery exercise. This launch-site recovery posture has been employed on all Gemini missions.

Suborbital Mission

The Gemini II flight was supported by 8 ships and 13 aircraft positioned along the ballistic ground track in such a way that they could reach any point in the area within 12 hours (fig. 21–9). At the planned landing point, an aircraft carrier with helicopter-borne swimmer teams was positioned to provide end-of-mission recovery capability. The aircraft were airborne along the ground track in order to provide on-scene assistance (flotation collar) and were capable of reaching the spacecraft within 4 hours of landing anywhere along the ground track or in the overshoot landing area.

Orbital Missions

The first manned Gemini flight was a three-orbit mission terminating in the West Atlantic area in the vicinity of Grand Turk Island (fig. 21–10). A total of 17 ships was employed to support the launch-abort landing areas and periodic emergency landing areas at the end of the first and second revolutions. A carrier and a destroyer having retrieval capability were pre-

FIGURE 21–8.—Gemini surf retrieval vehicle.

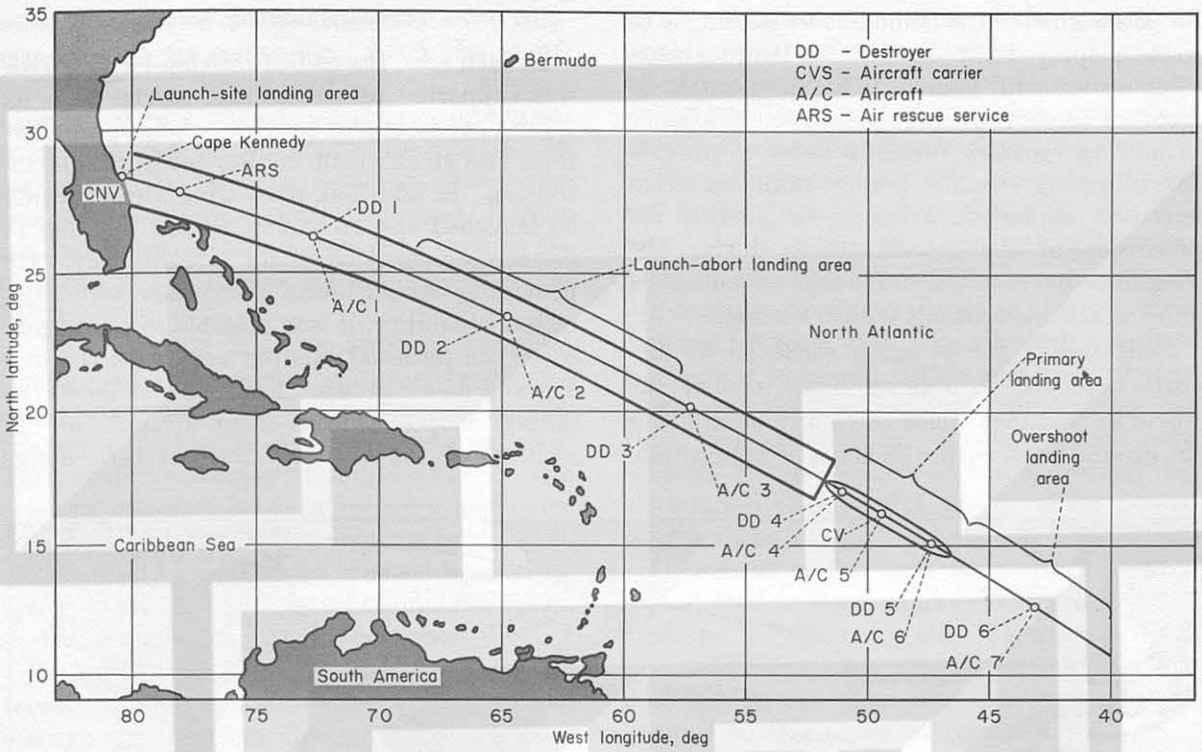


FIGURE 21–9.—Gemini II recovery-force deployment.

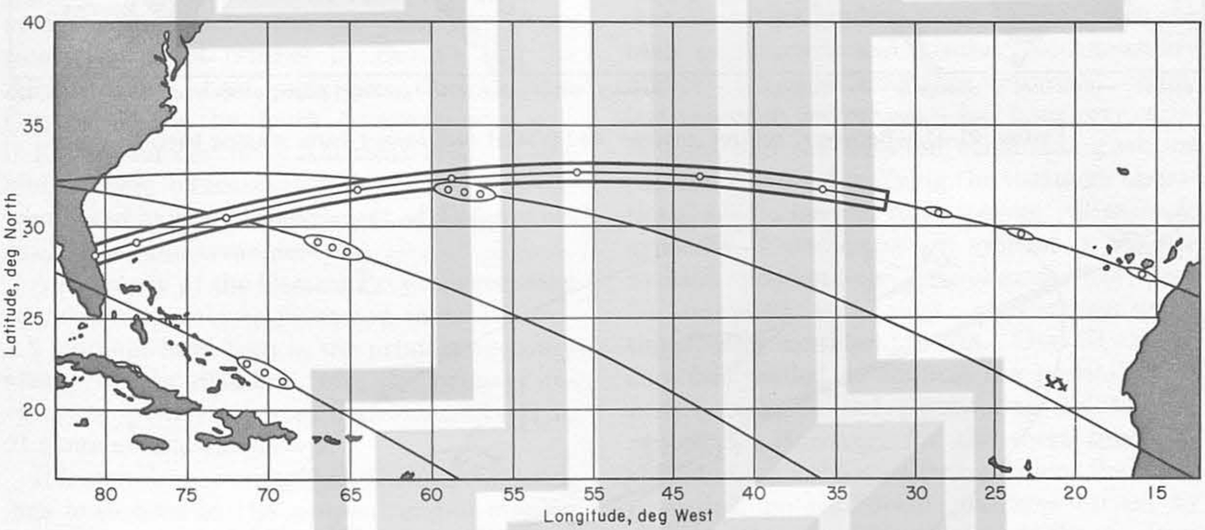


FIGURE 21–10.—Gemini III planned recovery area.

positioned in the end-of-mission landing area. Contingency forces consisted of aircraft located at stations around the world in such a way that they could reach any part of the worldwide ground track within 18 hours of a landing.

For long-duration missions, a recovery zone concept was adopted in which ships were placed in four zones around the world: West Atlantic, East Atlantic, West Pacific, and mid-Pacific. Landing areas were designated within these zones each time the ground track crossed the zone (fig. 21–11). One of the zones, the West Atlantic, was designated as the end-of-mission landing area and was supported by an aircraft carrier as well as destroyers. The other three zones were supported by destroyers and oilers.

Ships assigned to the launch-abort landing area were redeployed into the Atlantic landing zones after a successful launch. This distribution of recovery forces provided considerable flexibility in moving recovery forces in order to provide for changing aiming points resulting from variation in launch azimuth, to provide for precession of the ground tracks during the long-duration mission, and to take advantage of good weather conditions within the zone.

Contingency forces again consisted of aircraft deployed to staging bases around the world so that they could reach any point along the ground track within 18 hours of notification.

Primary Landing Area

In each case, the end-of-mission landing area was supported by an aircraft carrier with its special capability to provide a helicopter platform and an excellent facility for postflight activities. In addition, fixed-wing aircraft could be launched and recovered aboard in order to deliver personnel and data expeditiously. By providing carrier-borne helicopters with a location capability, it was possible to completely cover the terminal landing area with the carrier and its air group. Figure 21–12 shows the normal disposition of these aircraft in the vicinity of the carrier. One aircraft, desig-

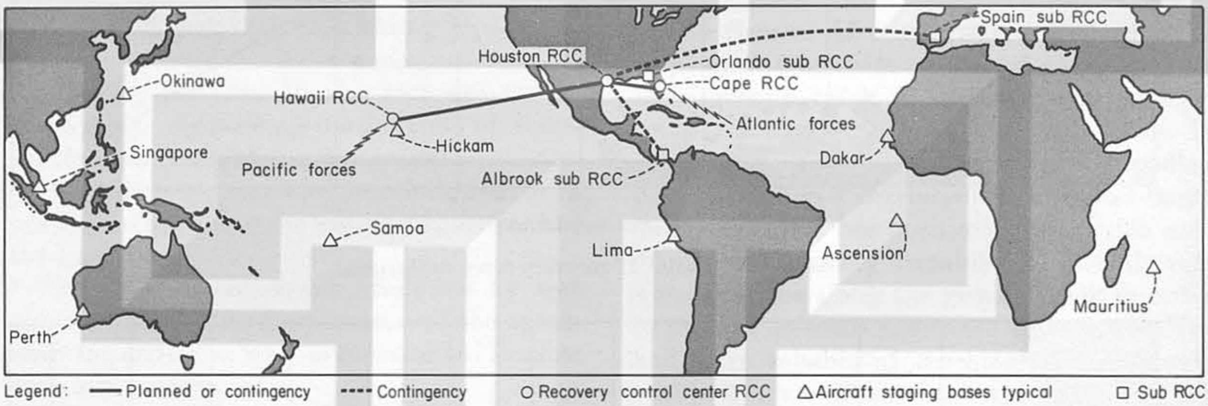


FIGURE 21–11.—Recovery control centers and typical contingency force staging bases.

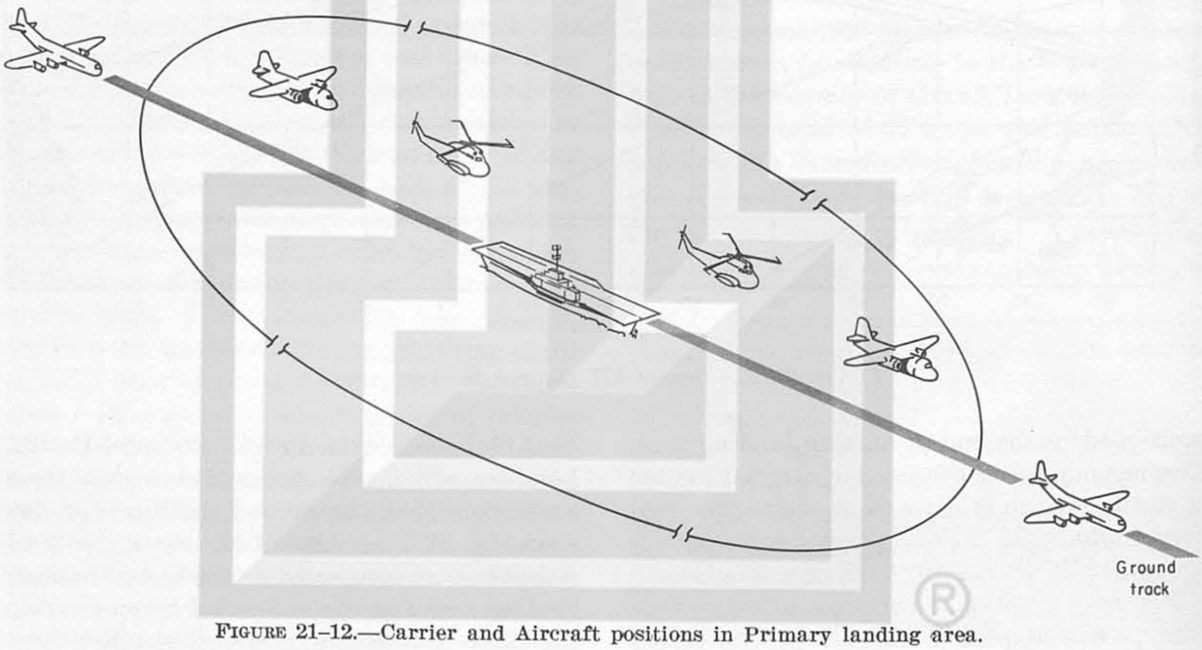


FIGURE 21–12.—Carrier and Aircraft positions in Primary landing area.

nated "Air Boss," served as an on-scene commander and air controller. After the search helicopters had located the spacecraft, swimmer helicopters were vectored-in to provide the on-scene assistance and to return the crew to the carrier, if desired. In addition, fixed-wing communications-relay aircraft relayed all radio transmissions in the recovery area back to the ship and to the various control centers on the beach.

The control of recovery forces is exercised through an arrangement of recovery control centers connected with the recovery forces through a worldwide communications network. These centers are depicted in figure 21-11. The primary interface between recovery and other mission operations activities occurs in the Mission Control Center at the Manned Spacecraft Center. The Mission Control Center also serves as the overall recovery control center.

Both planned and contingency recovery forces in the Atlantic area are controlled through the Recovery Control Center at Cape Kennedy, while Hawaii serves this function in the Pacific area. Contingency recovery forces in other command areas are controlled from recovery control centers in Europe for the Africa-Middle East area, in the Panama Canal Zone for the South American area, and in Florida for the North American area. These centers were established in order to take advantage of existing Department of Defense organizations and arrangements.

A summary of the Gemini Program recovery operations to date is presented in table 21-I. All landings have been in the primary recovery area, with the distance from the primary recovery ship varying from approximately 11 to 91 nautical miles, as shown.

It is significant to note that, although all landings have been in the nominal end-of-mission landing area in the Atlantic, the secondary landing areas in the Pacific were very beneficial during the 8-day Gemini V mission. During the early orbits in this mission, trouble developed with the spacecraft electrical-power source. Since the next several orbits did not pass through the primary landing area, the presence of these secondary recovery areas, with recovery forces on-station, allowed the flight to continue until the electrical-power problem could be evaluated. The electrical-power problem was eventually stabilized, and the mission was subsequently flown to its planned duration.

The primary recovery ship is positioned near the target landing point; therefore, the distances shown in table 21-I are a reasonable summary of landing accuracies to date. Postlanding recovery times are shown in the last three columns of table 21-I. In all landings, these times have been well within planning requirements, and the recovery force performance has been very satisfactory. Electronic aids were utilized in the location of the spacecraft for all but the Gemini VII flight, which landed within visual range of a deployed recovery aircraft. Even in this case the recovery aircraft was alerted to the near presence of the spacecraft by an electronic aid. In general, location techniques have proved very satisfactory and justify the close attention and training devoted to this phase of recovery.

For all Gemini missions, the landing area weather has been good, partially due to the fact that the target landing point is selected on the basis of forecasts and weather reconnaissance flights. On-scene assistance activities, including swimmer performance, has been very satisfactory, and the flotation collar has given no problems, again justifying the thorough operational evaluation and test program. Maximum exposure of the spacecraft systems to the unassisted postlanding environment has been 50 minutes, with most on-scene-assistance times being considerably less. Overall experience has tended to confirm the possibility of motion sickness and postlanding habitability problems. However, for the short times involved and for the weather conditions that have prevailed, no significant problems caused by the postlanding environment have been encountered.

All flight crews except the Gemini VI-A crew have been returned to the primary recovery ship by helicopter. The Gemini VI-A crew chose to remain with the spacecraft until it was retrieved by the recovery ship. Ship retrieval of the spacecraft has been nominal in all missions.

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TABLE 21–I.—*Recovery Operations Summary*

Flight	Location method	Description	Earth revolutions	Recovery forces		Weather		Distance from recovery ship to landing point, nautical miles	Event times after landing, minutes		
				Ships	Aircraft	Wind, knots	Wave height, feet		Flotation attached	Crew on ship	Spacecraft onboard
Gemini II	Electronic	Suborbital unmanned	1860 n. mi. downrange	8	13 aircraft, 9 helicopters	23	18	25	20	--------	90
Gemini III	Electronic	Orbital manned	3	17	44 aircraft, 11 helicopters	20	7	60	30	72	167
Gemini IV	Electronic	Orbital manned, 4 days	62	16	43 aircraft, 10 helicopters	13	4	48	20	57	136
Gemini V	Electronic	Orbital manned, 8 days	120	15	36 aircraft, 10 helicopters	8	3	91	50	91	235
Gemini VI–A	Electronic	Orbital manned, 1 day	16	14	38 aircraft, 10 helicopters	6	3	11	30	64	64
Gemini VII	Visual	Orbital manned, 14 days	205	14	38 aircraft, 10 helicopters	17	3	12	12	32	64

22. FLIGHT CREW PROCEDURES AND TRAINING

By DONALD K. SLAYTON, *Assistant Director for Flight Crew Operations, NASA Manned Spacecraft Center;* WARREN J. NORTH, *Chief, Flight Crew Support Division, NASA Manned Spacecraft Center; and* C. H. WOODLING, *Flight Crew Support Division, NASA Manned Spacecraft Center*

Summary

Flight crew preparation activities outlined herein include initial academic training, engineering assignments, and mission training. Pilot procedures are discussed in conjunction with the simulation equipment required for development of crew procedures for the various phases of the Gemini mission. Crew activity summaries for the first five manned flights are presented, with a brief evaluation of the training effort.

Introduction

Because the Gemini operational concept takes full advantage of the pilots' control capabilities, crew preparation involves a comprehensive integration and training program. Some of the pilots participated in the design phase. All have followed their spacecraft and launch vehicle from the later stages of production through the many testing phases at the contractors' facilities and at Cape Kennedy. A wide variety of static and dynamic simulators have been used to verify design concepts and to provide subsequent training.

Procedures and Training Facilities

To better illustrate the crew activities, successive flight phases will be discussed in conjunction with the procedures and major training facilities involved.

Launch

During the launch phase, the flight crew monitors the launch vehicle performance and is given the option of switching to spacecraft guidance or of aborting the mission, in the event of anomalies in the launch vehicle or in the spacecraft performance. Figure 22–1 shows a view of the left cockpit with the launch-vehicle display, the guidance switch, and abort controls. By observing propellant tank pressures, engine-chamber-pressure status lights, and vehicle rates and attitudes, the command pilot can monitor the launch vehicle performance. If the flight crew observe excessive drift errors, they can actuate the guidance switch to enable the spacecraft guidance system to guide the launch vehicle. Launch-vehicle guidance failures, which cause rapid attitude divergence, automatically trigger the backup spacecraft guidance system.

The launch-abort procedures are divided into four discrete modes which are dependent on dynamic pressure, altitude, and velocity. Although the Gemini Mission Simulator provides the overall mission training, the Dynamic Crew Procedures Simulator (fig. 22–2) is the primary simulator used to develop launch-vehicle monitoring and abort procedures. Variations of $\pm 90°$ in pitch are used to simulate the changing longitudinal acceleration vector. Yaw and roll oscillations and launch acoustic noise-time histories are also programed to improve the simulation fidelity. The motion, noise, and cockpit displays are driven by a hybrid computer complex. Approximately 80 launch cases are simulated in the familiarization and training program.

Rendezvous

The primary rendezvous controls and displays are shown on the instrument panel in figure 22–3. The crew utilizes the "8-ball" attitude indicator for local vertical or inertial reference, flight director needles for computer and radar-pointing commands, digital readout of the radar range and angles through the computer console, and analog range and range-rate display. Orthogonal velocity increments, displayed on the left panel, present to the pilot the three velocities to be applied during the various rendezvous phases. All of these displays are used to accomplish closed-loop rendezvous.

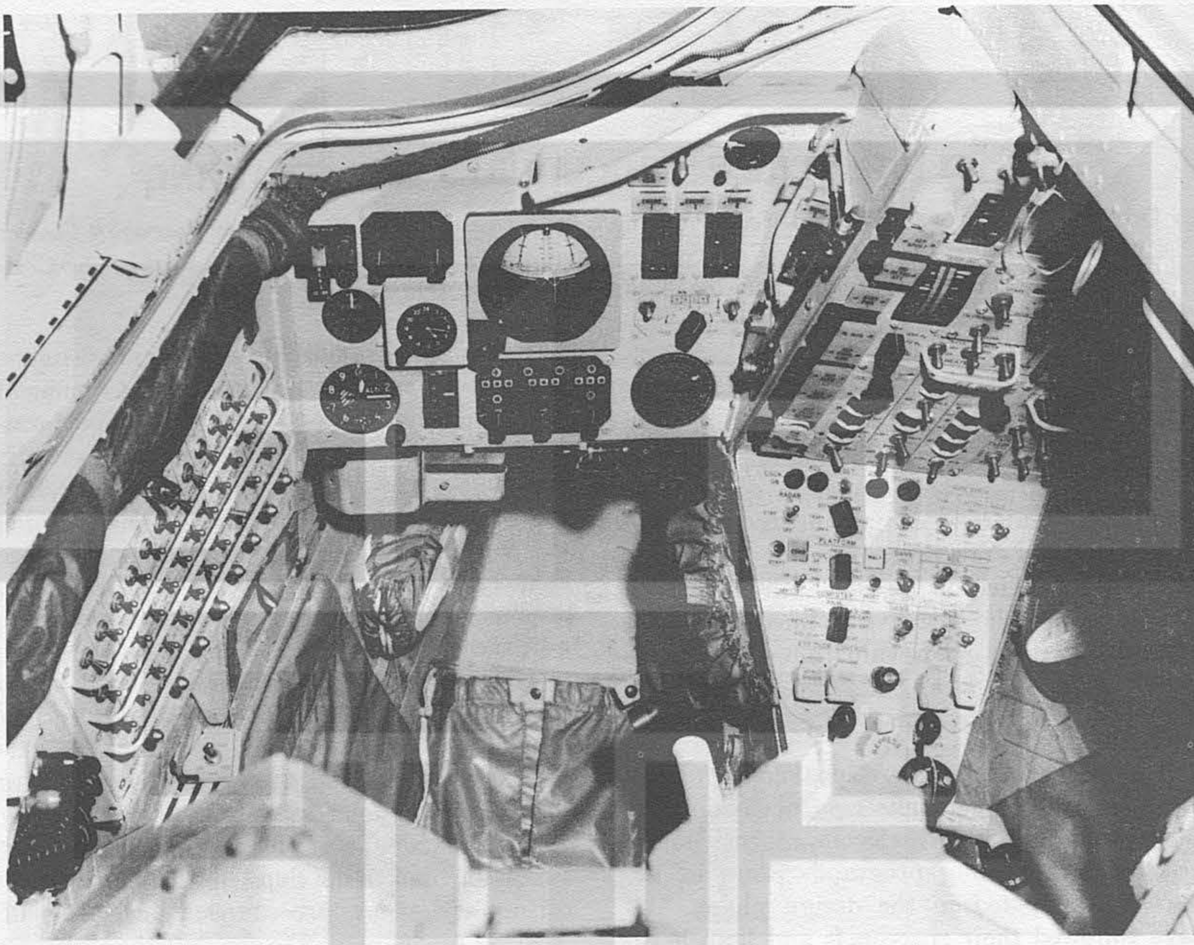


FIGURE 22-1.—Cockpit displays and controls normally accessible to the command pilot.

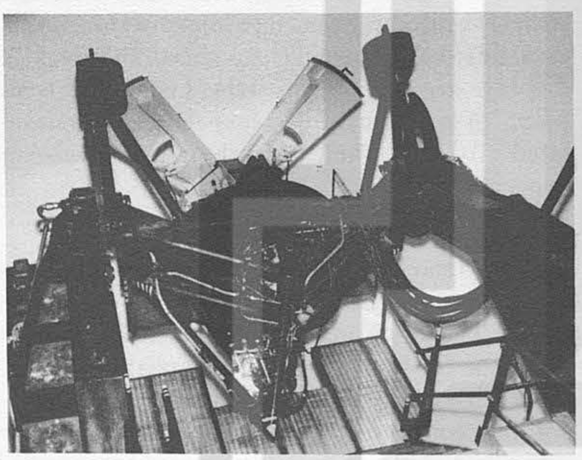
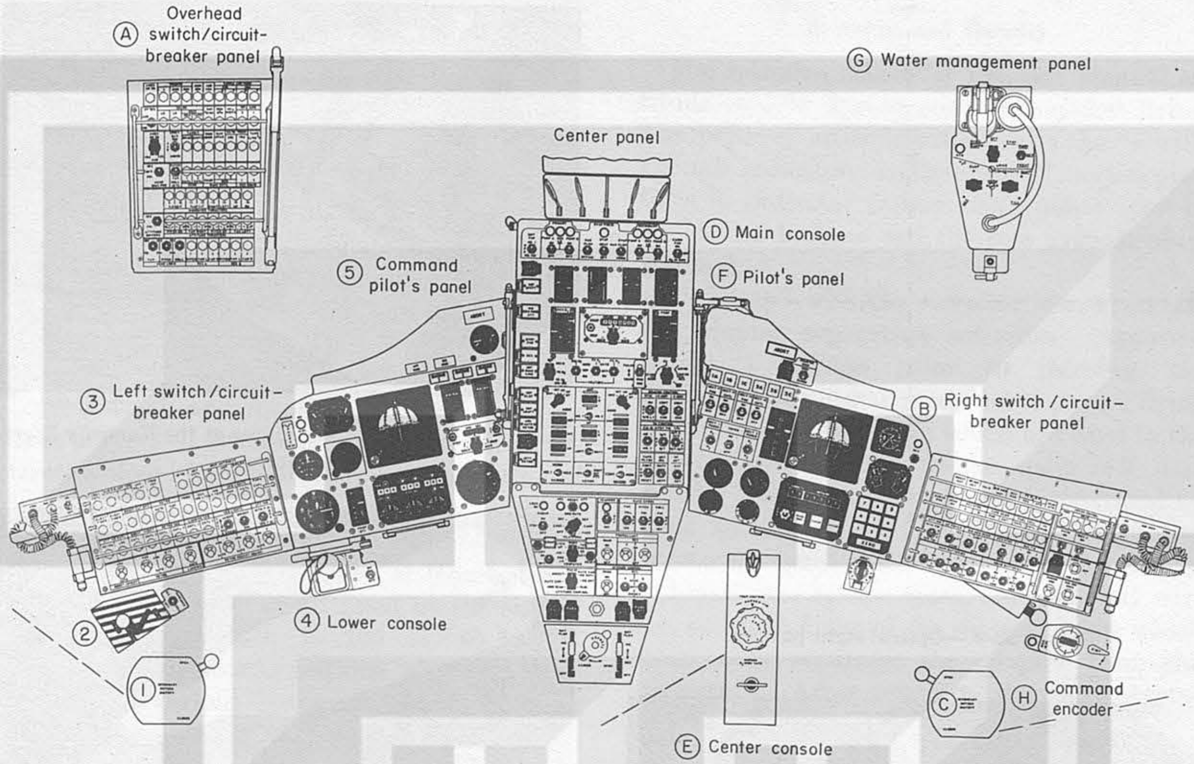


FIGURE 22-2.—Dynamic Crew Procedures Simulator.

A major portion of the rendezvous work, however, has been devoted to development of backup procedures. These backup procedures are required in the event of radar, computer, or inertial platform failures. The NASA and the spacecraft contractor have developed onboard charts which the pilot can use, with partial cockpit displays in conjunction with visual target observation, to compute the rendezvous maneuvers. To aid in the primary and backup rendezvous procedures, a collimated reticle is projected onto a glass plate in the left window (fig. 22-4). The brightness of the reticle is controlled by a rheostat. The pattern encompasses a 12° included angle. This device is used to aline the spacecraft on the target or starfield or to measure angular travel of the target over discrete time intervals.

Initial verification of the rendezvous procedures was accomplished on the engineering simulator (fig. 22-5) at the spacecraft contractor's plant. This simulator consists of a hybrid computer complex, a target and star display, and a crew station. Subsequent training was accomplished on the Gemini Mission Simulator



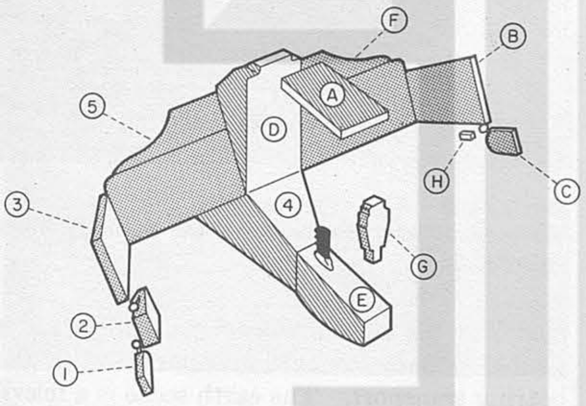


FIGURE 22-3.—Spacecraft instrument panel: (*1*) secondary oxygen shut-off (l.h.); (*2*) abort handle; (*3*) left switch/circuit-breaker panel; (*4*) lower console; (*5*) command pilot's panel; (*A*) overhead switch/circuit-breaker panel; (*B*) right switch/circuit-breaker panel; (*C*) secondary oxygen shut-off (r.h.); (*D*) main console; (*E*) center console; (*F*) pilot's panel; (*G*) water management panel; (*H*) command encoder.

(fig. 22–6), at the Manned Spacecraft Center. A second unit (fig. 22–7) is in the Mission Control Center facility at Cape Kennedy, Fla. The computer complex of both mission simulators consists of three digital computers with a combined storage capacity of 96 000 words. Six-degree-of-freedom computations are carried out during launch, orbit maneuvering either docked or undocked, and reentry. Maximum iteration rate for the six-degree-of-freedom equations is 20 cycles per second. Digital resolvers are incorporated to send analog signals to the various displays. Out-the-window visual simulation of the stars, the earth, and the rendezvous target are presented to each pilot through an infinity optics system. A spherical starfield is located within the crew-station visual display unit. The rendezvous target and the earth are generated remotely and are superimposed on the starfield scene by means of television, beam splitters, and mirrors within the crew-station display unit. Figures 22–8 and 22–9 shows an indication of the view available to the crew through the window of the simulator at Cape Kennedy. The rendezvous-target-vehicle scene is generated electronically, and the earth scene is televised from a filmstrip. The simulator at the Manned Spacecraft Center utilizes a $\frac{1}{6}$-scale

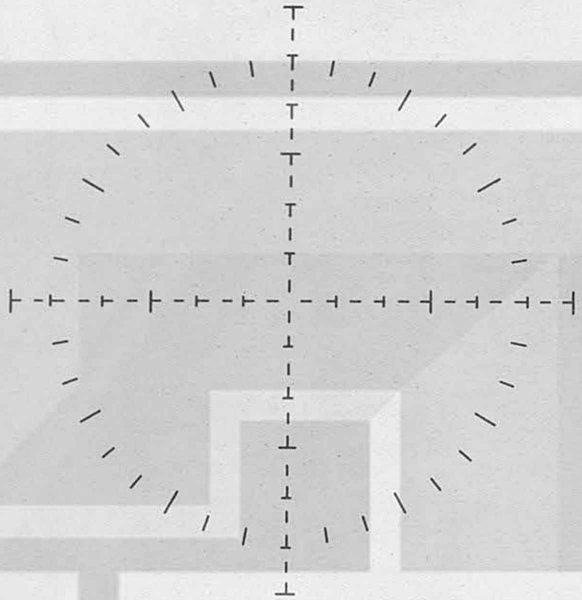


FIGURE 22-4.—Optical sight pattern.

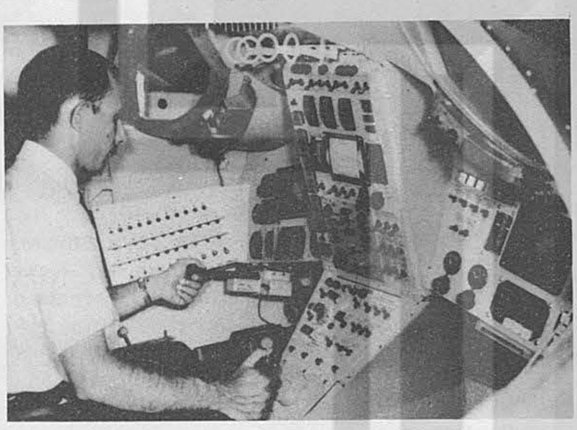


FIGURE 22-5.—Engineering Simulator.

FIGURE 22-6.—Mission Simulator at the Manned Spacecraft Center.

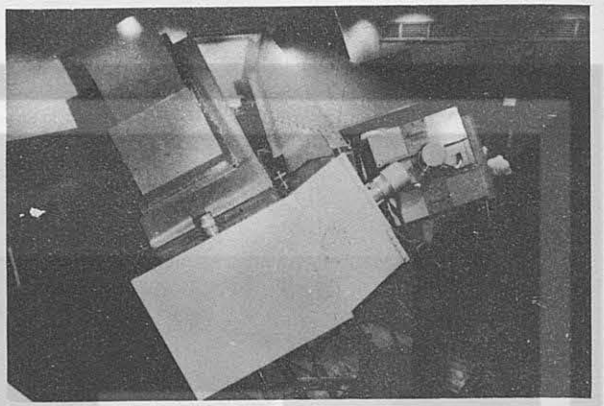


FIGURE 22-7.—Mission Simulator at the Kennedy Space Center.

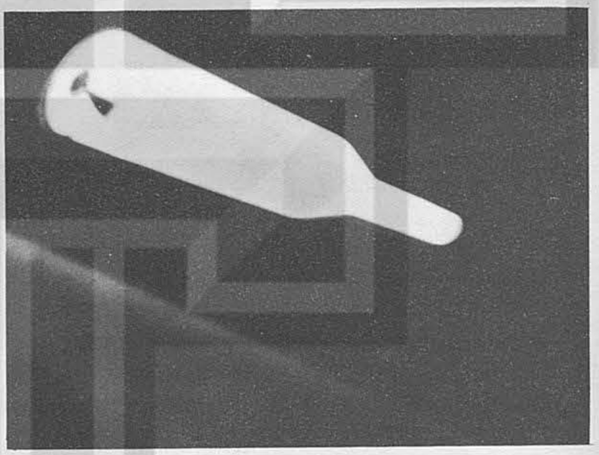


FIGURE 22-8.—Rendezvous target as seen through window of Mission Simulator at the Kennedy Space Center.

model of the rendezvous target vehicle and a gimbal-mounted television camera with air-bearing transport. The earth scene is a television picture of a 6-foot-diameter globe.

The crew stations for the simulators contain actual flight controls and displays hardware. The simulator at Cape Kennedy, which the crews utilize during the last 2 months prior to a flight, contains the exact cockpit stowage configuration in terms of operational equipment, experiments, cameras, and food. To provide additional crew comfort during the longer rendezvous simulations, the crew station was designed to pitch forward 30° from the vertical, thereby raising the crewman's head to the same level as his knees. Mission training is divided into segments so that no training period exceeds 4 hours. The simulator also generates approximately 300 telemetry signals which are transmitted to the worldwide communications and tracking network for use during integrated network simulations.

A part-task trainer which provides a full-scale dynamic simulation of the close-in formation flying and docking maneuvers is the Translation and Docking Simulator (fig. 22–10). The Gemini Agena target vehicle mockup is mounted on air-bearing rails and moves in two degrees of translation. The Gemini spacecraft is mounted in a gimbaled ring on another air-bearing track and incorporates the remaining four degrees of freedom. Cockpit controls activate a closed-loop control system consisting of an analog computer, servo amplifiers, and hydraulic servos. This simulator, located in the flight crew simulation building at Houston, has a maneuvering envelope defined by the size of the enclosure, which is 100 by 60 by 40 feet. Lighting configurations simulate day, night, and various spacecraft-target lighting combinations.

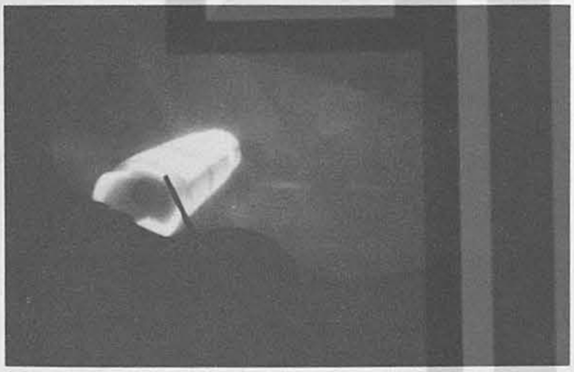


FIGURE 22–9.—View through window of Mission Simulator at the Manned Spacecraft Center.

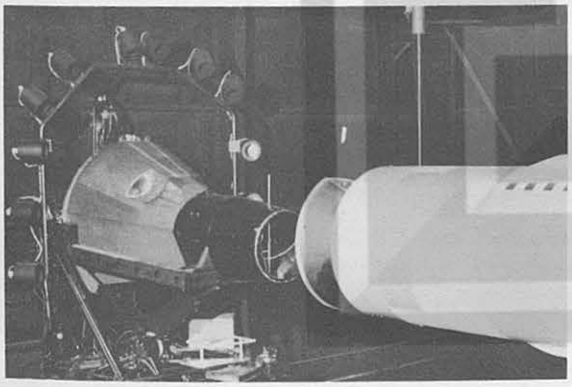


FIGURE 22–10.—Translation and Docking Simulator.

Retrofire and Reentry

The retrofire maneuver involves manual attitude control during solid retrorocket firing. The primary attitude reference is the "8-ball" attitude indicator. In the event of inertial platform or indicator failure, the window view of the earth's horizon and the rate gyro displays are used.

Associated with the retrofire maneuvers are the adapter separation activities. Approximately 1 minute prior to retrofire, the equipment adapter is separated to permit firing of the solid retrorockets, which are fixed to the retroadapter adjacent to the spacecraft heat shield. The equipment adapter is separated by three pilot actions: individual initiation of pyrotechnic guillotines for the orbital-attitude-and-maneuver-system lines, the electrical wiring, and then firing of the shaped charge which structurally separates the adapter from the spacecraft. After retrofire, the retroadapter separation is manually sequenced.

Reentry control logic is displayed to the pilots as roll commands in conjunction with down-range and cross-range errors. The down-range and cross-range error displays involve the pitch and yaw flight-director needles (fig. 22–3), which are used in a manner similar to the localizer and glide-slope display for an aircraft instrument-landing system. During the atmospheric deceleration portion of the reentry, the pilot must damp oscillations in pitch and yaw and, in addition, must control the roll in order to obtain proper lift-vector orientation. Good static and aerodynamic stability characteristics create a relatively easy damping task for the pilot.

Deployment of the drogue and the main parachutes is accomplished by the crew, based on altimeter readout and two discrete light indications which are triggered by separate barometric pressure systems.

The Gemini Mission Simulators have provided the majority of the training during the retrofire and reentry phase. Early familiarization and procedures development were conducted in the Gemini Part Task Trainer at the Manned Spacecraft Center, and in the engineering simulator at the spacecraft contractor's facility.

Systems Management

Overall management of spacecraft systems is similar to the concept used for aircraft. As shown in figure 22–3, the flight parameters are displayed directly in front of the pilots; the circuit breakers are located peripherally on the left, overhead, and right consoles; and the environmental control, fuel-cell heater, propulsion, communications, inertial platform, rate-gyro controls, and water-management panels are located on consoles between the pilots. The spacecraft separation, adapter separation, retro-rocket jettison, and deployment switches are guarded and interlocked with circuit breakers to prevent inadvertent operation during sleep periods, suit removal, and extravehicular operations.

The Agena control panel is located on the right side of the spacecraft. The pilot normally operates this control panel; however, by using a foot-long probe, called a swizzle stick, the simple toggle activities can be accomplished by the command pilot, even while he is wearing a pressurized suit.

Prior to the initial systems training on the Gemini Mission Simulator, six breadboard-type Gemini systems trainers are used for early familiarization. Figure 22–11 shows the electrical system trainer which portrays the control circuits and operational modes.

Extravehicular Activity

The crew procedures associated with extravehicular activity may be divided into two categories: first, preparation for extravehicular activity, which involves donning the specialized equipment; and second, flying the maneuvering unit and carrying out specific extravehicular tasks. Prior to egress, both crewmembers require approximately 2 hours of preparation for extravehicular activity. This activity includes removing the umbilical, the chest pack, and all other extravehicular equipment from stowage; then donning and checking out the equipment in the proper sequence. Each crewmember checks the life-support connections of the other crewman as each connection is made. Training for this phase of the extravehicular operation was carried out in specially prepared, static spacecraft mockups (fig. 22–12) located in the flight crew simulation building at the Manned Spacecraft Center, and in the Gemini Mission Simulator at Cape Kennedy. Also, training for egress and ingress and for extravehicular experiments is carried out under zero-gravity conditions in an Air Force KC–135 airplane (fig. 22–13) at Wright-Patterson Air Force Base. Spacecraft cockpit, hatches, and adapter section are installed in the fuselage for use during the aircraft flights. A 3-hour flight includes approximately 45 zero-g parabolas of 30 seconds'

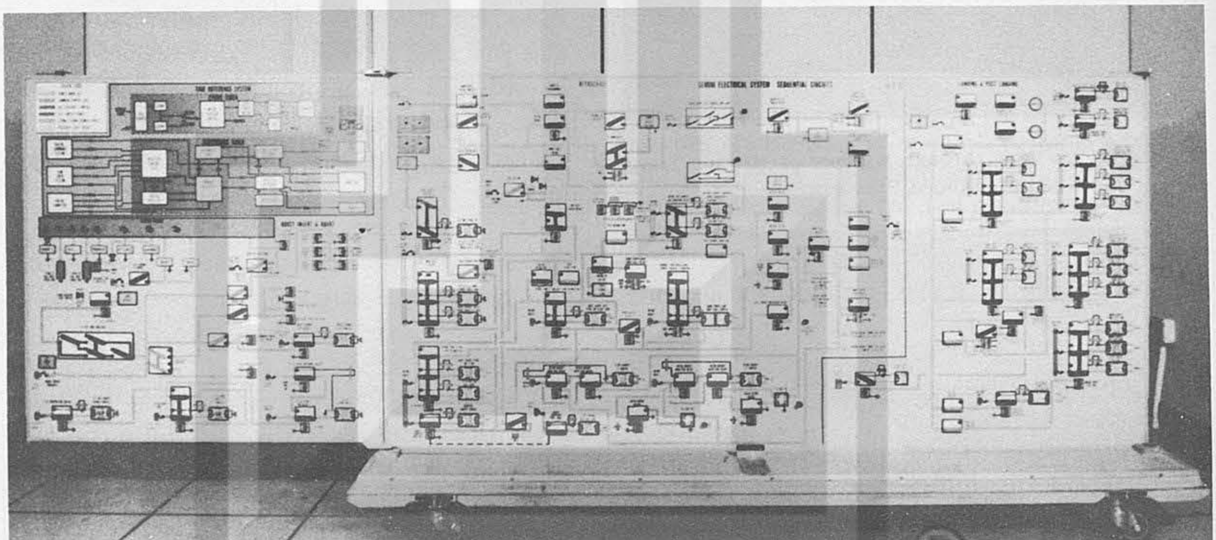


FIGURE 22–11.—Electrical System Trainer.

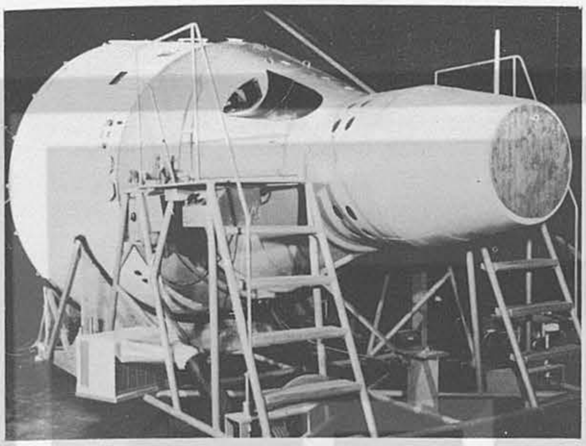


FIGURE 22-12.—Spacecraft mockup.

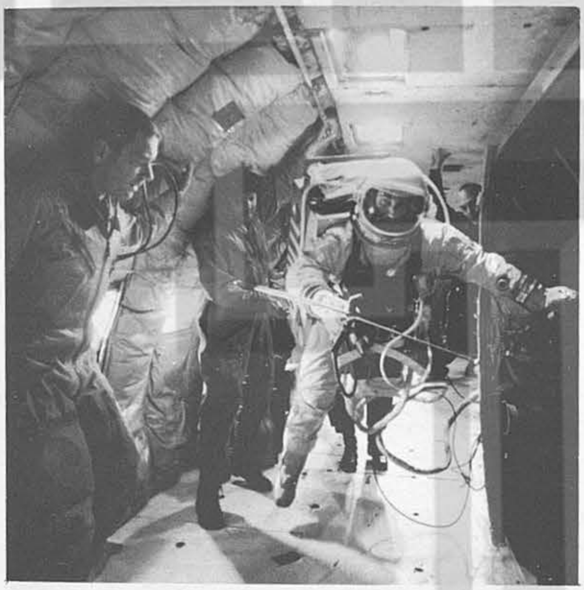


FIGURE 22-13.—Zero-g training in KC-135 airplane.

duration. The zero-g parabola involves a 45° pullup to 32 000 feet, then a pushover to zero-g with a minimum airspeed of 180 knots on top, followed by a gravity pitch maneuver to a 40° dive, after which a 2g pullout is accomplished with a minimum altitude of approximately 24 000 feet and an airspeed of 350 knots. The majority of the training for the extravehicular maneuvering procedures is carried out on three-degree-of-freedom simulators utilizing air bearings to achieve frictionless motion. Figure 22-14 shows a typical training scene, with the crewman in a pressurized suit practicing yaw control with a Gemini IV-type handheld maneuvering unit. The handheld unit (fig.

FIGURE 22-14.—Three-degree-of-freedom air-bearing simulator.

22-15) produces 2 pounds of thrust in either a tractor or pusher mode, as selected by a rocking trigger. The pilot directs the thrust with respect to his center of gravity to give a pure translation or to give a combination of translation and rotation. The low thrust level produces angular accelerations sufficiently low so that he can easily control his motion. Although the translation acceleration is also low, approximately 0.01g or 1/3 foot per second per second, this is sufficient thrust to give a velocity of 2 feet per second with a 6-second thrust duration. This general magnitude of velocity will accomplish most foreseeable extravehicular maneuvers.

In addition to the launch-abort training discussed previously, other contingency training includes practicing parachute and emergency egress procedures. Figure 22-16 shows parachute training activity which familiarizes the pilots with earth and water landings while wearing Gemini suits and survival equipment. This simplified parachute procedure involves a running takeoff and a predeployed parachute attached to a long cable which is towed by truck or motor launch.

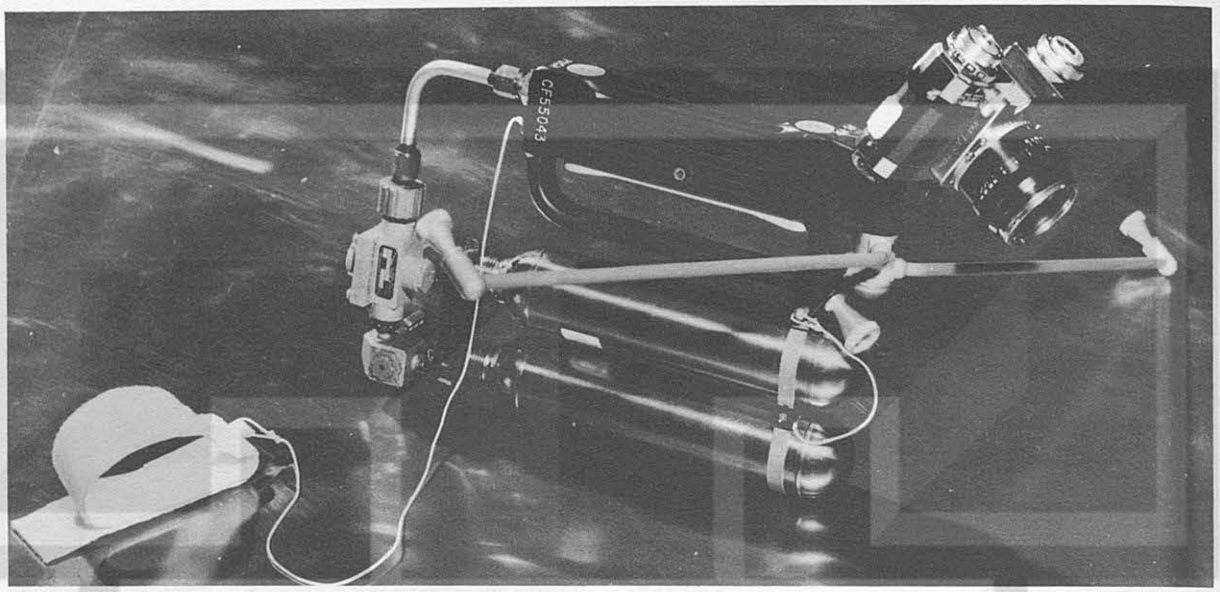


FIGURE 22-15.—Handheld maneuvering unit.

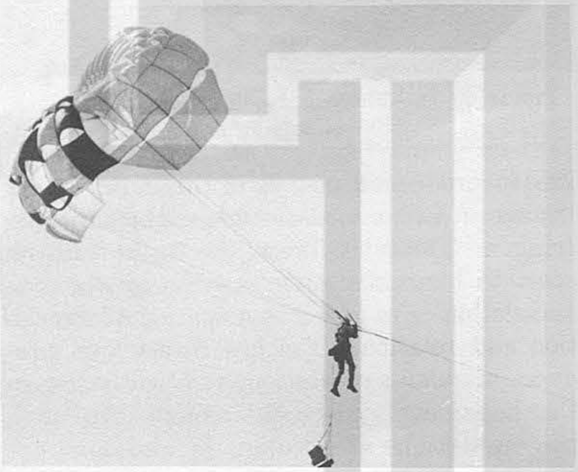


FIGURE 22-16.—Parachute training.

FIGURE 22-17.—Egress training.

Each crew undergoes an egress training session (fig. 22-17) in the Gulf of Mexico. Spacecraft systems procedures, egress techniques, water survival, and helicopter-sling techniques are rehearsed.

Flight Crew Preparation

Thirteen pilots were assigned as prime and backup crewmembers during the first five manned flights. As a partial indication of experience, their military aircraft pilot-rating date, total flight time, and assignment date to the astronaut program are listed in table 22-I. Considering that military aircraft ratings are achieved approximately 1 year after the start of flight training, their pilot experience ranges from 13 to 18 years; total aircraft flight time in high-performance aircraft varies from approximately 3000 to 5000 hours; and active affiliation with the NASA manned space-flight program varies from 20 months to nearly 7 years, at the time of launch. It is of interest to note that the man with the lowest flight time has also flown the X-15 rocket research airplane. They all obtained engineering degrees prior to or during the early stages of their engineer-pilot career. Age within the group ranges from 34 years to 42 years. All have undergone a three-part space-flight preparation program.

TABLE 22–I.—*Gemini Flight Crew Experience Summary*

Mission	Crew	Pilot rating date	Aircraft time, hours	Astronaut program	Flight date
Gemini III	Grissom	1951	4500	4/59	3/23/65
	Young	1954	3540	10/62	3/23/65
	Schirra	1948	3830	4/59	3/23/65
	Stafford	1953	4540	10/62	3/23/65
Gemini IV	McDivitt	1952	3450	10/62	6/ 3/65
	White	1953	4100	10/62	6/ 3/65
	Borman	1951	4940	10/62	6/ 3/65
	Lovell	1954	3550	10/62	6/ 3/65
Gemini V	Cooper	1950	3620	4/59	8/21/65
	Conrad	1954	3460	10/62	8/21/65
	Armstrong	1950	2760	10/62	8/21/65
	See	1953	3960	10/62	8/21/65
Gemini VI–A	Schirra [a]				12/15/65
	Stafford [a]				12/15/65
	Grissom [b]				12/15/65
	Young [b]				12/15/65
Gemini VII	Borman [c]				12/ 4/65
	Lovell [c]				12/ 4/65
	White [d]				12/ 4/65
	Collins	1953	3620	2/64	12/ 4/65

[a] Gemini III backup crew.
[b] Gemini III prime crew.
[c] Gemini IV backup crew.
[d] Gemini IV pilot.

The initial training phase involved a 6-month academic program, as shown in table 22–II. This particular curriculum was presented to the February 1964 group of astronauts. Because of the dual Gemini/Apollo training requirement, the curriculum is somewhat more comprehensive than the courses given to the first two groups.

TABLE 22–II.—*Astronaut Academic Program Basic Curriculum*

Course:	*Class hours*
Geology I	80
Geology II (laboratory—fieldwork)	80
Astronomy (laboratory—planetarium)	30
Math review	20
Flight mechanics	50
Basic aerodynamics	36
Aerodynamics	20
Rocket propulsion	34
Computers	16
Inertial systems	16
Navigational techniques	30
Guidance and control	34
Communications	12
Spacecraft control systems laboratory—simulations	16
Physics of the upper atmosphere and space	18
Basic physiology	32
Flight physiology and environmental systems	34
Meteorology	10
Total	568

The second phase of crew preparation involves assignment to engineering specialty areas. A typical breakdown of engineering categories is as follows:

(1) Launch vehicles

(2) Flight experiments and future programs

(3) Pressure suits and extravehicular activity

(4) Environmental control system, radiation protection, and thermal control

(5) Spacecraft, Agena, and service module propulsion

(6) Guidance and navigation

(7) Communications and tracking

(8) Electrical, sequential, and fuel cell systems

(9) Mission planning

(10) Crew safety, launch operations

(11) Landing and recovery systems

(12) Crew station integration
(13) Space vehicle simulators

The duration of this second phase, which extends to flight assignment date, varied from 8 months to 6 years. The Mercury flight assignment periods were included in phase II of Gemini flight preparation. All pilots, and in particular the Mercury-experienced crews, made many contributions to the design and operational concepts for the Gemini spacecraft.

The final phase begins with flight assignment and occurs approximately 6 months prior to launch date. At the start of this final phase, a detailed training plan is formulated by the training personnel and the assigned flight crew. A typical training schedule is summarized in figure 22–18. The assigned crews begin with detailed systems reviews using the systems trainers at the Manned Spacecraft Center, and actual participation in systems checkout activity at the spacecraft contractor's plant.

Training on the Gemini Mission Simulator starts about 3 months prior to launch. This training is carried out concurrently with all the other preparation activities. The initial training on the simulator is carried out at the Manned Spacecraft Center. Approximately 6 weeks prior to launch, the flight crew moves to Cape Kennedy in order to participate in the final spacecraft checkout and to continue training on the mission simulator.

Training time spent by the flight crews on the trainers and in the major areas is summarized in table 22–III. Differences in the time spent by the crews in the various activities are indicative of the type of missions and objectives.

In preparation for the first manned flight, a considerable number of hours were spent by the crews in the spacecraft systems activities at the spacecraft contractor's plant and with the spacecraft at Cape Kennedy. The extensive number of experiments carried out during the Gemini V and VII missions are reflected by the time spent in the preparation phase. For the first planned docking mission on Gemini VI, the prime crew spent 25 hours in the Translation and Docking Simulator, developing the control procedures for both formation flying and for docking.

Evaluation of Training

Although the adequacy of the astronaut training is difficult to measure, it is important that the value of the training facilities and activities

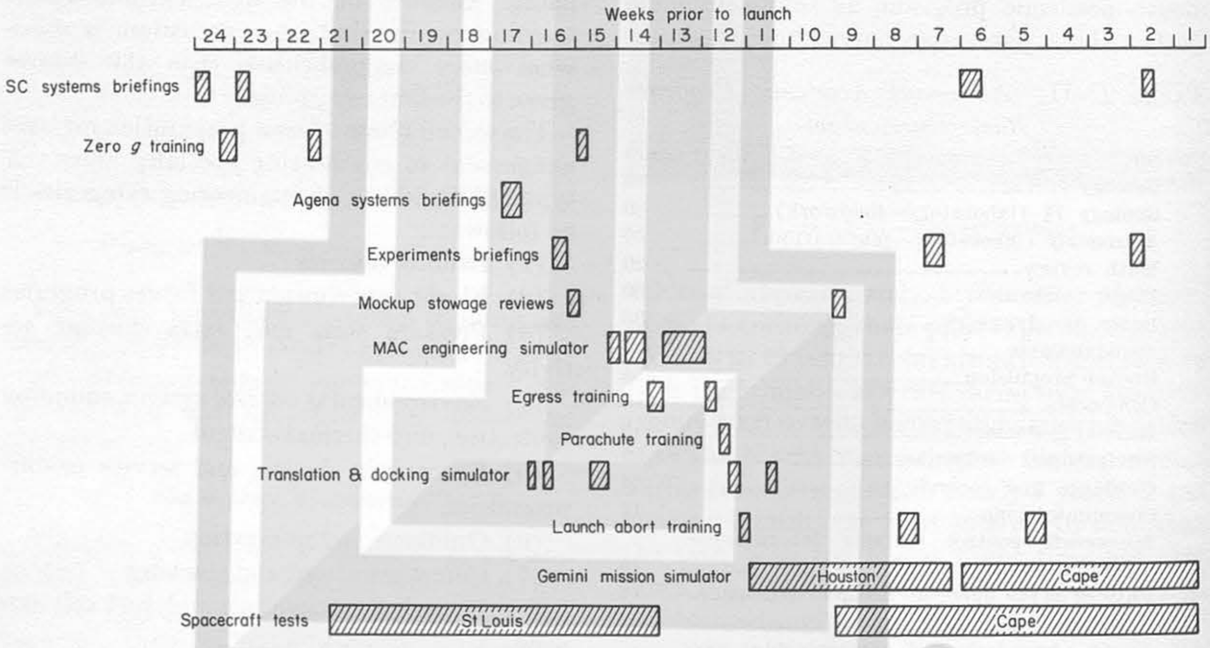


FIGURE 22–18.—Flight crew training schedule.

TABLE 22–III.—*Gemini Flight Crew Training Summary*

[Hours]

Training phase	Gemini III		Gemini IV		Gemini V		Gemini VI–A		Gemini VII	
	Prime	Backup	Prime	Backup	Prime	Backup	Prime[a]	Backup	Prime[b]	Backup
Mission simulator	118	82	126	105	107	110	107	76	113	114
Launch vehicle simulator	17	15	22	22	15	16	6	8	6	7
Docking simulator	1	5	6	6	2	12	25	17	4	4
Spacecraft systems tests and briefings	233	222	120	120	122	128	93	91	150	160
Experiments training	2	2	50	50	150	150	23	22	100	100
Egress and parachute training	18	15	23	23	12	12	6	6	9	13

[a] Prime crew on Gemini VI was backup on Gemini III.
[b] Prime crew on Gemini VII was backup on Gemini IV.

be examined at this point in the program. Comments made by the crews regarding their training are summarized as follows:

(1) Gemini mission simulator
 (a) Most important single training
 (b) Visual simulation invaluable
 (c) High fidelity required
 (d) Accurate crew station/stowage
(2) Spacecraft systems tests and briefings
 (a) Active participation in major spacecraft tests necessary
 (b) Briefings essential
(3) Contingency training
 (a) Egress and parachute training required
 (b) Launch-abort training essential

The crews were unanimous in their assessment of the importance of the Gemini Mission Simulator. The out-the-window visual simulation did not become fully operational until Gemini VI training at Cape Kennedy. The crews agree that this visual simulation is invaluable, particularly for the rendezvous training. Fidelity of hardware and software has been of utmost importance and should not be compromised. Practice in stowing and unstowing all the necessary cockpit gear, together with the operation of the total spacecraft systems, could be done only in the Gemini Mission Simulator, and this practice was found to be essential in establishing final cockpit procedures.

Although the time spent in the spacecraft tests and associated briefings varied with the crews, all crewmembers agreed that, without this participation and insight gained into the systems operation, the mission objectives could not have been carried out as they were.

Training for contingencies is considered by all as an essential part of the training for a flight. Water egress, as well as pad egress from the launch vehicle, is rehearsed by each pilot. Launch-abort training, both on the Dynamic Crew Procedures Simulator at the Manned Spacecraft Center, and the integrated network simulations on the Gemini Mission Simulator at Cape Kennedy, are believed to be very important.

Concluding Remarks

Extension of Gemini mission objectives from the initial three-orbit systems-verification flight to the long-duration missions with rendezvous and extravehicular activities have required a corresponding increase in the scope of simulation capability. The equipment which has been developed plus the experience gained on the simulators and in flight will provide a broad base from which to provide training for future Gemini flights as well as future programs.

23. SPACECRAFT LAUNCH PREPARATION

By WALTER J. KAPRYAN, *Resident Manager, Gemini Program Office, NASA Kennedy Space Center, and* WILEY E. WILLIAMS, *Manager, Gemini/LEM Operations, NASA Kennedy Space Center*

Summary

This paper presents a general résumé of Gemini spacecraft launch preparation activities. It defines basic test philosophy and checkout ground rules. It discusses launch site operations involving both industrial area and launch complex activities. Spacecraft test flow is described in detail. A brief description of scheduling operations and test procedures is also presented.

Introduction

In order to present the story of spacecraft launch preparation planning for the Gemini Program in its proper perspective, it is pertinent to first outline basic test philosophy and to discuss briefly the experience gained during the Mercury Program, because early Gemini planning was very heavily influenced by that experience. However, as will be pointed out later, actual Gemini experience has permitted some deviation from the ground rules established on the basis of Mercury Program experience.

The major tenets of the NASA test philosophy have been that, in order to produce a flight-ready vehicle, it is necessary to perform a series of comprehensive tests. These involve (1) detailed component level testing, (2) detailed end-to-end individual systems tests, and (3) complete end-to-end integrated tests of the spacecraft systems and between the spacecraft and its launch vehicle wherein the intent is to simulate as closely as practical the actual flight sequences and environment. This sequence of testing begins at the various vendors' plants, with predelivery acceptance tests, progresses through the prime contractor's facility, wherein a complete spacecraft systems test operation is performed, and concludes with the launch site operation. All data are cross-referenced so that the testing at each facility adds to and draws from the results obtained at each of the other facilities.

Test experience during the Mercury Program showed that it was necessary to perform extensive redundant testing in order to expose weak components, to assist in determining design deficiencies, and to continue developing reliability information. The plan that evolved was that, to a large extent, all prime contractor's in-plant tests would be repeated at the launch site. Further, due to the physical arrangement of systems within the spacecraft, it was generally necessary to invalidate more than one system when replacing a faulty component. This, of course, introduced additional testing. Finally, because special aerospace-ground-equipment (AGE) test points were not used, it was necessary to disconnect spacecraft wiring in order to connect test cables. When the wiring was finally connected for flight, additional validation testing was required.

Consideration of these factors on the Mercury program led to the following ground rules for early Gemini launch preparation planning:

(1) Spacecraft design would be of modular form so that simultaneous parallel work and checkout activities could be performed on several modules.

(2) Spacecraft equipment would be arranged for easy accessibility to expedite cabling operations so that component replacement would invalidate only the system affected.

(3) Aerospace-ground-equipment test points would be incorporated on the spacecraft and spacecraft components to minimize the need for disconnecting spacecraft wiring in order to monitor system parameters.

(4) The ground equipment would be designed so that problems could be isolated to the black-box level without requiring component removal from the spacecraft.

(5) The ground equipment to be used at the prime contractor's facility and at the launch site would be identical, where practical, so that test data could be more reliably compared than was possible in the Mercury program.

(6) The complete spacecraft systems test operation at the prime contractor's facility would be repeated at the Kennedy Space Center until such time that experience established no further need for these tests.

As the Gemini Program progressed toward its early operational phase, overall test planning underwent considerable review. The aforementioned ground rules were reexamined repeatedly and evaluated on the basis of the current status of qualification and development testing of Gemini spacecraft equipment. It soon became apparent that the state of the art had advanced to the extent that Gemini equipment was better than Mercury equipment, and some of the redundant testing planned for Gemini could be eliminated. Judicious reduction of redundant testing was very desirable from the standpoint of cost, manpower requirements, schedules, and wear and tear on the spacecraft systems and the test equipment. Accordingly, a decision was made to eliminate the complete repeat of the inplant spacecraft systems test operation at the launch site. However, in order to have a trained Gemini checkout team at the launch site, a special task force comprised of experienced test personnel was organized and sent to the prime contractor's facility for the purpose of participating in the spacecraft systems test operation on at least the first two all-systems spacecraft. At the conclusion of these tests this team returned to the launch site with these spacecraft.

Launch Site Preparation

Industrial Area Activity

The first Gemini spacecraft having all systems installed was spacecraft 2, and, by the time of its delivery to the Kennedy Space Center, the launch-site preparation plan had basically evolved into its present form. All launch-site testing would be performed at the launch complex. Except for special requirements, no spacecraft testing would be performed in the industrial area. Industrial area activity would be confined to only those functions which should logically be performed away from the launch complex, and to preparing the spacecraft for its move to the launch complex. Typical spacecraft industrial area activity is as follows:

(1) Receiving inspection.

(2) Cleanup of those miscellaneous manufacturing activities not performed at the prime contractor's facility, and incorporation of late configuration changes.

(3) Pyrotechnic installation.

(4) Fuel-cell installation.

(5) Flight-seat installation.

(6) Rendezvous and recovery section buildup.

(7) Weight and balance.

(8) Manufacturing cleanup and inspection.

(9) Preparations for movement to the launch complex.

In addition to these typical activities, complete end-to-end propulsion system verification tests were performed with spacecraft 2 and 3. These tests included static firing of all thrusters. They were performed primarily to provide an early end-to-end checkout of the servicing procedures and equipment prior to their required use at the launch complex. A further benefit derived from these tests was the completion of development and systems testing on Gemini hypergolic systems to the point that these specific systems could be committed to flight with a high degree of confidence. A demonstration cryogenic servicing was also performed on spacecraft 2. Spacecraft 3, the first manned Gemini spacecraft, received a communications radiation test at the Kennedy Space Center radar range. This test exercised spacecraft communications in a radiofrequency environment that more closely simulated the actual flight environment than was possible at any other available facility. The remaining nonrendezvous spacecraft did not undergo any systems tests in the industrial area. For the first two rendezvous spacecraft, a radiofrequency and functional-compatibility test between the spacecraft and the target vehicle was also performed at the radar range (fig. 23-1). This particular test is basically a proof-of-design test, and the need for its continuation is being reviewed.

Launch-Complex Operations

A chart of typical launch-complex test operations is presented as figure 23-2. Testing be-

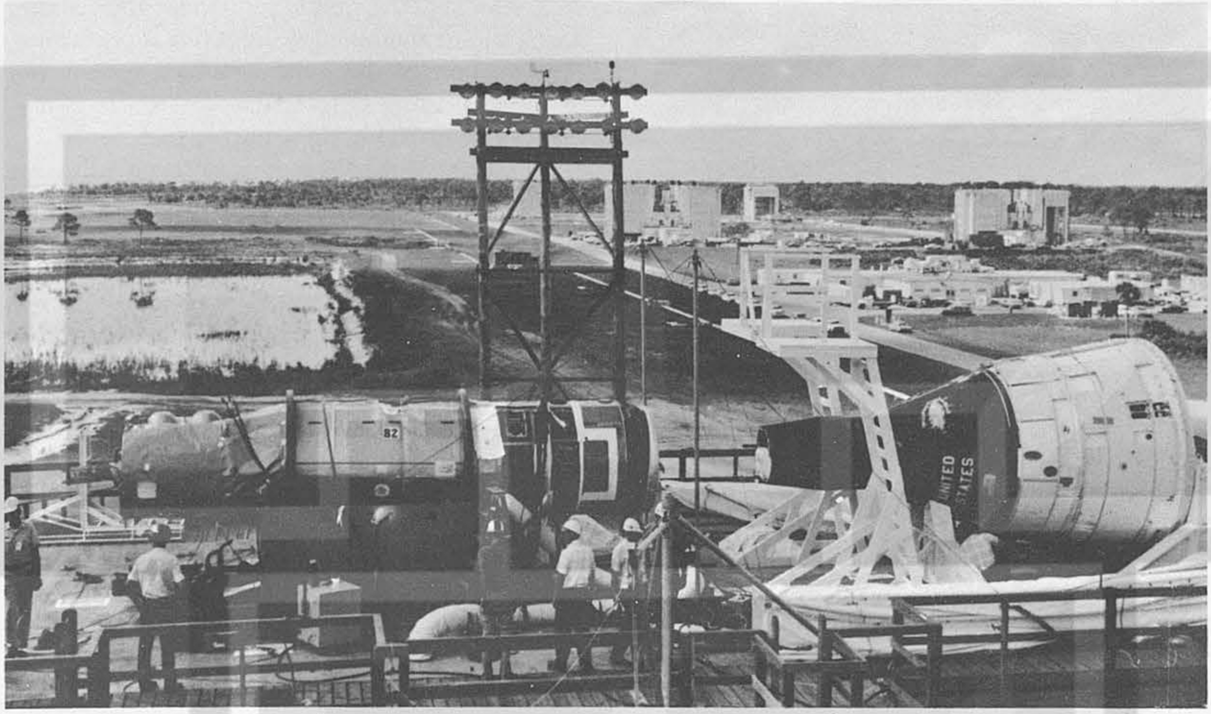


FIGURE 23-1.—Spacecraft and Gemini Agena target vehicle undergoing tests at radar range.

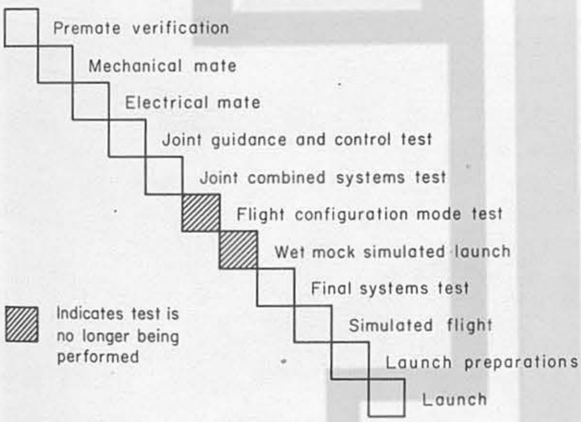


FIGURE 23-2.—Spacecraft test operations performed at launch complex.

gins with premate verification, which consists of thoroughly testing spacecraft systems down to the black-box level. The first fuel-cell activation is performed at this time. Data obtained are compared with data from the spacecraft systems tests at the prime contractor's facility and predelivery acceptance tests at the vendors' plants. The intent of this testing is to integrate the spacecraft with the launch complex and to get a last detailed functional look at all systems, especially those within the adapter, prior to performing mechanical mate and the assumption of integrated tests with the launch vehicle. Typical cabling configurations are shown in the next two figures; figure 23-3 shows the reentry module, and figure 23-4 shows the adapter. Following the successful completion of premate verification, the spacecraft and launch vehicle are mechanically mated. This operation is performed under the direction of a mechanical interface committee, which verifies that all clearances and physical interfaces are in accordance with the specifications.

Following mechanical mate, electrical-interface tests between the spacecraft and the launch vehicle are conducted to functionally or electrically validate the interface. All signals capable of being sent across the interface are tested in all possible modes and redundant combinations. Following the electrical mate, the joint guidance and control tests are performed. These tests consist largely of ascent runs involving primary guidance and switchover to secondary guidance. During these tests, such items as secondary static gains, end-to-end phasing, and switchover fade-in discretes are also checked for specification performance.

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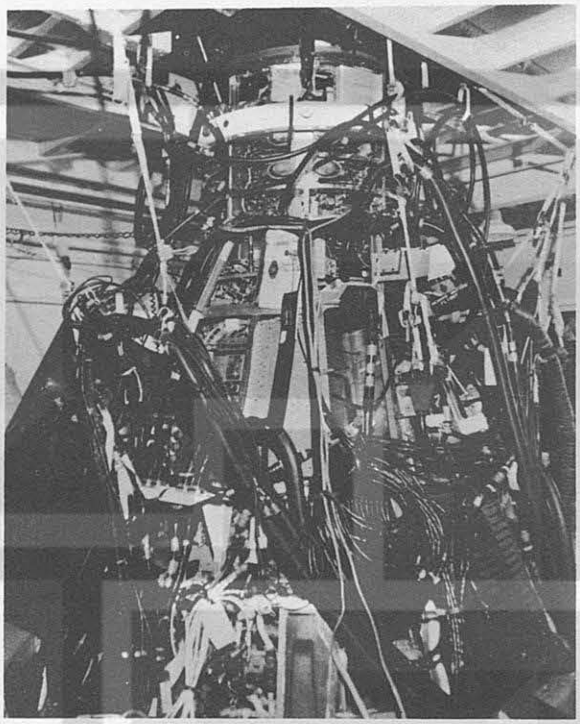


FIGURE 23-3.—Spacecraft reentry section with cables attached for systems test at launch complex.

Following the joint guidance and control tests, a joint combined systems test is performed. The purpose of the joint combined systems test is to perform a simulated mission. It is normally performed in three parts:

(1) Part 1 consists of exercising all abort modes and command links, both radiofrequency and hardline.

(2) Part 2 consists of an ascent run through second-stage engine cutoff, wherein there is a switchover from primary to secondary guidance.

(3) Part 3 consists of a full-blown simulated mission and involves a normal ascent on primary guidance, orbit exercises applicable to the specific mission, and rendezvous and catchup exercises. Finally, retrofire with a complete reentry to landing is simulated. Suited astronauts are connected to the environmental control system during this test. Thus, the joint combined systems test is a comprehensive, functional, integrated test of the entire space vehicle and serves as the first milestone for alerting the worldwide network and recovery forces to prepare to man their stations for launch.

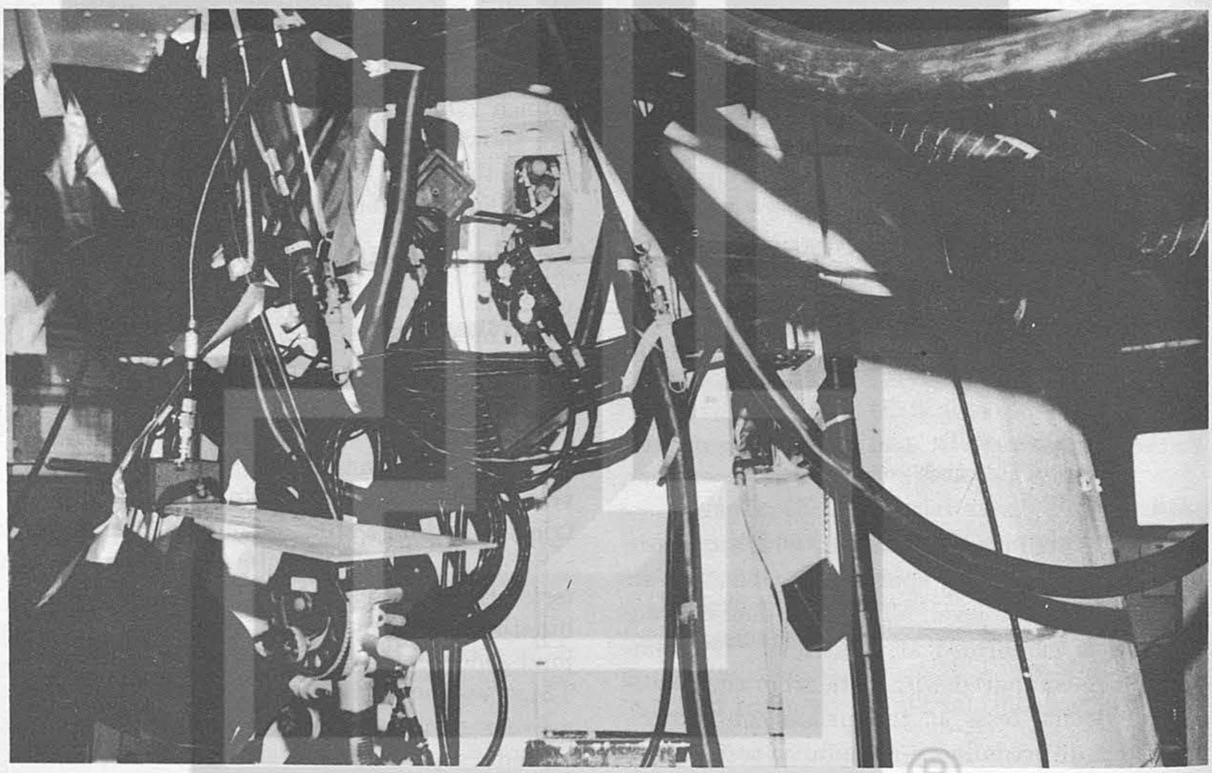


FIGURE 23-4.—Spacecraft adapter assembly with cables attached for systems test at launch complex.

Following the joint combined systems test, a flight configuration mode test has been performed. This test simulates an ascent run as close as possible to the true launch environment. For this test, all of the ground equipment was disconnected, all launch vehicle and spacecraft umbilicals were pulled in launch sequence, and the total vehicle was electrically isolated from the launch complex. All monitoring of systems performance was through cabin instrumentation and telemetered data. This test unmasked any problems that may have been obscured by the presence of the aerospace ground equipment and demonstrated systems performance in flight configuration. A test such as this was very valuable to the Gemini Program in its earlier phases; however, now that the program has reached its present phase of stabilized and proved flight and ground equipment configuration, the value of the test is somewhat diminished. For that reason, beginning with Gemini VII the flight configuration mode test was no longer being performed. However, since certain sequential functions cannot be demonstrated without umbilical eject, the umbilical-pull portion of this test has been retained and has been incorporated as an additional sequence of one of the other test days.

The wet mock simulated launch is a dress rehearsal of the launch operation itself. Both launch vehicle and spacecraft are serviced and prepared exactly as though they were to be launched. The complete countdown is rehearsed and runs to T−1 minute. Astronaut ingress is performed exactly the same as on launch day. This operation actually includes all launch preparation functions and starts on F−3 day. This test is primarily an operational demonstration on the part of the launch team and serves as the second major milestone of an impending launch. This test, too, is of greatest value in the early operational phases of a program. As the program progresses, the wet mock simulated launch provides diminishing returns. The last spacecraft for which a complete wet-mock-simulated launch was performed was spacecraft 6 prior to its first launch attempt. It is doubtful that any further complete wet-mock-simulated launches will occur.

For the rendezvous phase of the program, a simultaneous launch demonstration is being performed in lieu of the wet-mock-simulated launch. This test is a coordinated countdown of the Atlas-Agena and the Gemini space vehicles. It simulates an Atlas-Agena launch and the first orbit of the Agena. As during wet mock simulated launch, the spacecraft and Gemini launch vehicle count runs to T−1 minute. The simultaneous launch demonstration, however, does not include the servicing of any of the vehicles, nor does it include the precount and midcount. It is being performed closer to launch than was the wet-mock-simulated launch and will be discontinued when experience shows it to be no longer necessary.

The deletion of the wet-mock-simulated launch improves the launch-complex schedule by several days, and also eliminates the requirement for an early mechanical mate. Since the erector is lowered during wet-mock-simulated launch, the spacecraft must be mechanically mated to the launch vehicle for this test. Therefore, its elimination permits integrated testing to continue while demated, by the utilization of an electrical interface jumper cable. Thus, any activities requiring access into the spacecraft adapter can be performed much later in the sequence of launch-complex operations than was heretofore possible. Spacecraft 8, for example, is not scheduled to be mechanically mated until after the completion of final systems test.

Following the wet-mock-simulated launch, final spacecraft systems tests are performed. They encompass the same scope as during premate verification. These tests provide final detailed component-level data prior to launch. At this time, all data are closely scrutinized for any trends indicating degraded performance. Following the final systems test, the final simulated flight is conducted. This test is very similar to the joint combined systems test. The runs are identical, and suited astronauts participate. One important additional function performed during this test is to utilize high-energy squib simulators during appropriate sequencing functions involving pyrotechnics. Thus, all pyrotechnic circuits experience electrical loads just as though actual squibs were being fired. The simulated flight is the last major test of the spacecraft prior to launch. Immediately after the simulated flight, final launch preparations begin, leading to the precount on F−3 day. The primary purpose of the precount is to perform power-on stray voltage checks prior to making final flight hookup of spacecraft pyrotechnics.

Following the precount, final servicing operations begin, and the spacecraft buttoning-up process starts. On F−1 day the midcount is performed. At this time the spacecraft is remotely powered up in order to demonstrate the safety of the pyrotechnic configuration. The fuel cells are activated during the midcount and remain powered up through launch.

The final countdown is started early on launch day and is of 6 hours' duration. During the count, an abbreviated check of all systems is made and is timed to be completed prior to the schedule target vehicle launch so that during the critical time period following that launch, a minimum of test activity is required. This approach has put us in the posture of being exactly on time at T−0 for the two complete rendezvous countdowns thus far.

The sequence of testing just described provides for several distinct milestones for gaging test progress, and it also provides for the logical resumption of testing in the event a test recycle is required, as was the case during the Gemini VI mission. Following the inflight failure of the Agena target vehicle and the subsequent decision to attempt a double spacecraft rendezvous, spacecraft 6 was removed from the launch complex and essentially placed in bonded storage. Immediately after the launch of spacecraft 7, spacecraft 6 was returned to the launch complex. Testing resumed with final systems test, included the final simulated flight, and concluded with the launch. Thus, in a matter of days, a complete new set of test data was obtained and correlated with the data from the previous more-extended spacecraft 6 checkout operation and permitted the spacecraft to be launched with a high degree of confidence. It goes without saying that the Gemini launch vehicle test plan was equally flexible, or the rapid recycle could never have been performed.

The waterfall chart shown in figure 23–2 does not, of course, represent all of the spacecraft test activity at the launch complex. For example, for the Gemini II and III missions an extensive electrical-electronic interference investigation was conducted. Special instrumentation was installed to monitor the critical spacecraft and launch vehicle interface circuits. The performance of these tests basically added another joint combined systems test to the flow plan. Also, cabin-leak rates must be determined for all spacecraft. This chart does not present any experiment test activity, which for some missions is of significant magnitude. In general, these activities are scheduled on a parallel basis with other activities, but at times they do add serially to the schedule.

A significant portion of the effort expended at the launch complex is not directly related to the performance of tests. For example, the following servicing operations are required:

(1) Hypergolic and pressurant servicing of the propulsion system.

(2) Cryogenic servicing for the fuel cells and the environmental control system.

(3) Servicing of secondary oxygen.

(4) Replacement of the lithium hydroxide canister within the environmental control system.

(5) Sterilizing and servicing of the water management system.

Certain experiments also have special servicing requirements and crew-station stowage exercises are required, to name but a few of the nontest functions being performed. The incorporation of a few configuration changes must also be anticipated. In order to project realistic launch dates, sufficient allowances must be provided in the overall launch-complex schedule for all of these activities.

Scheduling

For a normal mission operation, launch-complex test activities are scheduled on a two-shift, 5-day-week basis. The third shift and weekends are utilized for shop-type activity and troubleshooting, as required. The weekend also serves as a major contingency period in the event of failure to maintain schedules during the normal workweek. Daily scheduling meetings are held, during which all test and work activities are scheduled for the ensuing 24 hours. Scheduling on this basis has resulted in meeting projected launch schedules for most missions, and has enabled management to make realistic long-range program commitments. The only spacecraft for which there has been any significant differences between projected and actual schedules is spacecraft 2. Much of this discrepancy can be accounted for by the fact that it was the first spacecraft to use the complete launch complex. During the operations for spacecraft 2, there were many launch-complex problems, primarily associated with electrical shielding and grounding. Test procedures reflected the early stage of the program and also required significant refinement. The lessons learned with spacecraft 2 have enabled subsequent spacecraft to progress substantially on or ahead of schedule.

Test Procedures

All significant test operations are performed utilizing formal test procedures. Every step of the test is defined in the procedure. All procedures and the data obtained are certified as having been accomplished by inspection personnel. Any deviations to these procedures are documented in real time and are also certified by inspection. The program, therefore, has a complete documented file of every important spacecraft test performed at the Kennedy Space Center since the inception of the program.

Spacecraft testing in the Gemini Program is a joint NASA/contractor effort. The tests are conducted for the NASA by the contractor, with the NASA lead engineers working closely with their contractor counterparts. This method of operation provides a system of built-in checks and balances and enables the NASA management to keep fully aware of test progress so that necessary management decisions can be readily made. This method of operation has contributed significantly to the success of manned space-flight programs to date.

Concluding Remarks

Experience with the Gemini Program has demonstrated the basic soundness of the early program planning. Further, the Gemini Program has benefited greatly from Project Mercury experience. For example, the more realistic qualification requirements for Gemini equipment have reduced the incidence of equipment failures significantly over that of the Mercury Program. This factor has contributed to a test environment requiring much less repeat testing. The fact that the program was successfully able to eliminate the repeat of the spacecraft systems test operation at the launch site reduced spacecraft operations at the launch site from a projected 125 working days to approximately 45 working days at the present phase of the program. Spacecraft test plans are continually being reevaluated from the standpoint of still further streamlining. Gemini ground equipment has provided a much greater capability to monitor systems performance in detail so that the spacecraft can be committed to launch with ever greater confidence. Greater equipment accessibility has also contributed significant time savings. The net result has been a test flexibility that has enabled the program to accelerate schedules when necessary, and has enabled the program to recover from the catastrophic target vehicle flight of last October 25 with a rapid recycle and the highly successful rendezvous in space during Operation 76. This experience is evidence of a maturing manned space-flight effort. Extension of this experience should contribute significantly to more efficient utilization of money and manpower in future space programs.

24. SPACECRAFT LAUNCH-SITE PROCESSING

By J. R. Atkins, *Chief, Safety Division, NASA Kennedy Space Center;* J. F. Thompson, *Test Conductor's Office, NASA Kennedy Space Center; and* R. J. Teti, *Test Conductor's Office, NASA Kennedy Space Center*

Summary

In this report, the data of interest with regard to the processing of the Gemini spacecraft are analyzed. The time required for processing any particular spacecraft is dependent not only upon the tests required but also upon the number of manufacturing tasks, the number of tasks that can be worked concurrently, and the amount of time available. The effort required to accomplish modifications, replacements, and repairs is accomplished in parallel with other activities and does not directly affect the schedule.

The influence of discrepancies found during testing and the number of discrepancies per testing hour can be predicted. In addition, such other parameters as the number of processing tasks and the number of testing shifts have been suitably combined with other factors into a mathematical model for predicting the number of days required at launch complex 19 at Cape Kennedy, Fla.

Introduction

The time required to complete the launch-pad processing of a Gemini spacecraft depends on several factors, such as testing, modification, part replacement, servicing time, and post-testing activities. Data on these factors have been analyzed and combined into a mathematical model which serves as a basis for predicting the launch-pad processing time required before a Gemini spacecraft can be launched from Cape Kennedy, Fla. Monitoring of the elements of the mathematical model provides a means of evaluating performance.

This model has been prepared by the Spacecraft Operations Analysis Branch at the Kennedy Space Center, using the following sources of data:

(1) Spacecraft test and servicing procedures from the spacecraft prime contractor.
(2) Inspection reports.
(3) The spacecraft test conductor's log.
(4) Daily activity schedules.
(5) Meeting attendance.
(6) Systems engineering reports.
(7) Operating personnel.

Clarification of the source material was obtained from systems engineers and spacecraft test conductors.

Spacecraft Schedule Performance

A comparison of schedules with performance (table 24–I) shows that spacecraft 2 was the only spacecraft that did not meet the planned checkout schedule. However, the spacecraft can be considered a special case for analysis purposes, since it was the first to use the new test facilities and flight hardware. This is supported by the fact that 102 aerospace-ground-equipment interim discrepancy records were recorded, as compared with 36 spacecraft interim discrepancy records. An interim discrepancy record is prepared whenever a problem is encountered on either ground equipment or on the spacecraft. The spacecraft discrepancies did not contribute significantly to the schedule slippage.

The original schedule for spacecraft 5 was exceeded by 15 days. This was caused by a 13-day extension due to several effects other than spacecraft testing, interim discrepancy records, troubleshooting, servicing, or modification, and is not included in this discussion. There was also a 2-day slip in the launch of spacecraft 5 caused by a countdown scrub.

Analysis of Spacecraft Processing Factors

Effects of Major Spacecraft Tests

The original checkout schedule consisted of 10 major tests. Later, four of the tests were combined into two, leaving eight major tests. The data from these tests form the basis for this phase of the evaluation.

TABLE 24–I.—*Scheduled Versus Actual Testing Time*

Planned test schedule, days				Actual performance, days				
						Countdowns		
Spacecraft	Prepad [a]	Pad [b]	Total	Prepad [a]	Pad [b]	1st	2d	3d
2	16	42	58	28	53	81	122	----------
3	24	53	77	31	47	78	----------	----------
4	12	48	60	10	51	61	----------	----------
5	7	43	50	7	56	63	65	----------
6	30	53	83	36	47	83	131	[c] 134
7	21	36	57	21	36	57	----------	----------

[a] Testing before the spacecraft is installed on the launch vehicle at launch complex 19.

[b] Testing after the spacecraft is installed on the launch vehicle.

[c] The third countdown for spacecraft 6 required an additional 51 days—38 prepad days and 13 pad days.

The majority of the scheduled tests were accomplished in the time allotted. Reruns of test sequences and troubleshooting were, on occasion, accomplished in times other than that scheduled, but in the majority of cases this testing and troubleshooting were done in parallel with the daily work schedule.

Only a minor portion of the troubleshooting was performed in serial time, which is time that delays completion of a particular task. Analysis of test preparation, testing, and troubleshooting times revealed that—

(1) Serial troubleshooting time can be estimated as 0.2 shift for each shift of testing.

(2) The test times (table 24–II and fig. 24–1) for individual tests provide a good basis for future planning.

(3) The time used for test preparation will increase as the time allotted increases.

(4) Five shifts were required, on the average, for spacecraft 3 through 7 serial troubleshooting time.

Figure 24–1 shows the distribution of the test and serial troubleshooting times. The data in this figure have been combined according to the test sequence evolution and are displayed on the basis of major tests.

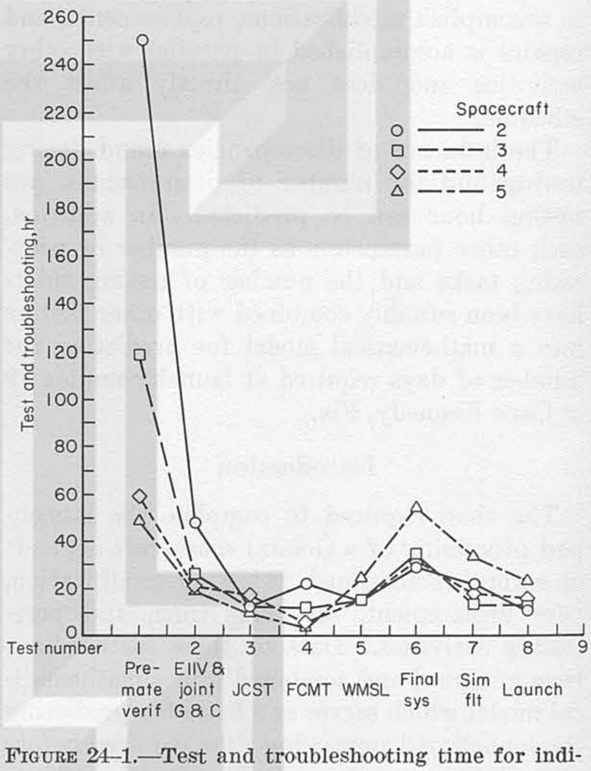


FIGURE 24–1.—Test and troubleshooting time for individual tests.

Effects of Spacecraft Discrepancies

The original spacecraft test sequence consisted of 10 major tests. On spacecraft 4, the electrical interface and integrated validation test and the joint guidance and control test were combined and performed as one test. On spacecraft 5, the premate systems test and the premate simulated-flight test were combined to form the premate verification test. As a result, the test sequence has evolved to the eight major tests shown in table 24–II.

TABLE 24-II.—*Spacecraft Performance Summary*

Test	Spacecraft	SEDR No.	Interim discrepancy records				Setup time		Testing time		Serial troubleshooting time		Total: Setup plus testing time		Total: Testing plus troubleshooting		Modification time	Discrepancies	Replacement items
			Spacecraft	AGE [a]	Unclassified	Total	Shifts	Hours	Shifts	Hours	Shifts	Hours	Shifts	Hours	Shifts	Hours			
1. (a) Premate systems test	2	453	7	53	0	60	9	72	6.6	53	10.6	85	26.2	210	17.2	138			
	3	-------	2	28	8	38	9	72	8.3	66	2.5	20	19.8	158	10.8	86			
	4	-------	7	10	11	28	12	96	4.8	38.5	.1	1	16.9	135.5	4.9	39.5			
(b) Premate simulated fit	2	454	11	25	5	41	0	0	6.5	52	7.5	60	14	112	14	112			
	3	-------	1	5	4	10	0	0	2.6	21	1.5	12	4.1	33	4.1	33			
	4	-------	1	1	6	8	1.5	12	2.5	20	0	0	4.0	32	2.5	20			
(c) Premate verification	5	453	11	18	14	43	6	48	2.9	23	3.3	26	12.2	97	6.2	49			
	6	-------	6	14	7	27	7	56	4.8	38.5	.9	7	12.7	101.5	5.7	45.5			
	7	-------	13	7	8	28	9	72	5.5	44	.1	1	14.6	117	5.6	45			
2. (a) Electrical interface and integrated validation	2	456	1	4	0	5	1	8	3.2	25.5	.5	4	4.7	37.5	3.7	29.5			
	3	-------	0	1	1	2	1	8	1.1	9	.8	6	2.9	23	1.9	15			
(b) Joint guidance and control	2	464	2	1	1	4	1.5	12	2.1	17	.3	2	3.9	31	2.4	19			
	3	-------	0	1	1	2	1.5	12	1.5	12	0	0	3.0	24	1.5	12			
(c) Electrical interface and integrated validation and joint guidance and control	4	456	1	1	0	2	6	48	2.7	21.5	0	0	8.7	69.5	2.7	21.5			
	5	-------	0	3	0	3	2	16	2.3	18.5	.3	2.5	4.6	37	2.6	21			
	6	-------	0	1	0	1	5	40	2.3	18.5	0	0	7.3	58.5	2.3	18.5			
	7	-------	1	3	2	6	6	48	2.4	19.5	.4	3	8.8	70.5	2.8	22.5			
3. Joint combined system test	2	457	4	4	4	12	1	8	1.4	11	.1	.50	2.5	19.5	1.5	11.5			
	3	-------	2	5	1	8	1	8	1.3	10	.6	5	2.9	23	1.9	15			
	4	-------	5	5	2	12	6	48	1.5	12	.7	6	8.2	66	2.2	18			
	5	-------	4	7	3	14	1.5	12	1.5	12	0	0	3.0	24	1.5	12			
	6	-------	3	1	2	6	3	24	1.1	9	0	0	4.1	33	1.1	9			
	7	-------	5	4	2	11	6	48	1.4	11	.1	1	7.4	60	1.5	12			
4. Flight configuration mode test	2	459	1	1	1	3	2	16	2.0	16	.9	7	4.9	39	2.9	23			
	3	-------	1	2	0	3	1.5	12	.8	6	.8	6	3.1	24	1.6	12			
	4	-------	1	0	0	1	1	8	.6	5	.4	3	2.0	16	1.0	8			
	5	-------	1	2	0	3	2	16	.6	5	.2	1.3	2.8	22.3	.8	6.3			
	6	-------	0	1	1	2	6	48	1.4	11.5	0	0	7.4	59.5	1.4	11.5			
	7	-------	N/A																
5. Wet mock simulated launch	2	458	5	3	1	9	9	72	1.3	10	.6	5	10.9	87	1.9	15			
	3	-------	5	7	5	17	9	72	1.9	15	0	0	10.9	87	1.9	15			
	4	-------	0	5	4	9	9	72	1.9	15	0	0	10.9	87	1.9	15			
	5	-------	7	7	0	14	9	72	2.6	20.5	.4	3	12.0	95.5	3.0	23.5			
	6	-------	2	8	5	15	13	104	2.6	21	.8	6	16.4	131	3.4	27			
	7	-------	N/A																

[a] Aerospace ground equipment.

TABLE 24-II.—*Spacecraft Performance Summary*—Continued

Test	Spacecraft	SEDR No.	Interim discrepancy records				Setup time		Testing time		Serial trouble-shooting time		Total				Modification time	Discrepancies	Replacement items
													Setup plus testing time		Testing plus troubleshooting				
			Spacecraft	AGE [a]	Unclassified	Total	Shifts	Hours	Shifts	Hours	Shifts	Hours	Shifts	Hours	Shifts	Hours			
6. Final systems test	2	460	2	2	2	6	1	8	3.1	25	0.8	6	4.9	39	3.9	31			
	3	-------	2	4	1	7	2	16	3.0	24	1.1	9	6.1	49	4.1	33			
	4	-------	5	5	3	13	3	24	3.6	28.5	0	0	6.6	52.5	3.6	28.5			
	5	-------	6	15	4	25	4	32	4.6	37	2.5	20	11.1	87	7.1	57			
	6	-------	7	6	4	17	11	88	4.4	35	.4	3	15.8	126	4.8	38			
	7	-------	8	2	3	13	2	16	3.9	31	0	0	5.9	4.7	3.9	31			
7. Simulated flight	2	461	0	6	1	7	1.5	12	2.0	16	.6	5	4.1	33	2.6	21			
	3	-------	4	2	2	8	1	8	1.4	11	.5	4	2.9	23	1.9	15			
	4	-------	6	2	6	14	3	24	2.2	17.5	.1	1	5.3	42.5	2.3	18.5			
	5	-------	4	6	4	14	4	32	3.4	27.5	.9	7.5	8.3	67	4.3	33			
	6	-------	3	9	1	13	9	72	2.9	23	1.9	15	13.8	110	4.8	38			
	7	-------	2	4	1	7	3.5	28	2	16	.4	3	5.9	47	2.4	19			
8. Launch	2	463	3	3	1	7	10.5	84	1.4	11	0	0	11.9	95	1.4	11			
	3	-------	0	0	0	0	10.5	84	1.6	12.5	.1	.5	12.2	97	1.7	13			
	4	-------	1	0	1	2	10.5	84	1.6	13	.1	1	12.2	98	1.7	14			
	5	-------	3	3	3	9	10.5	84	2.3	78	.4	3.5	13.2	105.5	2.7	21.5			
	6	-------	2	3	0	5	10.5	84	1.7	13.3	0	0	12.2	97.3	1.7	13.3			
	7	-------	2	4	2	8	10.5	84	2.2	17.5	0	0	12.7	101.5	2.2	17.5			
Total	2	-------	36	102	16	134	36.5	292	29.6	236.5	21.6	174.5	87.7	703	51.2	411	98	327	42
	3	-------	17	55	23	95	36.5	292	23.5	186.5	7.9	62.5	67.9	541	31.4	249	99	278	20
	4	-------	27	29	33	89	52.0	416	21.4	170.5	1.5	12	74.9	598.5	22.9	182.5	129	218	22
	5	-------	36	61	28	125	39	312	20.2	161.5	8	63.8	67.2	537.3	28.1	225.3	85	258	44
	6	-------	23	43	20	86	64.5	516	21.2	169.8	4	31	89.7	716.8	25.2	200.8	83	332	42
	7	-------	31	24	18	73	37	296	17.4	139	1	8	55.4	443	18.4	147	89	266	46

Of the total interim discrepancy records occurring in a test sequence, 31 to 40 percent occurred during the first test of the sequence. The wide range of interim-discrepancy-record occurrence (28 to 60) in the initial test is caused by modifications made on the test complex between missions and by methods which were, as yet, insufficient for verifying that the complex is in optimum operational condition. In this analysis, the first test has been deleted to avoid biasing the test average.

Table 24–III shows the average number of interim discrepancy records experienced by each spacecraft, exclusive of the first test. The high incidence of these records for spacecraft 2 was expected. The averages for spacecraft 3, 4, 6, and 7 are considered normal (accumulative average: 8.8). However, the high average experienced on spacecraft 5 was not anticipated. It is attributed to the large increase in ground equipment and unclassified interim discrepancy records which occurred during the last three tests; prior to those tests, the number of these records had been no higher than predicted. The high incidence of records for spacecraft 5 might also be attributed to a normal life breakdown of the ground equipment.

TABLE 24–III.—*Interim Discrepancy Record Summary by Spacecraft to First Countdown*

Spacecraft	Total tests	Average IDR[a] per test with first test deleted	Percent AGE[b] and unclassified IDR[a]
2	10	10.4	77
3	10	6.3	82
4	9	7.6	70
5	8	11.7	71
6	8	8.4	71
7	6	9.0	60

[a] Interim discrepancy record.
[b] Aerospace ground equipment.

Future spacecraft operations groups can benefit from spacecraft 5 experience. A sharp increase in the occurrence of interim discrepancy records indicated the need to start an investigation.

An analysis of test interim discrepancy records revealed that—

(1) Ground equipment and unclassified interim discrepancy records comprise approximately 70 percent of the total.

(2) The incidence of the interim discrepancy records and the amount of serial troubleshooting time are not directly related. This indicates that most of the interim-discrepancy-record tasks do not restrict further testing and are resolved in parallel with other activities.

(3) An analysis of the interim discrepancy records with respect to their occurrence in a test sequence (fig. 24–2) shows that 0.6 to 1.8 of these records per hour of testing can be expected for the first test of a series and 0.5 per hour of testing thereafter.

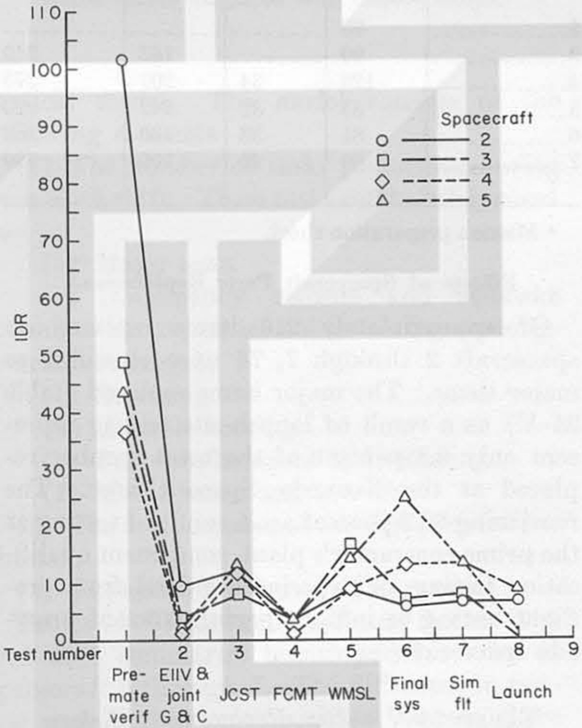


FIGURE 24–2.—Occurrence of interim discrepancy records for individual tests.

Effects of Spacecraft Modifications

Table 24–IV shows the modification times and the number of mission preparation sheets required on spacecraft 2 through 7 at the Kennedy Space Center. The mission preparation sheet is an engineering work order required for all manufacturing and testing accomplished on the spacecraft at the Kennedy Space Center. Thus far, modifications have been accomplished in parallel with scheduled testing and manu-

facturing and have not added serial time to the schedule. The number of the mission preparation sheets required to effect modifications on spacecraft 4 through 7 was 14 percent of the total required and 19 percent of the total required at the launch site. This shows that modifications are only a minor portion of the overall manufacturing and testing effort.

TABLE 24–IV.—*Modification and Mission-Preparation-Sheet Summary to First Countdown*

Spacecraft	Modification shifts	Modification MPS[a]	MPS[a] worked on pad	Total MPS[a] worked at launch site
2	98			
3	99		183	249
4	129	34	207	275
5	85	40	242	290
6	81	33	180	280
7	89	46	190	229

[a] Mission preparation sheet.

Effects of Spacecraft Parts Replacement

Of approximately 216 items replaced on spacecraft 2 through 7, 74 were classified as major items. The major items replaced (table 24–V) as a result of launch-site testing represent only 9.8 percent of the total number replaced at the Kennedy Space Center. The remaining 90.2 percent are a result of testing at the prime contractor's plant, component qualification testing, or experience gained from preflight testing or inflight performance of previous spacecraft.

TABLE 24–V.—*Item-Replacement History*

Spacecraft	Total items replaced	Major items replaced	Items replaced as a result of major tests
2	42	9	7
3	20	6	2
4	22	7	3
5	44	18	4
6	42	18	2
7	46	16	4
Total	216	74	22

Statistical Analysis of Overall Test Data

The data on testing, shown in table 24–II, were analyzed to determine functional relationships that could be used to plan and project spacecraft processing schedules. At corresponding points in a testing sequence, a high correlation (0.94) exists between the accumulative number of interim discrepancy records and the accumulative hours of testing and troubleshooting (fig. 24–3). From this relationship, the testing and troubleshooting time for a test sequence can be projected if the accumulative number of interim discrepancy records can be estimated.

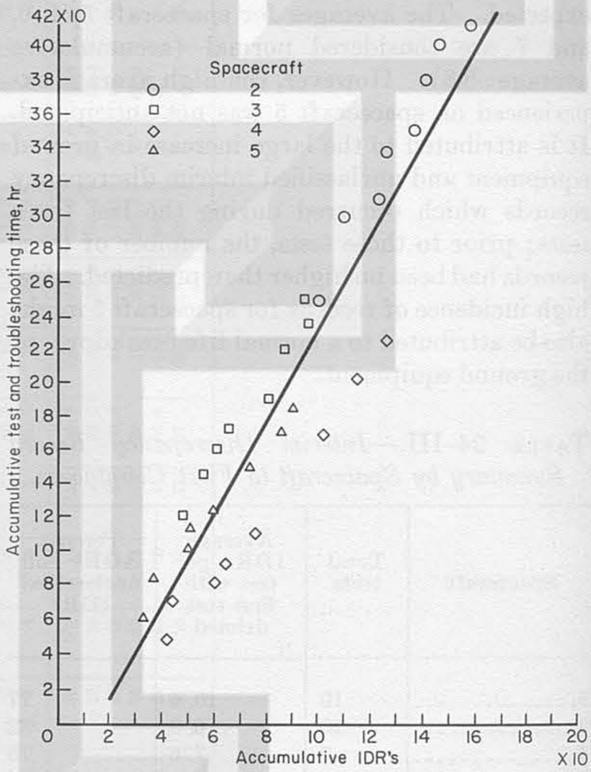


FIGURE 24–3.—Test and troubleshooting accumulative time compared with accumulative interim discrepancy records.

A method of estimating total interim discrepancy records reveals that a relationship (correlation: 0.88) exists between the test sequence and the accumulative number of these records. For example, the trend line shown in figure 24–4 is translated so that it passes through the estimated number of 27 interim discrepancy records for the first test on spacecraft 6. From the trend line, the projected value for 8 tests was

82 interim discrepancy records. From this forecast and from figure 24–3, a projection of 190 hours of testing and troubleshooting time was made for spacecraft 6. The actual result was 200 hours of testing and troubleshooting, with 86 interim discrepancy records recorded.

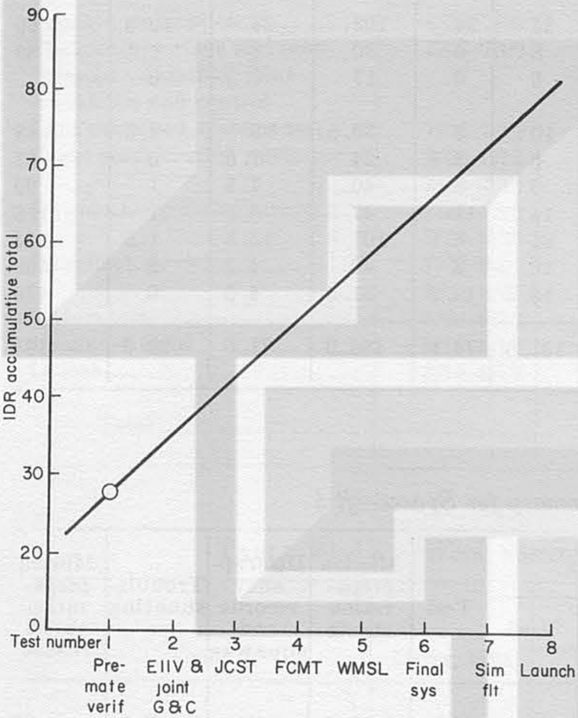


FIGURE 24–4.—Projection of accumulative quantity of interim discrepancy records.

Mathematical Model for Prediction of Processing Times

Assessment of Work Load

An examination of the mission-preparation-sheet logs and the daily schedules for spacecraft 3 through 7 led to the conclusion that nontesting tasks are virtually unaffected by testing. That is, during any given testing period, many nontesting tasks can be performed. Although the number of the mission preparation sheets has increased, no corresponding increase has been noted in the number of working shifts on the launch pad, indicating that there has been a steady improvement in the number of tasks that can be worked concurrently. Figures 24–5 and 24–6 present a synthesis of these observations.

Prediction Model

The spacecraft processing time required at launch complex 19 can be reduced to a mathematical model. The model consists of the following elements:

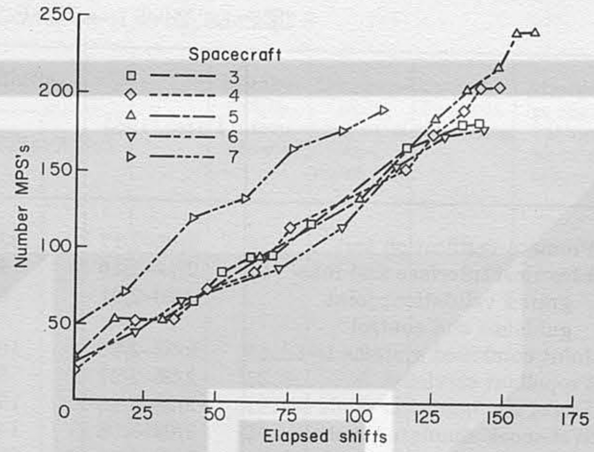


FIGURE 24–5.—Accumulative quantity of mission preparation sheets compared with elapsed shifts.

(1) The number of tasks performed during each work shift. These tasks can be categorized as—

(a) Major tests.

(b) Discrepancy records and squawks (minor discrepancies not involving a configuration change).

(c) Servicing.

(d) Troubleshooting.

(e) Parts replacement and retesting.

(f) Modification and assembly.

(2) The total number of mission preparation sheets.

(3) The actual number of shifts worked.

Tables 24–VI through 24–X and figures 24–5 and 24–6 summarize launch-pad histories of spacecraft 3 through 7. The difference in testing and troubleshooting times between these tables and table 24–II exists because table 24–II is based on serial troubleshooting time.

For the purpose of this study, the term "work unit" is defined as one task per work shift. Thus, in a given shift, as many as five mission preparation sheets could be processed using five work units. Discrepancy records and squawks have not been given the same consideration as the mission preparation sheets. Normally, one work unit has been found to equal six discrepancy records and squawks in any combination. Figure 24–7 shows a history of work units and work shifts required for spacecraft 3 through 7.

TABLE 24-VI.—*Work Summary for Spacecraft 3*

Task	Dates, 1965	Shifts		Test	Mission preparation sheets	Discrepancy records and squawks	Trouble-shooting	Mission preparation sheets release
		Available	Used					
Premate verification test	2/05–2/17	37	34	24	103	24	12.5	29
Electrical interface and integrated validation; joint guidance and control	2/17–2/19	8	8	6	30	1	1.5	63
	2/20–2/21	6	6	0	17	1.5	0	--------
Joint combined systems test	2/22–2/25	10	10	3	36.5	8	2.5	83
Propellant servicing	2/25–2/27	8	6	5.5	24	1.5	0	93
Flight configuration mode test	2/28–3/08	12	9	3	40	7.5	1	99
Wet-mock-simulated launch	3/04–3/08	14	14	11	47.5	3.5	1	116
System test	3/08–3/15	21	21	6.1	107.5	15.5	1.5	134
Simulated flight	3/15–3/18	10	10	3	49	4	2	169
Launch	3/19–3/23	13.5	13.5	12.5	31.5	4.5	0	176
Total	-------------	139.5	131.5	74.1	486.0	71.0	22.0	183

TABLE 24-VII.—*Work Summary for Spacecraft 4*

Task	Dates, 1965	Shifts		Test	Mission preparation sheets	Discrepancy records and squawks	Trouble-shooting	Mission preparation sheets release
		Available	Used					
Premate verification test	4/15–4/23	25	19	20	78.5	4	7.5	20
Electrical interface and integrated validation; joint guidance and control	4/24–4/27	12	6	8.5	29	1.5	2.5	52
Joint combined systems test	4/27–4/30	11	11	8.5	46	1.5	2.5	55
Propellant servicing	5/01–5/06	16	10	8	30	3	1	72
Flight configuration mode test	5/06–5/07	4	4	2	11.5	0	0	87
	5/07–5/10	7	7	0	20.5	2	0	-------
Wet-mock-simulated launch	5/10–5/13	11	11	11	24.5	2	1.5	114
	5/14–5/23	29	26	0	132	9.5	1	-------
System test	5/23–5/26	9	9	6.6	46	4.5	0	158
Simulated flight	5/26–5/30	10.5	10.5	5.5	45.5	2	0	173
Launch	5/30–6/03	12.5	12.5	12.5	39.5	2	0	192
Total	-------------	147.0	126.0	82.6	503.0	32	16.0	207

TABLE 24-VIII.—*Work Summary for Spacecraft 5*

Task	Dates, 1965	Shifts		Test	Mission preparation sheets	Discrepancy records and squawks	Troubleshooting	Mission preparation sheets release
		Available	Used					
Premate verification	6/28–7/02	15	15	12. 5	95. 5	3. 0	3. 0	28
Electrical interface and integrated validation; joint guidance and control	7/03–7/08	17	11	4. 5	32	1. 5	2. 0	51
Joint combined systems test	7/08–7/12	12	9	3	33. 5	2	2. 0	56
Flight configuration mode test	7/08–7/12	12	12	3	56. 5	3. 5	0	65
	7/12–7/16	9	6	0	19	0	0	--------
Wet-mock-simulated launch	7/20–7/22	12	12	12	20	2	2. 5	91
	7/23–7/29	21	18	0	114. 5	11	0	--------
Propellant servicing	7/30–8/01	9	9	6. 5	40	2	0	136
	8/02–8/07	18	18	0	135. 5	11	0	--------
System test	8/08–8/12	12. 5	12	11. 1	114. 5	7. 5	5	188
Simulated flight	8/12–8/14	8. 5	8. 5	8. 5	29	2	2	207
Launch	8/14–8/19	14	14	13. 5	74. 5	7. 5	0	220
Total	-------------	160. 0	145. 5	74. 6	764. 5	53. 0	16. 5	242

TABLE 24-IX.—*Work Summary for Spacecraft 6 to First Countdown*

Task	Dates, 1965	Shifts		Tests	Mission preparation sheets	Discrepancy records and squawks	Troubleshooting	Mission preparation sheets release
		Available	Used					
Premate verification	9/09–9/15	21	18	11. 5	90. 5	6. 5	1	45
Electrical interface and integrated validation	9/16–9/16	3	3	0	15	5	0	--------
Joint guidance and control	9/17–9/21	14	11	7. 5	32	4	0	65
Joint combined systems test	9/21–9/23	10	10	4. 5	22. 5	5	0	--------
Manufacturing	9/24–9/30	21	12	0	46	3. 5	0	--------
Flight configuration mode test	10/01	3	3	7. 5	9. 5	2. 5	--------	89
Wet-mock-simulated launch	10/02–10/07	18	15	15. 5	35. 5	7	--------	--------
Demate	10/08	3	3	0	11	3	--------	115
Final systems, electrical interface and integrated validation; joint guidance and control	10/09–10/15	20	17	15. 5	76	15	1	157
Simulated flight and special impact prediction test	10/15–10/20	16	13	12	39	6	2	175
Launch	10/21–10/25	14	14	11	29	4	0	180
Total	-------------	143	122	85	406	61. 5	5	--------

TABLE 24-X.—*Work Summary for Spacecraft 7*

Task	Dates, 1965	Shifts		Test	Mission preparation sheets	Discrepancy records and squawks	Troubleshooting	Mission preparation sheets release
		Available	Used					
Premate verification	9/30–10/04	18	18	14. 5	61. 5	8	0. 1	71
Electrical interface and integrated validation	10/05–10/12	24	24	8. 4	181. 5	16	. 4	120
Joint combined systems test	10/13–10/15	9	9	7. 4	42	5	. 1	122
Manufacturing	10/16–10/18	9	9	0	50	6	0	143
Final systems	10/19–10/23	15	15	5. 9	62	11	0	165
Simulated flight	10/24–10/29	18	15	5. 5	48. 5	6	. 5	178
Launch	10/30–11/04	14	14	12. 7	48	5	0	190
Total		107	104	54. 4	493. 5	57	1. 0	190

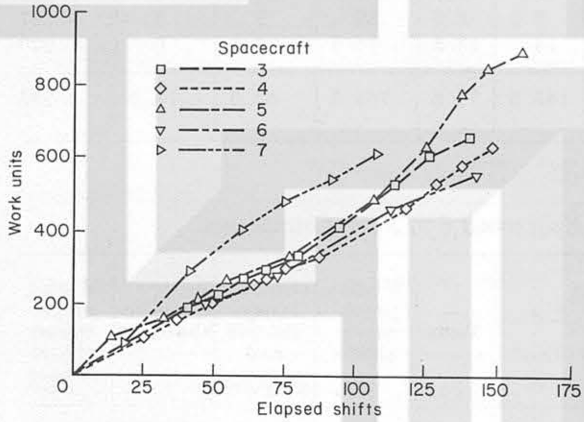


FIGURE 24-6.—Accumulative quantity of work units compared with elapsed shifts.

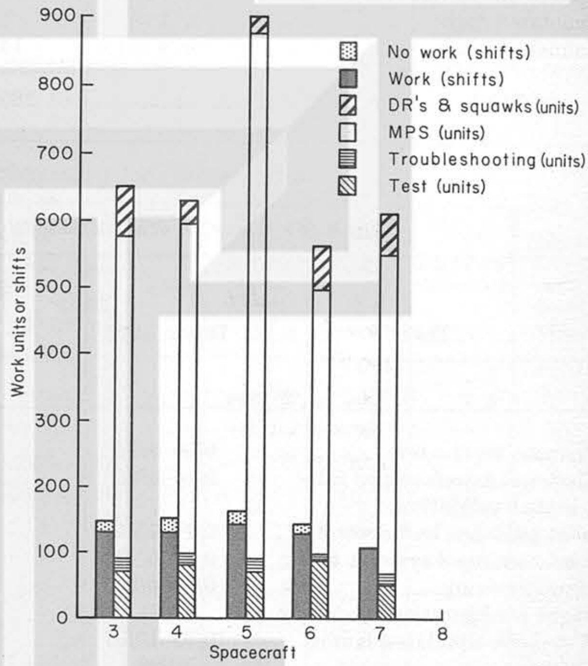


FIGURE 24-7.—Total work units and shifts required for each spacecraft.

The number of workdays necessary to process a Gemini spacecraft at the launch complex can be established using the following formula:

$$PD=\frac{\alpha(\text{number of mission preparation sheets})+\beta(\text{testing shifts})}{3\gamma}$$

where

PD=Total work required at the launch complex

$\alpha=\frac{\text{Nontest work units}}{\text{Nontest mission preparation sheets}}$ (Manufacturing mission-preparation-sheet performance factor)

$\beta=\frac{\text{Testing shifts}+\text{troubleshooting shifts}}{\text{Testing shifts}}$ (Testing factor)

$\gamma=\frac{\text{Total work units}}{\text{Total shifts worked}}$ (Overall work rate factor)

Figure 24–8 is a plot of α, β, and γ for spacecraft 3 through 7. These curves are the important factors used in predicting future spacecraft performance and processing time, as well as determining the present performance of a spacecraft being processed.

If no radical changes occur in spacecraft processing at the launch complex, the chart would infer that the following can be expected on the average:

(a) For every testing work shift, 0.2 of a troubleshooting shift can be expected.

(b) A nontest mission-preparation-sheet task will require three work shifts to accomplish.

(c) Approximately 5.75 tasks can be in progress concurrently.

These are, of course, estimates based on average figures. An examination of the data shows that as many as 10 tasks per shift have been worked concurrently on occasion; also, certain mission preparation sheets can be completed in less than one work shift. However, the use of total available data, rather than isolated cases, yields a better understanding of the factors and the relationships that affect overall processing time.

For example, the Spacecraft Operation Analysis Branch at Kennedy Space Center made the following predictions for spacecraft 7 using the process estimators:

(1) Based on an 8-test schedule, the predicted number of mission preparation sheets was less than 200, and the estimated number of work units was 672.

(2) Based on a 6-test schedule, the predicted number of mission preparation sheets was 190, and the number of work units was estimated at 580.

(3) For the 6-test schedule, 190 mission

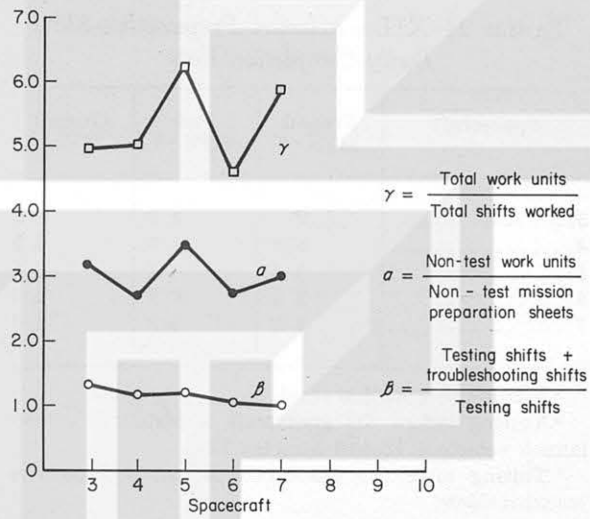


FIGURE 24–8.—Spacecraft processing estimators.

preparation sheets were recorded, and 607 work units were used.

The predicted versus the actual workload data was within a nominal 5 percent.

Analysis of Mission Preparation Sheets

The number of mission preparation sheets and the resulting workload account determine the spacecraft processing time. Table 24–XI shows the incidence of preparation sheets for spacecraft 3 through 5 at the launch pad. The daily completion rate of the preparation sheets is shown in table 24–XII.

The differences in completion rates by location and spacecraft were expected. Spacecraft 3 underwent hypergolic servicing and static firing before it went to the launch complex, with a resulting low daily completion rate of the preparation sheets. Spacecraft 4 through 7, however, were available prior to installation on the launch complex. All five spacecraft

TABLE 24-XI.—*Mission Preparation Sheets for Spacecraft 3, 4, and 5*

Spacecraft	Testing	Servicing	Replacement	Manufacturing	Open [a]	Unclassified [b]
3	26	41	14	83	15	4
4	41	31	29	97	0	9
5	44	44	51	89	7	12

[a] Mission preparation sheets released but not completed at the end of the spacecraft hoisting operation at the launch pad.

[b] Mission preparation sheets not identified as testing, servicing, replacement, or manufacturing.

TABLE 24-XII.—*Mission-Preparation-Sheet Daily Completion Rate*

Spacecraft	Prepad MPS [a b]	Pad MPS [a c]	Overall MPS [a]
3	2	3. 9	3. 2
4	6. 8	4. 6	4. 5
5	5. 4	4. 3	4. 5
6	2. 8	3. 8	4. 5
7	1. 8	5. 3	4. 0

[a] Mission preparation sheet.

[b] Testing before the spacecraft is installed on the launch vehicle at launch complex 19.

[c] Testing after the spacecraft is installed on the launch vehicle.

were subject to the same contraints of testing at the launch complex, and the difference in the rate of preparation sheet completion is attributed to a reduced workload and improved planning.

The total number of elapsed days has been used in the computation of the daily completion rates (table 24-XII) of the preparation sheets. If a comparison is to be made between these figures and those from the estimators used in the prediction model, an adjustment must be made for days not worked. This adjustment results in an increase from 4.6 to 5.0 days for spacecraft 4, and an increase from 4.3 to 5.0 days for spacecraft 5. Using the estimators from figure 24-8, the daily completion rates for mission preparation sheets are computed to be 5.5 to 5.3 for these spacecraft.

Concluding Remarks

The processing of Gemini spacecraft, from their arrival at the Kennedy Space Center through launch, is summarized as follows:

(1) Preparing for testing, testing, and troubleshooting constitute a maximum of 15 percent of the total processing work units. This constitutes an average of 57 percent of the scheduled work shifts.

(2) The number of interim discrepancy records, or problems resulting from testing, increases in direct proportion to the testing.

(3) All spacecraft met their schedules except spacecraft 2, when new test facilities were used for the first time.

(4) The time used for test preparation, as well as for total processing, tends to be the time allotted for these activities.

(5) To date, the time required for spacecraft modification and parts replacement has not directly affected any launch date because these activities have been accomplished in parallel with other scheduled work.

(6) The mathematical model provides an estimate for the processing time for future spacecraft.

(7) Monitoring of the process estimators provides an evaluation of the present processing of the spacecraft.

(8) A definite pattern in the occurrence of aerospace-ground-equipment interim discrepancy records has been established. Any significant increase from the normal pattern should be used as an indicator to start an investigation.

(9) The number of mission preparation sheets released against a spacecraft affects the total processing time. On the average, 1 day of processing time is required to complete five preparation sheets.

(10) To realize an accelerated processing schedule, consideration of the number of nontest work tasks is as important as consideration of the number of tests to be performed.

D

MISSION RESULTS

25. MAN'S RESPONSE TO LONG-DURATION FLIGHT IN THE GEMINI SPACECRAFT

By Charles A. Berry, M.D., *Chief, Center Medical Programs, NASA Manned Spacecraft Center;* D. O. Coons, M.D., *Chief, Center Medical Office, NASA Manned Spacecraft Center;* A. D. Catterson, M.D., *Center Medical Office, NASA Manned Spacecraft Center; and* G. Fred Kelly, M.D., *Center Medical Office, NASA Manned Spacecraft Center*

Summary

The biomedical data from the Gemini III through VII missions support the conclusion that man is able to function physiologically and psychologically in space and readapt to the earth's 1-g environment without any undue symptomatology. It also appears that man's response can be projected into the future to allow 30-day exposures in larger spacecraft.

Introduction

When contemplating such titles as "4 Days in June," "8 Days in August," and "14 Days in December," it is difficult to realize that just 2 years ago, only an uncertain answer could be given to the question, "Can man's physiology sustain his performance of useful work in space?" This is particularly true on this great day for space medicine when man has equaled the machine.

Prior to our first manned space flight, many people expressed legitimate concern about man's possible response to the space-flight environment. This concern was based upon information obtained from aircraft experience and from conjecture about the effects of man's exposure to the particular environmental variables known to exist at that time. Some of the predicted effects were anorexia, nausea, disorientation, sleeplessness, fatigue, restlessness, euphoria, hallucinations, decreased g-tolerance, gastrointestinal disturbance, urinary retention, diuresis, muscular incoordination, muscle atrophy, and demineralization of bones. It will be noted that many of these are contradictory.

This Nation's first probing of the space environment was made in the Mercury spacecraft which reached mission durations of 34 hours. The actual situation following the completion of the Mercury program may be summarized as follows:

No problem: Launch and reentry acceleration, spacecraft control, psychomotor performance, eating and drinking, orientation, and urination.

Remaining problems: Defecation, sleep, and orthostatic hypotension.

This first encounter with the weightless environment had provided encouragement about man's future in space, but the finding of orthostatic hypotension also warned that there might be some limit to man's exposure. The reported Russian experiences strengthened this possibility. No serious gross effects of simple exposure to the space-flight environment had been noted, but the first hint was given that the emphasis should shift to careful methods for observing more subtle changes. These findings influenced the planning for the Gemini mission durations, and the original plan was modified to include a three-revolution checkout flight, followed by an orderly approximate doubling of man's exposure on the 4-day, 8-day, and 14-day missions which have been completed. It was felt that such doubling was biologically sound and safe, and this has proved to be the case. The U.S. manned space-flight missions are summarized in table 25–I.

This plan required the use of data procured from one mission for predicting the safety of man's exposure on a mission twice as long.

Medical Operational Support

The Gemini mission operations are complex and require teamwork in the medical area, as in all others. Space-flight medical operations have consisted, in part, of the early collection of baseline medical data which was started at

TABLE 25-I.—*U.S. Manned Space Flights*

Astronauts	Launch dates	Duration, hr:min
Shepard	May 5, 1961	00:15
Grissom	July 21, 1961	00:15
Glenn	Feb. 20, 1962	4:56
Carpenter	May 24, 1962	4:56
Schirra	Oct. 3, 1962	9:14
Cooper	May 15, 1963	34:20
Grissom Young	Mar. 3, 1965	4:52
McDivitt White	June 3, 1965	96:56
Cooper Conrad	Aug. 21, 1965	190:56
Borman Lovell	Dec. 4, 1965	330:35
Schirra Stafford	Dec. 15, 1965	25:21

the time of the original selection of the astronauts and which has been added to with each exposure to the simulated space-flight environment during spacecraft testing. Physicians and paramedical personnel have been trained to become a part of medical recovery teams stationed in the launch area and at probable recovery points in the Atlantic and Pacific Oceans. Flight surgeons have been trained and utilized as medical monitors at the various network stations around the world, thus making possible frequent analysis of the medical information obtained in flight. A team of Department of Defense physician-specialists has also been utilized to assist in the detailed preflight and postflight evaluations of the condition of the flight crews. Without the dedicated help of all of these personnel functioning as a team, the conduct of these missions would not have been possible (fig. 25-1).

A high set of standards has been adhered to in selecting flight crews. This has paid off very well in the safety record obtained thus far. The difficult role that these flight crews must play,

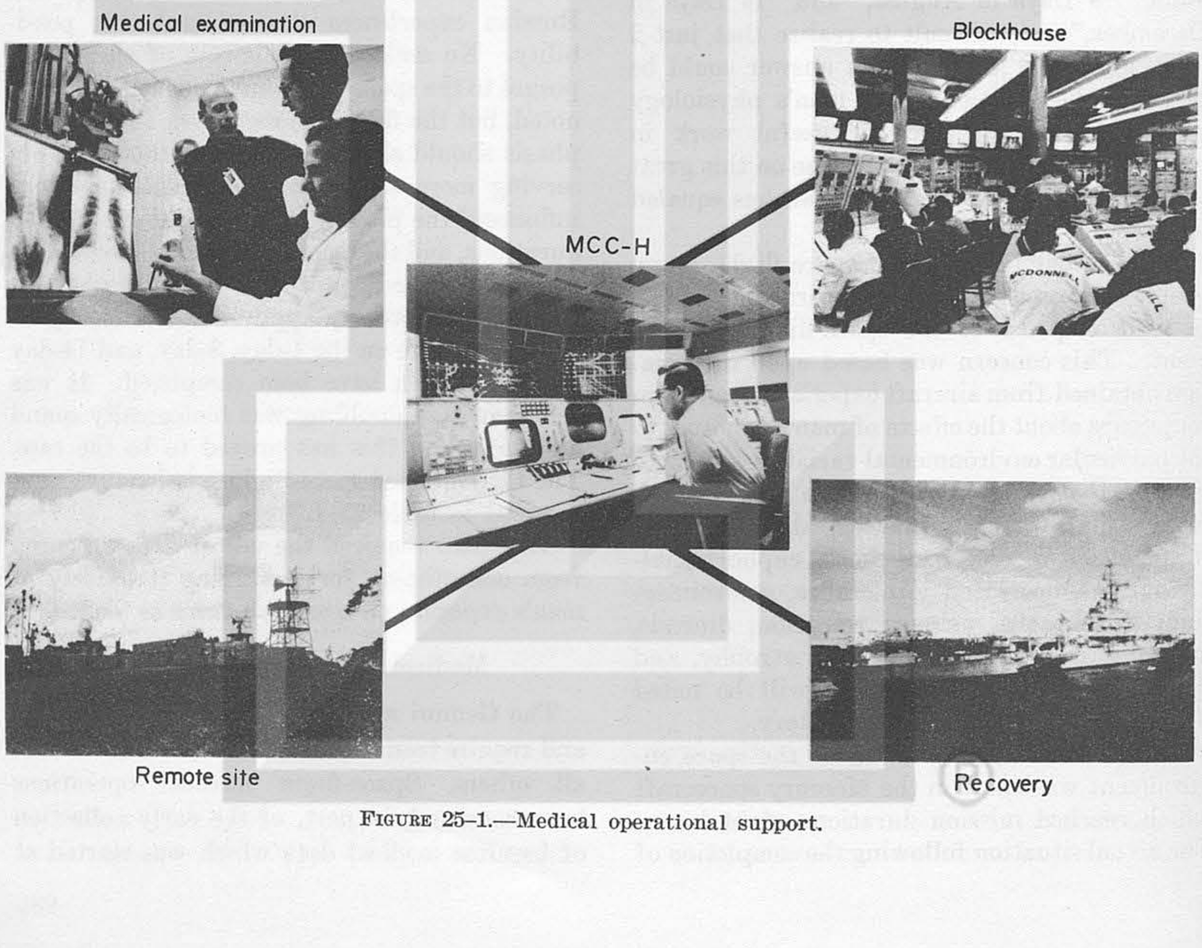


FIGURE 25-1.—Medical operational support.

both as experimenters and as subjects, deserves comment. From a personal point of view, the simpler task is to be the experimenter, utilizing various pieces of equipment in making observations. On these long-duration missions, the crews have also served as subjects for medical observations, and this requires maximum cooperation which was evidenced on these flights.

Data Sources

Physiological information on the flight crews has been obtained by monitoring voice transmissions; two leads of the electrocardiogram, a sternal and an axillary; respiration by means of an impedance pneumograph; body temperature by means of an oral thermistor; and blood pressure. These items make up the operational instrumentation, and, in addition, other items of bioinstrumentation are utilized in the experiments program. Also, some inflight film footage has been utilized, particularly during the extravehicular exercise on the 4-day mission. The biosensor harness and signal conditioners are shown in figure 25–2. A sample of the telemetered data, as received at the Mission Control Center, is shown in figure 25–3. These data were taken near the end of the 8-day flight, and it can be seen that the quality is still excellent. The Gemini network is set up to provide real-time remoting of medical data from the land sites to the surgeon at the Mission Control

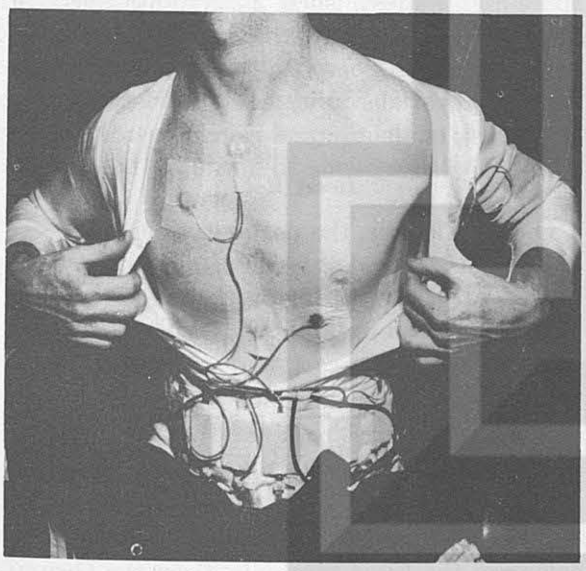


FIGURE 25–2.—Biosensor harness and signal conditioners.

Center. If requested, the medical data from the ships can be transmitted immediately after each spacecraft pass. The combined Gemini VI–A and VII mission posed a new problem in monitoring, in that it required the simultaneous monitoring of four men in orbit. The network was configured to do this task, and adequate data were received for evaluation of both crews.

It must be realized that this program has involved only small numbers of people in the flight crews. Thus, conclusions must be drawn from a minimum amount of data. Individual variability must be considered in the analysis of any data. Aid is provided in the Gemini Program by having two men exposed to the same conditions at the same time. Each man also serves as his own control, thus indicating the importance of the baseline data.

Preflight Disease Potential

As missions have become longer, the possibility of an illness during flight has become greater, particularly in the case of communicable diseases to which the crew may have been exposed prior to launch. The difficult work schedules and the stress imposed by the demands of the prelaunch period tend to create fatigue unless watched carefully, and thus become an additional potential for the development of flulike diseases. They also preclude any strict isolation. On each of the Gemini missions a potential problem, such as viral upper respiratory infections or mumps exposure, has developed during the immediate preflight period, but the situation has been handled without hampering the actual mission. No illness has developed in the flight crews while in orbit. However, strenuous effort must be exerted toward protecting the crew from potential disease hazards during this critical period.

Denitrogenation

The 5-psia cabin pressure and the 3.7-psia inflated suit pressure create the potential for the development of dysbarism, and this was particularly true on the 4-day mission which involved extravehicular activity. Care has been taken to denitrogenate the crews with open-loop breathing of 100 percent oxygen for at least 2 hours prior to launch. No difficulty has been experienced with this procedure.

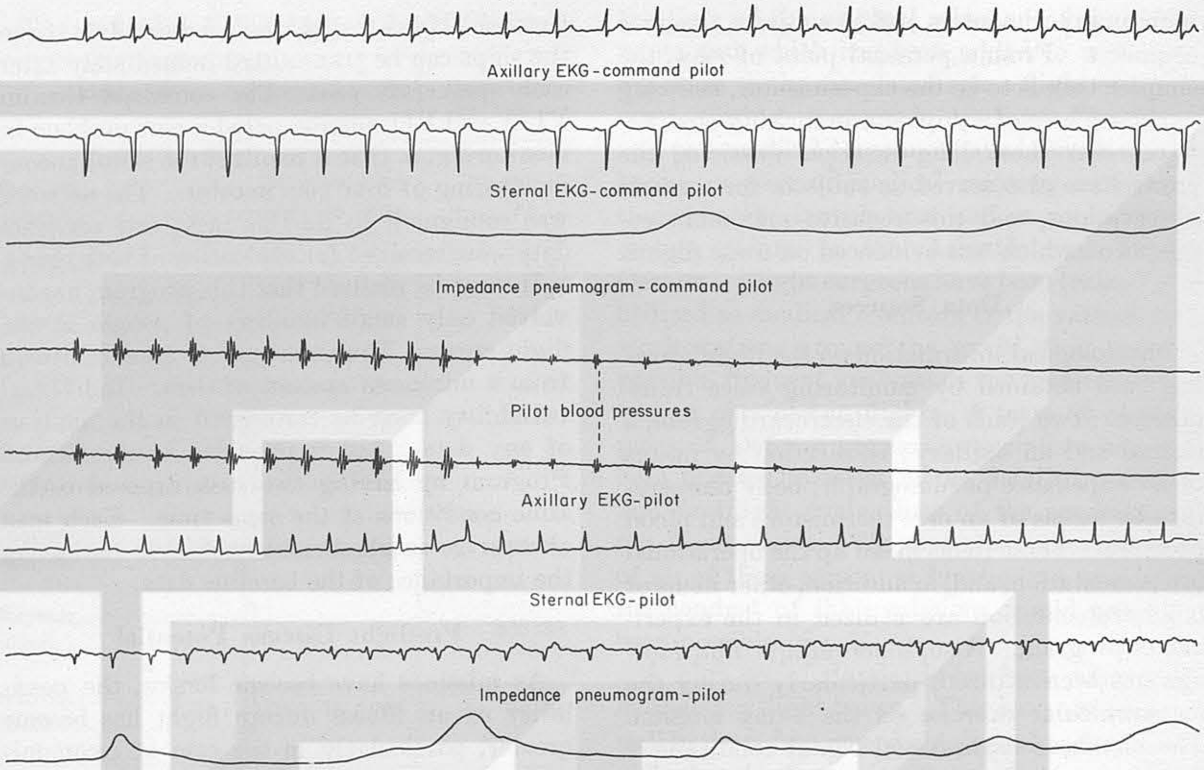


FIGURE 25–3.—Sample of biomedical data.

Preflight Exercise

The crews have used various forms of exercise to maintain a state of physical fitness in the preflight period. The peak of fitness attained has varied among the crewmembers, but they all have been in an excellent state of physical fitness. They have utilized running and various forms of activity in the crew-quarters gymnasium in order to maintain this state. Approximately 1 hour per day has been devoted to such activity.

Space-Flight Stresses

There has been a multiplicity of factors acting upon man in the space-flight environment. He is exposed to multiple stresses which may be summarized as: full pressure suit, confinement and restraint, 100 percent oxygen and 5-psia atmosphere, changing cabin pressure (launch and reentry), varying cabin and suit temperature, acceleration g-force, weightlessness, vibration, dehydration, flight-plan performance, sleep need, alertness need, changing illumination, and diminished food intake. Any one of these stresses will always be difficult to isolate. In a sense, it could be said that this is of only limited interest, for the results always would represent the effects of man's exposure to the total space-flight environment. However, in attempting to examine the effects of a particular space-flight stress, such as weightlessness, it must be realized that the responses observed may indeed be complicated by other factors such as physical confinement, acceleration, dehydration, or the thermal environment.

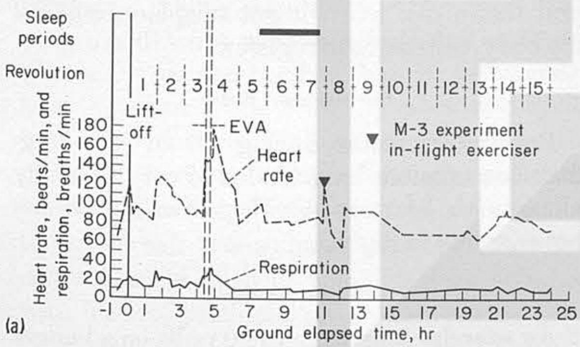
Heart Rate

On all missions, the peak elevations of heart rates have occurred at launch and reentry. The peak rates observed during the launch and reentry are shown in table 25–II. These detailed timeline plots of heart and respiratory rates demonstrate the peak responses associated with particular activities required by the flight plan, as was noted during the Mercury missions (fig. 25–4 (a) and (b)). As the mission durations have become longer, it has been necessary to compress the heart-rate data from the Gemini VII mission to the form shown in figure 25–5 (a) and (b). Such a plot demonstrates the di-

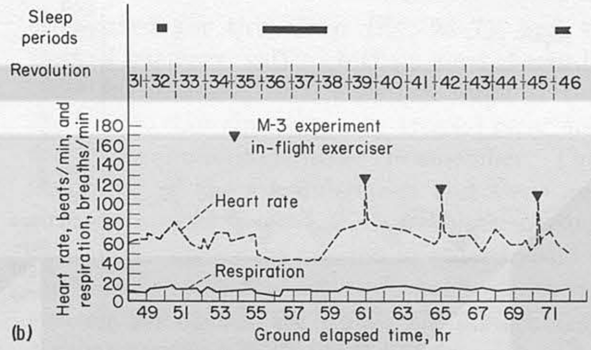
TABLE 25-II.—*Peak Heart Rates During Launch and Reentry*

Gemini mission	Peak rates during launch, beats per minute	Peak rates during reentry, beats per minute
III	152	165
	120	130
IV	148	140
	128	125
V	148	170
	155	178
VI-A	125	125
	150	140
VIII	152	180
	125	134

urnal cycles related to the nighttime and the normal sleep periods at Cape Kennedy, Fla. In general, it has been noted that there has been a decrease in the heart rate from the high levels at launch toward a rather stable, lower baseline rate during the midportion of the mission. This is altered at intervals since the heart has responded to demands of the inflight activities in a very normal manner throughout the mission. The rate appears to stabilize around the 36- to 48-hour period and remain at this lower level until two or three revolutions before retrofire. The anticipation and the activity associated with preparation for retrofire and reentry cause an increase in the heart rate for the remainder of the flight. The electrocardiogram has been very helpful in observing the response to the sleep periods when heart rates have frequently been observed in the forties and some in the high thirties. The graphing of such rates by mini-



(*a*) From lift-off to 24 hours ground elapsed time.
FIGURE 25-4.—Physiological measurements for Gemini IV pilot.



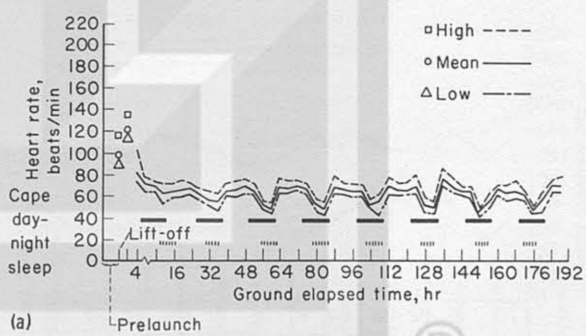
(*b*) From 48 to 72 hours ground elapsed time.
FIGURE 25-4.—Concluded.

mum, maximum, and mean has also been helpful in determining the quality of sleep. If the crewmen have awakened several times to check the condition of spacecraft controls and displays, there is a noted spread between the maximum and minimum rates.

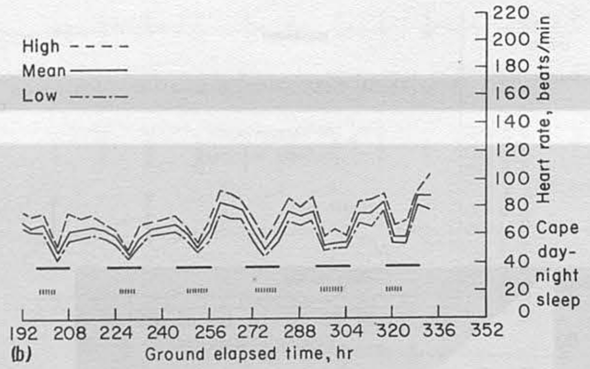
During the extravehicular operation, both crewmen noted increased heart rates. The pilot had a heart rate of 140 beats per minute while standing in the open hatch, and this rate continued to climb during the extravehicular activity until it reached 178 beats per minute at spacecraft ingress. Future extravehicular operations will require careful attention to determine the length of time these elevated rates are sustained.

Electrocardiogram

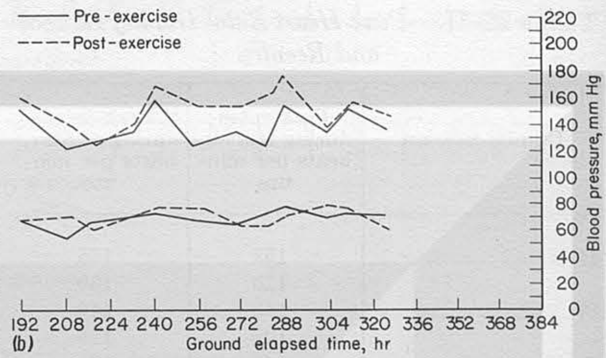
The electrocardiogram has been observed on a real-time basis, with a series of detailed measurements being taken during the Gemini VII flight. The electrocardiogram has also been evaluated postflight, and the only abnormalities of note have been occasional, and very rare, pre-



(*a*) From lift-off to 192 hours ground elapsed time.
FIGURE 25-5.—Physiological measurements for Gemini VII pilot.



(*b*) From 192 to 352 hours ground elapsed time.
FIGURE 25–5.—Concluded.

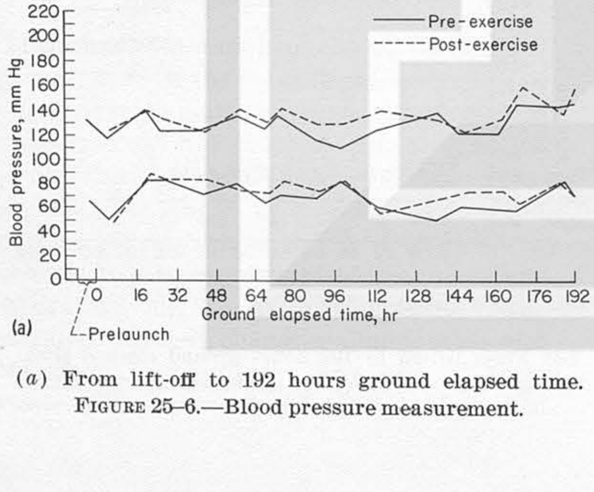


(*b*) From 192 to 384 hours ground elapsed time.
FIGURE 25–6.—Concluded.

mature auricular and ventricular contractions. The detailed analyses have shown no significant changes in the duration of specific segments of the electrocardiogram which are not merely rate related. On each of the long-duration missions, a special experiment has involved observation of the relationship of the Q-wave to the onset of mechanical systole, as indicated by the phonocardiogram. These data, in general, have revealed no prolongation of this interval with an increase in the duration of space flight.

Blood Pressures

The blood pressure values were determined three times in each 24 hours during the 4- and 8-day missions, and two times each 24 hours on the 14-day mission. These determinations were made before and after exercise on the medical data passes. The only truly remarkable thing in all blood pressures to date has been the normalcy with a lack of significant increase or decrease with prolonged space flight (fig. 25–6 (a) and (b)). The blood pressures have varied



(*a*) From lift-off to 192 hours ground elapsed time.
FIGURE 25–6.—Blood pressure measurement.

with heart rate, as evidenced by the 201 over 90 blood pressure obtained after retrofire during one of the missions. This was accompanied by a heart rate of 160, however, and is felt to be entirely normal.

Some blood pressures of particular interest were those determined on the 4-day mission: (1) just after retrofire and while the crew was still in zero g; (2) just before the transition to two-point suspension on the main parachute, which places the crew at about a 45° back angle; (3) just after the transition to two-point suspension; and (4) with the spacecraft on the water and the crew in a sitting position. All of these pressures were in the same general range as the inflight blood pressures and were all certainly normal, demonstrating no evidence of hypotension.

Body Temperature

The oral thermistor was used with each medical data pass, and all body temperatures recorded have been within the normal range. Occasional spurious readings were noted on the oral thermistor when it got misplaced against the body, causing it to register.

Respiratory Rates

Respiratory rates during all of the long-duration missions have tended to vary normally along with heart rate. Hyperventilation has not occurred in flight.

Inflight Exercise

An exercise consisting of 30 pulls on a bungee cord has been utilized to evaluate cardiovascular response on all of these missions. No significant difference in the response to this calibrated exercise load has been noted through the 14-day flight. In addition to these programed exercise response tests, the bungee cord has been utilized for additional exercise periods. Daily during the 14-day mission, the crew performed 10 minutes of exercise, including the use of the bungee cord for both the arms and the legs, and some isometric exercises. These 10-minute periods preceded each of the three eating periods.

Sleep

A great deal of difficulty was encountered in obtaining satisfactory sleep periods on the 4-day mission. Even though the flight plan was modified during the mission in order to allow extra time for sleep, it was apparent postflight that no long sleep period was obtained by either crewman. The longest consecutive sleep period appeared to be 4 hours, and the command pilot estimated that he did not get more than 7½ to 8 hours' good sleep in the entire 4 days. Factors contributing to this lack of sleep included: (1) the firing of the thrusters by the pilot who was awake; (2) the communications contacts, because the communications could not be completely turned off; and (3) the requirements of housekeeping and observing, which made it difficult to settle down to sleep. Also the responsibility felt by the crew tended to interfere with adequate sleep.

An attempt was made to remove a few of these variables on the 8-day mission and to program the sleep periods in conjunction with normal nighttime at Cape Kennedy. This required the command pilot to sleep from 6 p.m. until midnight eastern standard time, and the pilot to sleep from midnight until 6 a.m., each getting a 2-hour nap during the day. This program did not work out well due to flight-plan activities and the fact that the crew tended to retain their Cape Kennedy work-rest cycles with both crewmen falling asleep during the midnight to 6 a.m. Cape Kennedy nighttime period. The 8-day crew also commented that the spacecraft was so quiet that any communication or noise, such as removing items attached with Velcro, produced an arousal reaction.

On the 14-day flight, the flight plan was designed to allow the crew to sleep during hours which generally corresponded to nighttime at Cape Kennedy. There was a 10-hour period established for this sleep (fig. 25–7), and it worked out very well with their normal schedule. In addition, both crewmen slept at the same time, thus obviating any arousal reactions from the actions of the other crewmember. The beginning of the scheduled rest and sleep period was altered to move it one-half hour earlier each night during the mission in order to allow the crew to be up and active throughout the series of passes across the southern United States. Neither crewman slept as soundly in orbit as he did on the earth, and this inflight observation was confirmed in the postflight debriefing. The pilot seemed to fall asleep more easily and could sleep more restfully than the command pilot. The command pilot felt that it was unnatural to sleep in a seated position, and he continued to awaken spontaneously during his sleep period and would monitor the cabin displays. He did become increasingly fatigued over a period of several days, then would sleep soundly and start his cycle of light, intermittent sleep to the point of fatigue all over again. The cabin was kept quite comfortable during the sleep periods by the use of the Polaroid screen and some foil from the food packs on the windows. The noise of the pneumatic pressure cuff for Experiment M–1 did interfere with sleep on both the 8- and 14-day missions. The crew of the 4-day flight were markedly fatigued following the mission. The 8-day crew were less so, and the 14-day crew the least fatigued of all. The 14-day crew did feel there was some irritability and loss of patience during the last 2 days of the mission, but they continued to be alert and sharp in their responses, and no evidence of performance decrement was noted.

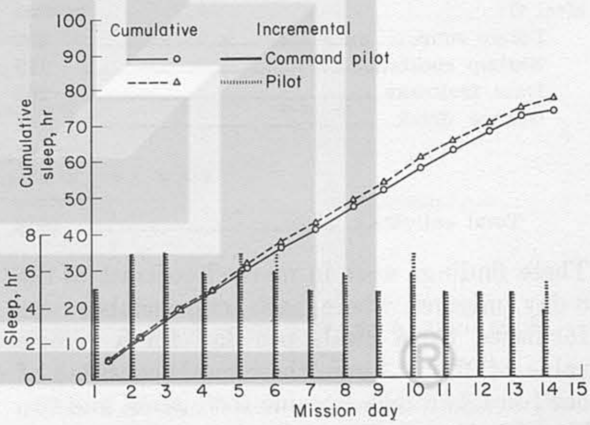


FIGURE 25–7.—Sleep data for Gemini VII flight crew.

Food

The diet has been controlled for a period of 5 to 7 days before flight and, in general, has been of a low residue. The Gemini VII crew were on a regulated calcium diet of a low-residue type for a period of 12 days before their 14-day mission. The inflight diet has consisted of freeze dehydrated and bite-size foods. A typical menu is shown in table 25–III. The crew are routinely tested with the inflight menu for a period of several days before final approval of the flight menu is given. On the 4-day flight, the crew were furnished a menu of 2500 calories per day to be eaten at a rate of four meals per day. They enjoyed the time that it took to prepare the food, and they ate all the food available for their use. They commented that they were hungry within 2 hours of ingesting a meal and that, within 4 hours after ingesting a meal, they felt a definite physiological need for the lift produced by food.

TABLE 25–III.—*Typical Gemini Menu*

[Days 2, 6, 10, and 14]

	Calories
Meal A:	
Grapefruit drink	83
Chicken and gravy	92
Beef sandwiches	268
Applesauce	165
Peanut cubes	297
	905
Meal B:	
Orange-grapefruit drink	83
Beef pot roast	119
Bacon and egg bites	206
Chocolate pudding	307
Strawberry cereal cubes	114
	829
Meal C:	
Potato soup	220
Shrimp cocktail	119
Date fruitcake	262
Orange drink	83
	684
Total calories	2418

These findings were in marked contrast to the 8-day mission where each crewmember was furnished three meals per day for a caloric value of 2750. Again these meals consisted of one juice, two rehydratable food items, and two bite-size items. The 8-day crew felt no real hunger, though they did feel a physiological lift from the ingestion of a meal. They ate very little of their bite-size food and subsisted principally on the rehydratable items. A postflight review of the returned food revealed that the average caloric intake per day varied around 1000 calories for this crew. Approximately 2450 calories per day was prepared for the 14-day mission and including ample meals for 14⅔ days. Inflight and postflight analyses have revealed that this crew actually consumed about 2200 calories per day.

Water Intake

There has been an ample supply of potable water on all of these missions, consisting of approximately 6 pounds per man per day. Prior to the 4-day and 8-day missions, the water intake was estimated by calibrating a standard mouthful or gulp for each crewman; then, during the flight, the crew would report the water intake by such measurements. On the 4-day mission, the water intake was less than desired in the first 2 days of the mission but increased during the latter part of the flight, varying from 2.5 to 5.0 pounds in a 24-hour period. The crew were dehydrated in the postrecovery period. On the 8-day mission, the crew did much better on their water intake, averaging 5.2 to 5.8 pounds per 24 hours, and they returned in an adequately hydrated state.

For the 14-day mission, the water dispensing system was modified to include a mechanism whereby each activation of the water dispenser produced ½ ounce of water, and this activated a counter. The number of counts and the number of ounces of water were laboriously logged by the crew. It has been obvious that the crewmen must be reminded of their water intake, and when this is done they manage very well. The 14-day crew were well hydrated at the time of their recovery, and their daily water intake is presented in figure 25–8.

Waste Disposal

A urine collection device has been utilized on each of the Gemini missions and has been modified according to need and experience. On the 14-day flight, for the first time, the system permitted the collection of urine samples. Prior to this time, all of the urine was flushed overboard. The system shown in figure 25–9 al-

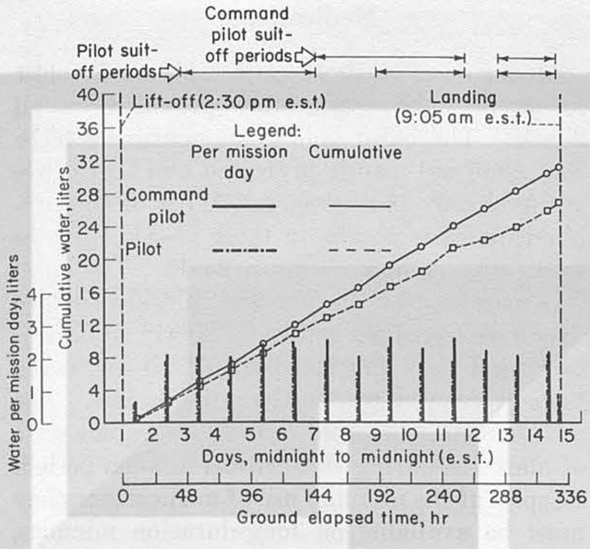


FIGURE 25–8.—Water intake per day for Gemini VII flight crew.

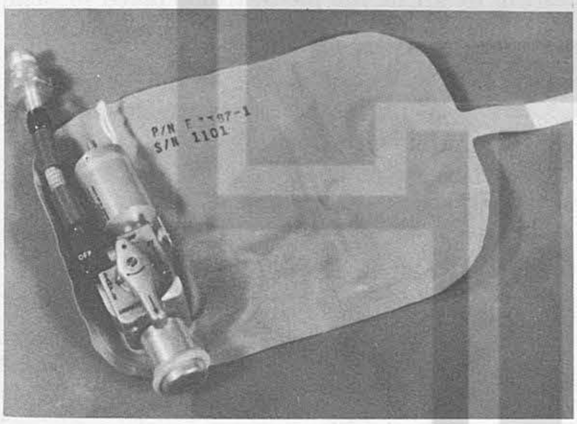


FIGURE 25–9.—Urine collection device.

lowed for collection of a 75-cc sample and the dumping of the remainder of the urine overboard. The total urine volume could be obtained by the use of a tritium-dilution technique.

The handling of fecal waste has been a bothersome inflight problem. Before the mission, the crews eat a low-residue diet, and, in addition, on the 8-day and 14-day missions, they have utilized oral and suppository Dulocolax for the last 2 days before flight. This has proved to be a very satisfactory method of preflight preparation. The fecal collection device is shown in figure 25–10.

The sticky surfaces of the bag opening can be positioned much easier if the crewman is out of the space suit, as occurred during the 14-day flight. The system creates only a minimum amount of difficulty during inflight use and is an adequate method for the present missions. On the 14-day flight, the system worked very well and allowed the collection of all of the fecal specimens for use with the calcium-balance experiment.

Bowel habits have varied on each of the three long-duration missions, as might be expected. Figure 25–11 lists the defecations recorded for these three missions, and the longest inflight delay before defecation occurred was 6 days on the 14-day mission. The opportunity to measure urine volume on the 14-day flight has been of particular interest, as it had been anticipated a diuresis would occur early in the flight. Figure 25–12 shows the number of urinations per day and the urine volume as determined from the flowmeter utilized on the 14-day mission. The accuracy of these data will be compared with that from the tritium samples.

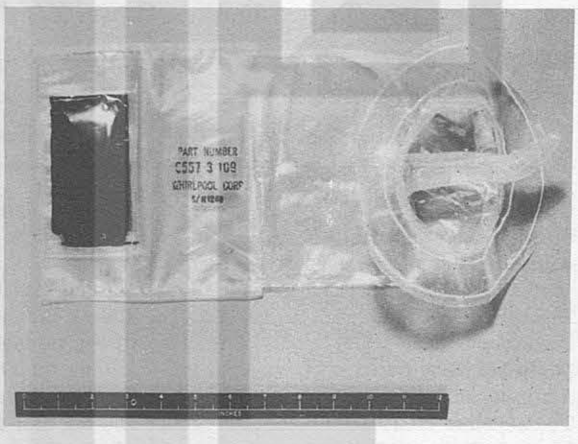


FIGURE 25–10.—Fecal bag.

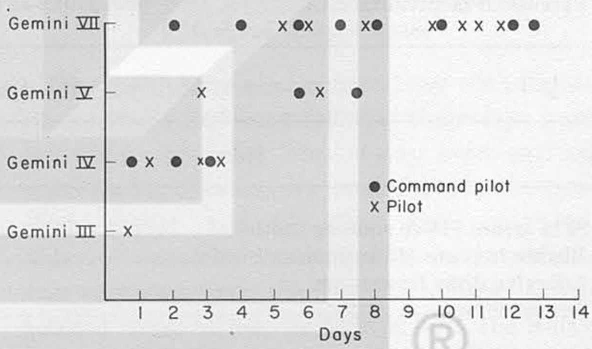


FIGURE 25–11.—Inflight defecation frequency.

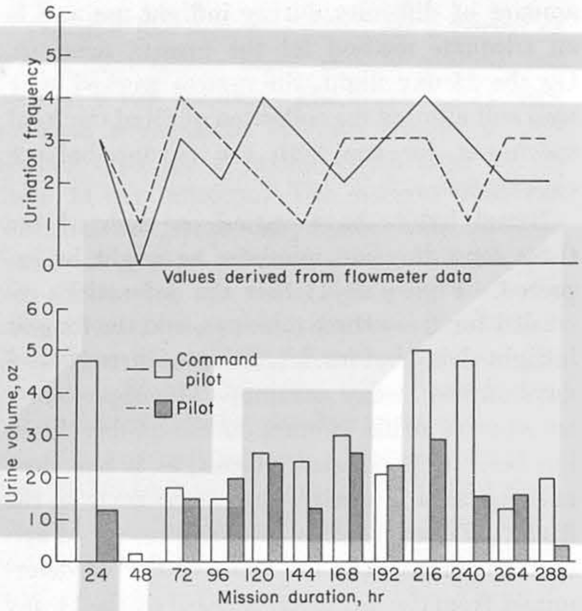


FIGURE 25-12.—Urine volume and urination frequency of Gemini VII flight crew.

Medications

Medications in both injectable and tablet forms have been routinely provided on all flights. The basic policy has continued to be that a normal man is preferred and that drugs are used only if necessary. A list of the supplied drugs is shown in table 25-IV, and the medical kit is shown in figure 25-13. The injectors may be used through the suit, although to date none have been utilized. The only medication used thus far has been dexedrine, taken prior to reentry by the Gemini IV crew. The dexedrine was taken to insure an adequate state of alertness during this critical mission period. In spite of the minimal use of medications, they must be available on long-duration missions, and each crewmember must be pretested to any drug which may potentially be used. Such pretesting of all of the medications listed in table 25-IV has been carried out with each of the crews.

TABLE 25-IV.—*Gemini VII Inflight Medical and Accessory Kits*

(a) Medical kit

Medication	Dose and form	Label	Quantity
Cyclizine HCl	50-mg tablets	Motion sickness	8
d-Amphetamine sulfate	5-mg tablets	Stimulant	8
APC (aspirin, phenacetin, and caffeine)	Tablets	APC	16
Meperidine HCl	100-mg tablets	Pain	4
Triprolidine HCl	2.5-mg tablets	Decongestant	16
Pseudoephedrine HCl	60-mg tablets		
Diphenoxylate HCl	2.5-mg tablets	Diarrhea	16
Atropine sulfate	0.25-mg tablets		
Tetracycline HCl	250-mg film-coated tablet	Antibiotic	16
Methylcellulose solution	15-cc in squeeze-dropper bottle	Eyedrops	1
Parenteral cyclizine	45-mg (0.9-cc in injector)	Motion sickness	2
Parenteral meperidine HCl	90-mg (0.9-cc in injector)	Pain	2

(b) Accessory kit

Item	Quantity
Skin cream (15-cc squeeze bottle)	2
Electrode paste (15-cc squeeze bottle)	1
Adhesive disks for sensors	12 for EKG, 3 for phonocardiogram leads
Adhesive tape	20 in.

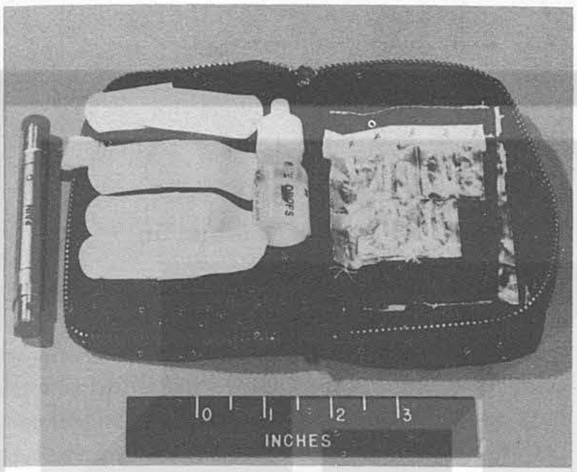


Figure 25–13.—Medical kit carried onboard the spacecraft.

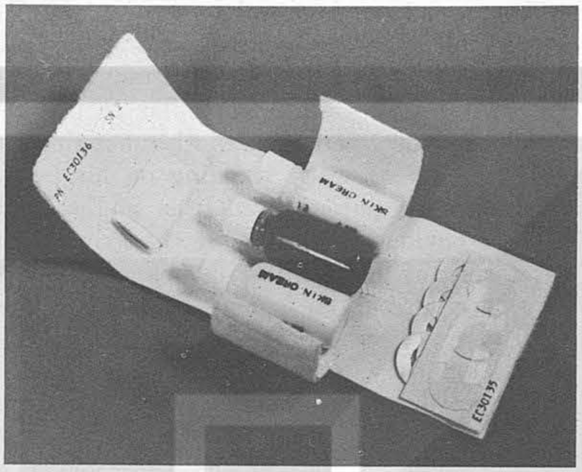


Figure 25–14.—Medical accessory kit carried onboard the spacecraft.

On the 14-day mission, a medical accessory kit, shown in figure 25–14, was carried to allow the reapplication of medical sensors should they be lost during the flight. The kit contained the sensor jelly, and the Stomaseal and Dermaseal tape for sensor application. In addition, the kit contained small plastic bottles filled with a skin lotion, which was a first-aid cream. During the 14-day mission, this cream was used by both crewmen to relieve the dryness of the nasal mucous membranes and was used occasionally on certain areas of the skin. During the mission, the lower sternal electrocardiogram sensor was replaced by both crewmen, and excellent data were obtained after replacement.

Psychology of Flight

Frequent questions are asked concerning the ability of the crewmembers to get along with one another for the long flight periods. Every effort is made to choose crewmembers who are compatible, but it is truly remarkable that none of the crews, including the long-duration crews, have had any inflight psychological difficulties that were evident to the ground monitors or that were discussed in postflight debriefings. They have had some normal concerns for the inherent risks of space flight. They were well prepared for the fact that 4, 8, and 14 days in space in such a confined environment as the Gemini spacecraft would not be an easy task. They had trained well, done everything humanly possible for themselves, and knew that everyone connected with the program had done everything possible to assure their stay. There is some normal increased tension at lift-off and also prior to retrorocket firing. There was some normal psychological letdown when the Gemini VII crew saw the Gemini VI–A spacecraft depart after their rendezvous. However, the Gemini VII crew accepted this very well and immediately adjusted to the flight-plan activity.

A word should be said about overall crew performance from a medical point of view. The crews have performed in an exemplary manner during all flights. There has been no noted decrease in performance, and the fine control tasks such as reentry and, notably, the 11th-day rendezvous during the Gemini VII mission have been handled with excellent skill.

Additional Inflight Observations of Medical Importance

The crews have always been busy with flight-plan activity and have felt that their days were complete and full. The 14-day crew carried some books, occasionally read them in the presleep period, and felt they were of value. Neither crewman completed a book. Music was provided over the high-frequency air-to-ground communications link to both the 8-day and the 14-day crews. They found this to be a welcome innovation in their flight-plan activity.

The crews have described a sensation of fullness in the head that occurred during the first 24 hours of the mission and then gradually disappeared. This feeling is similar to the increase of blood a person notes when hanging on parallel bars or when standing on his head. There was no pulsatile sensation in the head and no obvious reddening of the skin. The exact cause of this condition is unknown, but it may be related to an increase of blood in the chest area as a result of the readjustment of the circulation to the weightless state.

It should be emphasized that no crewmembers have had disorientation of any sort on any Gemini mission. The crews have adjusted very easily to the weightless environment and accepted readily the fact that objects will stay in position in midair or will float. There has been no difficulty in reaching various switches or other items in the spacecraft. They have moved their heads at will and have never noticed an aberrant sensation. They have always been oriented to the interior of the spacecraft and can orient themselves with relationship to the earth by rolling the spacecraft and finding the horizon through the window. During the extravehicular operation, the Gemini IV pilot oriented himself only by his relationship to the spacecraft during all of the maneuvers. He looked repeatedly at the sky and at the earth and had no sensations of disorientation or motion sickness at any time. The venting of hydrogen on the 8-day flight created some roll rates of the spacecraft that became of such magnitude that the crew preferred to cover the windows to stop the visual irritation of the rolling horizon. Covering the windows allowed them to wait for a longer period of time before having to damp the rates with thruster activity. At no time did they experience any disorientation. During the 14-day flight, the crew repeatedly moved their heads in various directions in order to try to create disorientation but to no avail. They also had tumble rates of 7° to 8° per second created by venting from the water boiler, and one time they performed a spin-dry maneuver to empty the water boiler, and this created roll rates of 10° per second. On both occasions they moved their heads freely and had no sensation of disorientation.

The crews of all three long-duration missions have noted an increased g-sensitivity at the time of retrofire and reentry. All the crews felt that they were experiencing several g when the g-meter was just beginning to register at reentry. However, when they reached the peak g-load, their sensations did not differ from their centrifuge experience.

Physical Examination

A series of physical examinations have been accomplished before each flight in order to determine the crewmembers' readiness for mission participation, and also after each flight to evaluate any possible changes in their physical condition. These examinations normally have been accomplished 8 to 10 days before launch, 2 days before launch, on launch morning, and immediately after the flight and have been concluded with daily observations for 5 to 10 days after recovery. These examinations thoroughly surveyed the various body systems. With the exception of items noted in this report, there have been no significant variations from the normal preflight baselines. The 14-day crew noted a heavy feeling in the arms and legs for several hours after recovery, and they related this to their return to a 1-g environment, at which time their limbs became sensitive to weight. In the zero-g condition, the crew had been aware of the ease in reaching switches and controls due to the lack of weight of the arms. The 8-day crew also reported some heaviness in the legs for several hours after landing. Both the 8-day and 14-day crews reported some muscle stiffness lasting for several days after recovery. This was particularly noted in the legs and was similar to the type of stiffness resulting from initial athletic activity after a long period of inactivity.

On all missions there has been minimum skin reaction surrounding sensor sites, and this local irritation has cleared rapidly. There have been a few small inclusion cysts near the sternal sensors. In preparing for the 8-day flight the crews bathed daily with hexachlorophene for approximately 10 days before the flight. In addition, the underwear was washed thoroughly in hexachlorophene, and attempts were made to keep it relatively free of bacteria until donning. The 14-day crew showered daily with a standard hexachlorophene-containing soap and also used Selsun shampoos for a 2-week period. Following the 8-day and 14-day missions, the crewmembers' skin was in excellent condition. The 8-day flight crewmembers did have some dryness and scaling on the extremities and over the sensor sites, but, after using a skin lotion for several days, the condition cleared rapidly. The 14-day crewmembers' skin did not have any dryness and required no treatment postflight. After their flight, the 8-day crew had some marked dandruff and seborrheic lesions of the scalp which required treatment with Selsun for a period of time. The 14-day crew had virtually no dandruff in the postflight examination, nor was it a problem during flight.

The crew of the 14-day mission wore new lightweight space suits and, in addition, removed them for a portion of the flight. While significant physiological differences between the suited and unsuited crewman were difficult to determine, it was noted that the unsuited crewman exercised more vigorously, slept better, and had higher urine output because fluid was not being lost as perspiration. The excellent general condition of the crewmembers, particularly their skin condition, is to a large extent attributable to the unsuited operations.

Bacterial cultures were taken from each crewmember's throat and from several skin areas before and after the long-duration missions. The numbers of bacteria in the throat flora were reduced, and there was an increase in the fecal flora in the perineal areas. All fungal studies were negative. These revealed no significant difference in the complexity of the microflora. No significant transfer of organisms between crewmembers has been noted, and there has been no "locking in" of floral patterns through 14 days.

Postflight ear, nose, and throat examinations have consistently been negative, and caloric examinations before and after each flight have been normal. On each of the long-duration missions, the crews have reported nasal drying and stuffiness, and this has been evident by the nasal voice quality during voice communication with the surgeon at the Mission Control Center. This symptom has lasted varying amounts of time but has been most evident in the first few days of the mission. The negative postflight findings have been of interest in view of these inflight observations. The crews have reported they found it necessary to clear their ears frequently in inflight. Some of this nasal and pharyngeal congestion has been noted in the long-duration space cabin simulator runs in a similar environment. It may be related to dryness, although the cabin humidity would not indicate this to be the case, or another cause might be the pure oxygen atmosphere in the cabin. It may also be related to a possible change in blood supply to the head and thorax as a result of circulatory adaptation to weightlessness.

The oral hygiene of the crewmembers has been checked closely before each flight and has been maintained inflight by the use of a dry toothbrush and a chewable dental gum. This technique provided excellent oral hygiene through the 14-day flight.

Weight

A postflight weight loss has been noted for each of the crewmembers; however, it has not increased with mission duration and has varied from 2.5 to 10 pounds. The majority of the loss has been replaced with fluid intake within the first 10 to 12 hours after landing. Table 25–V shows the weight loss and postflight gain recorded for the crewmen of the long-duration flights.

TABLE 25–V.—*Astronaut Weight Loss*

Gemini mission	Command pilot weight loss, lb	Pilot weight loss, lb
III	3	3.5
IV	4.5	8.5
V	7.5	8.5
VI–A	2.5	8
VII	10	6

Hematology

Clinical laboratory hematologic studies have been conducted on all missions, and some interesting findings have been noted in the white-blood-cell counts. The changes are shown in figure 25–15 (a) and (b). It can be seen that on the 4-day flight there was a rather marked absolute increase in white blood cells, specifically neutrophiles, which returned to normal within 24 hours (though not shown in the figure). This finding was only minimally pres-

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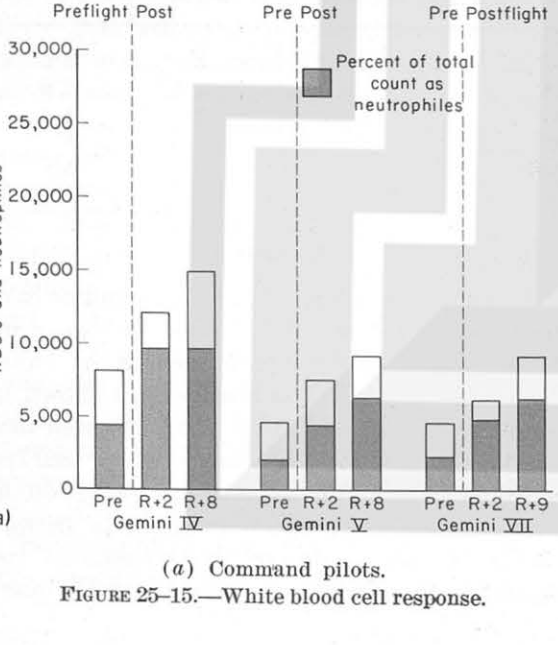
ent following the 8-day flight and was noted again following the 14-day flight. It very likely can be explained as the result of an epinephrine response. The red-cell counts show some postflight reduction that tends to confirm the red-cell mass data to be discussed.

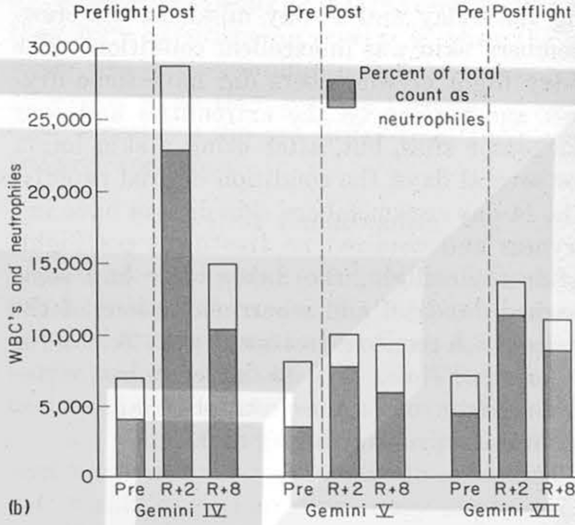
Urine and blood chemistry tests have been performed before and after each of the missions, and the results may be seen in tables 25–VI and 25–VII. The significant changes noted will be discussed in the experiments report.

Blood Volume

On each of the long-duration flights, plasma volume has been determined by the use of a technique utilizing radio-iodinated serum albumin. On the 4-day mission, the red-cell mass was calculated by utilizing the hematocrit determination. Analysis of the data caused some concern as to the validity of the hematocrit in view of the dehydration noted. The 4-day mission data showed a 7- and 15-percent decrease in the circulating blood volume for the two crewmembers, a 13-percent decrease in plasma volume, and an indication of a 12- and 13-percent decrease in red-cell mass, although it had not been directly measured. As a result of these findings, red cells were tagged with chromium 51 on the 8-day mission in order to get an accurate measurement of red-cell mass while continuing to utilize the radio-iodinated serum albumin technique for plasma volume. The



(*a*) Command pilots.
FIGURE 25–15.—White blood cell response.



(*b*) Pilots.
FIGURE 25–15.—Concluded.

chromium-tagged red cells also provided a measure of red-cell survival time. At the completion of the 8-day mission, there was a 13-percent decrease in blood volume, a 4- to 8-percent decrease in plasma volume, and a 20-percent decrease in red-cell mass. These findings pointed to the possibility that the red-cell mass decrease might be incremental with the duration of exposure of the space-flight environment. The 14-day flight results show no change in the blood volume, a 4- and 15-percent increase in plasma volume, and a 7- and 19-percent decrease in red-cell mass for the two crewmembers. In addition to these findings, the red-cell survival time has been reduced. All of these results are summarized in figure 25–16. It can be concluded that the decrease in red-cell mass is not incremental with increased exposure to the space-flight environment. On the 14-day flight, the maintenance of total blood volume, by increasing plasma volume, and the weight loss noted indicated that some fluid loss occurred in the extracellular compartment but that the loss had been replaced by fluid intake after the flight. The detailed explanation of the decreased mass is unknown at the present time, and several factors, including the atmosphere, may be involved. This loss of red cells has not interfered with normal function and is generally equivalent to the blood withdrawn in a blood-bank donation, but the decrease occurs over a longer period of time, and this allows for adjustment.

TABLE 25-VI.—*Gemini VII Urine Chemistries*

[All dates 1965]

Determination	Command pilot							Pilot						
	Preflight	Postflight						Preflight	Postflight					
		Dec. 18		Dec. 20		Dec. 21			Dec. 18		Dec. 20		Dec. 21	
	Nov. 23 and Dec. 1	Measured	Percent of preflight	Measured	Percent of preflight	Measured	Percent of preflight	Nov. 23 and Dec. 1	Measured	Percent of preflight	Measured	Percent of preflight	Measured	Percent of preflight
Sodium, $\frac{\text{meg}}{\text{24 hr}}$	143	95	66	182	127	150	105	150	76	51	94	63	-----	-----
Potassium	71	118	166	93	131	90	127	70	60	86	89	127	-----	-----
Chlorine	141	89	63	168	119	145	103	141	67	48	73	52	-----	-----
Calcium, $\frac{\text{mg}}{\text{24 hr}}$	228	269	118	260	114	210	92	184	89	48	105	57	-----	-----
Phosphate	1131	2133	188	936	83	978	86	1200	996	83	1345	112	-----	-----
17-hydroxycorticosteriods	7.7	18.6	241	7.3	95	9.1	118	6.2	11.3	183	8.1	130	8.2	132
Ephinephrine, $\frac{\mu\text{g}}{\text{24 hr}}$	7.8	16.4	210	([a])	-----	([a])	-----	10.2	-----	-----	-----	-----	-----	-----
Norepinephrine	50.3	103.0	204	([a])	-----	([a])	-----	42.7	-----	-----	-----	-----	-----	-----
Aldosterone, $\frac{\mu\text{g}}{\text{24 hr}}$	26	75	288	-----	-----	28	108	26	47	181	-----	-----	60	230
Creatine, $\frac{\text{mg}}{\text{24 hr}}$	2035	3297	162	1380	68	2070	102	2230	2003	90	2225	100	-----	-----

[a] Not significant.

TABLE 25-VII.—*Gemini VII Blood Chemistry Studies for Command Pilot*

Determination	Preflight		Postflight			
	Nov. 24 and Nov. 25, 1965	Nov. 30 and Dec. 2, 1965	Dec. 18, 1965 11:30 a.m., e.s.t.	Dec. 18, 1965 6:20 p.m., e.s.t.	Dec. 19, 1965	Dec. 20 and Dec. 21, 1965
Blood urea nitrogen, mg percent	19	16	16	20	25	18
Bilirubin, total mg percent	.4	.2	.3	----------	.3	.4
Alkaline phosphatase (B–L units)	1.7	2.0	1.7	----------	----------	----------
Sodium, meq/liter	147	146	138	140	144	143
Potassium, meq/liter	4.7	5.4	4.1	4.7	4.7	4.9
Chloride, meq/liter	103	103	100	102	103	106
Calcium, mg percent	9.0	9.2	8.6	9.2	9.0	9.2
Phosphate, mg percent	3.2	3.7	4.0	3.2	3.1	3.6
Glucose, mg/100 ml, nonfasting	71	90	98	----------	----------	----------
Albumen, g percent	4.6	4.73	5.16	----------	4.5	4.6
Alpha 1, g percent	.23	.26	.08	----------	----------	----------
Alpha 2, g percent	.40	.39	.40	----------	----------	----------
Beta, g percent	.63	.84	.72	----------	----------	----------
Gamma, g percent	1.03	.97	.72	----------	----------	----------
Total protein, g percent	6.9	7.2	7.1	7.6	7.0	7.1
Uric acid, mg percent	6.8	6.6	4.6	6.0	5.9	6.0

Tilt Studies

The first abnormal finding noted following manned space flight was the postflight orthostatic hypotension observed on the last two Mercury missions. Study of this phenomenon has been continued in order to develop a better appreciation of the physiological cost of manned space flight. A special saddle tilt table, shown in figure 25-17, has been used, and the tilt-table procedure has been monitored with electronic equipment providing automatic monitoring of blood pressure, electrocardiogram, heart rate, and respiration. The procedure consists of placing the crewman in a horizontal position for 5 minutes for stabilization, tilting to the 70° head-up position for 15 minutes, and then returning to the horizontal position for another 5 minutes. In addition to the usual blood pressure and pulse rate determinations at minute intervals, some mercury strain gages have been used to measure changes in the circumference of the calf. On the 4-day, 8-day, and 14-day missions there were no symptoms of faintness experienced by the crew at any time during the landing sequence or during the postlanding operation. Abnormal tilt-table responses, when compared with the preflight baseline tilts, have been noted for a period of

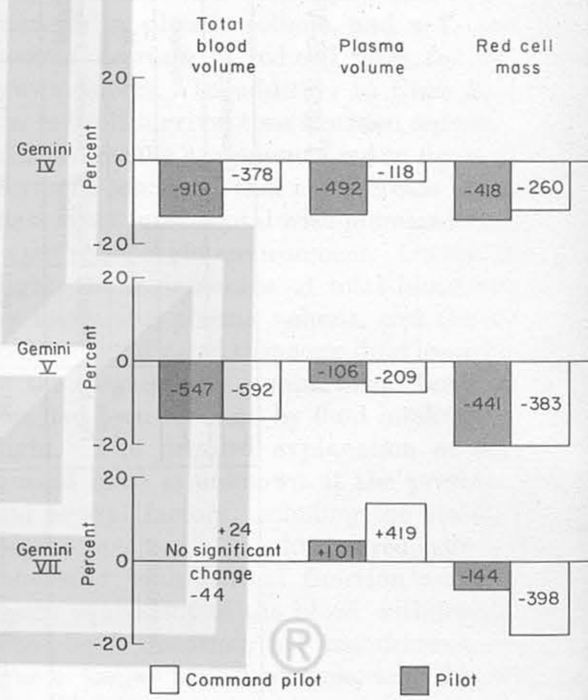


FIGURE 25-16.—Blood volume studies.

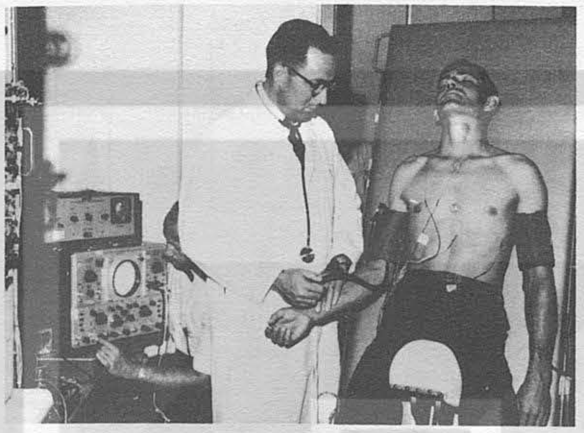


FIGURE 25-17.—Tilt-table test.

48 to 50 hours after landing. Typical initial postlanding tilt responses are graphed for the 4-day and 8-day mission crews in figures 25-18 through 25-21. A graph of the percentage increase in heart rate from baseline normal to that attained during the initial postflight tilt can be seen in figure 25-22. All of the data for Gemini III through VI-A fell roughly on a linear curve. The projection of this line for the 14-day mission data would lead one to expect very high heart rates or possible syncope. It was not believed this would occur. The tilt responses of the 14-day mission crew are shown in figures 25-23 and 25-24.

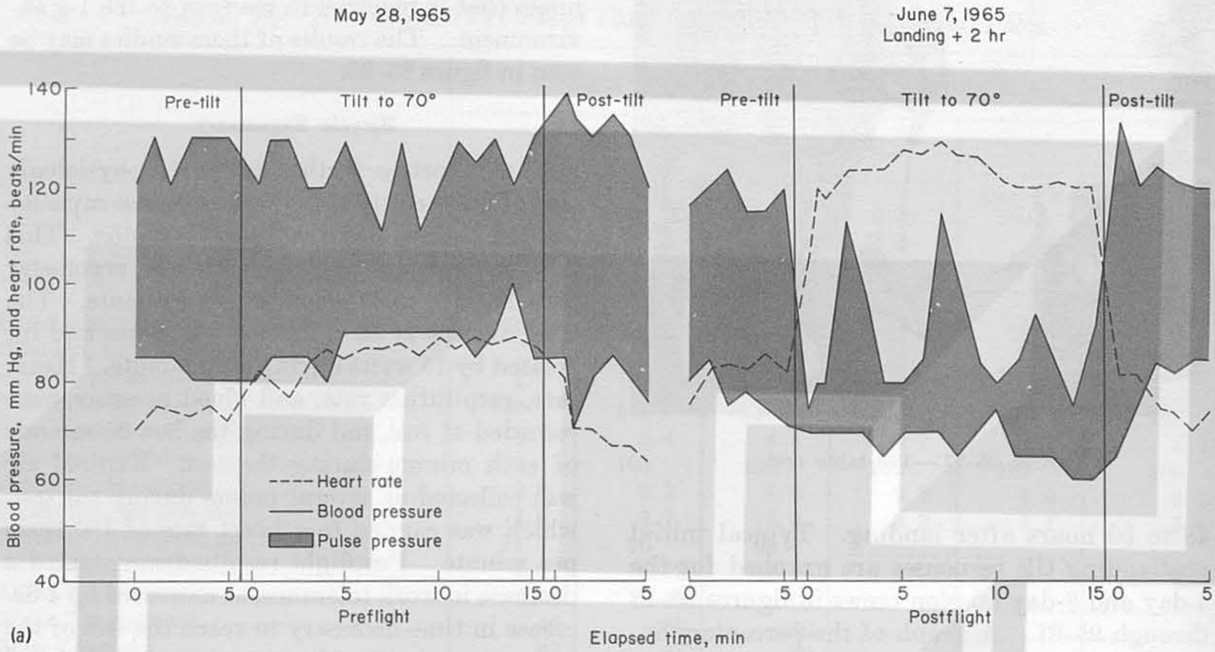
The response of the command pilot is not unlike that of previous crewmen, and the peak heart rate attained is more like that seen after 4 days of space flight. The tilt completed 24 hours after landing is virtually normal. The pilot's tilt at 1 hour after landing is a good example of individual variation, for he had a vagal response, and the heart rate, which had reached 128, dropped, as did the blood pressure, and the pilot was returned to the horizontal position at 11 minutes. Subsequent tilts were similar to previous flights, and the response was at baseline values in 50 hours. When these data are plotted on the curve in figure 25-22, it will be noted that they more closely resemble 4-day mission data. There has been no increase in the time necessary to return to the normal preflight tilt response, a 50-hour period, regardless of the duration of the flight. The strain-gage data generally confirm pooling of blood in the lower extremities during the period of roughly 50 hours that is required to readjust to the 1-g environment. The results of these studies may be seen in figure 25-25.

Bicycle Ergometry

In an effort to further assess the physiologic cost of manned space flight, an exercise capacity test was added for the 14-day mission. This test utilized an electronic bicycle ergometer pedaled at 60 to 70 revolutions per minute. The load was set at 50 watts for 3 minutes and increased by 15 watts during each minute. Heart rate, respiration rate, and blood pressure were recorded at rest and during the last 20 seconds of each minute during the test. Expired air was collected at several points during the test, which was carried to a heart rate of 180 beats per minute. Postflight results demonstrated a decrease in work tolerance, as measured by a decrease in time necessary to reach the end of the test, amounting to 19 percent on the command pilot and 26 percent on the pilot. There was also a reduction in physical competence measured as a decrease in oxygen uptake per kilogram of body weight during the final minute of the test.

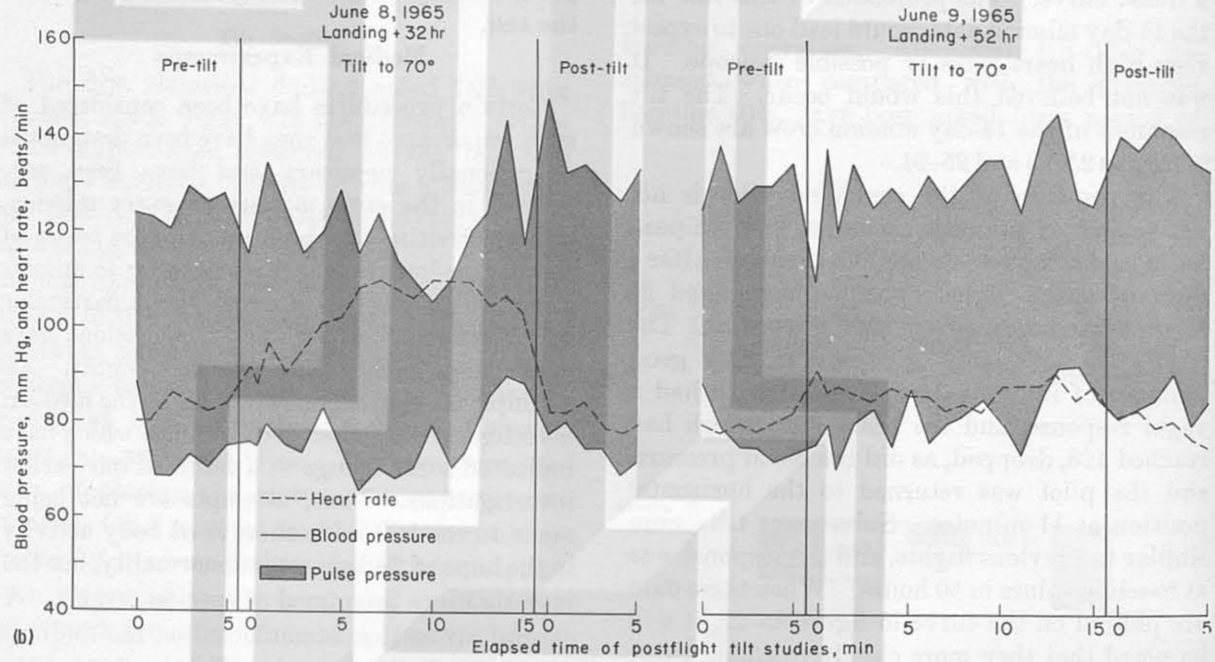
Medical Experiments

Certain procedures have been considered of such importance that they have been designated operationally necessary and have been performed in the same manner on every mission. Other activities have been put into the realm of specific medical experiments in order to answer a particular question or to provide a particular bit of information. These investigations have been programed for specific flights. An attempt has been made to aim all of the medical investigations at those body systems which have indicated some change as a result of our earlier investigations. Thus, attempts are not being made to conduct wide surveys of body activity in the hope of finding some abnormality, but the investigations are aimed at specific targets. A careful evaluation is conducted on the findings from each flight, and a modification is made to the approach based upon this evaluation in both the operational and experimental areas. Table 25-VIII shows the medical experiments which have been conducted on the Gemini flights to date.



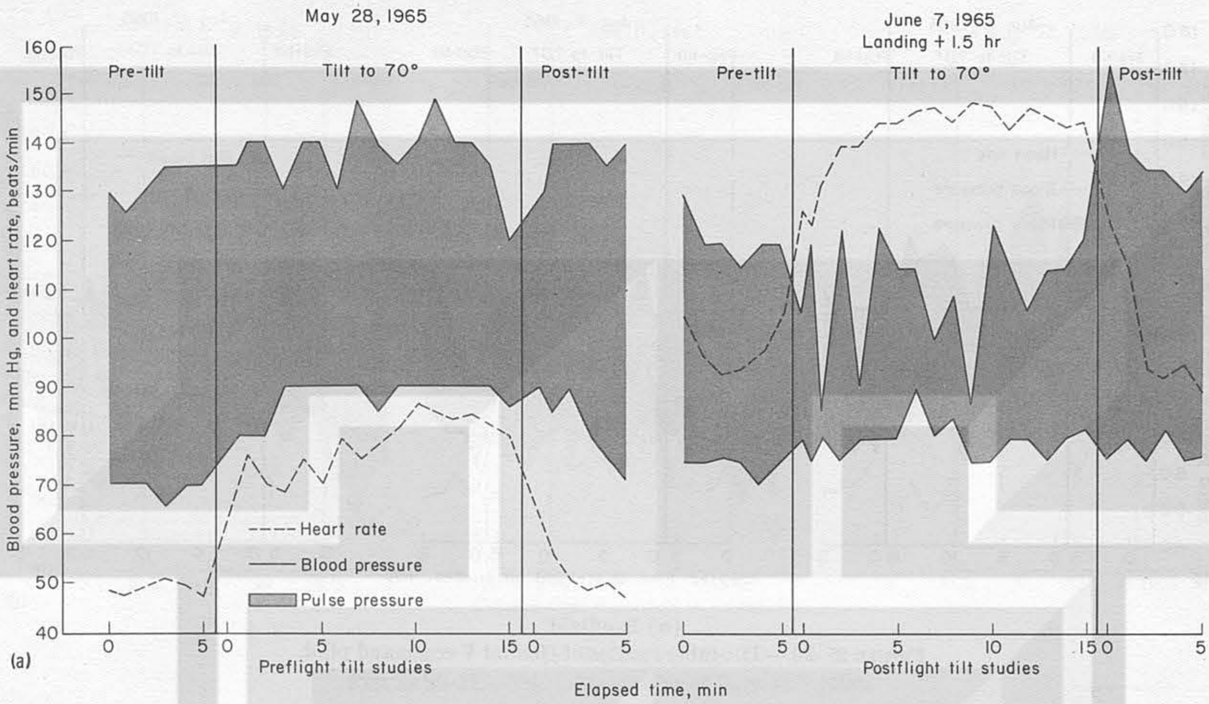
(*a*) Studies conducted preflight and at 2 hours after landing.

FIGURE 25-18.—Tilt-table studies of Gemini IV command pilot.

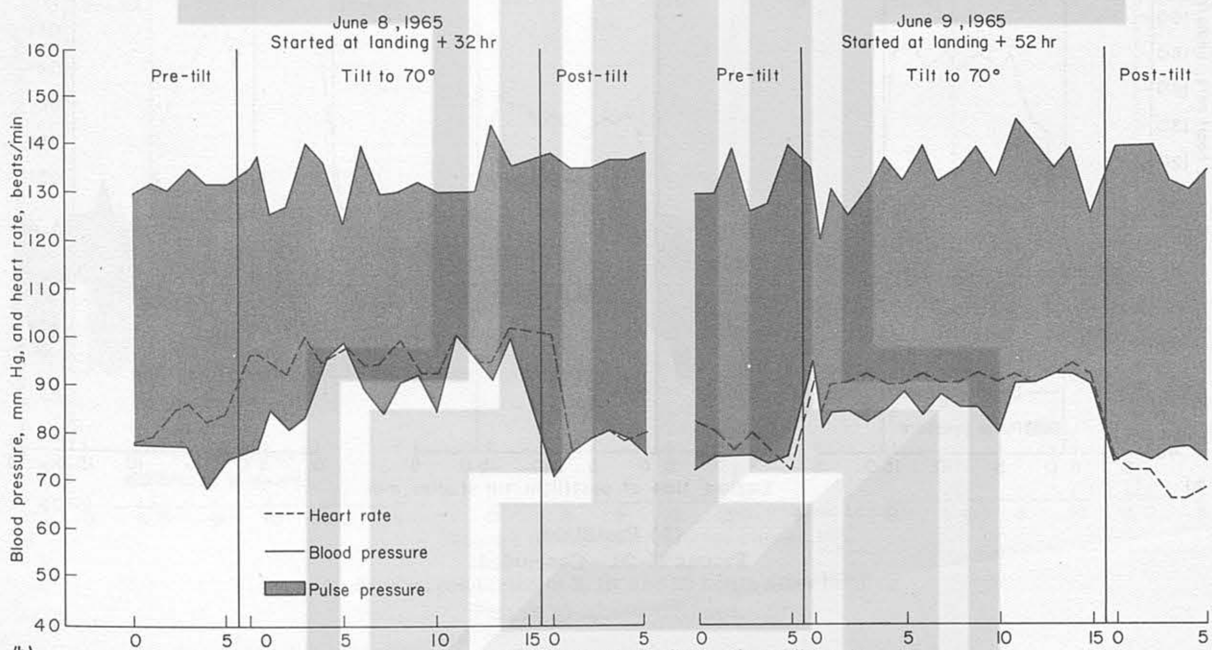


(*b*) Studies conducted 32 hours and 52 hours after landing.

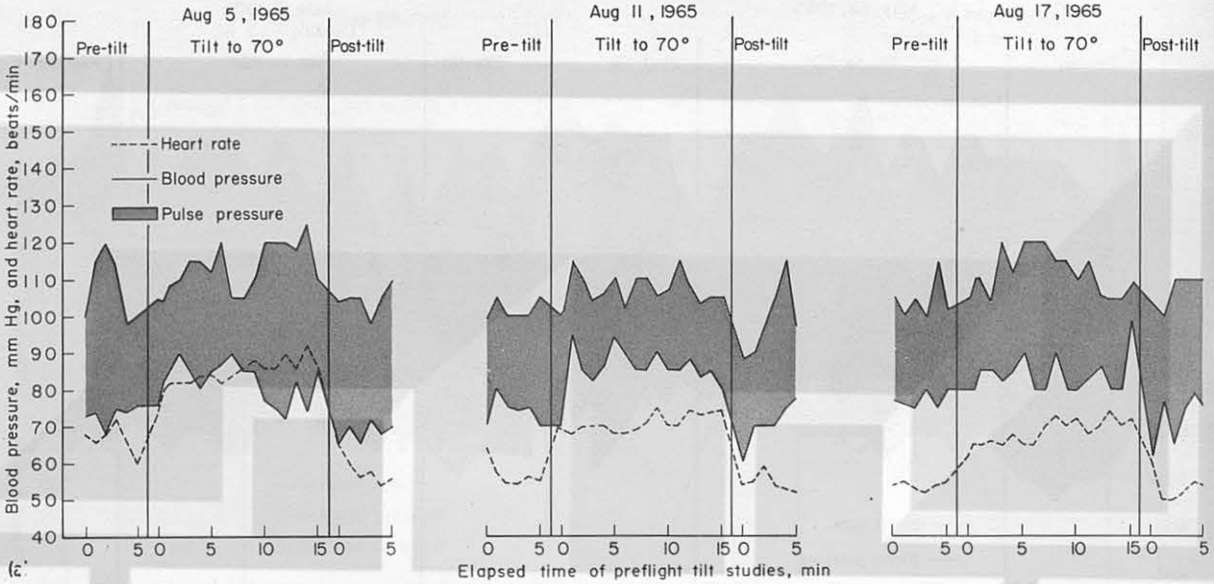
FIGURE 25-18.—Concluded.



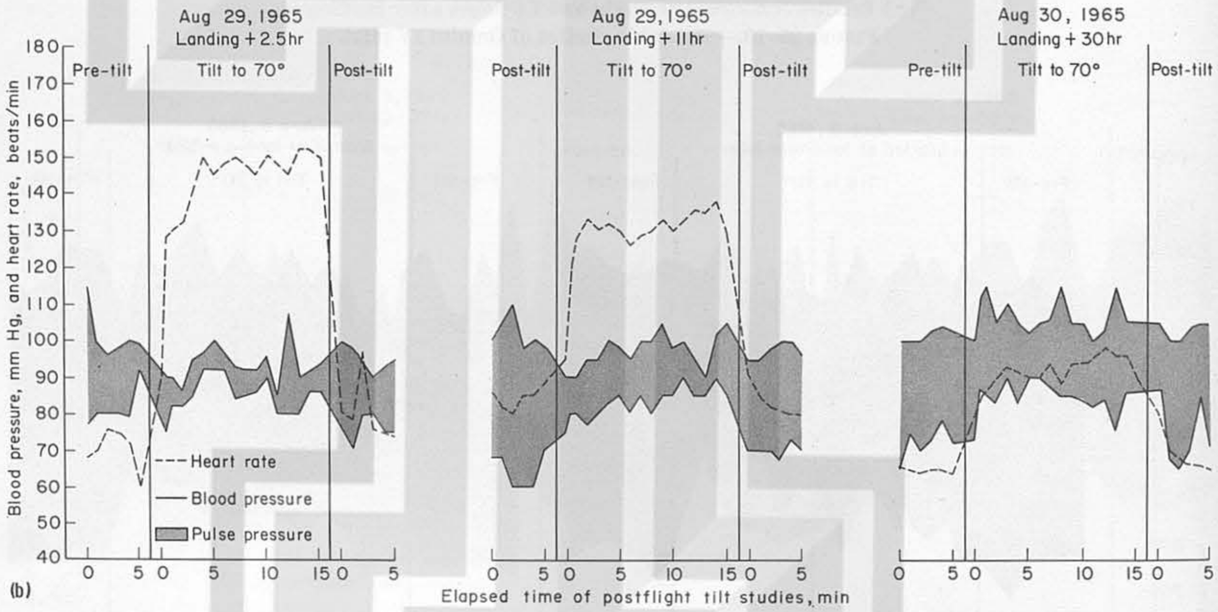
(*a*) Studies conducted preflight and 1.5 hours after landing.
FIGURE 25-19.—Tilt-table studies of Gemini IV pilot.



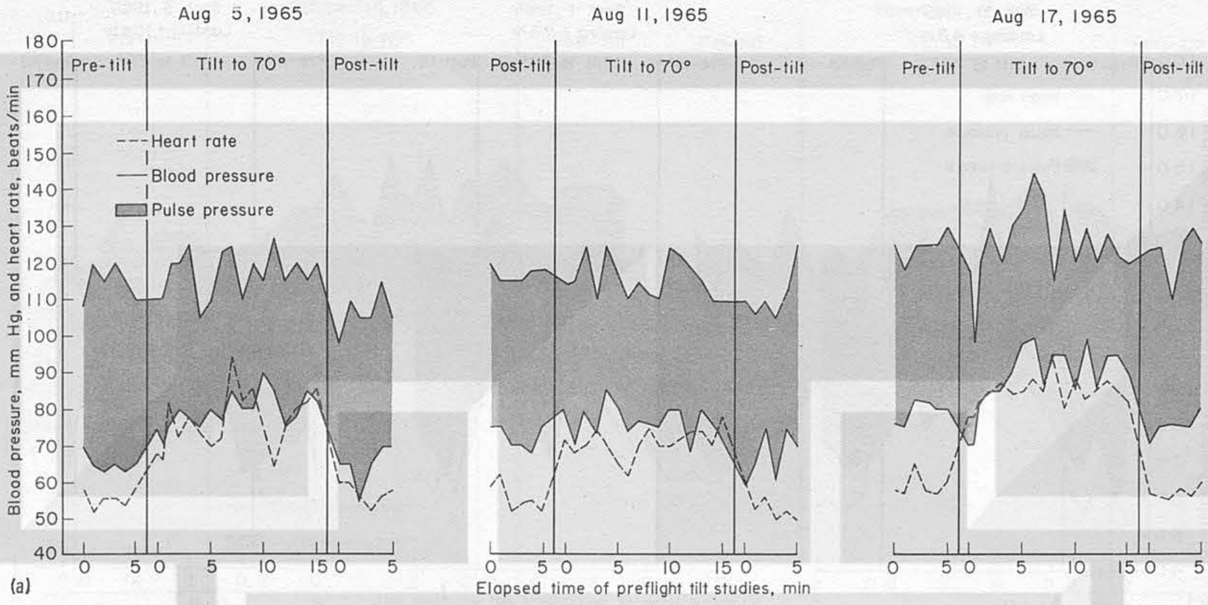
(*b*) Studies conducted 32 hours and 52 hours after landing.
FIGURE 25-19.—Concluded.



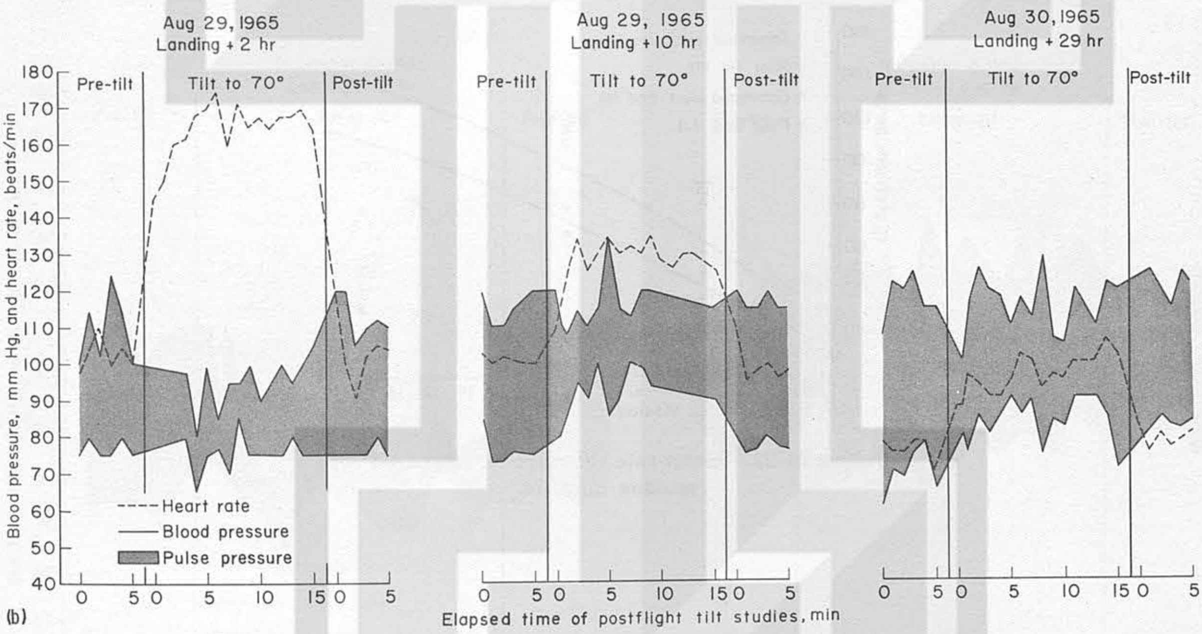
(*a*) Preflight.
FIGURE 25–20.—Tilt-table studies of Gemini V command pilot.



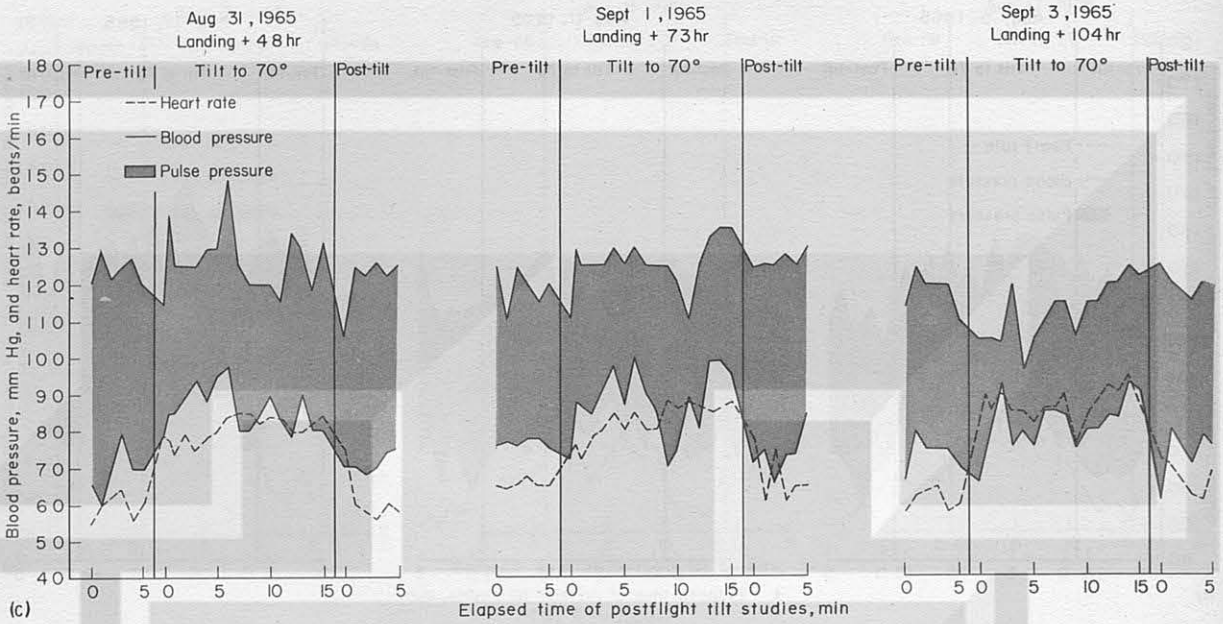
(*b*) Postflight.
FIGURE 25–20.—Concluded.



(*a*) Preflight.
FIGURE 25–21.—Tilt-table studies of Gemini V pilot.



(*b*) Studies conducted at 2, 10, and 29 hours after landing.
FIGURE 25–21.—Continued.



(c) Studies conducted at 48, 73, and 104 hours after landing.
FIGURE 25-21.—Concluded.

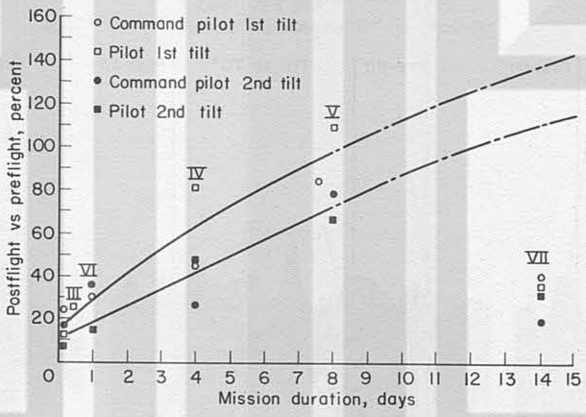
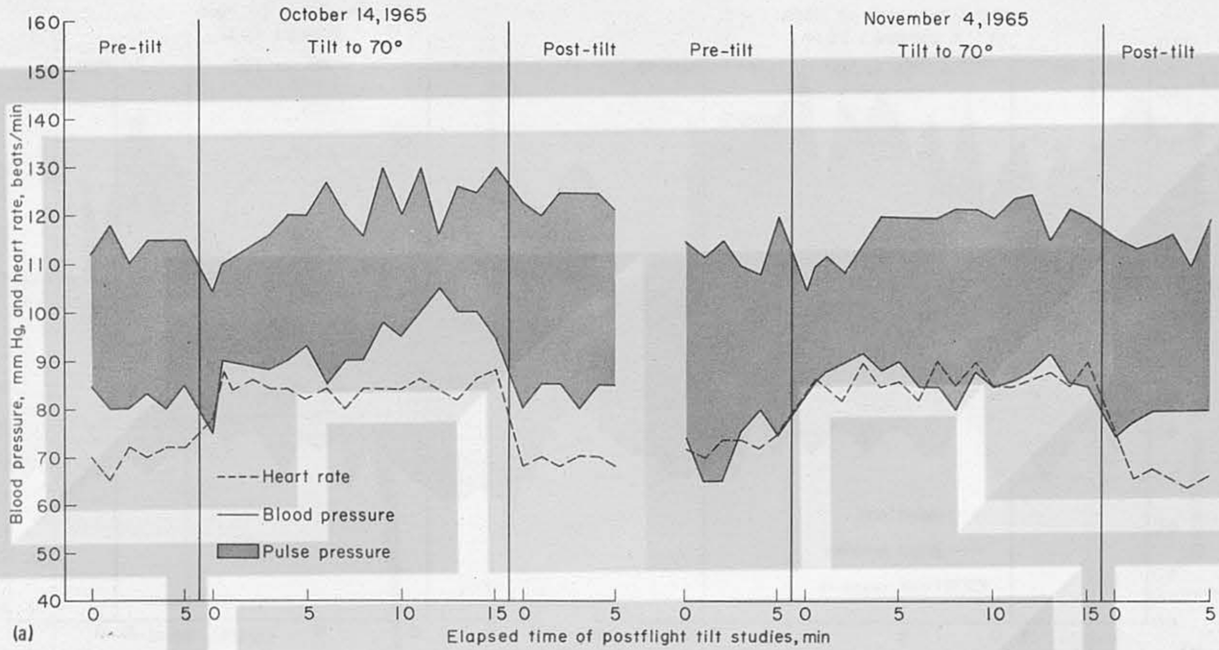
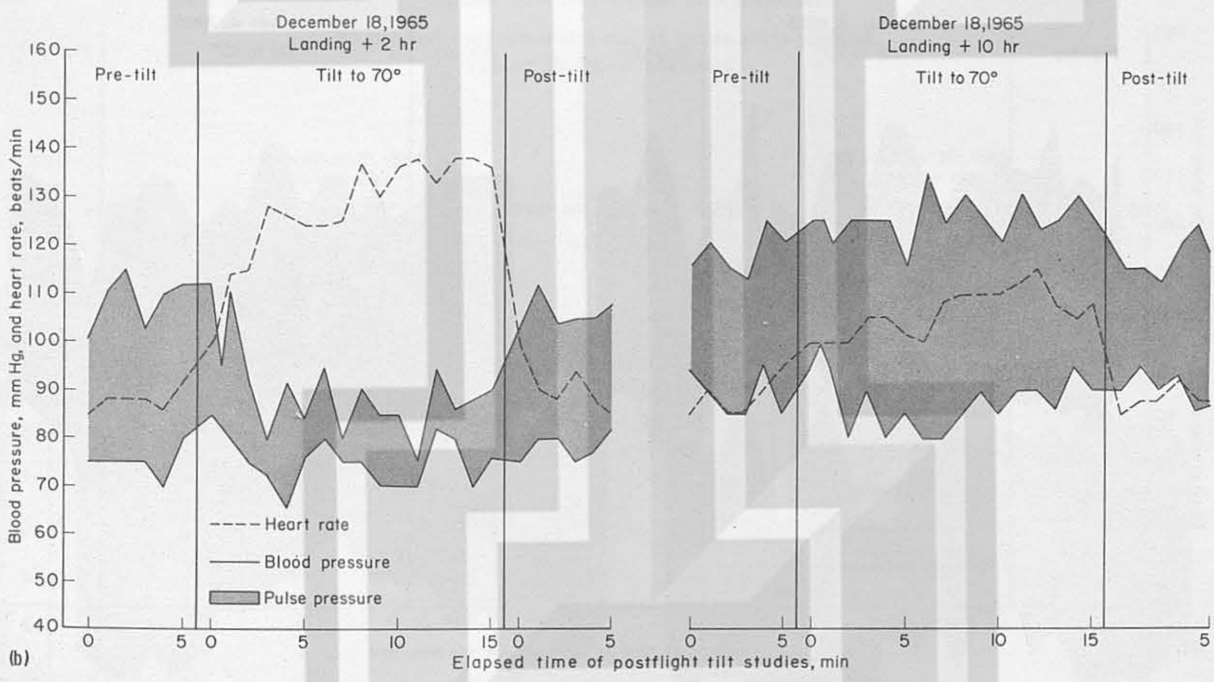


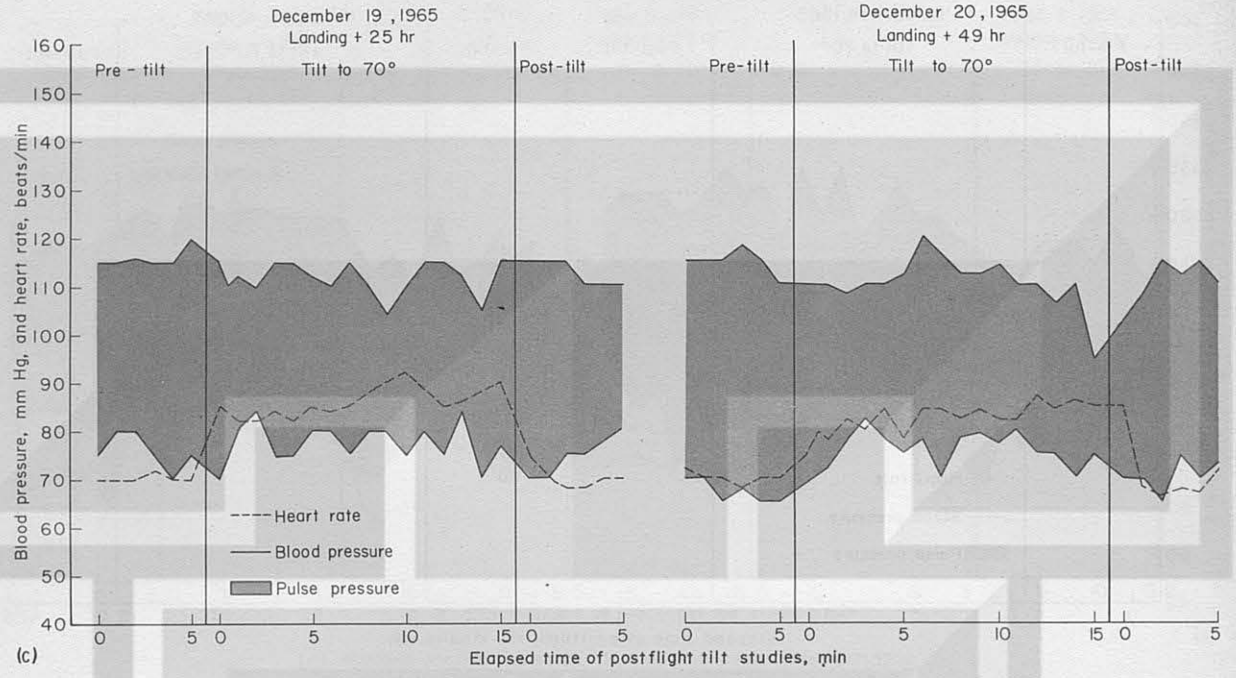
FIGURE 25-22.—Heart-rate tilt response compared with mission duration.



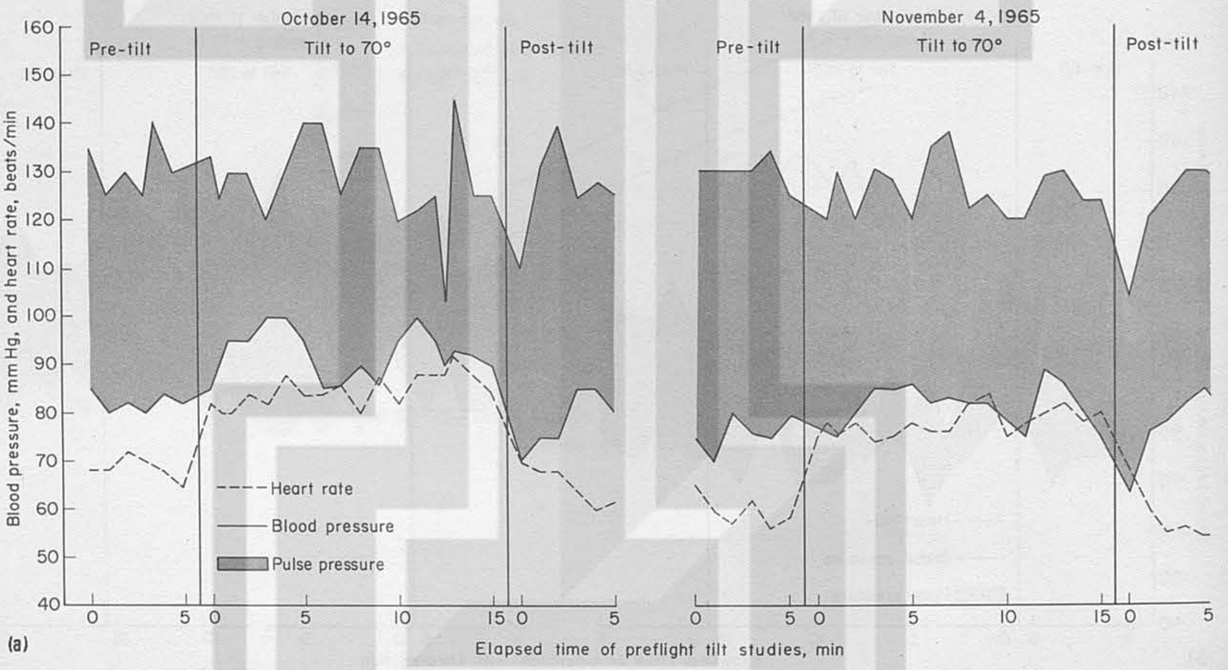
(*a*) Preflight.
FIGURE 25–23.—Tilt-table studies of Gemini VII command pilot.



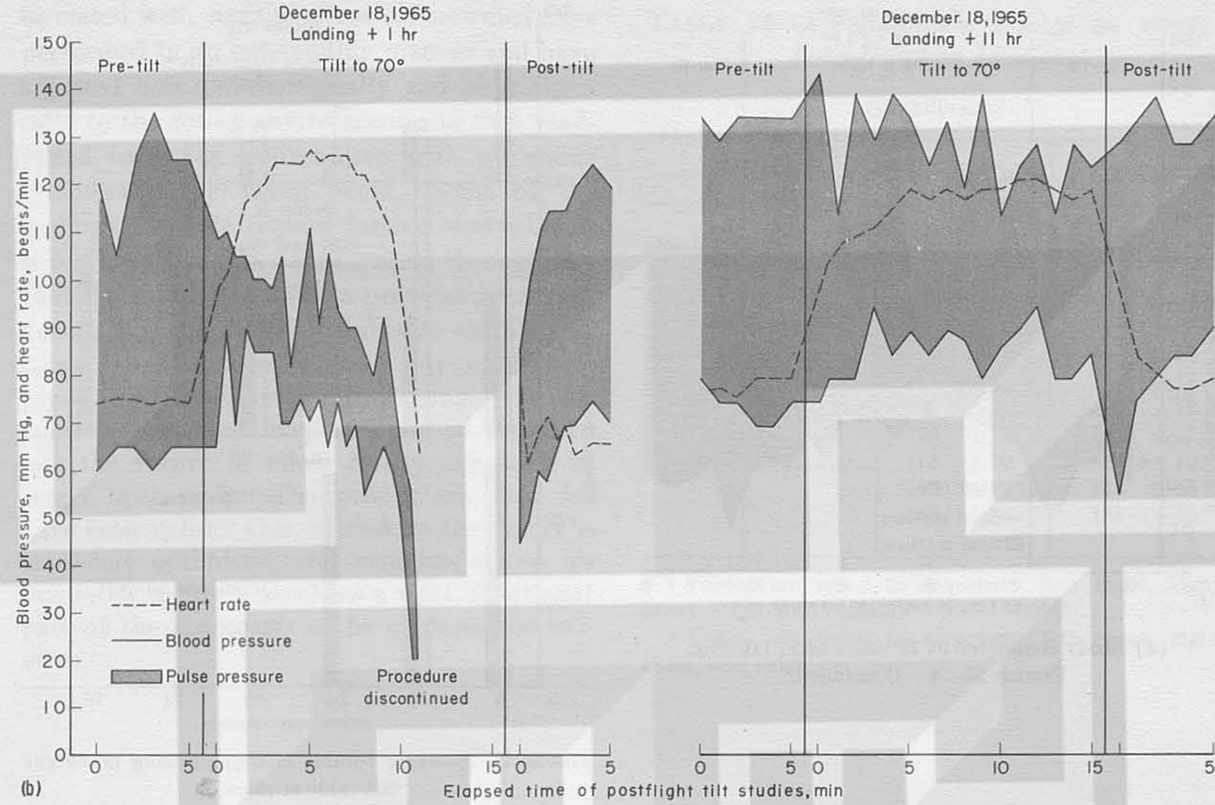
(*b*) Studies conducted at 2 and 10 hours after landing.
FIGURE 25–23.—Continued.



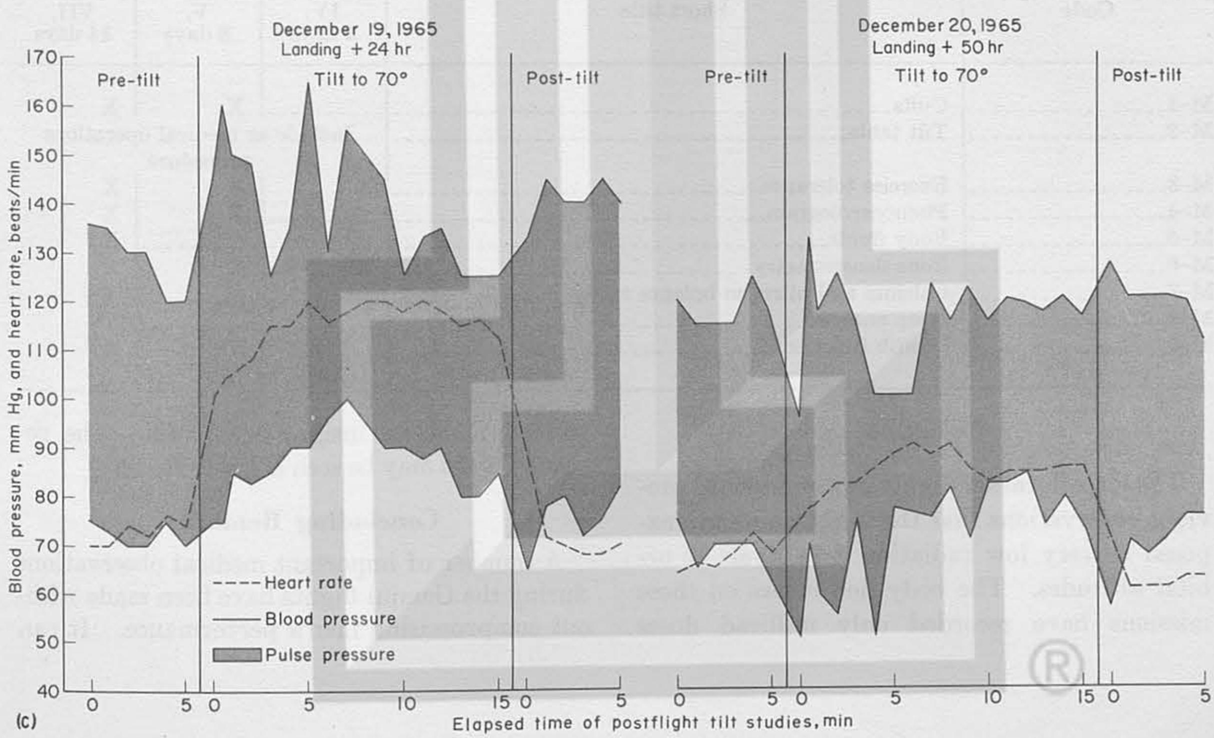
(c) Studies conducted at 25 and 49 hours after landing.
FIGURE 25-23.—Concluded.



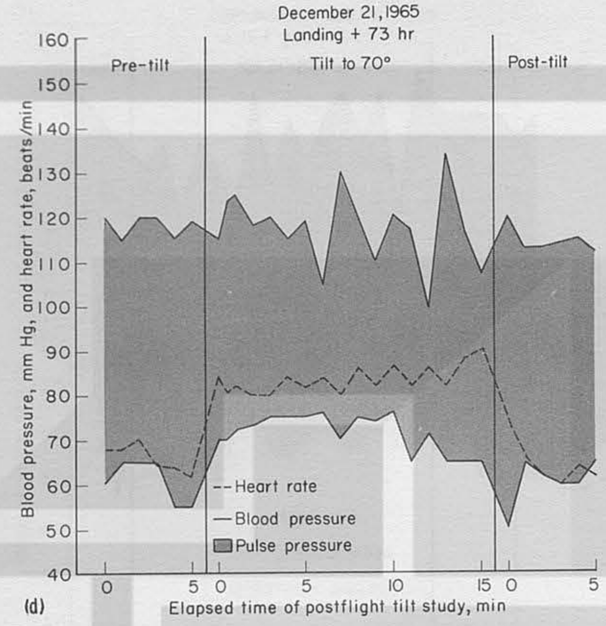
(a) Preflight.
FIGURE 25-24.—Tilt-table studies of Gemini VII pilot.



(*b*) Studies conducted at 1 and 11 hours after landing.
FIGURE 25-24.—Continued.



(*c*) Studies conducted at 24 and 50 hours after landing.
FIGURE 25-24.—Continued.



(*d*) Study conducted at 73 hours after landing.
FIGURE 25–24.—Concluded.

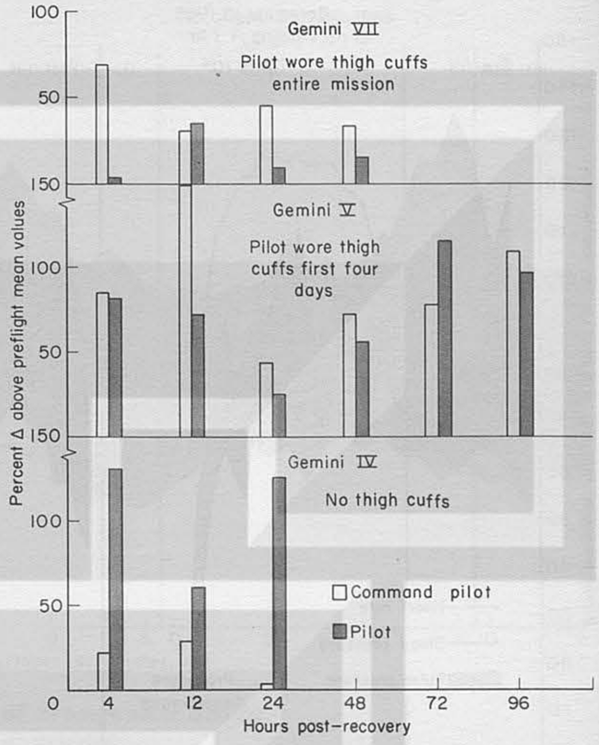


FIGURE 25–25.—Leg volume changes during postflight tilt-table studies.

TABLE 25–VIII.—*Medical Experiments on Gemini Long-Duration Missions*

Code	Short title	Gemini IV, 4 days	Gemini V, 8 days	Gemini VII, 14 days
M–1	Cuffs		X	X
M–2	Tilt table	Include as medical operations procedure		
M–3	Exercise tolerance	X	X	X
M–4	Phonocardiogram		X	X
M–5	Body fluids			X
M–6	Bone densitometry	X	X	X
M–7	Calcium and nitrogen balance study			X
M–8	Sleep analysis			X
M–9	Otolith function		X	X

Radiation

The long-duration flights have confirmed previous observations that the flight crews are exposed to very low radiation dose levels at orbital altitudes. The body dosimeters on these missions have recorded only millirad doses which are at an insignificant level. The recorded doses may be seen in table 25–IX.

Concluding Remarks

A number of important medical observations during the Gemini flights have been made without compromising man's performance. It can be stated with certainty that all crewmen have performed in an outstanding manner and have adjusted both psychologically and physiologically to the zero-g environment and then readjusted to a 1-g environment with no undue symptomatology being noted. Some of the findings noted do require further study, but it is felt that the experience gained through the 14-day Gemini VII mission provides great confidence in any crewman's ability to complete an 8-day lunar mission without any unforeseen psychological or physiological change. It also appears that man's responses can be projected into the future to allow 30-day exposures in larger spacecraft. The predictions thus far have been valid. Our outlook to the future is extremely optimistic, and man has shown his capability to fulfill a role as a vital, functional part of the spacecraft as he explores the universe.

TABLE 25-IX.—*Radiation Dosage on Gemini Long-Duration Missions*

[In millirads]

Mission	Command pilot	Pilot
Gemini IV [a]	38.5 ± 4.5	42.5 ± 4.7
	40.0 ± 4.2	45.7 ± 4.6
	42.5 ± 4.5	42.5 ± 4.5
	45.0 ± 4.5	69.3 ± 3.8
Gemini V [a]	190 ± 19	140 ± 14
	173 ± 17.3	172 ± 17.2
	183 ± 18.3	186 ± 18.6
	195 ± 19.5	172 ± 17.2
Gemini VII [b]	178 ± 10	98.8 ± 10
	105 ± 10	215 ± 15
	163 ± 10	151 ± 10

[a] Values are listed in sequence: left chest, right chest, thigh, and helmet.

[b] Values are listed in sequence: left chest, right chest, and thigh.

26. DATA ANALYSIS AND REPORTING

By Scott H. Simpkinson, *Manager, Office of Test Operations, Gemini Program Office, NASA Manned Spacecraft Center;* Victor P. Neshyba, *Gemini Program Office, NASA Manned Spacecraft Center;* and J. Don St. Clair, *Gemini Program Office, NASA Manned Spacecraft Center*

Summary

The acquisition of vast quantities of data combined with a need to evaluate and quickly resolve mission anomalies has resulted in a new approach to data reduction and test evaluation. The methodology for selective reduction of data has proved effective and has allowed a departure from the traditional concept that all test data generated must be reduced. Real-time mission monitoring by evaluation engineers has resulted in a judicious selection of flight segments for which data need to be reduced. This monitoring, combined with the application of compression methods for the presentation of data, has made it possible to complete mission evaluations on a timely basis.

Introduction

Data reduction and flight test evaluation plans for the Gemini Program were conceived in 1963, and implementation began with the first unmanned qualification flight in April 1964. The objective of these plans was to insure swift but thorough mission evaluations, consistent with the schedule for Gemini flights.

Data Processing

The quantity of data to be made available during each Gemini flight had a significant effect on the planning for data reduction. Table 26–I shows the impossible data-reduction task on the spacecraft alone that confronted the data processors in the planning stage. Obviously, even if all of these data were reduced, the manpower and time could not be afforded to examine it. Gemini is not being flown to provide information on its system, but rather for studying the operational problems associated with space flight. However, the inevitable system problems that occur must be recognized and corrected. Overall system performance was stressed in the selection of parameters to be measured. This action, however, succeeded only in reducing the data acquisition to what is shown in table 26–I. In developing the overall Gemini data reduction and evaluation plans, two main questions had to be answered: (1) Where would the data be reduced? (2) How much of the orbital telemetry data could be processed effectively?

Table 26–I.—*Gemini Flight Data Production Rate*

Each second:	
Real time	51 200 bits
Delayed time	5120 bits
Each revolution:	
Delayed-time analog	2 000 000 data points
Delayed-time events	4 000 000 interrogations
Gemini V (8-day mission):	
Delayed-time analog	250 000 000 data points
Tabulations required	1 000 000 pages
Plots required	750 000 pages

A review was initiated to study the experience gained during Project Mercury and to determine the reduction capabilities that existed within the various Gemini organizations, or that would exist in the near future. The data reduction plan that emerged from this review was documented in a Gemini Data Reduction and Processing Plan. A summary of where the telemetry data were to be reduced is shown in table 26–II.

Recognizing that all data from the first, second, and third missions could be reduced and analyzed, it was decided to do just that and to develop the approach for data reduction and analyses for later missions from that experience. It rapidly became apparent that selective data reduction and analyses would be necessary. It was decided that key systems engineers from the appropriate organizations—such as the spacecraft contractor or his subcontractor, the

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target vehicle contractor, the Air Force, and NASA—should closely monitor the flight by using the real-time information facilities in the Mission Control Center at Houston and the facility at the Kennedy Space Center. This close monitoring of engineering data would permit the selection of only those segments of the mission data necessary to augment or to verify the real-time information for postflight evaluation. All the data for periods of high activity covering dynamic conditions such as launch, rendezvous, and reentry would be reduced and analyzed. Any further data reduction would be accomplished on an as-required basis. The outcome of these plans is shown in table 26–III. The percentage of flight data processed for postflight evaluation was substantially decreased after the first manned, three-orbit flight.

Reduction Operations

Even with the reduced percentage of flight data processed, the magnitude of the task cannot be discounted. Table 26–IV shows the data processing accomplished in support of the postflight evaluation of the 8-day Gemini V mission. More than 165 different data books were produced in support of the evaluation team. For this mission, the Central Metric Data file at the Manned Spacecraft Center received 4583 data items.

TABLE 26–II.—*Telemetry Data Processing Plan*

Mission	Computer-processed data			Kennedy Space Center
	Manned Spacecraft Center	McDonnell Aircraft Corp.	Air Force	
Gemini I	Backup, spacecraft	Prime, spacecraft	Launch vehicle	Quick-look oscillographs, spacecraft and launch vehicle
Gemini II	Prime, spacecraft	Backup, spacecraft	Launch vehicle	Quick-look oscillographs, spacecraft and launch vehicle
Gemini III through Gemini VII	Launch and orbit, spacecraft	Reentry, spacecraft	Launch vehicle	Quick-look computer plots: Launch Real-time, spacecraft Delayed-time, spacecraft (Cape Kennedy passes)

TABLE 26–III.—*Postflight Data Reduction for Mission Evaluation*

Mission	Data available	Data reduced
Gemini I	Launch plus 3 revolutions	All
Gemini II	Launch, flight and reentry	All
Gemini III	Launch, reentry, 3 revolutions	All
Gemini IV	Launch, reentry, 62 revolutions	Launch, reentry, 29 revolutions
Gemini V	Launch, reentry, 120 revolutions	Launch, reentry, 39 revolutions
Gemini VII	Launch, reentry, 206 revolutions	Launch, reentry, 41 revolutions, 14 station passes
Gemini VI–A	Launch, reentry, 16 revolutions	Launch, reentry, 9 revolutions, 3 station passes

Very few data reduction centers have grown as fast as the one at the Manned Spacecraft Center. Just 4 years ago this Center was only a field of grass, and, today, combining the Mission Control Center and the Computation and Analysis Division computer complexes, it houses one of the largest data processing and display capabilities in the world. Figure 26-1 shows a floor plan and some of the major devices employed for data processing in the Computation and Analysis Building.

It became very clear during the evaluation of the first three flights that it would be impossible to plot or tab all of the selected data from the longer duration flights. Computers can look at volumes of data in seconds, but they require many hours to print data in a usable form. Many more tedious hours are required to manually scan the data for meaningful information. Recognizing these facts, the data processing programs were revised to include compression methods of the presented data. These methods include presentation of the mean value over a specified time interval along with the maximum and minimum values during the interval or presentation of only data that go beyond a predetermined value of sigma. Also possible is the presentation of only the data falling outside a predetermined band having a variable mean as a function of time or as a function of other measured or predetermined values. Smoothing and wild-point editing may also be applied in a judicious manner. An example might be the presentation of all valid points of the fuel-cell voltage-current curve falling outside a predetermined band. This involves bus voltage multiplied by the sum of the stack currents in a section along a predetermined degradation curve for given values of total section current.

Systems evaluation during the flight for selection of requirements, combined with compression methods for data processing, made possible the processing of the mass of recorded data for support of the mission evaluation team on a schedule consistent with the Gemini Program requirements.

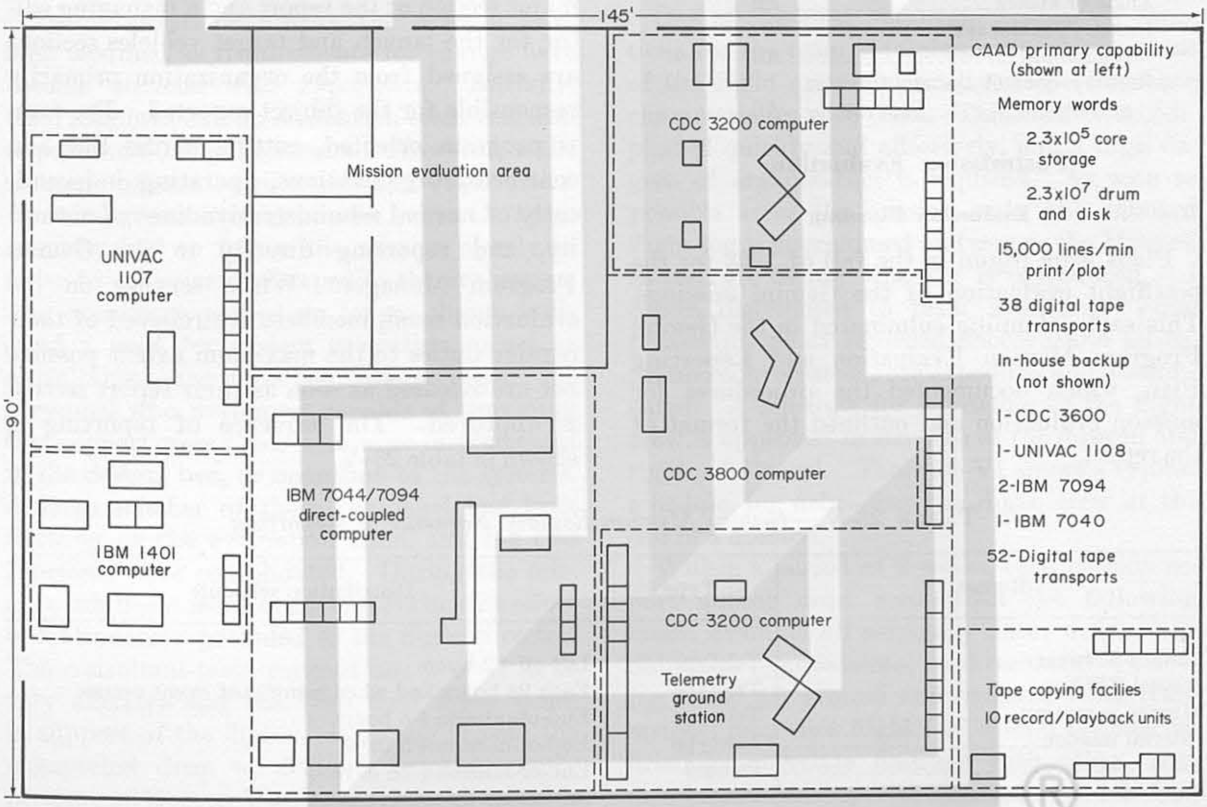


FIGURE 26-1.—Data reduction facilities of the Computation and Analysis Division.

TABLE 26-IV.—*Gemini V Reduction Task*

Telemetry tapes processed:	
Delayed-time data	55 tapes
Real-time data	16 tapes
Time edit analysis	129 tapes
Time history presentation:	
Plots (selected parameters)	14 revolutions
Tabulations (selected parameters)	15 revolutions
Statistical plots	15 revolutions
Statistical tabulations	30 revolutions
Event tabulations	30 revolutions
Ascent phase special computations:	
Computer word time correction	All
Aerodynamic parameters	All
Steering deviations	All
Angle of attack	All
Orbital phase special computations:	
Ampere-hour	24 revolutions
Orbital attitude and maneuver system propellant remaining	6 revolutions
Orbital attitude and maneuver system thruster activity	3 revolutions
Experiment MSC-1	90 minutes of flight
Coordinate transformation	20 minutes of flight
Reentry phase:	
Lift-to-drag ratio	All
Angle of attack	All
Reentry control system propellant remaining	All
Reentry control system thruster activity	All

Postmission Evaluation

Evaluation Planning

Plans were begun in the fall of 1963 for the postflight evaluation of the Gemini missions. This early planning culminated in the Gemini Program Mission Evaluation and Reporting Plan, which documented the procedures for mission evaluation and outlined the format of the report.

The most important consideration of these plans was to assure that evaluation was completed and a report generated for each mission in sufficient time to apply the knowledge gained to the next mission. Optimum use of personnel and time was required. It was obvious that the personnel responsible for the design, testing, and qualification of the vehicle and its systems, and those personnel responsible for conduct of the flight were the most knowledgeable and, therefore, the most logical personnel to accomplish the evaluation. It was decided to utilize these personnel rather than a separate evaluation organization. The most important criteria in the selection of team personnel were that they be intimately familiar with their subject or system and that they be cognizant of mission events that affected that subject or system.

The reporting organization shown in figure 26-2 consists of a management staff including a team manager, a chief editor, a deputy chief editor, an editorial staff, and a data support group. In addition, a senior editor for each major section of the report and a managing editor for the launch and target vehicles sections are assigned from the organization primarily responsible for the subject reported. The team is program oriented, cutting across line and contractor organizations, operating independently of normal administrative lines of authority, and reporting directly to the Gemini Program Manager. While serving on the evaluation team, members are relieved of their regular duties to the maximum extent possible but are released as soon as their report section is approved. The sequence of reporting is shown in table 26-V.

TABLE 26-V.—*Gemini Mission Reports, Sequence of Reporting*

Report	Type	Distribution schedule
Launch summary	Teletype	Lift-off+2 hours
Special TWX	Teletype	Each 24 hours and when significant event occurs
Mission summary	Teletype	End-of-mission+6 hours
Interim mission	Teletype	End-of-mission+5 days
Final mission	Printed	End-of-mission+35 days
Supplementary mission	Printed	As defined by mission report

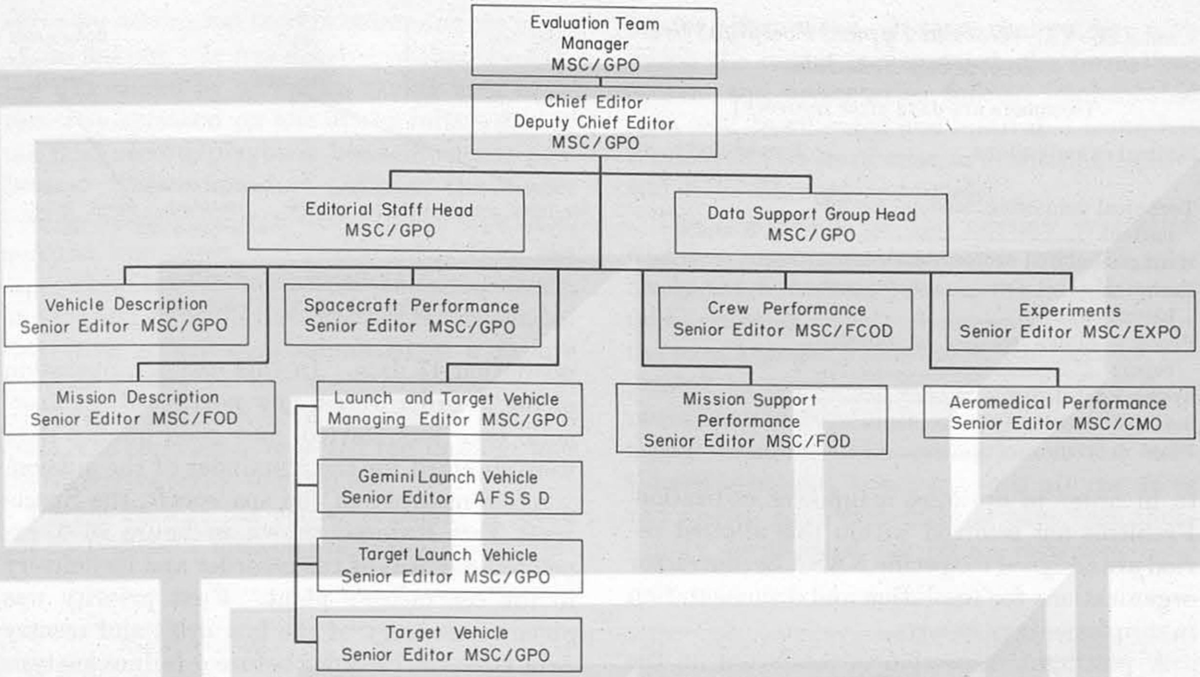


FIGURE 26–2.—Gemini Mission Evaluation Team organization.

Operations During the Mission

Team operations during the mission have been modified as requirements for change have become obvious with experience. Initially, team members had no evaluation-team function to perform during the mission. However, as the missions became more complex, a requirement for mission monitoring became evident. Team members had to follow the mission closely in order to optimize and expedite the evaluation. The experience gained on longer flights indicated a need for system specialists to act as consultants to the flight controllers. Again, the personnel who were most capable of providing this support were those who were instrumental in the design, test, or operation of the systems. A large number of these personnel had been working on the evaluation team, and the two functions were consolidated. During the mission, this flight monitoring and evaluation effort is continuously provided to the flight director. The consultant-team concept has proved to be very effective and has been used many times in support of the flights. Working around the unexpected drop in fuel-cell oxygen supply pressure on Gemini V and restoring the delayed-time telemetry recorder to operational status on the same flight are examples of this support.

Report Development During the Postmission Period

One of the most important evaluation functions for the team is to obtain the observations of the flight crew and to discuss performance characteristics with them. This must be accomplished quickly and effectively, and a high degree of organization is required. As soon as possible after the mission ends, the onboard flight log is microfilmed and sent to the Manned Spacecraft Center where it is reproduced and copies distributed to team members. Voice transcriptions of recorded onboard and air-to-ground conversations are expedited and disseminated. A schedule for debriefing of the flight crew is approved in advance of the mission and rigidly followed. Table 26–VI shows a typical schedule for debriefing the flight crew at the end of a mission.

Within a period of 2 weeks, each mission report author must accomplish the following tasks: examine all necessary data; define data reduction requirements; read technical debriefing; read air-ground and onboard voice transcripts; read crew flight log; attend systems debriefing; correlate findings with other team members; submit special test requests for failure analysis; and prepare report section. Evaluation cutoff dates are assigned and firmly adhered

TABLE 26-VI.—*Gemini Typical Postflight Crew Debriefing Schedule*

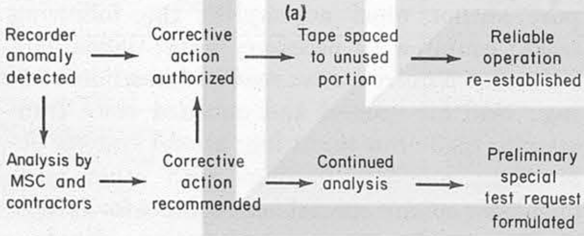
[Numbers are days after recovery]

Medical examinations	Immediately after recovery
Technical debriefing, medical examinations	1, 2, 3, and 4
Management and project debriefing	5
Technical debriefing, photograph identification	6
Prepare pilot's section of mission report	7
Systems debriefing	8
Scientific debriefing	9
Final debriefing	10

to in order to optimize manpower utilization. Problems not resolved within this allotted period are assigned to specific NASA or contractor organizations for resolution and documentation in supplementary reports.

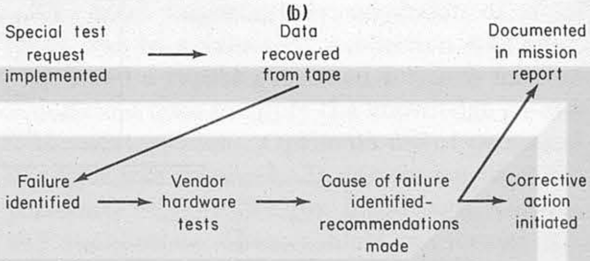
A postflight inspection is conducted on the spacecraft after each mission. This inspection is expanded as a result of special test requests generated during the mission evaluation. A representative of the evaluation team is assigned to insure that the postflight inspection and testing of each spacecraft are coordinated with the mission evaluation effort. This representative submits daily reports by teletype to the mission evaluation team.

The evaluation required to formulate and implement corrective action is begun at the earliest possible moment. Figure 26-3 shows a typical reaction to an inflight failure which occurred in the following manner. Starting with the telemetry tape dump during revolution 30, poor quality data were received by the worldwide network stations. As a result of mission evaluation team consultation with the spacecraft contractor, the tape recorder vendor, and the flight controllers, a decision was made to record data for both revolutions 46 and 47 and then dump only the



(*a*) Activities during mission.

FIGURE 26-3.—Gemini V PCM recorder anomaly check.

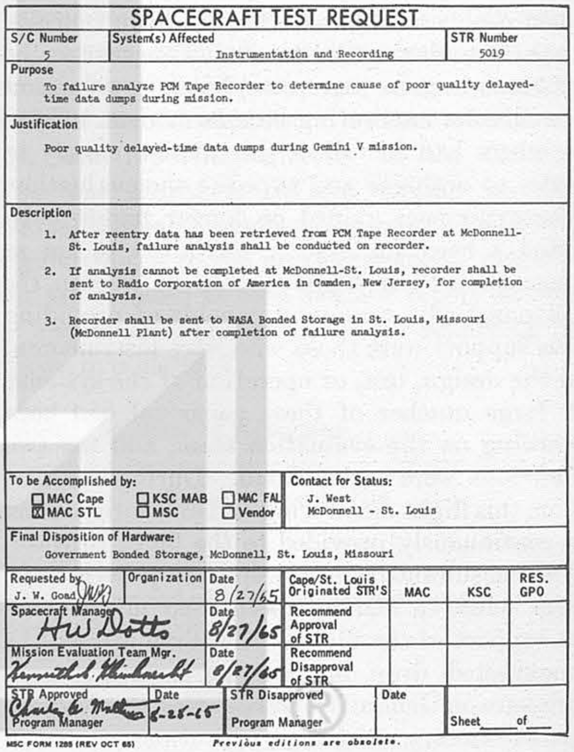


(*b*) Postflight activities.

FIGURE 26-3.—Concluded.

revolution 47 data. In this manner, operation of the recorder over a new portion of the magnetic tape was started, and good quality data were obtained for the remainder of the mission.

After recovery of the spacecraft, the Spacecraft Test Request, shown in figure 26-4, expedited removal of the recorder and its delivery to the contractor's plant. First priority was given to recovery of the last orbit and reentry data from the recorder before a failure analysis was begun. With a mission evaluation team member and personnel from the contractor, vendor, and resident quality assurance office in attendance, the recorder was opened, and the failure isolated to flaking of oxide from the tape. The recorder was then sent to the vendor's fa-



SPACECRAFT TEST REQUEST

S/C Number: 5 | System(s) Affected: Instrumentation and Recording | STR Number: 5019

Purpose
To failure analyze PCM Tape Recorder to determine cause of poor quality delayed-time data dumps during mission.

Justification
Poor quality delayed-time data dumps during Gemini V mission.

Description
1. After reentry data has been retrieved from PCM Tape Recorder at McDonnell-St. Louis, failure analysis shall be conducted on recorder.
2. If analysis cannot be completed at McDonnell-St. Louis, recorder shall be sent to Radio Corporation of America in Camden, New Jersey, for completion of analysis.
3. Recorder shall be sent to NASA Bonded Storage in St. Louis, Missouri (McDonnell Plant) after completion of failure analysis.

To be Accomplished by: ☐ MAC Cape ☒ MAC STL ☐ KSC MAB ☐ MSC ☐ MAC FAL ☐ Vendor

Contact for Status: J. West, McDonnell - St. Louis

Final Disposition of Hardware: Government Bonded Storage, McDonnell, St. Louis, Missouri

Requested by J. W. Goad	Organization	Date 8/27/65	Cape/St. Louis Originated STR'S	MAC	KSC	RES. GPO
Spacecraft Manager		Date 8/27/65	Recommend Approval of STR			
Mission Evaluation Team Mgr.		Date 8/27/65	Recommend Disapproval of STR			

STR Approved, Program Manager | Date 8-28-65 | STR Disapproved, Program Manager | Date | Sheet ___ of ___

MSC FORM 1288 (REV OCT 65) *Previous editions are obsolete.*

FIGURE 26-4.—Spacecraft Test Request form.

cility for additional tests to determine the cause of the flaking. It was discovered that the flaking was caused by an epoxy having been inadvertently splashed on one of the rollers during the final record/playback head-alinement procedure. This epoxy had softened the binder used to adhere the iron oxide to the tape base, and the iron oxide had peeled away from the tape. The vendor duplicated the failure mode, and the results of the tests and the recommended corrective action were submitted in a failure analysis report to the spacecraft contractor. As a reply to the NASA Spacecraft Test Request, the contractor reported the findings and the corrective action to be taken.

Figure 26–5 is the actual schedule of work for the Gemini V mission evaluation and is typical for all missions. Despite the rapidity with which the report is completed, the formalized content and presentation format, implemented by a well coordinated and motivated team, has resulted in a series of mission evaluation reports which are thorough and timely.

The completion of the mission evaluation within a time frame compatible with the relatively short interval between missions is a notable accomplishment. A concentrated effort by the most knowledgeable specialists has been expended to reveal all anomalies, to find their cause, and to formulate corrective action in a timely manner. The evaluation is not considered complete, however, until all the facts and figures from each mission have been thoroughly documented for future reference.

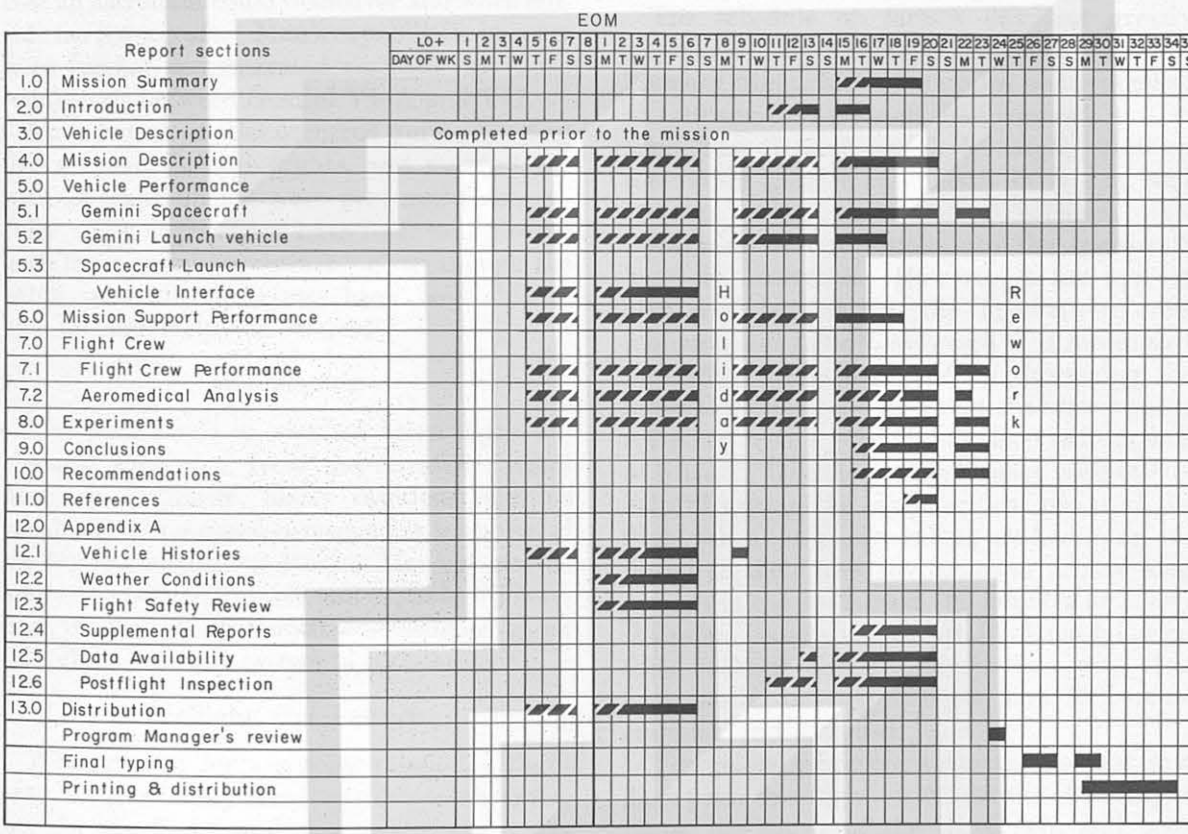


FIGURE 26–5.—Gemini mission reporting schedule.

27. ASTRONAUTS' REACTIONS TO FLIGHT

By Virgil I. Grissom, *Astronaut, Astronaut Office, NASA Manned Spacecraft Center;* James A. McDivitt, *Astronaut, Astronaut Office, NASA Manned Spacecraft Center;* L. Gordon Cooper, Jr., *Astronaut, Astronaut Office, NASA Manned Spacecraft Center;* Walter M. Schirra, *Astronaut, Astronaut Office, NASA Manned Spacecraft Center; and* Frank Borman, *Astronaut, Astronaut Office, NASA Manned Spacecraft Center*

Summary

The Gemini spacecraft was designed to make use of man's ability to function in the space environment. The extravehicular activity carried out during the Gemini IV flight demonstrated that an astronaut could maneuver and work outside his spacecraft. Man's capabilities in space were further demonstrated with the successful rendezvous between Gemini VI-A and VII.

Very few anomalies occurred during the first five manned Gemini flights, and most of the planned experiments were performed successfully. The flight crews have been well pleased with the Gemini spacecraft. Even though the cabin is small, the crews have been able to operate effectively and efficiently.

Introduction

The pilot's role in manned space flight has changed somewhat from the days of Project Mercury. Initially, man's reactions and his capabilities in a space environment were two of the big unknowns, but Project Mercury proved man to be both adaptable and capable. Therefore, the Gemini spacecraft was designed to use the pilot as the key system in its operation.

Preflight and Launch

When chosen for a specific mission, a flight crew is immediately faced with two tasks: training for the flight, and checkout of the spacecraft. The emphasis in these areas has changed from concentrating the major effort on spacecraft testing and checkout for the Gemini III mission to concentrating on training for the Gemini VI-A and VII missions. This was a natural evolution in that Gemini III was the first mission to use the new spacecraft for a manned flight, and the flight plan was designed to check out the spacecraft systems. The crews of the Gemini VI-A and VII spacecraft had high confidence in their vehicles through their association with previous missions, but they had difficult flights to accomplish since the emphasis was on operational mission requirements.

The schedule on launch day has greatly improved since the Mercury flights. For the Mercury flight, MR-4, the pilot was awakened at 1:10 a.m. and manned the spacecraft at 3:58 a.m. The Gemini launch is usually between the rather gentlemanly hours of 9 a.m. and 11 a.m. Also, the interval between crew awakening and insertion into the spacecraft has been shortened. However, it has not yet been possible to shorten the time between crew insertion and lift-off, although it is recognized that efficiency is increased by shortening the interval between the time that the crew awakes refreshed from a good night's sleep and the time of lift-off. This increased efficiency is especially helpful during the early, critical phase of the flight when the crewmembers are becoming adjusted to their new environment. After long periods in the spacecraft (90 minutes or more) the pilots become uncomfortable from lying on their backs in the Gemini ejection seat. The back, neck, and leg muscles tend to become cramped and fatigued.

The pilots concentrate during the last few days prior to a flight on the details of the flight plans, the status of the spacecraft, and both normal and emergency operational procedures. During this period, the backup crew and the flight-crew director endeavor to keep the crew from being disturbed by anything not connected with the operation of the mission.

Some experiments do place heavy burdens on the crew at this time, and an attempt should be made to avoid adding to the crew's workload during this period. A typical example of one of the heavy prelaunch activities was the preparation for the medical experiment M–7 by the Gemini VII flight crew. The preparation involved a rigid diet, complete collection of all body wastes, and two controlled distilled-water baths each day. The diet went well; the food was well prepared and tasty; however, the collection of body wastes was difficult to integrate with other activities, because the waste could only be collected at the places most frequented by the flight crew, such as the launch complex, the simulator, and the crew quarters. Fortunately, the fine cooperation of the M–7 experimenters resulted in a minimum number of problems.

Even though some of the flight crews, especially the Gemini V crew, had a comparatively limited time to prepare for their missions, they were well trained in all phases and were ready to fly on launch day.

During the prelaunch period, the backup crew is used extensively in the checkout of the spacecraft, and, at the same time, this crew must prepare to fly the mission. But their prime responsibility, by far, is spacecraft testing and monitoring.

Powered Flight

All flight crews have reported lift-off as being very smooth. The Gemini VI–A crew indicated that they could tell the exact moment of lift-off by the change in engine noise and vibration, and all crews agree that vertical motion is readily apparent within seconds of lift-off. Even without clouds as a reference, it is easy to determine when the launch-vehicle roll program starts and ends.

The noise level is quite low at lift-off, increasing in intensity until sonic speed is reached. At that time, it becomes very quiet and remains quiet throughout the remainder of powered flight.

With one exception, the launch has been free from any objectionable vibration. On the Gemini V flight, longitudinal oscillations, or POGO, were encountered. The crew indicated that the vibration level was severe enough to interfere with their ability to read the instrument panel. However, POGO lasted only a few seconds and occurred at a noncritical time.

The second stage of the launch vehicle ignites prior to separation from the first stage. This causes the flame pattern to be deflected and apparently to engulf the second stage and the spacecraft. The crew of Gemini VI–A indicated that the flame left a residue on the exterior of the window, and every crew has reported a thin film on the outside of the window. The pilot of Gemini VI–A noted that a string of cumulus clouds was very white and clear prior to staging and that the clouds were less white and clear afterward, indicating that the port window obscuration could have occurred during staging.

The horizon is in full view during second-stage flight while the radio guidance system is guiding the launch vehicle. Each correction that the guidance system initiates can be readily observed by the crew. It would appear that, given proper displays and an automatic velocity cutoff, the crew could control the launch vehicle into a satisfactory orbit.

Second-stage engine cutoff is a crisp event. The g-level suddenly drops from approximately 7 to zero, and in no case has any tail-off been felt by the crews.

The powered-flight phase has been closely duplicated on the dynamic crew procedures simulator trainer at the Manned Spacecraft Center. After the first flight, the vibration level and the sounds were changed to correspond with what the pilots actually heard during launch. The simulation has such fidelity that there should be no surprises for the crew during any portion of powered flight.

Orbit Insertion

The insertion into orbit has been nominal for every flight. The separation and turnaround of the spacecraft and the operation of the onboard computer have been as planned.

At spacecraft separation and during turnaround, there is quite a bit of debris floating all around the spacecraft. Some of these small pieces stay in the vicinity for several minutes.

During insertion, the aft-firing thrusters cannot be heard, but the acceleration can be felt. The firing of the attitude and translation thrusters can be heard, and the movement of the spacecraft is readily apparent.

System Operation

Inflight Maneuvering

The flight crews have found the pulse-control mode to be excellent for fine tracking, and the fuel consumption to be negligible. The direct mode was needed and was most effective when large, rapid attitude changes were required. However, the use of the direct and also the rate-command mode is avoided whenever possible because of the high rate of fuel consumption. Rate command is a very strong mode, and it is relatively easy to command at any desired rate up to full authority. It is the recommended mode for the critical tasks, such as retrofire and translation burns, that are beyond the capability of the platform mode.

The platform mode is a tight attitude-hold control mode. It has the capability of holding only two indicated attitudes on the ball display—zero degrees yaw and roll, and zero or 180 degrees pitch. But the platform mode can be caged and the spacecraft pointed in any direction and then the platform released. This gives an infinite number of attitudes. It is the recommended mode for platform alinement and for retrograde or posigrade translation burns. The horizon-scan mode is a pilot-relief mode and is used when a specific control or tracking task is not required. It is better than drifting flight because it controls the spacecraft through a wide dead band in pitch and roll, although it has no control of yaw. Drifting flight is perfectly acceptable for long periods of time, as long as the tumbling rates do not become excessive (5° per second or more). Spacecraft control with the reentry control system is very similar to that of the orbital attitude and maneuver system. Slightly more authority is available with the orbital attitude and maneuver system than with both rings of the reentry control system. This results in some tendency to overcontrol and waste fuel. Actually the one-ring reentry control system operation is satisfactory for most tasks. All pilots used both rings for retrofire, but some used only one ring for reentry. The reentry rate-command mode has not been used by any crew except that of Gemini IV. The automatic reentry mode also has not been employed.

Two orbital maneuvers during the flight of Gemini VII were accomplished in a spacecraft powered-down configuration. This means they were without the platform, the computer, and the rate needles. The yaw attitude was established by using a star reference obtained from ground updates and the celestial chart. Roll-and-pitch attitudes were maintained with respect to the horizon, which was visible to the night-adjusted eye. The pilot made the burns, maintaining attitude on the star with attitude control and rate command, while the command pilot timed the burn. No unusual difficulty was encountered when performing the no-platform maneuvers, and the crew considered this procedure acceptable.

For this long-duration flight, it was found desirable to adhere to the same work-rest cycle that the crew was used to on the ground. To support this schedule, both crewmembers slept simultaneously, except during the first night. The ground was instructed not to communicate except for an emergency.

The Gemini IV mission was a good test of the life-support systems for extravehicular activity. Preparations for extravehicular activity started during the first revolution and continued into the second. Extravehicular activity demonstrated that man can work in a pressurized suit outside the spacecraft and can use a maneuvering unit to move from one point to another. The maneuvering unit used short bursts of pulse mode. During extravehicular activity, the pilot used the spacecraft as a visual, three-dimension orientation reference. At no time did the pilot experience disorientation. The pilot made general observations and investigated tether dynamics. Control with the tether was marginal, but it was easy to return to the hatch area using the tether. When the pilot pushed away, the spacecraft pitched down at rates of 2° per second from the resultant force, and the pilot moved perpendicular to the surface of the spacecraft. It was difficult to push away from the surface of the spacecraft at an angle. After the pilot had reentered the spacecraft, the hatch was to be closed, but the latch handle malfunctioned. However, the pilot had been trained thoroughly in both the normal and failure modes of the hatch and was able to close it successfully.

Life-Support Systems

The bite-size foods for the crews were not as appetizing as had been expected. The rehydratable foods were good and were preferred to the bite-size foods. Preparing and consuming the meal takes time and must be done with care. The food is vacuum-packed to eliminate any waste volume, but this capability does not exist when the crew is trying to restow the empty food bags. Thus, they have a restowage problem. Most of the food is in a semiliquid form, and any that remains in the food bags is a potential source of free moisture in the cabin. The water has been good and cold. Even so, there seems to be a tendency to forget to drink regularly and in sufficient quantities.

On the first long-duration mission, the crewmen had a difficult time sleeping when scheduled. The spacecraft is so quiet that any activity disturbed the sleeping crewman. For the later missions, the crewmembers slept simultaneously, when it was possible.

Defecation is performed carefully and slowly; the whole procedure is difficult and time consuming, but possible. A major problem for long-duration flights was the storage of waste material. It was normally stowed in the aluminum container which held the food. It was necessary that a thorough housekeeping and stowage job be done every day. Otherwise, the spacecraft would have become so cluttered that it would have been difficult for the crewmen to find anything.

The Gemini VII crewmen wore the G5C space suit, which is 8 to 10 pounds lighter than the normal suit. This suit contains no bumper material and has only two layers of nylon and rubber. The G5C space suit includes a zipper-type hood, which is designed to be worn over an ordinary pilot helmet.

For the Gemini VII mission, fully suited operations were conducted during launch, rendezvous, and reentry. When the hoods were on, there was considerable noise in the intercom system because of the airflow in the hood. Visibility while wearing the hood was acceptable during orbital flight, but during reentry vision was somewhat obscured and the command pilot removed his hood. When fully suited, the crew found it difficult to see the night horizon and to observe and operate switches in the overhead and water-management panels. In the partially suited configuration, which was maintained for approximately 2 days, there was a loss in suit cooling efficiency, and some body areas did not receive sufficient cooling. Intercommunication was improved with the hoods off, but mobility was restricted because of the hood being on the back of the head. On the second day, the pilot removed his suit, and his comfort was definitely improved. Ventilation was adequate, and the skin was kept dry. In the suit-off configuration, there was increased mobility. It was easier to exercise, unstow equipment, and perform other operations. It took approximately 20 minutes to remove the suit, including the time required to place the plugs in the suit openings in case emergency donning was required. During the sixth day of the mission, both pilots had their suits off. One apparent improvement was that all crews on the long-duration flights felt a need to exercise. Even though exercise periods were scheduled regularly, most crews requested more frequent and longer periods of exercise.

System Management

One of the crew's prime functions is to monitor and control the spacecraft's various systems. This requires a thorough knowledge of the details of each system, as well as how to operate the system in any failure mode. It is true that the ground complex has much more information concerning the operation of systems than the crew does, and they have a staff of experts for each system. But, unfortunately, the crew is in contact with the ground stations for only a small percentage of the flight. The crew must be prepared to rapidly analyze problems and make the correct decisions in order to complete the mission safely. Every flight has had an example of this. Gemini III had the dc-dc converter failure and suspected fuel leak; Gemini IV experienced a computer memory alteration; and Gemini V experienced fuel-cell oxygen-supply degradation while performing the rendezvous evaluation pod experiment. Gemini VI-A probably had the most difficult problem of all. The shutdown on the pad occurred in a manner that it had not considered during training. Gemini VII had flight control and fuel-cell problems. These are the times that it pays to have a well-trained crew onboard.

Visual Sightings

The Gemini III crew were surprised at the flame that appeared around the spacecraft during staging. During the remainder of the flight, the Gemini III crew observed thruster firings, Northern and Southern Hemisphere constellations, and the town of Mexicali, Mexico.

The Gemini IV crew were impressed at the clarity with which objects could be seen from directly overhead. Roads, canals, oil tanks, boat wakes, and airfields could be seen. The moon was a bright light; however, the stars close to it as well as the stars of the seventh magnitude could be seen. When the spacecraft passed from darkness into light, the airglow was clearly observed, and the planets seemed to increase in brightness. Meteors could be seen as they burned in the earth's atmosphere below the orbital flight path.

The Gemini VI–A crew made some very accurate visual sightings which have been reported in the presentation of the rendezvous.

The Gemini VII crew tracked their launch vehicle during the station-keeping exercise by using the acquisition lights on the launch vehicle, but they could not estimate the range. The spacecraft docking lights were turned on, but they did not illuminate the launch vehicle. As the time approached for rendezvous, spacecraft 6, at a range of approximately 2 to 3 miles, appeared to the Gemini VII flight crew like a point of reflected light against the dark earth background just before sunset. At approximately 0.5-mile range, thruster firings could be seen as thin streams of light shooting out from the spacecraft.

All crews reported that accurately tracking an object on the ground is an easy task. The difficult part is identifying and acquiring the target initially. It requires that the ground transmit accurate acquisition times and pointing angles. Also, a careful preflight study of maps and aerial photographs aids in early identification.

Experiments

Experiments and their results are covered in other papers. But, the point should be made here that, for the crew to successfully complete any experiment, they must have a thorough understanding of what the experimenter is attempting to do. And, even more important, they must have equipment available at an early date to use in their training. One of the biggest problems is getting the actual flight equipment to work well in its environment. A ground rule has been established that all flight gear, experimental and operational, must be available and in the spacecraft for the altitude chamber test.

Retrofire and Reentry

During the Gemini III mission, a reentry control system plume-observation test was conducted. Because the reentry control system yaw thrusters obstruct the view of the horizon at night, a nightside retrofire would be impossible when using the horizon or stars as a reference. When the retroadapter was jettisoned, there was an audible noise. Jettisoning could be felt, and there was debris around the spacecraft. During reentry the spacecraft was stable, and there were no difficulties in damping out the oscillations.

During the Gemini IV reentry, the rate-command system provided excellent control, and the attitudes were held within ±1 degree. The reentry rate command with the roll gyro turned off was used so that the hand controller did not have to be held deflected in roll for the entire reentry. The spacecraft rolled about its longitudinal axis at the beginning of reentry, and, after aerodynamics started to take effect, the spacecraft rolled about its trim axis and reentered in a wide spiral.

The Gemini V crew performed retrofire during the middle of the night, using the attitude ball as a reference. At retrofire, the outside appeared to be a fireball. The command pilot reported that it felt as though the spacecraft were going back west, and the pilot reported that he felt that he was going into an inside loop.

The Gemini VI–A crew also performed their retrofire at night and did not see the horizon until just before the 400 000-foot-altitude point because of losing their night visual adaptation.

The Gemini VII crew had communications problems during retrofire, since the vented air noise in the helmets hindered good communications. During reentry, the command pilot had to remove his hood because it interfered with his vision of the horizon.

Landing and Reentry

The drogue parachute is normally deployed at 50 000 feet to stabilize the spacecraft prior to main parachute deployment. After deployment, the spacecraft appears to oscillate about 20° to 30° on each side. The onboard recordings indicated that these oscillations have never exceeded ±10°.

Main-parachute deployments take place in full view of the crew, and it is quite a beautiful and reassuring sight. Up to this point, all events have been quite smooth, with all loads being cushioned through line stretching and reefing. But, changing from the single-point attitude to the landing attitude causes quite a whip to the crew. After the Gemini III flight, all crews have been prepared, and there have been no problems.

The impact of landing has varied from a very soft impact to a heavy shock. The amount of spacecraft swing, and at what point during the swing the landing occurs, changes the landing loads. The amount of wind drift, the size of the waves, and the part of the wave contacted also vary the load. Even the hardest of the landings has not affected crew performance.

Concluding Remarks

In conclusion, the flight crews have been well pleased with the Gemini spacecraft. Even though the cabin volume is very limited, they have been able to operate effectively and efficiently.

28. GEMINI VI–A RENDEZVOUS MISSION PLANNING

By Edgar C. Lineberry, *Mission Planning Analysis Division, NASA Manned Spacecraft Center*

Summary

This paper discusses the mission planning effort for the Gemini VI–A mission which applied directly to rendezvous. Included are a discussion of the basic design criteria and a brief history of the considerations which led to the selection of the particular Gemini VI–A mission plan. A comparison between the nominal and actual flight trajectories is also presented.

Introduction

The basic Gemini VI–A mission design criteria were, in effect, quite simple. Consideration was given almost exclusively to the development of a plan which would provide the highest probability of mission success. The desire was to develop a plan which could routinely depart from the nominal in response both to trajectory dispersions and to spacecraft systems degradation, while minimizing dispersed conditions going into the terminal phase of rendezvous. More specifically, the plan would provide flexibility without introducing undue complexity; that is, the flight controllers would have the capability, in the event of dispersed conditions, to select alternate maneuver sequences that would not be dissimilar to the basic maneuver sequence.

Selection of the Basic Mission Plan

Prior to the selection of the Gemini VI–A mission plan, three significantly different plans (fig. 28–1) were analyzed to the extent necessary to permit a realistic choice consistent with the desired flexibility criteria. The first of these was the tangential mission plan. The salient feature of this plan was a final tangential approach to the target vehicle, preceded by several orbits during which midcourse maneuvers would be commanded from the ground. The last maneuver in the ground-controlled sequence would be designed to place the spacecraft on an intercept trajectory. The onboard system would be utilized to correct this final trajectory to effect rendezvous. The second plan investigated the coelliptic plan, utilized the same midcourse-maneuver sequence as the tangential plan, except that the final maneuver in the ground-controlled sequence would be designed to place the spacecraft in an orbit with a constant differential altitude below the target orbit. The onboard system in this plan would be utilized to establish an intercept trajectory departing from the coelliptic orbit. The third plan which was investigated incorporated a rendezvous at the first spacecraft apogee. In effect, a nominal insertion would place the spacecraft on

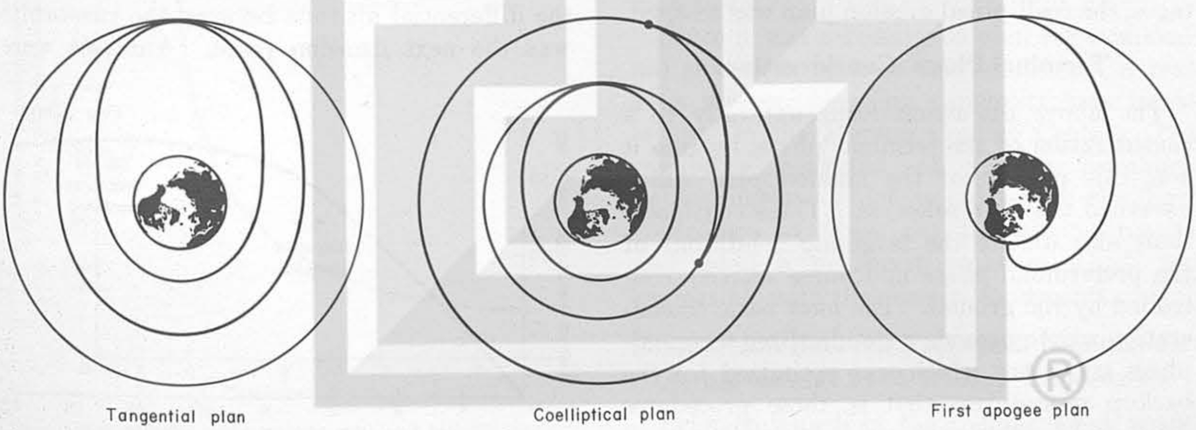


Figure 28–1.—Rendezvous mission plan development.

an intercept trajectory, and the onboard system would be utilized to correct for dispersed conditions, thereby placing the spacecraft on a final intercept trajectory.

As can be seen, two of these three plans incorporated a parking-orbit mode of operation prior to the establishment of a final intercept trajectory, whereas the third plan incorporated a direct intercept mode. Based upon various analyses conducted for the plans, a recommendation was made to adopt the coelliptical mission plan. Two major considerations, as well as a number of lesser ones, influenced this recommendation.

First of all, the mission plan for rendezvous at first apogee was eliminated as a contender, as compared with the other plans, for the Gemini VI–A mission because of its increased spacecraft propellant requirements for reasonable trajectory dispersions. Secondly, the terminal-phase initiation conditions of the coelliptical plan afforded a certain advantage over the tangential plan. Without going into detail, the basic desired feature of the coelliptical plan is that the relative terminal-phase trajectory of the spacecraft with respect to the target is not particularly affected by reasonable dispersions in the midcourse maneuvers. On the other hand, it is grossly affected when initiating from the tangential approach. More simply stated, the coelliptical approach affords a standardized terminal-phase trajectory, yielding obvious benefits in the establishment of flight-crew procedures and training. Another benefit derived from this plan is that the rendezvous location can be controlled to provide the desired lighting conditions. As a consequence of these advantages, the coelliptical mission plan was selected.

Terminal-Phase Considerations

The above discussion leads naturally to a consideration of the terminal phase, because it was this portion of the mission plan which governed the plan selection. These considerations also dictate the targeting conditions of the preterminal-phase midcourse activity controlled by the ground. The most basic consideration was to provide a standardized terminal-phase trajectory which was optimized for the backup procedures—that is, those procedures developed for use in the event of critical systems failure. It was possible to optimize the trajectory for the backup procedures with no degradation of the primary inertial-guidance-system closed-loop rendezvous-guidance technique.

Since it is possible to select any particular transfer trajectory to serve as a standard, extensive analyses were performed to provide a transfer trajectory with certain desired characteristics. It was desired, first of all, that the transfer initiation maneuver for a nominal coelliptical trajectory be alined along the line of sight to the target. This procedure has the obvious advantage of providing the crew with an excellent attitude reference for this critical maneuver, should it be needed. The second characteristic desired in the transfer trajectory was a compatibility between the closed-loop guidance mode and the final steering and braking performed manually by the flight crew. Based upon the transfer initiation criteria, the desired feature in the resultant trajectory would be a situation in which the nominal trajectory would create low inertial line-of-sight rates during the time period prior to and including braking. Such a trajectory would be consistent with the steering technique utilized by the flight crew to null the line-of-sight rate to zero. The analyses resulted in a choice of 130° orbital travel of the target vehicle between the terminal-phase initiation and braking. As can be seen in figure 28–2, the 130° transfer trajectory not only satisfies the second desired characteristic, but also fulfills a third desired condition, in that the approach of the spacecraft, relative to the target, is from below, thus assuring a star background which could be utilized as an inertial reference.

After the selection of the transfer trajectory, the differential altitude between the two orbits was the next decision point. Analyses were

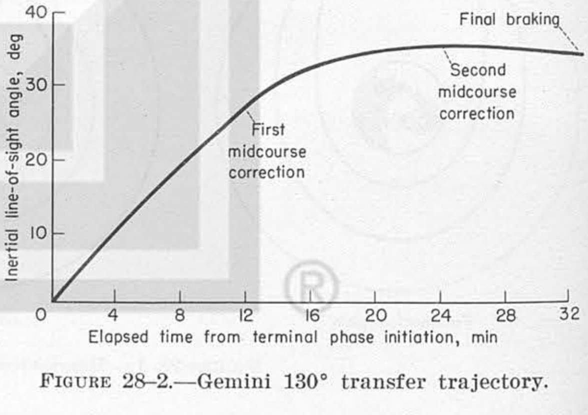


FIGURE 28–2.—Gemini 130° transfer trajectory.

carried out and resulted in a decision to utilize a 15-nautical-mile differential altitude between the orbits of the two vehicles. This choice resulted from a trade-off between a desire to be close enough to insure visual acquisition of the target prior to terminal-phase initiation, and a desire to minimize the influence of dispersions in the previous midcourse maneuvers on the desired location of terminal-phase initiation. Figure 28–3 shows that the effect of dispersions on the terminal-phase initiation time increases as the differential altitude is decreased. For the selected differential altitude of 15 nautical miles, the 3-sigma dispersion of the timing of the terminal-phase initiation maneuver is on the order of ±8 minutes. Factors governing the choice of the desired lighting condition for terminal-phase initiation cannot be considered here; however, the decision was made for the nominal initiation time to be 1 minute into spacecraft darkness. This condition and the selected differential altitude of 15 nautical miles established the targeting conditions for the ground-controlled maneuvers at the time of the coelliptical maneuver.

Ground-Control Midcourse-Phase Considerations

As previously noted, the intention was to provide a plan as insensitive to dispersions and spacecraft systems degradation as possible. This led to the provision of three spacecraft

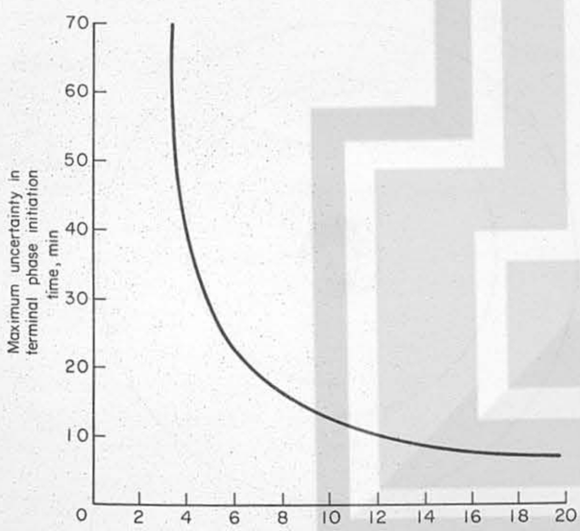


FIGURE 28–3.—Terminal phase maneuver time dispersion analysis.

revolutions in the nominal plan, with preestablished maneuver points to compensate for any of the dispersions likely to occur either in target altitude and ellipticity or in spacecraft insertion. Emphasis was given to minimizing the demands of this phase of the mission on the spacecraft propulsion system. Because the propulsion requirements for the terminal rendezvous phase could increase significantly from degraded systems performance, it was imperative that the maximum amount of spacecraft propulsion capability exist at the time those activities were initiated. These decisions were reflected in the following mission plan characteristics:

(1) Maneuvers were carried out with the Gemini VII spacecraft to provide the best possible launch opportunities and optimum orbital conditions for rendezvous.

(2) The Gemini launch vehicle was targeted to provide a differential altitude of 15 nautical miles between the two orbits at first spacecraft apogee. The launch vehicle was targeted also to launch the spacecraft into the target plane; that is, launch-vehicle guidance was utilized to fly a dog-leg launch trajectory in order to minimize spacecraft propulsion requirements in orbit for making a plane change.

(3) During the first orbit the flight crew were left free of rendezvous activity. This period of time was used for spacecraft systems checks. It was also used by the Mission Control Center—Houston to determine the precise spacecraft 6 orbit.

(4) Ground tracking, computation and display, and command capability were provided to carry out the ground-controlled midcourse maneuvers.

Since it was necessary to plan for nonnominal situations such as delayed lift-off, a real-time mission planning capability was implemented in the Mission Control Center. This capability consisted of various computer-driven displays which would permit the flight controllers to assess any particular situation and select a maneuver sequence which was compatible with the mission constraints.

Comparison Between Prelaunch Nominal and Actual Gemini VI–A Mission Trajectories

Prior to launch of the Gemini VI–A spacecraft, the maneuver plan selected consisted of two nonzero maneuvers: (1) A phase-adjustment maneuver to be performed at the second spacecraft apogee to raise the perigee to approximately 117 nautical miles; and (2) the coelliptical maneuver to be made at the third spacecraft apogee. However, in order to account for insertion dispersions, two additional maneuver points were established: (1) a height-adjustment maneuver to be made at first spacecraft perigee following first apogee; and (2) a plane-change maneuver to be performed at a common node following the phase-adjustment maneuver. Since the launch vehicle was targeted to achieve the correct differential altitude and plane location, these two maneuvers were nominally zero.

Ground network tracking during the first orbit revealed an underspeed condition at insertion, as well as a small out-of-plane condition. This can be seen in figure 28–4. Whereas the targeted condition for first apogee was a differential altitude of 15 nautical miles, the actual value which resulted was approximately 23 nautical miles. Consequently, the height-adjustment maneuver at first perigee (fig. 28–5) was 14 feet per second. The additional refinement of the spacecraft orbit following the height-adjustment maneuver indicated that a second height adjustment would be required, and the maneuver sequence was altered to include this adjustment at the second spacecraft perigee. The phase-adjustment maneuver to be performed at second spacecraft apogee was adjusted accordingly (fig. 28–6). Because of the underspeed condition at insertion, the Gemini VI–A spacecraft was actually catching up too fast; therefore, during the phase-adjustment maneuver at second apogee, the prelaunch nominal value of 53 feet per second was changed to 61 feet per second. This maneuver adjusted the catchup rate to establish the correct phasing condition at the time of the coelliptical maneuver.

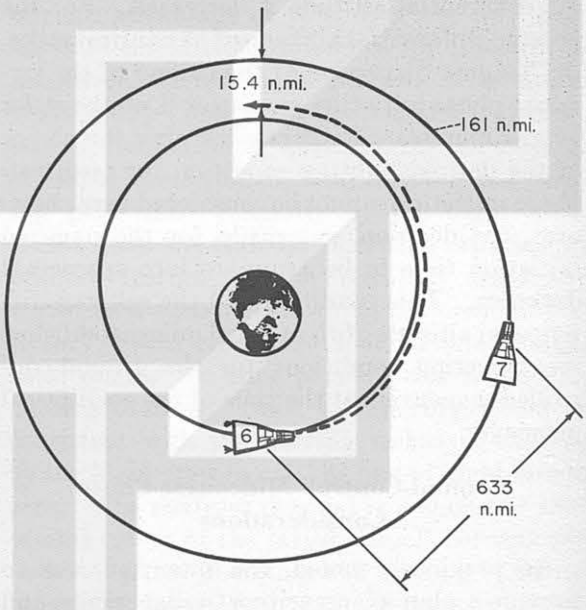


FIGURE 28–5.—Gemini VI–A first adjustment.

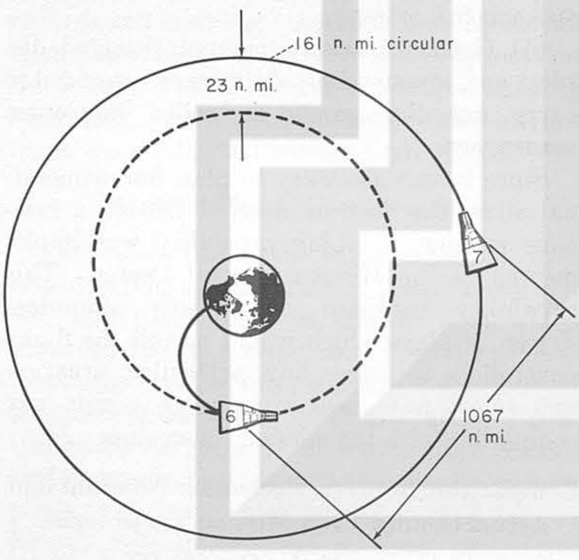


FIGURE 28–4.—Gemini VI–A insertion.

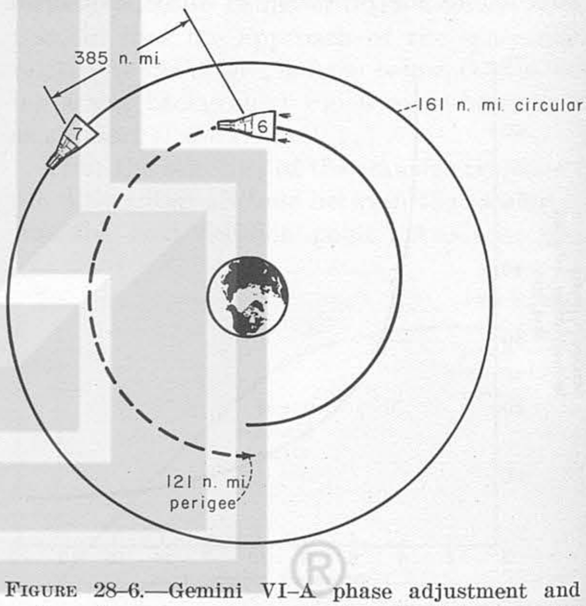


FIGURE 28–6.—Gemini VI–A phase adjustment and plane change maneuvers (common node) at second apogee.

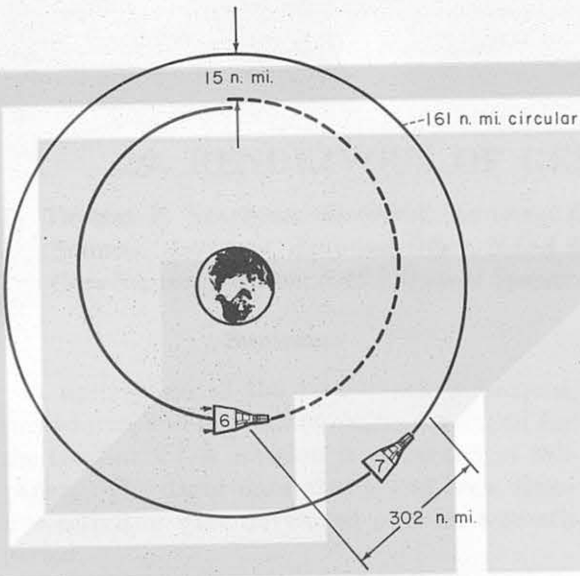


FIGURE 28–7.—Gemini VI–A second height adjustment maneuver at second perigee.

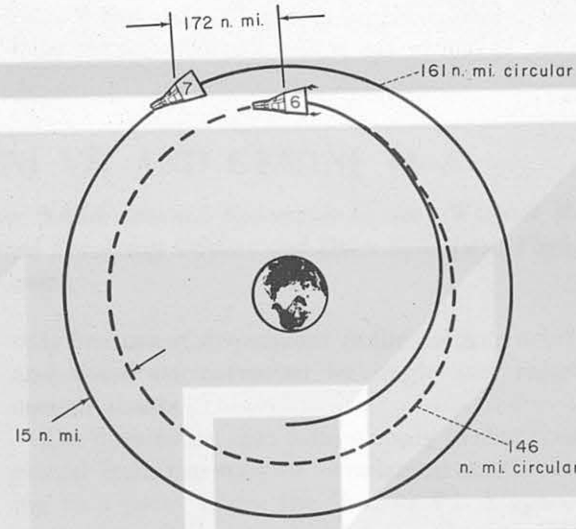


FIGURE 28–8.—Gemini VI–A coelliptical maneuver at third apogee.

Following the phase-adjustment maneuver, a plane change of 34 feet per second was performed to place the Gemini VI–A spacecraft in the plane of the Gemini VII spacecraft. At the next spacecraft perigee, the second height-adjustment maneuver of 0.8 foot per second was performed to correctly adjust the differential altitude to 15 nautical miles (fig. 28–7). At the third spacecraft apogee, a coelliptical maneuver of 43 feet per second was performed (fig. 28–8). Following this maneuver, radar tracking indicated a downrange-position error of approximately 2 miles at the time of the coelliptical maneuver, so that the actual downrange displacement was approximately 172 nautical miles, compared with the desired value of 170 nautical miles. The result, as determined on the ground, was a predicted slip of approximately 2 minutes in the terminal-phase-initiation maneuver. This information, as well as a ground-computed terminal-phase-initiation maneuver, was passed to the flight crew to serve as a comparative value with onboard computations.

Concluding Remarks

The discussion dealing primarily with the terminal-phase portion of the mission will be discussed in the following paper. The Gemini VI–A mission-planning effort resulted in the successful rendezvous with the Gemini VII spacecraft.

29. RENDEZVOUS OF GEMINI VII AND GEMINI VI–A

By Thomas P. Stafford, *Astronaut, Astronaut Office, NASA Manned Spacecraft Center;* Walter M. Schirra, *Astronaut, Astronaut Office, NASA Manned Spacecraft Center; and* Dean F. Grimm, *Flight Crew Support Division, NASA Manned Spacecraft Center*

Summary

A description of the rendezvous techniques, procedures, and flight data charts developed for the Gemini VI–A mission is presented in this paper. The flight data charts and crew timeline activities were developed over an 8-month period.

Successful rendezvous is critically dependent on the presentation to the flight crew of sufficient information developed onboard the spacecraft. The Gemini VI–A flight crew used this information to evaluate the rendezvous progress by several different methods and made critical decisions based on their evaluation. The system combination found most effective in making these evaluations was the range-rate data from the radar, and the angle data from the platform.

Introduction

The Gemini spacecraft was designed to use four subsystems in determining the rendezvous maneuver and presenting information to the crew. These subsystems are the radar, computer, platform, and cockpit displays. In all cases, the crew has independent operational control over each system and performs the function of selecting how these systems will be integrated.

The Gemini VI–A rendezvous flight plan was based on the use of flight data displayed to the crew in a manner to allow monitoring and backup for each spacecraft maneuver. The philosophy of maximum manual backup capability begins with the mission profile in which a coelliptical spacecraft-catchup orbit is employed prior to initiation of rendezvous. This permits use of a standard transfer change in velocity (ΔV) in both magnitude and direction, with the time of initiation determined by the elevation angle of the target line of sight above the local horizontal. Thus, the transfer maneuver varies only because of dispersions in the catchup orbit, and these are corrected by angle and range measurements.

The discussions that follow apply to that time period from the start of circularization thrusting to a point where the Gemini VI–A spacecraft was within 100 feet of the Gemini VII spacecraft, and had no attitude rates and less than 0.5-foot-per-second relative velocity in all translational axes (station keeping). Although the closed-loop guidance technique is considered the primary method to accomplish rendezvous, backup guidance techniques were developed to assure rendezvous in the event of equipment failures. Accordingly, the procedures are presented for both the closed-loop guidance technique and the backup guidance techniques required in the event of radar, computer, or platform failure. In addition, flight data charts were developed specifically for the Gemini VI–A mission. These charts provide a means for determining the proper transfer maneuver and midcourse corrections, for monitoring the performance of closed-loop guidance, and for the calculation of the required backup maneuvers in the event of equipment malfunctions or failures.

Optical tracking of the target is a mandatory requirement in case a radar or platform failure is encountered. Thus the day-night cycle becomes an increasingly important parameter for the rendezvous mission. Lighting conditions for the terminal-phase maneuver were investigated after the coelliptical mission plan, involving a 130° transfer trajectory, was developed. At an altitude of 161 nautical miles, the target is in daylight for 55 minutes and in darkness for 36 minutes. The lighting conditions, displayed in figure 29–1, are planned so that the crew can track the target by reflected sunlight just prior to transfer to obtain data for the transfer maneuver. During the transfer maneuver and all subsequent maneuvers, the crew tracks the target's artificial lighting with respect to the stars for inertial angular measurement or uses platform angles when the optical sight is boresighted on the target. The braking maneuver occurs just as the target becomes lighted at sunrise. Thus it can be seen that the rendezvous initiation is normally planned to occur at 1 minute after sunset and the braking maneuver to occur at a range of 3000 feet when the target is starting to be illuminated by sunlight.

Closed-Loop Rendezvous Procedures

Closed-loop rendezvous procedures are presented in the left column of figure 29-2; they are listed in the exact order that the crew performs them. Cockpit responsibility is assigned by the

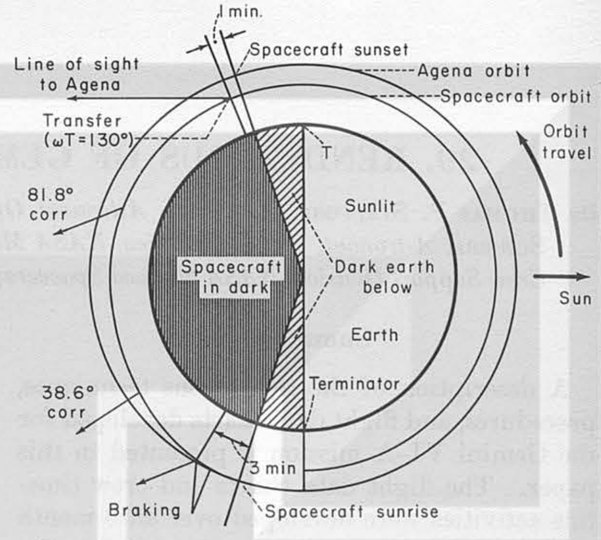


FIGURE 29-1.—Terminal-phase lighting conditions.

(a)

NOMINAL	RADAR FAILURE	COMPUTER FAILURE	PLATFORM FAILURE
INITIATION CUE - ANGLE/MDU OUTPUT	INITIATION CUE - ANGLE/MDU INPUT COMPUTER - CATCH-UP AT FAILURE ZERO ADD 25, 26, 27	INITIATION CUE - "8" BALL	INITIATION CUE - RANGE (MDU) OUTPUT COMPUTER - CATCH-UP AT FAILURE
0:00 APPLY CIRCULARIZATION TRANS (C) START GET (P) AT 0,0,0 ATT, APPLY THRUST TO ZERO READOUTS FROM ADD 80,81,82 GO TO RDR ACQ ATT, ACQUIRE LOCK-ON FDR - RDR FDM - ATT	0:00 APPLY CIRCULARIZATION TRANS (C) START GET (P) AT 0,0,0 ATT, APPLY THRUST TO ZERO ADD 80, 81, 82 (C) ZERO ADD 25, 26, 27 (P) COMPUTER - RNDZ/CTCH-UP (P) FDR - COMP FDM - ATT	0:00 APPLY CIRCULARIZATION TRANS (C) START GET (P) GO TO RDR ACQ ATT, ACQUIRE LOCK-ON FDR - RDR FDM - ATT/RATE	0:00 APPLY CIRCULARIZATION TRANS (C) START GET (P) GO TO RDR ACQ ATT, ACQUIRE LOCK-ON FDR - RDR FDM - ATT/RATE
ATT CNTL - PULSE MAN CONT - OFF SET E.T. TO 4:00 BORESIGHT ON AGENA BY NULLING FDI'S (C)	ATT CNTL - PULSE MAN CONT - OFF SET E.T. TO 4:00 (C)	ATT CNTL - PULSE MAN CONT - OFF SET E.T. TO 4:00 BORESIGHT ON AGENA BY NULLING FDI'S (C)	ATT CNTL - PULSE MAN CONT - OFF SET E.T. TO 4:00 BORESIGHT ON AGENA BY NULLING FDI'S (C)
4:00 ON MARK (P) START E.T. UP (C) COMPUTER - RNDZ (P)	4:00 ON MARK (P) START E.T. UP (C)	4:00 ON MARK (P) START E.T. UP (C)	4:00 ON MARK (P) START E.T. UP (C)
NOTE READ θ (59) AND R (69) (EACH 100 SEC PT) (P) INPUT WT = 83:13000; ΔWT = 93:04820 (P) VERIFY ADD 83, 93, 54, 53, 24, 92 IF REQ (P) NOTE θ WHICH EXCEEDS 20.1° AND CIRCLE IT. IF CIRCLED θ IS NEARER 20.1° THAN 21.4°, LABEL IT PT A. IF NOT, LABEL IT PT B AND THE PREVIOUS ONE PT A. ADD 3:20 TO PT A TIME TO OBTAIN TIME OF PT C. CALCULATE GET RESET TIME BY ADDING 4:30 TO PT C TIME (P). 3:20 AFTER PT A (PT C), READ θ (59) AND R (69) (P) AFTER PT C, START COMP - PUSH CALCULATE ΔR & Δθ CORR (P)	NOTE CONTROL θ TO NOMINAL UNTIL AGENA IS VISIBLE, THEN CONTROL S/C TO KEEP AGENA AT CENTER OF RETICLE. MONITOR θ (59) EVERY 100 SEC WHEN θ = 19°, READ θ (59) EVERY 10 SEC RECORD TIME WHEN θ = 20.1° (59) (LABEL POINT A) ADD 3:20 AND RECORD θ (59) AT THIS TIME (LABEL POINT C) (P)	NOTE WHEN VISIBLE, CONTROL S/C TO KEEP AGENA AT TOP OF RETICLE. MONITOR RANGE ON R - Ṙ METER (C) MONITOR "8" BALL (P) WHEN ATT BALL READS 15.5° (P) SELECT STAR PATTERN ON MARK (P) HOLD STARS FIXED IN RETICLE (C) START WATCH (P) ON MARK (P) READ Δα OVER 01:40 (C) CALCULATE UP/DOWN ΔV CORR (P) FWD ΔV NOMINAL	NOTE WHEN VISIBLE, CONTROL S/C TO KEEP AGENA AT TOP OF RETICLE. READ R (69) (EACH 100 SEC PT) MONITOR RANGE ON R - Ṙ METER (C) WHEN R = 43.00 N.M. READ EVERY 10 SEC WHEN R ≤ 41.00 N.M. SELECT STAR PATTERN ON MARK (P) HOLD STARS FIXED IN RETICLE (C) START WATCH AND READ R (69) (P) ON MARK FROM (P) READ Δα OVER 01:40 (C) READ R (69) (P) CALCULATE UP/DOWN AND FWD ΔV (P)
	INPUT: 25:00284; 26:90147; 27:00000 (P) NULL FDI'S (COMP) (ATT) START COMP - PUSH (C) CALCULATE UP/DOWN ΔV CORR (P) FWD ΔV NOMINAL SET UP/DOWN IVI BY MAN KNOBS (C)	BORESIGHT ON AGENA (C)	MONITOR R (69) EVERY 10 SEC (P) BORESIGHT ON AGENA (C)
ATT CNTL - RATE CMD MAN CONT - ON (C)	ATT CNTL - RATE CMD MAN CONT - ON (C)	ATT CNTL - RATE CMD MAN CONT - ON (C)	ATT CNTL - RATE CMD MAN CONT - ON (C)
COMP LITE ON NOMINALLY 03:50 AFTER PT C, THEN START THRUST TO ZERO IVI (C) (S/C BORESIGHT ON AGENA)	WHEN AGENA IN CENTER OF RETICLE (θ = 27.4°) START THRUST TO ZERO IVI (C)	WHEN BALL READS 27.5° (P) START THRUST (C)	WHEN R = 32.96 (P) START THRUST (C)

(a) Determination of terminal phase initiation.

FIGURE 29-2.—Closed-loop and backup rendezvous procedures.

(b)

(b) Determination of 82° correction.
FIGURE 29–2.—Continued.

letters C for command pilot and P for pilot. The procedures start with the initiation of the circularization maneuver. The stopwatch feature of the clock, which is located on the pilot's instrument panel, is started and is used throughout the remainder of the rendezvous phase as the basic time reference for crew procedures. The event timer, which is located on the command pilot's instrument panel, is synchronized to the pilot's time and is used as a reference for the command pilot's critical events.

At 4 minutes after the circularization maneuver, the event timer is synchronized, and the computer is switched to the rendezvous mode. The command pilot controls the spacecraft attitude to boresight on the target, while the pilot verifies the pertinent computer constants, and, at the specific times requested by the charts, he records elevation angle and range to the target vehicle. This is continued until the initiation cue is reached.

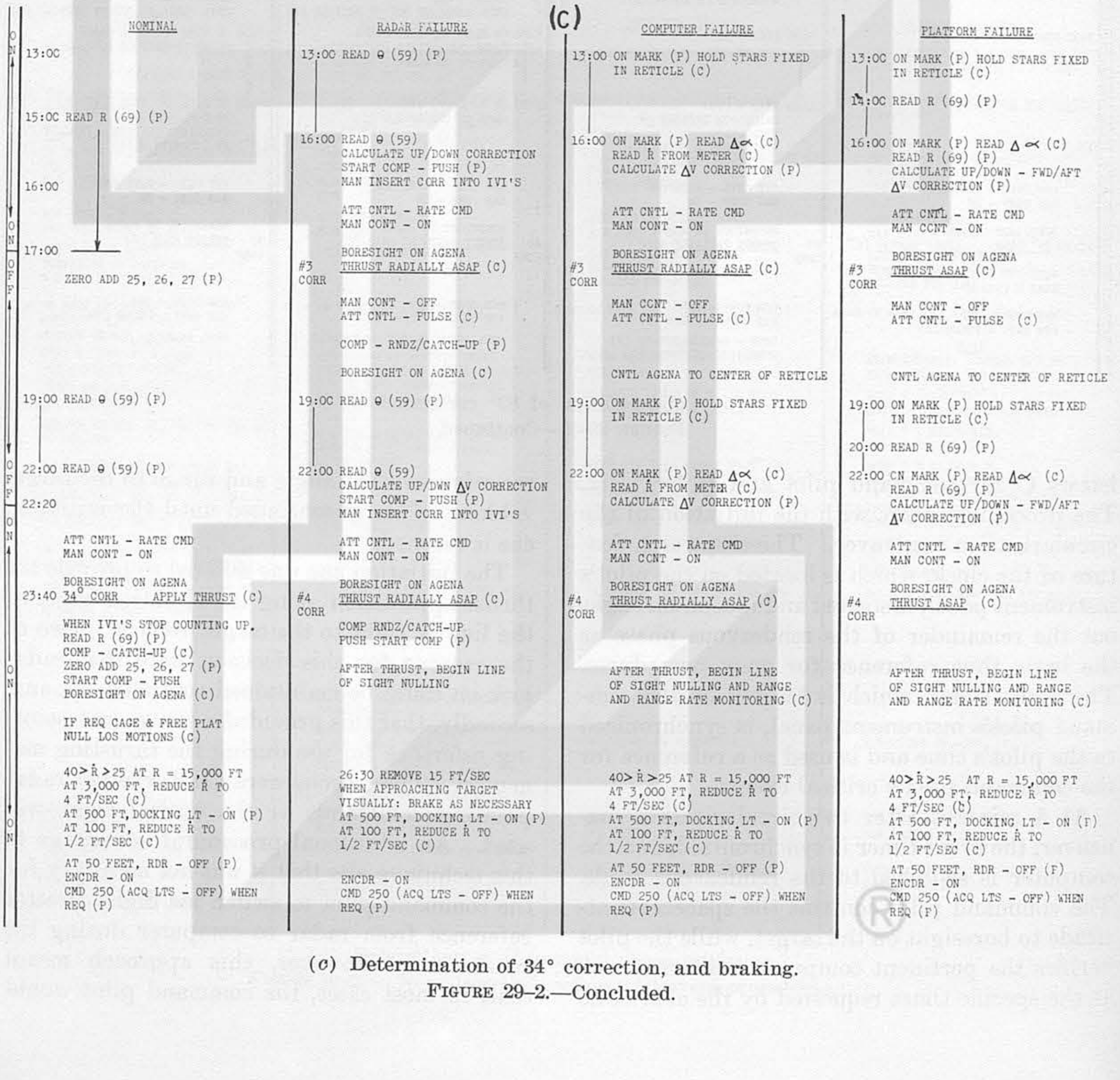
The initiation cue was selected to provide the thrust application along the elevation angle of the line of sight to the target vehicle. Two of the reasons for this decision were that radar lock-on could be maintained continuously, and, secondly, that this provided a convenient pointing reference for use during the thrusting maneuver. The reasons were valid whether radar pointing commands or the optical sight was used. An additional procedural advantage to this technique was that it was not necessary for the command pilot to switch his flight director reference from radar to computer during the rendezvous. However, this approach meant that, in most cases, the command pilot would have some small velocity components to thrust-out individually in the lateral and vertical axes. This disadvantage was deemed an insufficient reason to sacrifice a reference which could be the same for all modes of operation.

After the initiation point is determined, the pilot initiates the closed-loop guidance sequence by depressing the START COMP button. The pilot then calculates the thrust required for the transfer maneuver from the flight data recorded on the charts. The data used are pitch angle and range. The purpose of this calculation is to check the onboard computer solution and to provide backup data in case a system should fail.

After the initiation point for transfer has been selected and backup solutions have been calculated, the pilot then determines when the clock is to be resynchronized with the onboard computer.

When the START COMP button is depressed, the required change in velocity is presented on a cockpit display. When the START COMP light comes on, the command pilot applies thrust to bring the displayed velocity values to zero and, at the same time, maintains boresighting on the target. This event completes the transfer maneuver. At the previously described time, the pilot resets the stopwatch to zero to synchronize it with the computer for the remainder of the rendezvous.

After the transfer maneuver, the command pilot remains boresighted on the target vehicle, and between the 3- and 5-minute period the computer collects radar data at intervals of 20 seconds to be used for the first midcourse cor-



(c) Determination of 34° correction, and braking.

FIGURE 29-2.—Concluded.

rection. During this time, the pilot interrogates the computer to obtain the necessary data to analyze closed-loop guidance and trajectory parameters. This information is recorded on a monitor sheet (fig. 29–3). When the radar data collection is completed by the computer at 5 minutes, the START COMP light goes off, indicating that the computer is sequencing to the next part of its program. The crew now has an option of alining the platform during the next 5 minutes 20 seconds or of ignoring it. Their decision is based upon premission rules regarding accuracy requirements of the platform. The pilot then takes certain data from the computer in order to obtain the change in velocity requirements for a backup solution to the first midcourse maneuver. The first midcourse correction occurs at a point in the trajectory where 81.8° central angle travel of the target remains until intercept. Just prior to the first midcourse maneuver, the spacecraft must be boresighted for a final radar data collection by the computer. As soon as this occurs, the required velocities for the first midcourse correction are displayed. The command pilot then applies thrust to drive the displays to zero. Upon the completion of thrusting, the first midcourse correction is complete, and the identical cycle is repeated for the second midcourse correction which occurs at 33.6° central angle travel to go to rendezvous. This maneuver corresponds to a time of 23 minutes 40 seconds after the midpoint of the transfer maneuver.

When the second correction has been completed, the computer is switched from the rendezvous mode to the catchup mode. This allows radar data to the computer to be updated every one-eighth second. From this point in the trajectory, the target motion with respect to the stars should be essentially zero; therefore, the command pilot is required to note any motion of the target vehicle with respect to the celestial

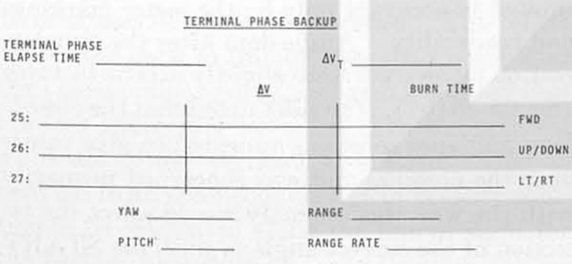


FIGURE 29–3.—Terminal phase backup monitor sheet.

background and null the motion. The pilot, meanwhile, is continuously monitoring pitch angle, range, and range rate to determine trajectory characteristics and is assisting the command pilot by giving him position reports and providing backup information. Braking thrust at the termination of rendezvous is applied as a function of range. The nominal range for initiation of braking is 3000 feet, and at 1500 feet the range rate is reduced to 4 feet per second.

Backup Procedures

Columns 2, 3, and 4 on figures 29–2 through 29–4 present the sequence of the backup rendezvous procedures in the event of radar, computer, or platform failure. It should be noted that the procedures and the arrangement of the procedures were specifically tailored to insure that an orderly transfer could be made in the event of system failure. Four midcourse corrections are used in the backup procedures, while only two are used in closed-loop guidance. The increased number was required to detect a trajectory error as early as possible and to make the appropriate corrections. The second and fourth backup measurements provide a check of the first and second closed-loop maneuvers. An optical sight with a collimated reticle was one of the essential pieces of hardware to implement the backup procedures. This sight was used to track the target and measure inertial angular rates.

Radar Failure

A radar failure eliminates range and range rate from the analog meter and the computer. In this event, the initiation cue is based upon line-of-sight elevation angle. The spacecraft is controlled to a specified pitch attitude of 27.4° using the flight director indicators, and the target vehicle is visually observed. Visual observation is a mandatory requirement unless thrusting is initiated on ground-calculated time. When the target passes through the center of the reticle, thrusting is initiated. Once again the nominal change in velocity is applied along the line of sight, and a correction normal to the line of sight is based upon the measured change in the elevation angle as read from the computer. The intermediate corrections rely upon this capability to read elevation angle from the computer to enable the pilot to calculate corrections normal to the line of sight. Since ranging information is not available, a small braking maneuver is selected by time, and the final braking thrust is not applied until the command pilot can visually detect size growth of the target vehicle.

Computer Failure

A computer failure precludes the use of accurate elevation or pitch angle as an initiation cue. The reference then used to provide this cue is the attitude indicator ball. Loss of the computer also prevents use of the velocity displays. The transfer thrusting application is therefore based on the nominal change in velocity along the line of sight and a calculated change normal to the line of sight. The calculation is based on the change from nominal of the inertial elevation angle. The first two intermediate corrections are based only upon the variation of the inertial elevation angle from nominal, using the optical reticle as the measuring device and the celestial background as the inertial reference. The last two corrections include range-rate data from the analog meter. The pilot uses the stopwatch feature of his wristwatch to measure the time of thrust in each axis which corresponds to the required change in velocity.

Platform Failure

In the event of a platform failure, the initiation cue is ranged obtained from the computer. The initial transfer and the four intermediate corrections are based upon deviations in the change of range and inertial elevation angle from the nominal. The change in inertial elevation angle is measured by using the optical reticle. The reticle pattern and markings were designed to insure the required accuracy for this measurement. The procedures for the trajectory from the end of the fourth backup midcourse maneuver to termination of rendezvous are the same as previously discussed under closed-loop rendezvous procedure.

Flight Charts

The flight charts are an extension of the Gemini V charts and were tailored for the Gemini VI–A mission. The Gemini V charts were developed specifically for the planned exercise with the rendezvous evaluation pod. The Gemini VI–A charts have been refined considerably from Gemini V charts due to experience gained from simulations and crew training. Figure 29–3 is the form used for recording the ground-computed termination phase initiation. Figure 29–4 is the form used for recording data necessary to monitor the trajectory and for the determination of the proper point for transfer. Figure 29–5 is used to determine the initial thrusting required for transfer as a check on the closed-loop solution and as a backup in case of a system failure. Figure 29–6 is used to calculate intermediate corrections in the backup procedures and to check the closed-loop solution for the two midcourse maneuvers. All measurements and thrust applications are made orthogonally with respect to an axis system oriented along the spacecraft axes. The spacecraft X-axis is alined with the line of sight to the target. Figure 29–7 is the monitor sheet used for closed-loop guidance. Figure 29–8 is a curve used to determine separation from the target vehicle using only range from the computer.

Figure 29–9 is a polar plot of the nominal Gemini VI–A trajectory from the circularization maneuver to termination of rendezvous. Nominal range, range rates, elevation angles, and ground elapsed times are provided at various points along the trajectory.

Discussion of the Gemini VI–A Rendezvous

The closed-loop guidance technique was used satisfactorily during the Gemini VI–A rendezvous mission. The radar range data that were read from the computer were highly accurate throughout the entire maneuver and provided the crew with the necessary information to monitor the trajectory, shown in figure 29–10(a). Radar range-rate data from the analog meter showed close correlation to computed data with less than 3-feet-per-second difference, and was limited in accuracy only by the meter markings and readability. Angle data after the circularization maneuvers were slightly erratic in value (fig. 29–10(b)). The pilot noted that the closed-loop guidance solutions appeared to give values near the nominal and was concerned primarily with the way this anomaly would affect the selection of the correct angle to push the START COMP button during the transfer maneuver.

(a)

GT–6 RENDEZVOUS FLIGHT CHARTS
NOMINAL AND ACTUAL CONDITIONS – CIRCULARIZATION TO TERMINAL INITIATION

AFTER SWITCHING COMP TO RENDEZVOUS MODE, PERFORM THE FOLLOWING:

VERIFY r_T: 54 73082
T′: 53 53776
$1/A_T$: 24 12690
RLO: 92 00000

INPUT ωT : 83 13000
Δ : 93 04820

RDR DATA POINTS	TIME FROM NSR INITIATE MIN:SEC	Θ NOM DEG	Θ ACTUAL ADD 59 DEG	R NOM N.M.	R ACTUAL ADD 69 N.M.	ΔR ACTUAL N.M.	ΔR NOM N.M.		ΔV_I NOM FPS	ΔV_I ACTUAL ADD 71 FPS	ΔV_T NOM FPS
1	4:00	5.4		136.09			2.60				
2	5:40	5.5		133.49			2.60				
3	7:20	5.7		130.89			2.60				
4	9:00	5.8		128.29			2.60				
5	10:40	6.0		125.69			2.60				
6	12:20	6.2		123.09			2.60				
7	14:00	6.3		120.49			2.60				
8	15:40	6.5		117.89			2.60		230.0		518
9	17:20	6.7		115.29			2.60		222.1		502
10	19:00	6.9		112.69			2.60		214.2		486
11	20:40	7.1		110.09			2.60		206.3		470
12	22:20	7.3		107.49			2.60		198.4		454
13	24:00	7.5		104.89			2.60		190.5		438
14	25:40	7.7		102.30			2.60		182.6		422
15	27:20	7.9		99.71			2.59		184.7		406
16	29:00	8.2		97.12			2.59		176.9		390
17	30:40	8.5		94.53			2.59		169.1		374
18	32:20	8.8		91.94			2.59		161.3		358
19	34:00	9.1		89.35			2.59		153.5		342
20	35:40	9.4		86.76			2.59		145.7		327

(*a*) Between 4 minutes and 35 minutes 40 seconds from coelliptical maneuver (NSR).
FIGURE 29–4.—Transfer maneuver monitor sheet.

The backup solution calculated from the flight data charts indicates that an angle bias existed. The fact that range and range rate prior to transfer were exactly nominal led to a belief that elevation angle and elevation angle rate also should have been nominal. This difference may have been partly due to a platform alinement. The cause of the remainder of the difference has not been determined. This effect caused the crew to transfer one data point later than the nominal point, and also indicated that the two spacecraft were less than the nominal 15-nautical-mile vertical separation. This in turn led to an erroneous change in velocity solution to be calculated along the line of sight for the backup procedure.

The ground-calculated backup solution showed close agreement with the closed-loop data. In subsequent missions, however, ground solutions will not be available for some rendezvous transfers; hence, the requirement will continue to exist to provide the crew with an independent onboard method of calculating transfer velocities.

The target-center polar plot was used to provide backup verification. The data are correct for direction and generalized for magnitude of the thrust vector. The five values that were available to the crew for the transfer solution are shown in table 29–I.

It was noted by the pilot, immediately after the final backup calculation, that the 23-foot-per-second solution along the line of sight

(LOS) was in error, as the data from points prior to this gave 32 feet per second. As noted in table 29–I, the polar plot and the change in range-change ($\Delta\Delta R$) solutions indicate that 32 feet per second should be applied along the line of sight. The ground-calculated solution was additional verification of this number. Had the computer failed to arrive at a solution or given an erroneous value, sufficient information existed onboard from the polar plot and $\Delta\Delta R$ method to correctly determine that the transfer change in velocity was in fact 32 feet per second along the line of sight. This was the change in velocity that the crew would have applied in case of a failure mode. This problem highlights the fact that the crew must have ample onboard methods to correctly interpret and execute the transfer maneuver.

(b)

RDR DATA POINTS	TIME FROM NSR INITIATE MIN:SEC	Θ NOM DEG	Θ ACTUAL ADD 59 DEG	R NOM N.M.	R ACTUAL ADD 69 N.M.	ΔR ACTUAL N.M.	ΔR NOM N.M.		ΔV_T NOM FPS	ΔV_T ACTUAL ADD 71 FPS	ΔV_T NOM FPS
21	37:20	9.7		84.18			2.58		137.9		311
22	39:00	10.0		81.60			2.58		130.2		296
23	40:40	10.4		79.02			2.58		122.5		281
24	42:20	10.8		76.44			2.58		114.8		265
25	44:00	11.2		73.87			2.57		107.1		249
26	45:40	11.7		71.30			2.57		99.5		234
27	47:20	12.2		68.73			2.57		92.0		219
28	49:00	12.7		66.17			2.56		84.5		204
29	50:40	13.3		63.61			2.56		77.1		189
30	52:20	13.9		61.06			2.55		69.9		174
31	54:00	14.5		58.52			2.54		62.8		159
32	55:40	15.3		55.98			2.54		56.1		145
33	57:20	16.1		53.45			2.53		49.7		131
34	59:00	16.9		50.93			2.52		43.9		118
35	00:40	17.9		48.43			2.50		38.9		106
36	02:20	19.0		45.93			2.50		35.0		95
37	04:00	A 20.1		43.45			2.48		32.6		86
38	05:40	B 21.4		40.99			2.46		32.0		80
39	07:20	C 22.9		38.55			2.44		33.3		75

(*b*) Between 37 minutes 20 seconds and 1 hour 7 minutes 20 seconds from coelliptical maneuver (NSR).

FIGURE 29–4.—Concluded.

TABLE 29–I.—*Transfer Solution Values*

Thrust	Closed-loop	Backup charts	Ground	Polar plot	$\Delta\Delta R$
Along line of sight	31 ft/sec forward	23 ft/sec forward	32 ft/sec forward	32 ft/sec forward	32 ft/sec forward
Normal line of sight	4 ft/sec up	2 ft/sec up	2 ft/sec up	0 ft/sec	0 ft/sec
Lateral line of sight	1 ft/sec right	----------	2 ft/sec left	----------	

GT–6 RENDEZVOUS FLIGHT CHARTS
INITIAL THRUST CALCULATION

ANGULAR RATE CORRECTION

GET: θ_A ___ : ___ +3:20= GET: θ_C ___ : ___ → +4:30= ___ : ___ GET TO STOP - RESET - START

θ_{Aa} DEG	θ_{Ca} DEG	θ_{CN} DEG	$\Delta\theta_C$ DEG	$\Delta\theta_C$ DEG	I	II NOM	III	Δt SEC	Δt UP-DWN	ΔV UP-DWN
19.5	-	22.1 =		+2.0				29	130 SEC	46 FPS
19.6	-	22.3 =		+1.0				15	67 SEC	24 FPS
19.7	-	22.4 =		+ .8				12	54 SEC	19 FPS
19.8	-	22.5 =		+ .6				9	39 SEC	14 FPS
19.9	-	22.7 =		+ .4				6	26 SEC	9 FPS
20.0	-	22.8 =		+ .2				3	13 SEC	4 FPS
20.1	-	22.9 =		0	0.0	0.0	C.0	0	0 SEC	0 FPS
20.2	-	23.1 =		- .2				3	13 SEC	4 FPS
20.3	-	23.2 =		- .4				6	26 SEC	9 FPS
20.4	-	23.3 =		- .6				9	39 SEC	14 FPS
20.5	-	23.4 =		- .8				12	54 SEC	19 FPS
20.6	-	23.6 =		-1.0				15	67 SEC	24 FPS
20.7	-	23.7 =		-2.0				29	130 SEC	46 FPS

RADAR FAILURE
POINTING COMMAND AFTER PT C:

$\Delta\dot{X}$ = 25 00284
$\Delta\dot{Y}$ = 26 90147
$\Delta\dot{Z}$ = 27 00000

COMP FAILURE: → BALL 15.5 TGT AT TOP

TIME: ___ : ___ +1:40 = ___ : ___

α_{CN} 5.1 − α_{Ca} ___ = $\Delta\alpha_C$ ___ x2= $\Delta\theta_C$ ___ INITIATE BALL: 27.5

PLAT FAILURE:

R_{Ba} ___ − R_{Ca} ___ = ___ x2 = ΔR_a ___

R = 41.00

INITIATE RANGE: 32.96 NM

ΔV OR ΔT APPLIED
FWD: ___
AFT: ___
UP: ___
DWN: ___
LT: ___
RT: ___

R_{Ba} ___ . ___
+ 2.50
R_A ___ . ___

RANGE RATE CORRECTION

	R_A NM	R_A NM	R_C NM	ΔR_a NM	ΔR_N NM	$\varepsilon\Delta R$ NM		$\varepsilon\Delta R$ NM	$\Delta t_{\Delta R}$ SEC	Δt SEC	Δt FWD	ΔV FWD
I	39.00	-	±		- 4.29 =		RADAR OR COMP FAILURE ↔ APPLY NOMINAL	-.50	60 -		= SEC	47 FPS
I	40.00	-	±		- 4.42 =			-.40	56 -		= SEC	44 FPS
I	41.00	-	±		- 4.56 =			-.30	52 -		= SEC	41 FPS
II NOM	42.00	-	±		- 4.71 =			-.20	48 -		= SEC	38 FPS
II NOM	43.00	-	±		- 4.84 =			-.10	44 -		= SEC	35 FPS
II NOM	43.45	-	±		- 4.90 =			0	41 -		= SEC	32 FPS
II NOM	44.00	-	±		- 4.97 =			+.10	37 -		= SEC	29 FPS
II NOM	45.00	-	±		- 5.11 =			+.20	33 -		= SEC	26 FPS
III	46.00	-	±		- 5.24 =			+.30	29 -		= SEC	23 FPS
III	47.00	-	±		- 5.39 =			+.40	25 -		= SEC	20 FPS
III	48.00	-	±		- 5.52 =			+.50	22 -		= SEC	17 FPS

FIGURE 29–5.—Initial thrust calculation sheet.

A significant problem developed when the Gemini VII spacecraft went into darkness. The Gemini VI–A crew was not able to acquire it visually until a range of 25.7 nautical miles, when the spacecraft's docking light became faintly visible. The observed light was not sufficient to provide tracking for the first two backup midcourse corrections. The flashing acquisition lights were not seen until 14.5 nautical miles because the apparent intensity of the docking light was much greater. The crew had previously been briefed that the acquisition light should be visible for tracking at a range of 30 nautical miles.

The platform alinement performed during the period from 5 to 10 minutes after transfer precluded any backup solution to the first midcourse maneuver. The backup solution for the second midcourse maneuver was calculated and requested 6 feet per second up, versus 3 feet per second up, and 4 feet per second forward for the closed loop (table 29–II). The backup solution would have been adequate to provide an intercept with the Gemini VII spacecraft.

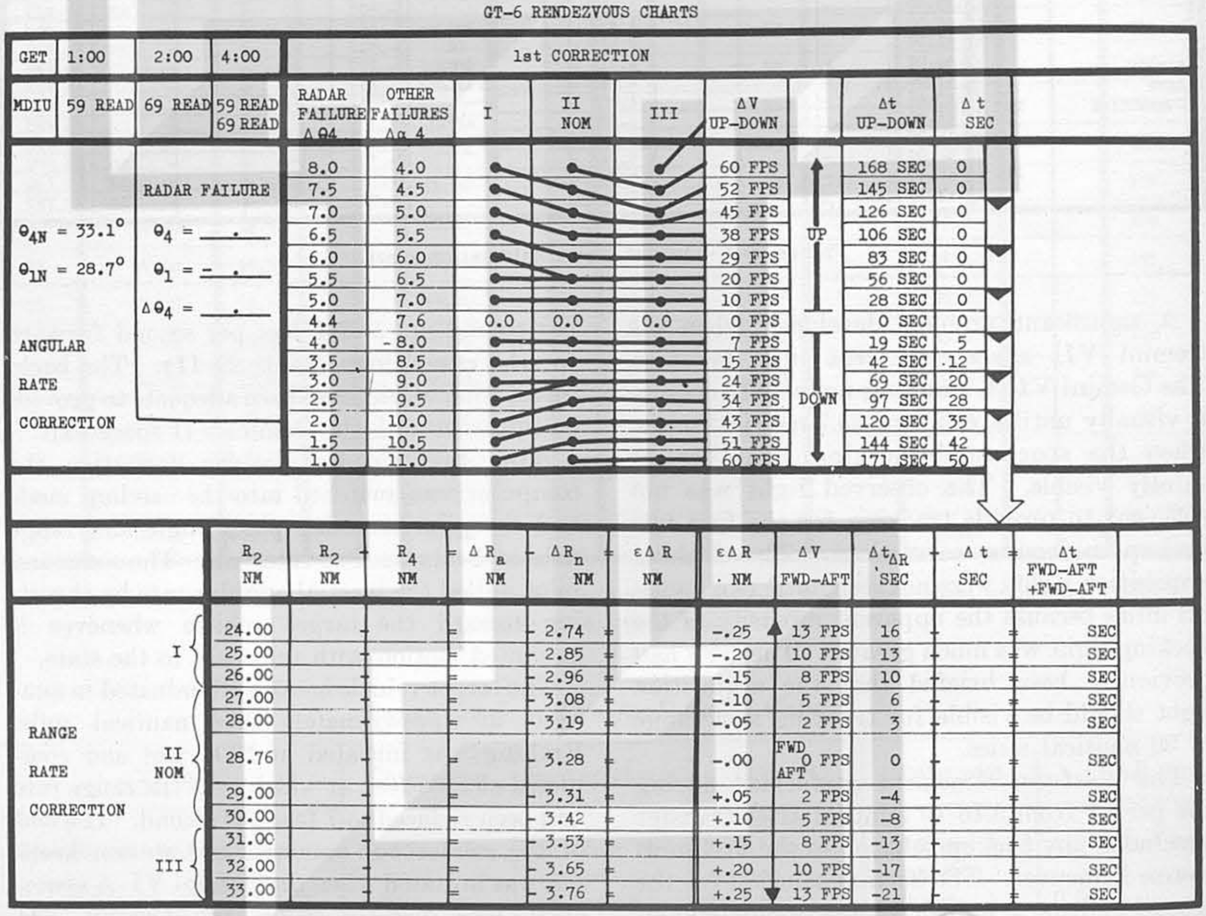
After the second midcourse correction, the computer was switched into the catchup mode and the pilot recorded pitch angle and range data at 1-minute time intervals. The command pilot nulled the inertial angular rate by thrusting toward the target vehicle whenever it exhibited motion with reference to the stars.

The target vehicle became illuminated in sunlight at approximately 0.74 nautical mile. Braking was initiated at 3000 feet and completed at 1500 feet, at which time the range rate had been reduced to 7 feet per second. The end of the rendezvous occurred and station keeping was initiated when the Gemini VI–A spacecraft was directly below the Gemini VII spacecraft at a distance of 120 feet.

TABLE 29-II.—*Midcourse Maneuver Values*

Thrust	Closed-loop	Backup charts	Polar plot
(a) First midcourse maneuver			
Along line of sight	7 ft/sec forward	Not available due to computer program	5 ft/sec forward
Normal line of sight	7 ft/sec up	Not available due to platform alinement	5 ft/sec up
Lateral line of sight	5 ft/sec left	Not calculated	Not calculated
(b) Second midcourse maneuver			
Along line of sight	4 ft/sec forward	Not available due to computer program	5 ft/sec forward
Normal line of sight	3 ft/sec up	6 ft/sec up	5 ft/sec up
Lateral line of sight	6 ft/sec right	Not calculated	Not calculated

(a)



(*a*) First correction maneuver.

FIGURE 29-6.—Intermediate correction calculation sheets.

(b)

GT-6 RENDEZVOUS FLIGHT CHARTS

GET	7:00	8:00	10:00	2nd CORRECTION								
MDIU	59 READ	69 READ	59 READ 69 READ	RADAR FAILURE $\Delta\theta_{10}$	OTHER FAILURES $\Delta\theta_{10}$	I	II NOM	III	ΔV UP-DOWN		Δt UP-DOWN	Δt SEC
		RADAR FAILURE		9.5	2.5				42 FPS		118 SEC	0
				9.0	3.0				36 FPS		101 SEC	0
				8.5	3.5				30 FPS		85 SEC	0
$\theta_{10K} = 44.1^\circ$		θ_{10}: ___		8.0	4.0				24 FPS	UP	69 SEC	0
				7.5	4.5				18 FPS		51 SEC	0
$\theta_{7N} = 38.1^\circ$		θ_7 :- ___		7.0	5.0				12 FPS		32 SEC	0
				6.5	5.5				6 FPS		16 SEC	0
ANGULAR		$\Delta\theta_{10}$: ___		6.0	6.0	0.0	0.0	0.0	0 FPS		0 SEC	0
				5.5	6.5				6 FPS		16 SEC	5
RATE				5.0	7.0				12 FPS		32 SEC	9
				4.5	7.5				18 FPS		51 SEC	15
CORRECTION				4.0	8.0				24 FPS	DOWN	69 SEC	20
				3.5	8.5				30 FPS		85 SEC	25
				3.0	9.0				36 FPS		101 SEC	29
				2.5	9.5				42 FPS		118 SEC	34

		R_8 NM	− R_8 NM	= R_{10} NM	− ΔR_a NM	= ΔR_n NM	$\varepsilon\Delta R$ NM	$\varepsilon\Delta R$ NM	ΔV FWD-AFT	$\Delta t_{\Delta R}$ SEC	+ Δt SEC	= Δt FWD-AFT +FWD -AFT
	I	17.00	−	=	− 2.43	=		−.25	13 FPS	16	+	= SEC
	I	17.50	−	=	− 2.50	=		−.20	10 FPS	13	+	= SEC
	I	18.00	−	=	− 2.57	=		−.15	8 FPS	10	+	= SEC
RANGE	II NOM	18.50	−	=	− 2.65	=		−.10	5 FPS	6	+	= SEC
RATE	II NOM	19.00	−	=	− 2.72	=		−.05	2 FPS	3	+	= SEC
CORRECTION	II NOM	19.37	−	=	− 2.77	=		.00	FWD 0 FPS AFT	0	+	= SEC
	II NOM	20.00	−	=	− 2.86	=		+.05	2 FPS	−4	+	= SEC
	II NOM	20.50	−	=	− 2.93	=		+.10	5 FPS	−8	+	= SEC
	III	21.00	−	=	− 3.00	=		+.15	8 FPS	−13	+	= SEC
	III	21.50	−	=	− 3.08	=		+.20	10 FPS	−17	+	= SEC
	III	22.00	−	=	− 3.15	=		+.25	13 FPS	−21	+	= SEC

(*b*) Second correction maneuver.
FIGURE 29–6.—Continued.

Status of Gemini Rendezvous Procedures and Charts

Numerous modifications to the Gemini VI–A procedures and flight data charts have been made for the Gemini VIII mission. In addition, possible changes are contemplated for subsequent missions. A format change in the charts was indicated by usage of the Gemini V and VI–A charts. The charts used for the backup transfer, as well as the four intermediate correction charts, have been changed to a nomograph presentation. This allows the user to interpolate directly without calculation, as in the case of the present charts. In addition, this presentation provides a far greater expansion of the data and limits than was possible with the tabular format. This was not critical with the present charts and mission requirements, but future applications may require a much greater flexibility; thus it was deemed advisable to change from this standpoint.

The calculations required have been changed to make them additive only, rather than additive or subtractive. The concept of the intermediate correction charts for monitoring and backup has also been changed. Previously, the charts were designed using a reference trajectory with a perfect intercept of the target. When an error in the trajectory was noted, the present charts tried to force the trajectory back to nominal; consequently, the rendezvous trajectory was shifted, and rendezvous was obtained earlier or later, depending on the error. This approach is sufficient to complete rendezvous but does not constrain the target's total central angle travel to 130°; therefore, the time to rendezvous becomes a variable. The new charts provide that the backup procedures present the same calculated corrections as the closed-loop guidance, and further insure that the same total central angle travel is obtained.

Changes to the computer program and readout capability have decreased crew workload and have increased ability to obtain key parameters at the required times. These items are instantaneous range, range rate, and pitch angle. Range and pitch angle were formerly available only at specified intervals and defined times in the programing sequence. Range rate had to be calculated from range points. Monitoring of the closed-loop guidance previously has been restricted to only certain time intervals, due to inability to obtain these parameters. The crew will now have access to these values over a greatly extended time period. This change greatly enhances monitoring of the closed-loop guidance and provides far greater latitude in developing procedures which are more consistent with operational constraints. This point should not be overlooked in the design of future space applications.

The flight director attitude displays were marked in a manner whereby the reading accuracy could be read to only ±2° in most areas and to ±5° when the spacecraft was within ±30° of 90° pitch. The displays are presently being re-marked to 1° increments and will provide reading accuracy to within ±0.5° at all pitch angles. This new marking will provide accurate angle measurements for the transfer maneuver and for midcourse corrections in case of computer failure.

Concluding Remarks

The closed-loop rendezvous guidance system performed satisfactorily. The radar range in-

(C)

GT-6 RENDEZVOUS FLIGHT CHARTS

GET	13:00	14:00	16:00	3rd CORRECTION
MDIU	59 READ	69 READ	59 READ 69 READ	

ANGULAR RATE CORRECTION

$\theta_{16N} = 59.4^\circ$

$\theta_{13N} = 51.0^\circ$

RADAR FAILURE

θ_{16} = ___.___

θ_{13} = ___.___

$\Delta\theta_{16}$ = ___.___

RADAR FAILURE $\Delta\theta 16$	OTHER FAILURES $\Delta\alpha 16$	I	II NOM	III	ΔV UP-DOWN		Δt UP-DOWN	Δt SEC
12.0	0				28 FPS	UP	80 SEC	0
11.5	.5				24 FPS		68 SEC	0
11.0	1.0				20 FPS		56 SEC	0
10.5	1.5				16 FPS		44 SEC	0
10.0	2.0				12 FPS		33 SEC	0
9.5	2.5				8 FPS		22 SEC	0
9.0	3.0				4 FPS		11 SEC	0
8.4	3.6	0.0	0.0	0.0	0 FPS		0 SEC	0
8.0	4.0				3 FPS	DOWN	8 SEC	2
7.5	4.5				6 FPS		16 SEC	5
7.0	5.0				9 FPS		25 SEC	7
6.5	5.5				12 FPS		34 SEC	10
6.0	6.0				16 FPS		44 SEC	13
5.5	6.5				20 FPS		55 SEC	16
5.0	7.0				24 FPS		69 SEC	20

RANGE RATE CORRECTION	R_{14} NM	R_{14} NM −	R_{16} NM =	ΔR_a NM +	ΔR_n NM =	$\varepsilon\Delta R$ NM	$\varepsilon\Delta R$ NM	ΔV FWD-AFT	$\Delta t_{\Delta R}$ SEC +	Δt SEC =	Δt FWD-AFT +FWD −AFT	$\dot{R}$ ANALOG 16:00
I	9.00				1.58		−.25	13 FPS	16		SEC	85
I	9.50				1.66		−.20	10 FPS	13		SEC	88
I	10.00				1.75		−.15	8 FPS	10		SEC	90
II NOM	10.50				1.84		−.10	5 FPS	6		SEC	93
II NOM	11.00				1.93		−.05	2 FPS	3		SEC	96
II NOM	11.76				2.06		.00	FWD 0 FPS AFT	0		SEC	98
II NOM	12.00				2.10		+.05	2 FPS	−4		SEC	100
II NOM	12.50				2.19		+.10	5 FPS	−8		SEC	103
III	13.00				2.28		+.15	8 FPS	−13		SEC	106
III	13.50				2.36		+.20	10 FPS	−17		SEC	108
III	14.00				2.45		+.25	13 FPS	−21		SEC	111

(*c*) Third correction maneuver.
FIGURE 29–6.—Continued.

(d)

GT-6 RENDEZVOUS FLIGHT CHARTS

GET	19:00	20:00	22:00	4th CORRECTION
MDIU	59 READ	69 READ	59 READ 69 READ	

		RADAR FAILURE $\Delta\theta_{22}$	OTHER FAILURES $\Delta\alpha_{22}$	I	II NOM	III	ΔV UP-DOWN		Δt UP-DOWN	Δt SEC
	RADAR FAILURE	18.5	-6.5				30 FPS	↑	84 SEC	0
$\theta_{22N} = 80.7°$	θ_{22}: ____.____	17.5	-5.5				25 FPS		72 SEC	0
$\theta_{19N} = 69.2°$	θ_{19}:-____.____	16.5	-4.5				20 FPS		56 SEC	0
	$\Delta\theta_{22}$:____.____	15.5	-3.5				15 FPS	UP	42 SEC	0
		14.5	-2.5				10 FPS		30 SEC	0
		13.5	-1.5				6 FPS		18 SEC	0
		12.5	- .5				3 FPS		9 SEC	0
ANGULAR		11.5	+ .5	0.0	0.0	0.0	0 FPS		0 SEC	0
		10.5	+1.5				3 FPS		9 SEC	3
RATE		9.5	+2.5				6 FPS		18 SEC	5
		8.5	+3.5				10 FPS		30 SEC	9
CORRECTION		7.5	+4.5				15 FPS	DOWN	42 SEC	12
		6.5	+5.5				20 FPS		56 SEC	16
		5.5	+6.5				25 FPS		72 SEC	21
		4.5	+7.5				30 FPS	↓	84 SEC	25

		R_{20} NM	R_{20} NM −	R_{22} NM =	ΔR_a NM +	ΔR_n NM =	$\varepsilon\Delta R$ NM	$\varepsilon\Delta R$ NM	ΔV FWD-AFT	$\Delta t_{\Delta R}$ SEC +	Δt SEC =	Δt FWD-AFT +FWD -AFT	$\dot{R}$ ANALOG 22:00
	I	4.00				0.86		-.25	13 FPS	16		SEC	51
	I	4.50				0.97		-.20	10 FPS	13		SEC	54
	I	5.00				1.08		-.15	8 FPS	10		SEC	56
	II NOM	5.50				1.18		-.10	5 FPS	6		SEC	59
RANGE	II NOM	6.00				1.29		-.05	2 FPS	3		SEC	62
RATE	II NOM	6.32				1.36		.00	FWD 0 FPS AFT	0		SEC	64
CORRECTION	II NOM	7.00				1.51		+.05	2 FPS	-4		SEC	66
	II NOM	7.50				1.61		+.10	5 FPS	-8		SEC	69
	III	8.00				1.72		+.15	8 FPS	-13		SEC	72
	III	8.50				1.83		+.20	10 FPS	-17		SEC	74
	III	9.00				1.94		+.25	13 FPS	-21		SEC	77

(*d*) Fourth correction maneuver.
FIGURE 29–6.—Concluded.

formation obtained through the computer was very accurate and provided good data to monitor the closed-loop solution. The angle data obtained were slightly erratic and had a possible bias prior to the transfer maneuver. The angle data alone would provide a poor basis on which to base a rendezvous maneuver.

The backup charts and the polar plot gave the crew good information on the rendezvous trajectory and provided a means to complete the rendezvous maneuver in case system failures were encountered.

A continuously updated local-horizontal reference on the platform is highly desirable. The flight director attitude indicator that is referenced to local horizontal provides the flight crew an excellent reference for both the closed-loop and the backup guidance systems.

The optical sight is a mandatory piece of equipment for backup guidance techniques.

The acquisition lights used on Gemini VII were unsatisfactory and precluded optical tracking for transfer and the first two backup midcourse corrections. The lights should provide adequate means of tracking the target at the initiation of the transfer maneuver.

Orientation of the rendezvous phase was optimally located to present the most favorable lighting conditions for target acquisition and tracking, and use of the star background for measurements and braking. These considerations are a requirement for future missions.

218–556 O—66——20

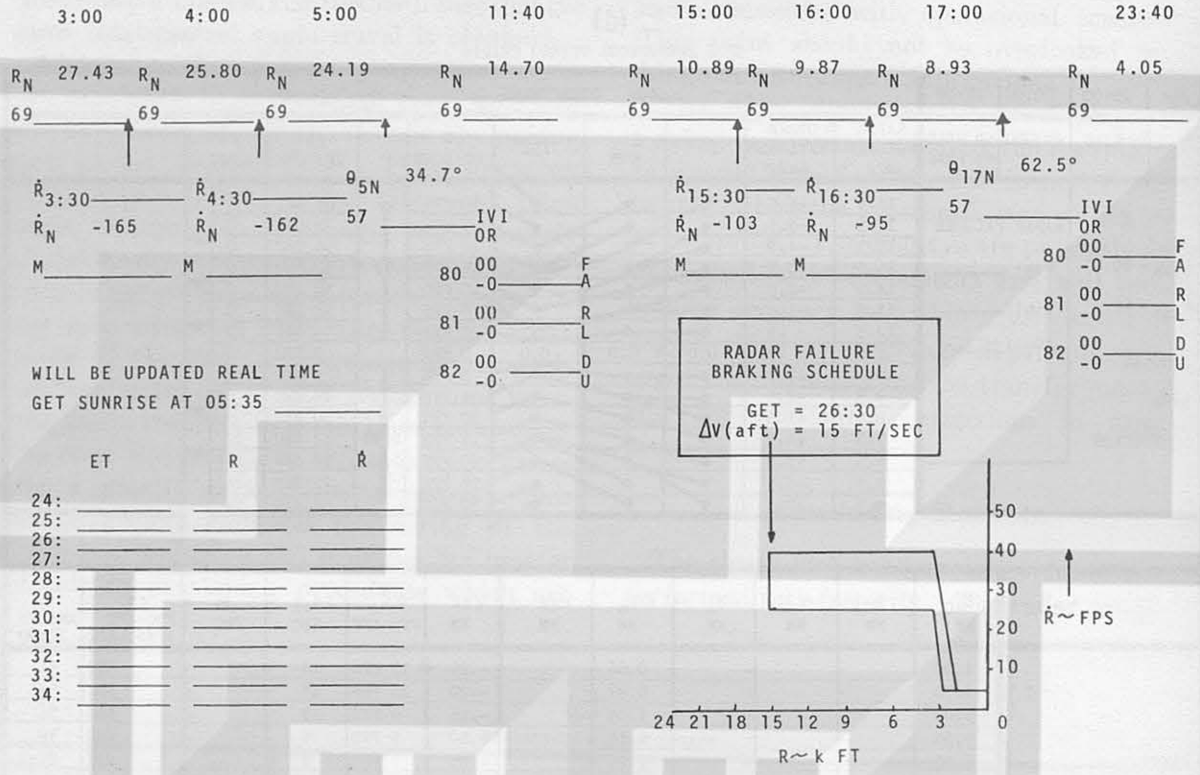


FIGURE 29–7.—Closed-loop intermediate correction monitor sheet.

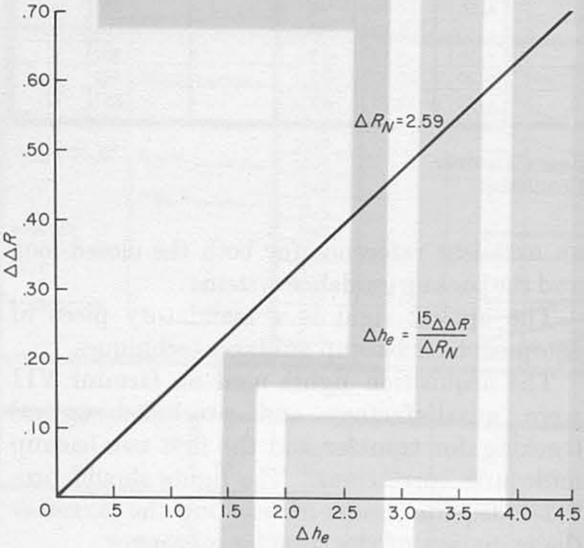


FIGURE 29–8.—Separation determination sheet.

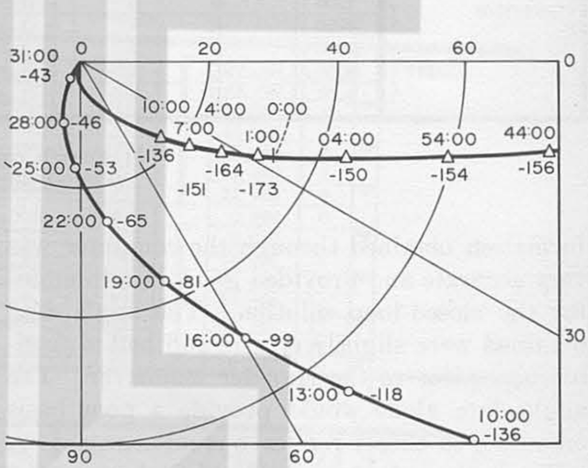
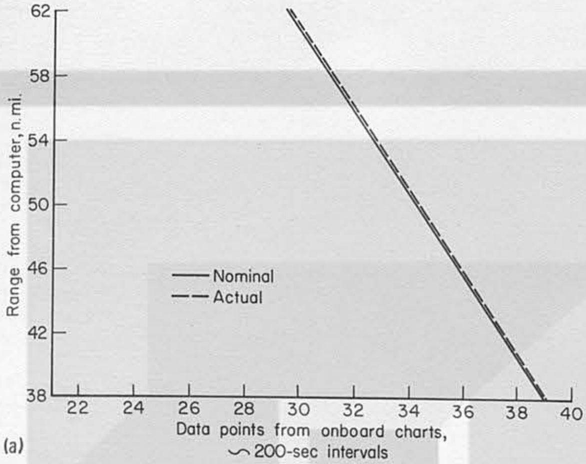
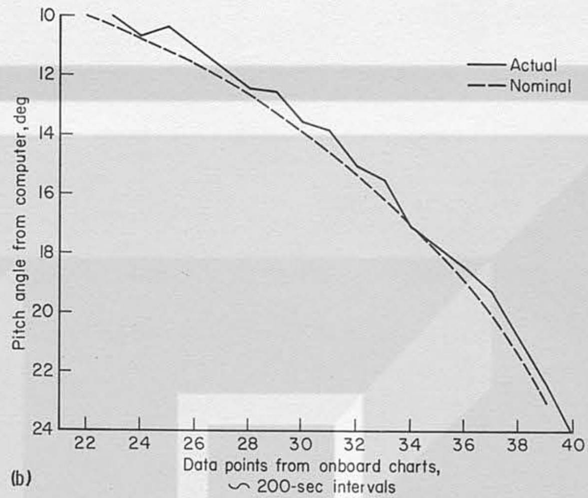


FIGURE 29–9.—Polar plot of nominal Gemini VI–A trajectory.



(*a*) Range versus time output.

FIGURE 29–10.—Gemini VI–A onboard data.



(*b*) Angle versus time computer output.

FIGURE 29–10.—Concluded.

CONCLUDING REMARKS

30. CONCLUDING REMARKS

By James C. Elms, *Deputy Associate Administrator for Manned Space Flight, NASA*

The preceding papers presented an interim report of the Gemini Program at its midpoint, and describe the objectives, designs, missions, and accomplishments to date—in short, a detailed report of a successful program. The major goal of the U.S. space program is to make this country conclusively and emphatically preeminent in space. The Nation is indeed proud of the Gemini Program's contributions, which include long-duration space flight, rendezvous, extravehicular activities, experiments, and the demonstration of active control of reentry to achieve a precise landing point. All the accomplishments have significantly contributed to the basic technology and to a better understanding of the space environment. These contributions will continue to be made throughout the remainder of the Gemini Program. The rapid increase in flight duration to 4 days, then 8 days, and finally 14 days, the extravehicular activities, the rapid turnaround, the accomplishment of major events on schedule in spite of adversity, all demonstrate the greatly increased capability of NASA, and are made even more meaningful by the policy of encouraging the world to observe the program. Much has been said about real-time flight planning, which has proved to be a requirement in the Gemini Program and which the Gemini team has been able to satisfy. The performance of the combined team of the Department of Defense, the contractors, NASA, and other Government agencies in planning and executing the Gemini VI–A and VII missions is an example of real-time management. This is a capability that will serve the Nation well in future missions. Gemini, in addition to being a giant step bridging the gap between Mercury and Apollo, is providing a means of program qualification for Apollo itself, and will continue to do so.

At the close of the Mercury Program, NASA had demonstrated that man could live in the weightless state for 1½ days, perform his job satisfactorily, and return unharmed. However, it is a long way from 1½ days to the 8 days required for the lunar trip. There were some optimists, not the least of whom were the astronauts themselves, but as recently as 1 year ago, diverse medical opinions existed as to the consequences of prolonged weightlessness, and many were greatly concerned. The Gemini Program produced the necessary evidence to prove that weightlessness would not be a limiting factor in the lunar program. As was discussed, the more sophisticated medical experiments which are planned for the remainder of the Gemini Program and for the Apollo Program will examine the total body system functions rather than simply gross postflight changes. This will provide necessary information regarding the possible effects of flights of much longer duration than the lunar landing mission.

The Gemini Program, because of the successful rendezvous mission, has also gone a long way toward removing the second constraint on the lunar landing program, that of rendezvous and docking. The successful rendezvous, as well as the long-duration flight, not only proved that man can survive weightlessness but demonstrated once and for all the vital role played by the astronauts in the performance of those missions. Because development of the rendezvous and docking techniques is of vital importance to the Apollo missions, subsequent Gemini flights are being tailored to simulate the constraints that will be imposed by the rendezvous of the lunar excursion module and the command and service modules in lunar orbit. The Gemini VII/VI–A rendezvous was conducted under ground direction in the initial phase, and by the crew using the onboard radar-computer system for the terminal phase. It has always been considered necessary to back up any rendezvous systems with optical techniques and equipment. In Apollo missions, where lives may depend upon successful rendezvous, the importance of simple reliable techniques cannot be overemphasized. Future Gemini missions will continue to evaluate these backup techniques. Several re-rendezvous and docking exercises on each mission will explore the relative effects of light and darkness as well as the effects of stars and earth background on vital acquisition and tracking of a rendezvous target. In spite of the great contributions already made to their program, the Apollo personnel are vitally interested in what will be learned in the remaining five Gemini missions.

What has Gemini contributed to other programs? An obvious example is the transfer of technology to the Manned Orbital Laboratory Program. This is a bit of reverse lend-lease to the Department of Defense as a partial repayment for the excellent support NASA has received and will continue to receive in the Gemini Program. In addition to Gemini's medical experiments, NASA has made a modest start in the development and performance of experiments and other disciplines. This has begun to stimulate the interest required to take full advantage of the capability of this program, and the Apollo Program which follows, to carry more advanced experiments.

Extravehicular activity has and will continue to increase our knowledge of man's ability to work in space outside the spacecraft itself. One result is the increased capability to perform useful experiments in space which will reduce the requirement for carrying equipment in the spacecraft or having it immediately available to the crew from inside the spacecraft. We can begin formulating plans for activities which will require resupply of personnel and life-support equipment or performance of maintenance on unmanned equipment.

NASA is halfway through the Gemini flight program. You have read a very optimistic series of presentations because the results have been excellent to date. In order to reach this halfway point in such an enthusiastic mood, NASA has had to solve many problems along the way. It cannot be overemphasized how hard this Gemini team has had to work to make it look so easy. You can be assured that it has not been a "piece of cake."

A word of general caution must be added in closing. The success of the manned space program to date is no guarantee in itself of future successes. As the Nation builds, step by step, the total capability in space, continued full support and even harder work than in the past will be required. A major setback could still require reassessment of the ability to meet goals on schedule. The Nation is now truly at the beginning of a major adventure in the exploration of space, but still has a long way to go.

PART II

31. EXPERIMENTS PROGRAM SUMMARY

By R. O. Piland, *Manager, Experiments Program Office, NASA Manned Spacecraft Center,* and P. R. Penrod, *Experiments Program Office, NASA Manned Spacecraft Center*

Introduction

The successful completion of the Mercury Program had shown without reservation that man can function ably as a pilot-engineer-experimenter for periods up to 34 hours in weightless flight. It was thus a primary objective of the Gemini Program to explore man's capabilities in an extension of these rules which would encompass both increased duration and complexity. Man's proved effectiveness as a scientific observer from the vantage point of orbital flight was amply supported by the capabilities of the Gemini spacecraft in the areas of scientific equipment accommodation, fuel budget and system for accurate attitude control, and habitability for extended missions. All of the above, in context with the planned mission profiles, afforded an unprecedented opportunity for the conduct of a comprehensive program of inflight experiments. From the very inception of the Gemini Program, therefore, there was a parallel and concerted effort by the National Aeronautics and Space Administration to seek out and foster the generation of suitable experiments from all sources. Among others, these would include educational institutions, varied U.S. Government agencies, NASA field centers, the Department of Defense, and industry laboratories.

The resultant complement of experiments included those of medical, scientific, and technological significance. The total program is summarized in table 31–I which shows, for each experiment, the numerical identification, name, principal investigator, principal-investigator organizational affiliation, and flights to date. It is noted that a total activity of 54 experimental efforts has so far been included in the flight program. By way of information, it is anticipated that the remainder of the Gemini Program (missions VIII through XII) will include some 56 experimental flight activities, which are similarly identified on table 31–I. Since final flight assignment has not been made, flight distribution is not shown.

It is also apparent that the concentration of experiments has been on the longer-duration missions. This, of course, is due to the inherent influence of time, which permits a larger data yield for time-sensitive parameters, repeated contacts with preselected subjects, and increased potential for objects of opportunity. Of major significance, however, was the increased crew time available for the operation of equipment and participation in experimental protocol. It should also be emphasized that planning on a programwide basis permits the scheduling of experiments on multiple flights if these additional data points with the associated continuity in time and procedures are particularly significant. Finally, more ambitious mission objectives such as crew extravehicular activities and rendezvous-and-docking permitted the programing of experiments which extend beyond the cabin confines of a single spacecraft, even beyond the limitations of a single mission.

Procedures

In order to most effectively take advantage of the capabilities described above, the procedures which are summarily defined here were employed.

Experiment proposals received were evaluated by NASA within the framework of the following major considerations:

(1) Scientific, technical, or biomedical merit
(2) Effect on safety of flight
(3) Extent of changes required to spacecraft
(4) Mission compatibility
(5) State of readiness and qualification of equipment
(6) Degree of crew participation
(7) Attitude-control fuel budget
(8) Weight and volume
(9) Instrumentation and electrical power

TABLE 31-I.—*Gemini Experiments*

[January 14, 1966]

Experiment number	Title	Principal investigator	Affiliation	Mission no.—					
				III	IV	V	VI	VII	VIII to XII
M-1	Cardiovascular conditioning	L. F. Dietlein	NASA-MSC			X		X	
M-3	Inflight exerciser	L. F. Dietlein	NASA-MSC		X	X		X	
M-4	Inflight phonocardiogram	L. F. Dietlein	NASA-MSC		X	X		X	
M-5	Bioassays body fluids	L. F. Dietlein	NASA-MSC					X	X
M-6	Bone demineralization	Pauline Mack	Texas Woman's University		X	X		X	
M-7	Calcium balance study	Whedon	National Institutes of Health					X	
M-8	Inflight sleep analysis	R. Adey and P. Kellaway	Baylor Medical School					X	X
M-9	Human otolith function	A. Graybiel	U.S. Navy			X		X	
MSC-1	Electrostatic charge	P. E. Lafferty	NASA-MSC		X	X			
MSC-2	Proton electron spectrometer	J. Marbach	NASA-MSC		X			X	
MSC-3	Tri-axis flux-gate magnetometer	W. D. Womack	NASA-MSC		X			X	X
MSC-4	Optical communication	D. Lilly	NASA-MSC					X	
MSC-5	Lunar UV spectral reflectance	R. C. Stokes	NASA-MSC						X
MSC-6	Beta spectrometer	J. Marbach	NASA-MSC						X
MSC-7	Bremsstrahlung spectrometer	R. S. Lindsey	NASA-MSC						X
MSC-8	Color patch photography	J. R. Brinkmann	NASA-MSC						X
MSC-10	Two-color earth's limb photography	M. Peterson	MIT		X				
MSC-12	Landmark contrast measurement	C. E. Manry	NASA-MSC					X	X
T-1	Reentry communications	L. C. Schroder	NASA-Langley	X					
T-2	Manual navigation sightings	D. Smith and B. Greer	NASA-Ames						X
D-1	Basic object photography	AF Avionics Lab	Wright-Patterson AFB			X			
D-2	Nearby object photography	AF Avionics Lab	Wright-Patterson AFB			X			
D-3	Mass determination	Air Force Field Office	NASA-MSC (DOD)						X
D-4	Celestial radiometry	AF Cambridge Lab	USAF-Hanscom Field			X		X	
D-5	Star occultation navigation	AF Avionics Lab	Wright-Patterson AFB					X	X
D-6	Surface photography	AF Avionics Lab	Wright-Patterson AFB			X			
D-7	Space object radiometry	AF Cambridge Lab	USAF-Hanscom Field			X		X	
D-8	Radiation in spacecraft	AF Weapons Lab	Kirkland AFB		X		X		
D-9	Simple navigation	AF Avionics Lab	Wright-Patterson AFB		X			X	
D-10	Ion-sensing attitude control	AF Cambridge Lab	USAF-Hanscom Field						X
D-12	Astronaut maneuvering unit	Air Force Field Office	NASA-MSC (DOD)						X
D-13	Astronaut visibility	S. Duntley	University of California			X		X	

D-14	UHF-VHF polarization	Naval Research Lab	U.S. Navy						X
D-15	Night image intensification	AF Avionics Lab	Wright-Patterson AFB						X
D-16	Power tool evaluation	Air Development Center	U.S. Navy						X
S-1	Zodiacal light photography	E. P. Ney	University of Minnesota			X			X
S-2	Sea urchin egg growth	R. S. Young	NASA-Ames	X					
S-3	Frog egg growth	R. S. Young	NASA-Ames						X
S-4	Radiation and zero g on blood	M. Bender	Atomic Energy Commission	X					X
S-5	Synoptic terrain photography	P. Lowman	NASA-Goddard		X	X	X	X	X
S-6	Synoptic weather photography	K. M. Nagler	U.S. Weather Bureau		X	X	X	X	X
S-7	Cloud top spectrometer	F. Saiedy	Natl. Environ. Sat. Center			X			X
S-8	Visual acuity	S. Duntley	University of California					X	
S-9	Nuclear emulsion	M. Shapiro and C. Fichtel	NRL and Goddard						
S-10	Agena micrometeorite collection	Dr. D. Hemenway	Dudley Observatory						X
S-11	Airglow horizon photography	H. Friedman	Naval Research Lab.						X
S-12	Micrometeorite collection	C. Hemenway	Dudley Observatory						X
S-13	UV astronomical camera	K. Henize	Dearborn Observatory						X
S-26	Ion wake measurement	D. Medved	Electro-Optical Systems, Inc.						X
	Total: 49 experiments			3	11	17	3	20	56

Having selected experiments which were in concert with the criteria in the above areas, the principal investigators for the proposed experiments were "contracted" by NASA to design, develop, qualify, and deliver flight equipment in accordance with the Gemini Program management and design criteria. Included also is the requirement to establish the necessary experiment protocol and support the preflight, flight, and postflight activities associated with the particular experiment.

Activities in the immediate preflight interval are variable and somewhat unique to the experiment. Crew familiarization with objectives and training in procedures are the responsibility of the principal investigators, and the principal investigator was required to define and assist as required in implementation. Similarly, where baseline data on crew physiological parameters are required, the principal investigator has an equivalent responsibility. Preparation and state of readiness of special ground targets or ground-located participating equipment is a principal-investigator task. Participation in final crew briefings, equipment checks, and NASA-sponsored press conferences is required.

During the flight, principal-investigator availability for consulting on real-time adjustment of experimental procedures is essential. Also, the manning and operation of ground targets and participating equipment sites are required.

Postflight activities include participation in the scientific debriefing of the crew. A summary compilation of experimental results is required for incorporation in the mission report during the immediate postflight interval. It is NASA policy to sponsor, within 90 days after flight, a public report of the experimental results in the degree of reduction and analysis that exists at the time. A final publication of results is required when data analysis is complete and conclusions are firmly established.

Summary Results

The results of the experiments included in the Gemini VI–A and VII missions that had a significant data yield will be reported in detail by the respective principal investigators later in this series of papers. In the cases where those experiments had flown previously, the total experimental results will be reflected. The results of experiments included on previous missions which were not included on VI–A and VII have been reported previously by the principal investigators but will be summarily reviewed here. References 1 and 2 contain experiment evaluations for the Gemini III, IV, and V missions, respectively. (A complete listing of reference material used by the principal investigators in the publication of their results is not repeated here but is concurrently recognized.)

The following synopsis is derived, for the most part, from the above references. It is emphasized that some of the results are tentative. In some cases the experimenters have not completed their analysis of the data. Moreover, a number of the experiments are repeated on several missions, and the total experiment is not complete until all missions have been conducted and the results correlated and analyzed.

S–1 Zodiacal Light Photography

Data from the Mercury Program had shown conclusively that experiments on extraterrestrial light could be performed above 90 kilometers without airglow contamination. The S–1 experiment flown on the Gemini V mission, then, was to address the following questions:

(a) What is the minimum angle from the sun at which the zodiacal light could be studied without twilight interference?

(b) Can the gegenschein be detected and measured above the airglow layer?

The experiment was successfully completed, and it demonstrated that approximately 16° is the smallest elongation angle at which zodiacal light may be studied without external occulting. Photographic results appear to show the gegenschein, the first time such efforts have been successful. Its center appears to have an angular size of about 10° and is within a very few degrees of the anti-sun direction. There is no evidence of the westerly displacement which might be expected if the phenomena resulted from a cometlike dust tail of the earth.

This single set of data (ref. 1) is interesting but does not establish firm conclusions, especially with respect to the source of the gegenschein. The experiment is to be flown on subsequent Gemini missions for additional data on these two, plus other dim light phenomena.

S–2 Sea Urchin Egg Growth

The objective of the S–2 experiment was to evaluate the effects of subgravity fields on fertilization, cell division, differentiation, and growth of a relatively simple biological system.

Inasmuch as the experimental results were negated by a mechanical failure of the inflight equipment, equipment description and experimental protocol are not included in detail.

S–4 Zero G and Radiation Effects on Blood

Biological effects of the types usually associated with radiation damage have been observed following space flight. These effects include mutation, production of chromosome aberrations, and cell killing. This could be due to either or both of two things: effects of the heavy-primaries component of radiation which is not available for test in terrestrial laboratories, or synergistic interaction between radiation and "weightlessness" or other space flight parameters. The S–4 experiment was to explore such possibilities.

The procedure was to irradiate a thoroughly studied biological material with a known quality and quantity of radiation during the zero-g phase of flight. This, with concurrent and equivalent irradiation of a duplicate ground-located control sample, would yield a comparative set of data and would be evidence of synergism, if it existed, between the radiation administered and some space flight parameter. Since chromosomal aberration is one of the best known effects of radiation, it was selected as a suitable response for the study.

The equipment operated properly, and the experimental procedures were successfully completed (ref. 2). The lack of aberrations in the postflight blood samples from the crew makes the possibility of residual effects of radiation encountered on such a space flight very unlikely, at least on genetic systems. The yield of single-break aberrations (deletions) for the inflight sample was roughly twice that seen in the ground control and previous samples. All physical evidence contradicts the possibility of variant radiation doses to the ground control and flight samples. It appears then that some space-flight parameter does interact synergistically with radiation. Although this effect is not large from the point of view of radiation cytogenics, it is of interest. Further experiments will be necessary in order to confirm the synergistic effect and to determine just which space-flight parameter or parameters are involved, as well as the mechanism of the action.

S–7 Cloud-Top Spectrometry

Tiros weather satellites have provided meteorologists with information on geographic distribution of cloudiness and a qualitative indication of cloud types. Meteorologists are further interested in cloud altitudes because altitude is indicative of the dynamic and thermodynamic state of the atmosphere on which weather forecasts are based. Basically, the method of the S–7 experiment consists of comparing the cloud's radiance in the oxygen A-band at 7600 angstroms (Å), with its radiance in an atmospheric window outside the band. The ratio will show the absorption or transmission of oxygen in the atmosphere above the cloud top.

The objective of the experiment was to test the feasibility of measuring cloud altitude by this method. As a correlation and calibration technique, concurrent cloud-top measurement by civilian and military aircraft was programed.

During the flight of Gemini V, 26 spectrographic observations were obtained on various cloud types, some for low clouds over the west coast of Baja California, some for relatively high clouds on a tropical storm in the Eastern Pacific, and some for tropical storm Doreen. From the data yield, it is quite apparent, qualitatively, that transmission in the oxygen band for high clouds is much larger than that for low clouds. The results (ref. 1) prove the feasibility of the cloud-altitude measurement from a spacecraft by this method. Already, system design requirements are being formulated for a more sophisticated second-generation weather satellite instrument.

D–1 Basic Object Photography, D–2 Nearby Object Photography, D–6 Surface Photography

The purpose of Experiments D–1, D–2, and D–6 was to investigate man's ability to acquire, track, and photograph objects in space and objects on the ground from earth orbit. These three experiments used the same equipment, and the experiment numbers primarily designate the type of object which served as the aiming point. In D–1 the aiming points were celestial bodies and the rendezvous evaluation pod (REP) at relatively long photographic range. The D–2 designated the short-range tracking and photographing of the REP, and the D–6 aiming points were objects on the ground.

Since investigation of acquisition and tracking techniques was the primary objective of these experiments, two acquisition modes and three tracking modes were employed using commercially available equipment.

On the Gemini V flight (ref. 1), D–1 was accomplished using celestial bodies as aiming points. Distant photography of the REP, however, was not possible because of spacecraft electrical-power difficulties which developed after REP ejection. The planned D–2 close-range photography of the REP was not possible for the same reason. The D–6 terrestrial photography was accomplished within the limitations dictated by weather conditions and by spacecraft electrical power and thruster conditions. The photographs obtained were significant only as an element of the data to be used in the evaluation of techniques. The other elements of data were time-correlated position and pointing information, atmospheric conditions, sun angle, exposure settings, and astronauts' flight logs and verbal comments.

D–5 Star Occultation Navigation

The objectives of the D–5 experiment were to determine the usefulness of star occultation measurements for space navigation, and to determine a horizon density profile to update atmospheric models for horizon-based measurement systems.

Knowledge of the time of occultation of a known star by a celestial body, as seen by an orbiting observer, determines a cylinder of position whose axis is the line through the star and the body center, and whose radius is equal to the occulting body radius. The times of six occultations provide information to uniquely determine all orbital parameters of the orbiting body. Determination of these times of occultation by the earth is difficult because of atmospheric attenuation of the star light. The star does not arbitrarily disappear but dims gradually into the horizon. Measurement of the percentage of dimming with respect to the altitude of this grazing ray from the star to the observer provides a percentage altitude for occultation. That is, the star can be assumed to be occulted when it reaches a predetermined percentage of its unattenuated value. The procedure for the D–5 experiment provides the means of measuring this attenuation with respect to time in order to determine the usefulness of the measurements for autonomous space navigation. In addition, the measurements would provide a density profile of the atmosphere which could be used to update the atmospheric model for this system and to refine models used for other forms of horizon-based navigation, orbit prediction, and missile launches.

Results of this experiment were negative due to a malfunction of the experimental hardware. A postflight analysis identified the source of failure. Corrective action has been implemented, and the experiment will be flown again later in the program.

D–8 Radiation in the Gemini Spacecraft

Prerequisite to successful completion of future manned-space-mission planning is the availability of data on the radiation environment and its shielding interactions. The D–8 experiment was for the purpose of gaining reliable empirical dosimetry data to support the above activities.

The quantitative and qualitative characterizations of the radiation levels associated with the Gemini mission originated, in the main, with those energetic protons and electrons present in the inner Van Allen belt and encountered each time the spacecraft passed over the South Atlantic Anomaly.

Instrumentation consisted of both active and passive dosimetry systems. The active instrument included tissue-equivalent chambers with response characteristics which match closely that of soft muscle. An active sensor was placed in a fixed location in the spacecraft, and another portable unit was used for survey purposes. Meticulous calibration of the instruments and inflight adherence to experimental protocol lend confidence in the validity of results (ref. 2). The average dose rate for all "non-anomaly" revolutions analyzed was found to be 0.15 millirad per hour.

Dose-rate data obtained from the South Atlantic Anomaly region shows a rapid and pronounced rise in magnitude over the cosmic levels; that is, rises of two orders in magnitude, or to more than 100 millirads per hour average. This is associated with an average "anomaly" transit time of 12 minutes.

The five passive dosimetry packages were to ascertain both total accumulated dose and the intensity of radiation causing it. They were located in areas of maximum, minimum, and intermediate shielding. Preflight investigation of the extraneous effects of onboard sources revealed this to be less than 1 millirad per day; therefore, all recorded data could be considered cosmic in nature.

There was a very good correlation between the integrated dose readings from the active and the passive dosimeters located in the same area. The difference was only 12 percent for the discharge ionization chamber. The variations that do exist are for known reasons, which will permit generation of suitable correction factors for the passive devices so that they can provide a reliable assessment of radiation dose on future missions.

D–9 Simple Navigation

The objective of the D–9 experiment was to demonstrate the utility of a technique for manual navigation during space flight. Considerable efforts prior to flight had been devoted to reducing the very complex orbital determination mathematics to a rather simple model which could be exercised by the use of tables or a simple handheld analog computer. The solution derived consisted of dividing the normally used six-degree-of-freedom analysis into two separate and distinct three-degree-of-freedom problems. The first would determine the size and shape of the orbit, and the second would yield in-orbit orientation. All of the data to support these calculations could be derived using a simple handheld sextant for making the necessary celestial and horizon observations.

The role this experiment has in the program is simple procedures and technique development. The equipment and experimental protocol have been reported previously and are described in reference 1. A detailed accounting of the sightings made is not included here, but on both Gemini IV and VII the procedures were successfully completed, the data yield was up to expectations, and only detailed analysis is required to arrive at the final conclusion. In summary, the basic concept was demonstrated to be feasible; however, the stability of the observables, specifically horizon determination on which system accuracy depends, needs further investigation.

MSC–1 Electrostatic Charge

The objective of the MSC–1 experiment was to establish a definition of the electrostatic potential on an orbiting Gemini spacecraft. This would permit calculation of the energy available for an electrical discharge between the Gemini spacecraft and another space vehicle.

The field readings on Gemini IV (ref. 2) were extremely large compared with what was expected; however, the data gave no reason to suspect any electrical or mechanical malfunction of the equipment. Investigations were initiated to determine whether the apparent electric field was due to some cause other than a true field at the surface of the spacecraft. A test series confirmed that the instrument was responsive to radiated radiofrequency energy and to charged plasma-current particles. The Gemini V instrument was modified to shield the sensor from electric fields terminating on the spacecraft. However, readings obtained on Gemini V were as high as those from Gemini IV. Investigations are continuing to identify the extraneous source of sensor stimuli. One hypothesis which is supported from a number of standpoints is enhanced ionospheric charged-particle concentrations resulting from outgassing of the spacecraft. Correlation with day/night cycle (thermal gradients), operation of the water boiler, fuel-cell purging, and mission time profile lends emphasis to this.

MSC–4 Optical Communications

The objectives of the MSC–4 experiment were to evaluate an optical communications system, to evaluate the crew as a pointing element, and to probe the atmosphere using an optical coherent radiator outside the atmosphere.

Inasmuch as unfavorable cloud conditions and operating difficulties for ground-based equipment all but negated a data yield, no significant discussion is included here. It was shown, however, that the laser beacon is visible at orbital altitudes, and static tests have shown that adequate signal-to-noise ratios can be obtained.

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MSC–10 Two-Color, Earth Limb Photography

The plans for guidance and navigation for the Apollo mission require observation of the earth, potentially its limb, in order to make a navigational fix. In this case, a precise definition of the observable limb is essential. The uncertain state of the lower atmosphere, with its tropospheric storms and the accompanying clouds, prompts a consideration of observing higher levels of the atmosphere that have a satisfactory predictability.

On the Gemini IV earth limb photographs, primary attention was given to the comparison of the terrestrial elevation of the blue above the red portion of each photographed limb. The profiles of the blue are more regular than the red in their brighter parts. Comparative values of the peak radiances, blue and red, of the limbs vary by nearly 50 percent. This is preliminary, and work still remains to evaluate the densitometric photography data in order to judge the validity of scattering theory to account for the blue limb profiles. (Detailed accounting is included in ref. 2.)

MSC–12 Landmark Contrast Measurement

The objective of the MSC–12 experiment was to measure the visual contrast of landmarks against their surroundings. These data were to be compared to calculated values of landmark contrast in order to determine the relative visibility of these landmarks when viewed from outside the atmosphere. The landmarks are potentially a source of data for the onboard Apollo guidance and navigation equipment.

This experiment depended on photometric data to be obtained by the photometer included in the D–5 equipment complement. As noted earlier, a malfunction of the photometer was experienced, which negated a data yield from this experiment.

T–1 Reentry Communication

The T–1 experiment was conducted during the Gemini III mission to determine whether water injection into the flow field around the spacecraft is effective in maintaining communications links during the reentry portion of the flight.

Attenuation levels were measured at ultra high frequency (UHF) and C-band frequencies with and without water injection. UHF signals which had been blacked out were restored to significant levels by high flow rate injection. The C-band signal was enhanced by medium to high flow rates. The recovered UHF signal exhibited an antenna pattern beamed in the radial direction of injection from the spacecraft. Postflight analysis shows that the UHF recovery agrees very well with injection penetration theory. More optimum antenna locations and injection sites should minimize the problem of resultant signal directionality. (Ref. 1 contains a detailed report.)

Conclusion

It is felt that the inflight experiments completed to date have been very successful and clearly indicate the desirability of fully exploiting the capabilities of subsequent spacecraft designs and missions for the conduct of an experiments program. Accordingly, the following programs are in effect:

(1) The remainder of the Gemini Program will reflect a continued emphasis on the conduct of inflight experiments. Certain of these will be an extension of a series which has already begun on missions III through VII. Others will be introduced as new experiments, some of which are of considerably increased complexity. As noted earlier, some 56 experimental activities are included.

(2) A series of experiments is being incorporated in Apollo earth-orbital flights.

(3) A lunar-surface experiments package is being developed for deployment on the lunar surface during a lunar-landing mission.

(4) An experiments pallet for Apollo service module accommodation of a heavier, more sophisticated payload is being developed.

(5) An extensive airplane flight-test program for remote-sensor development has been developed.

The results of these and similar programs should contribute immeasurably to the related technologies as well as to the basic and applied sciences.

References

1. Manned Space Flight Experiments Symposium, Gemini Missions III and IV, Oct. 18, 1965. (NASA publication.)

2. Manned Space-Flight Experiments Interim Report, Gemini V Mission, Jan. 6, 1966. (NASA publication.)

A
PHYSICAL SCIENCE EXPERIMENTS

32. GEOASTRONOMICAL OBSERVATIONS

By Franklin E. Roach, Ph. D., *Deputy Director, Aeronomy Division, Environmental Science Services Administration;* Lawrence Dunkelman, *Laboratory for Space Sciences, NASA Goddard Space Flight Center;* Jocelyn R. Gill, *Ph. D., Office of Space Science and Applications, NASA; and* Robert D. Mercer, *Flight Crew Support Division, NASA Manned Spacecraft Center*

Introduction and Summary

The manned Mercury orbital flights conducted from February 6, 1962, to May 16, 1963, established the following general features through visual observations by the astronauts:

(1) The night airglow band, centered some 90 kilometers above the earth, is visible at all times on the nightside of the earth. Visual measurements were made of the altitude, width, and luminance of the airglow (ref. 1) and were confirmed by rocket observations.

(2) As seen through the spacecraft window, the faintest stars observed at night, even under relatively ideal conditions, were described as of the fifth magnitude.

(3) With no moon, the earth's horizon is visible to the dark-adapted eye. The earth's surface is somewhat darker than the space just above it, which is filled with the diffuse light of airglow, zodiacal light, integrated starlight, and resolved stars.

(4) With the aid of starlight but no moon, zodiacal light, airglow, clouds, and coastlines are just visible to the dark-adapted eye.

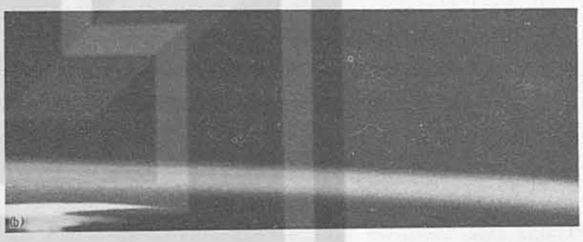
(5) With moonlight reflected on the earth, the horizon is still clearly defined, but, in this case, the earth is brighter than the background of space. Indeed, with moonlight, the clouds can be seen rather clearly, and their motion is distinct enough to provide a clue to the direction of the motion of the spacecraft.

(6) The night sky (other than in the vicinity of the airglow band and horizon) appears quite black, with the stars as well-defined points of light which do not twinkle. Lights on the earth do twinkle when viewed from above the atmosphere.

(7) The zodiacal light was successfully observed by Cooper in the last of the Mercury flights but was not seen during the previous Mercury flights, presumably because of the cabin lights which could not then be extinguished.

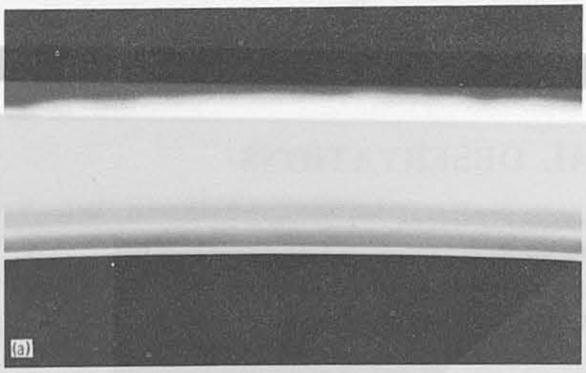
(8) A "high airglow" was observed on one occasion on the nightside by both Schirra and Cooper. Schirra described this as a brownish "smog-appearing" patch which he felt was higher and wider than the normal nightglow layer. Schirra observed this patch while over the Indian Ocean, and Cooper while over South America. It is possible that this phenomenon may have been a tropical 6300 angstroms (Å) atomic oxygen emission, first reported by Barbier and others (ref. 2).

(9) Twilight is characterized by a brilliant, banded, multicolored arc which exists along the horizon in both directions from the position of the sun. On MA–8, during twilight an observation was made, for the first time, of a very remarkable scene. The scene is shown in figure 32–1(a), which is a black-and-white reproduction of a color painting. The painting was made from Schirra's description (refs. 3 and 4) of a series of blue bands. Figure 32–1(b) is a black-



(*a*) Painting made from a MA–8 description of blue bands.

Figure 32–1.—Banding in the twilight horizon zone.



(*b*) Print from 16-mm color film exposed on Gemini IV.
FIGURE 32-1.—Concluded.

and-white reproduction of one of many frames of color, 16-mm movie film taken by McDivitt and White during Gemini IV. These color photographs were the first physical proof of the bands seen by Schirra, which had also been visually observed by Cooper during MA-9 (ref. 4).

(10) Finally, during the Mercury flights, the following phenomena were not observed:

(a) Vertical structure in the nightglow
(b) Polar auroras
(c) Meteors
(d) Comets

From the Gemini flights, additional information was derived which included:

(1) Specific information on day and night star sightings.

(2) Observations of aurora australis from Gemini IV and VII.

(3) Meteors were first observed by the Gemini IV crew and again by the Gemini VII crew.

(4) Vertical structure in the night airglow was first observed and noted in the logbook by Gemini IV crewmen.

In the following sections, more detailed discussions of these observations are given.

Observation of Stars

Nighttime

Information on star sightings at nighttime from the Gemini spacecraft indicates that, on the average, crews can generally observe stars slightly fainter than the sixth magnitude. The most objective evidence of this to date was reported by the Gemini VI-A and VII crews

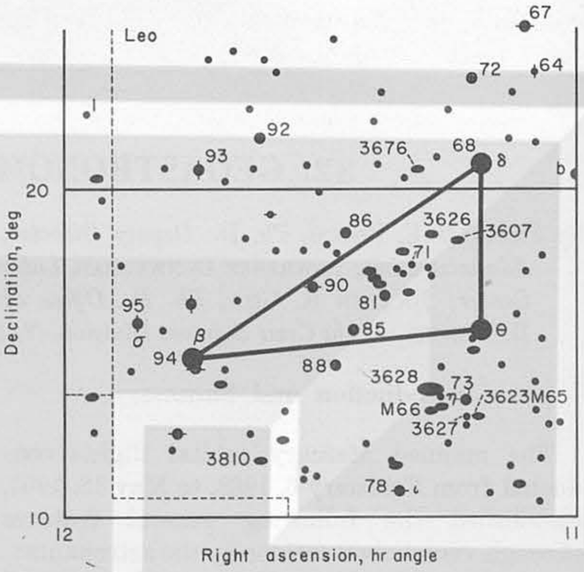


FIGURE 32-2.—Data on nighttime star observations by the Gemini VI-A flight crew.

through simple tests. Both Gemini VI-A crewmembers counted the number of stars they could see within the triangle Denebola and δ and *θ* Leonis shown in figure 32-2. The command pilot reported seeing two stars, and the pilot saw three. Referring to figure 32-2, this report indicates that at the moment of observation the command pilot could see to a magnitude between 6.00 and 6.05, while the pilot could see to a value greater than 6.05. Figure 32-3 is a test card, carried aboard the Gemini VII space-

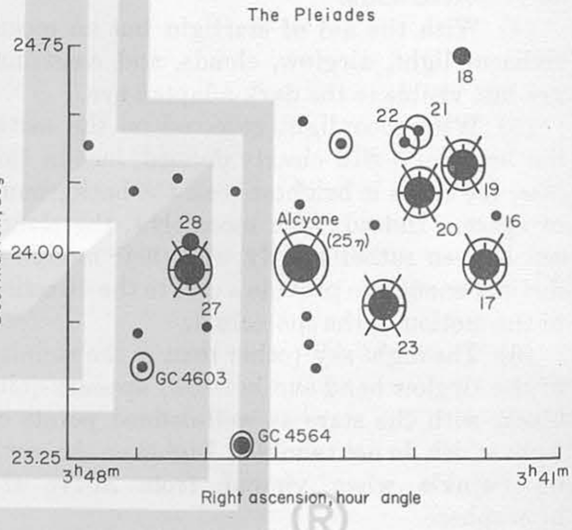


FIGURE 32-3.—Data on nighttime star observations by the Gemini VII flight crew.

craft, showing the area of the Pleiades with the crew's markings of observed stars. For purposes of this report, the stars shown here are identified in more detail than on the original card used by the crew so that a comparison can be made between the crew's markings and the accompanying list of identified stars and their magnitudes. The command pilot observed stars down to magnitudes in the range of 6.26 to 6.75, while the pilot could see to at least 4.37. Except for the pilot's observation, these compare well with less objective, but nevertheless important, sightings by the Gemini IV crew who carried a card showing the relative locations and magnitudes of stars in more than five well-known constellations in their nighttime sky. The constellation Corona Australis provided the most stringent test, with stars identified down to 5.95 magnitude. Both members of the crew reported that they could easily see all the stars on their card as well as fainter stars, whose brightness they estimated to be in the order of the seventh magnitude. All crews have made subjective comment that the number of nighttime stars seen from the spacecraft was greater than the number seen from their ground-based observations, and about the same or perhaps a little more than from a high-flying jet aircraft. The reports varied within this range from individual to individual during scientific debriefings of Gemini flight crews.

In the interest of accuracy and precision, it must be noted that even the best of these reported tests contain some subjectivity. A vigorous analysis of these results is simply not possible because of the many unknowns that have a great bearing on the results. Therefore, it seems appropriate at this time to briefly review the variable parameters whose value and/or constancy must be assumed in the absence of precise supporting data on values and on test procedures.

The end instrument in these tests is the human eye itself—a device whose extreme adaptability and whose variability makes its response characterization very difficult to ascertain. The subjectivity of results is also reinforced by the psychophysical nature of studies in vision.

Figure 32–4 shows a collection (refs. 5 and 6) of relationships which have a bearing on nighttime vision. Precise experiments concerning brightness sensitivity required a detailed knowledge of such parameters as—

(1) Retinal position of the image.

(2) Contrast between point source image and background.

(3) Degree of dark adaptation.

(4) Duration of point source exposure.

(5) Relative movement of the image (induced by subject or spacecraft).

(6) Color or hue of the image.

In most cases these parameters are composite functions that can be divided into even more detailed variables.

Several purely physical parameters associated with sightings from the Gemini spacecraft also have a great bearing on the end results. The effect of the transmission, absorption, and scattering of light as it passes through the triple-layered windowpanes is not completely known. In addition, each crewman has noted deposits on the spacecraft window, primarily on the outermost of the six surfaces. These deposits can be greatly restrictive to vision. Astronaut Lovell's results, which were two star magnitudes fainter than his associate's, are tentatively accredited to a more severe case of material deposition. Although the effect of this on light transmission—so important when dealing with very low light levels—is not known, its effect of light scattering during Gemini V and VII has been well documented by the visual acuity experimenters in section 34 of this report. However, during the nighttime the fraction of interior spacecraft light scattered and reflected into the crewmen's line of vision can present the most significant degradation to seeing, even with bright moonlight (either direct or reflected from the earth) incident on the heavily coated outer window surfaces. The problem of undesirable internal light, which is sometimes unavoidable for operational reasons, is clearly shown in figure 32–5. This is a nighttime photograph of the moon taken as part of the Gemini VII Dim Light Study reported separately. Although full information is not yet available, it should be noted that the photograph is a time exposure with the light inte-

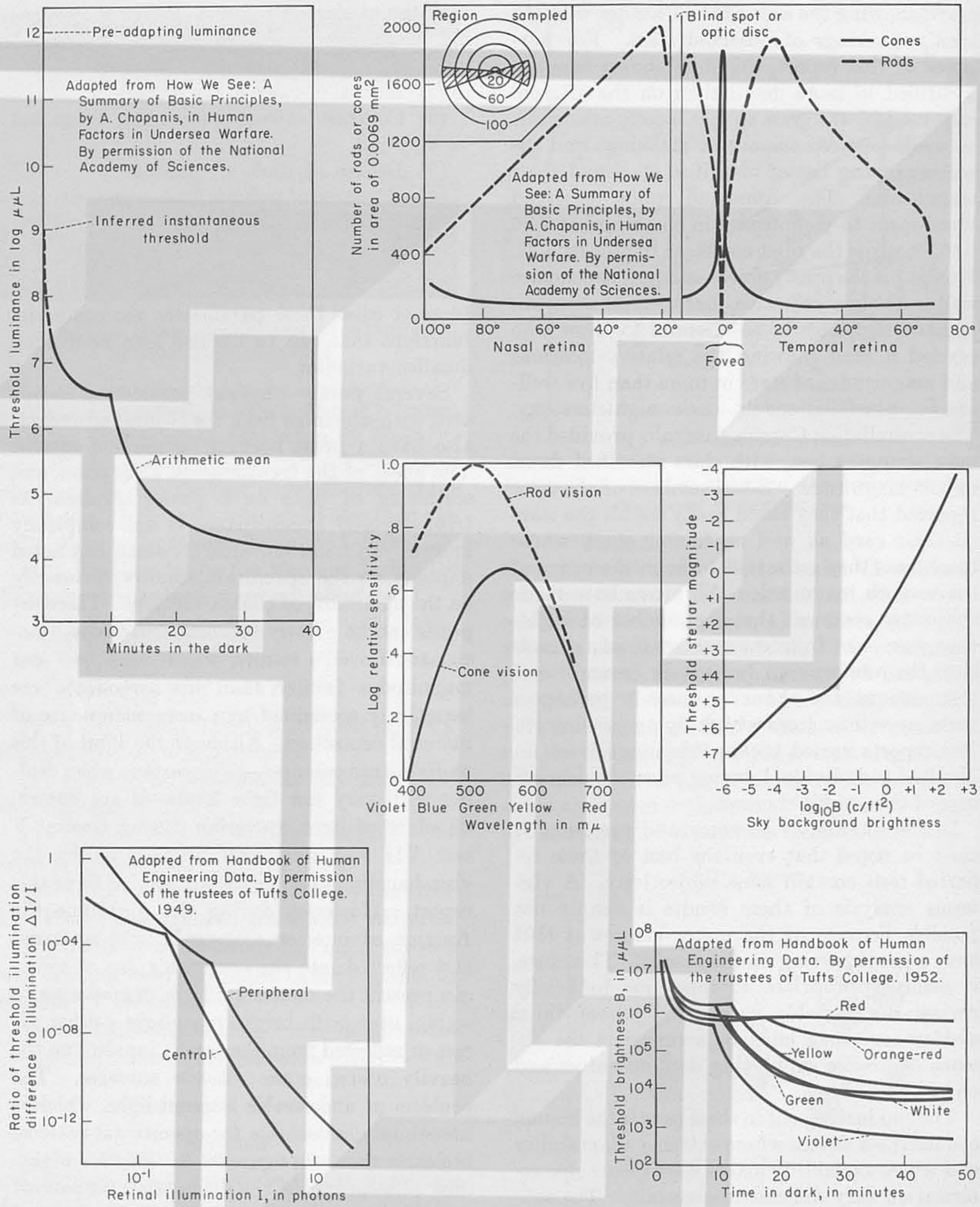


FIGURE 32-4.—Collection of important parameters in vision.

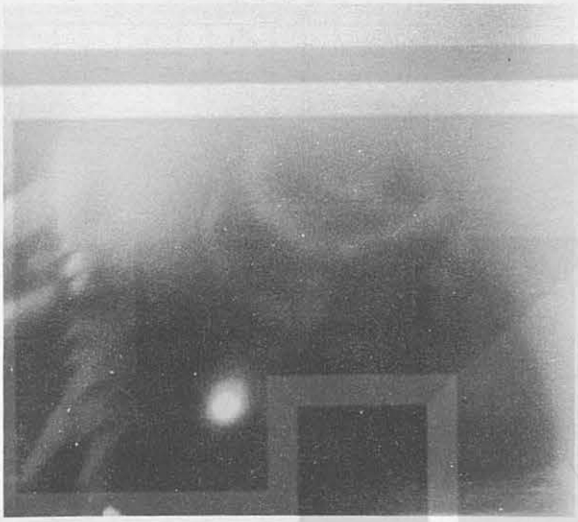


FIGURE 32-5.—Time exposure of moon with scattering and internal light reflections.

grated over several seconds. Thus, it does not necessarily represent the visual scene that would be apparent to the crew, but does exemplify a limiting factor in nighttime star observations by contrast reduction and interference with the low level of dark adaptation required.

Daytime

The sighting of stars in the daytime (when the sun is above the horizon as viewed from the spacecraft) has been difficult. Most of the difficulty comes from scattered sunlight and earthlight on the spacecraft window. Even sunlight or earthlight illuminating the interior of the spacecraft through the window other than the viewing window (in the shade) makes visual observations of stars difficult, if not impossible.

Stars were definitely observed in daylight in several instances. Two of these occurred in Gemini V and VI–A. In a paper being prepared by E. P. Ney, W. F. Huch, C. Conrad, and L. G. Cooper, evidence is given that first and second magnitude stars were seen in the daytime sky. This occurred when proper precautions were taken during the performance of the S–1 experiment.

In a paper under preparation by D. F. Grimm, W. M. Schirra, and T. P. Stafford, the sightings of stars in the daytime prior to and during rendezvous exercises are analyzed. Briefly, from the data on the observations of various stars in Orion, it is concluded that Schirra was able to see stars as faint as the fourth magnitude. This is deduced from his observation of several stars in the Sword of Orion. The subject of visibility of stars and planets during twilight has been treated comprehensively by Tousey and Koomen (ref. 5). As a result of that work, the current analyses from the Gemini flights, and from future flights where photometric observations are made simultaneously with visual observations of known stars, a rather complete analysis will be possible.

Observations of the Aurora Australis

The fact that the Mercury and Gemini orbits have been confined within geographic latitudes of about ±32° means that observation of the polar aurora should be infrequent. The zone where auroras are most frequently observed is some 23° from the geomagnetic pole, thus at a geomagnetic latitude of about 67°. The fact that the geomagnetic pole is approximately 11° from the geographic pole means that the auroral zone occurs at geographic latitudes in the range of 56° to 78°. The dip of the horizon from the spacecraft is significant—for example, about 17° for a spacecraft 150 nautical miles (278 kilometers) above the earth's surface. Thus, a spacecraft at such a height, at its extreme geographic latitude, affords line-of-sight visibility to the apparent horizon to 49° geographic latitude, only 7° from the auroral zone.

The auroral zone is not "well behaved" and actually affords a more favorable circumstance for spacecraft auroral observation than the preceding general discussion implies. Just to the south of western Australia (fig. 32–6), the auroral zone comes as far north as 51° S, which means that the southern horizon for a spacecraft at 150 nautical miles in this region, namely 49° S, is only about 2° from the auroral zone. It is well to recall that auroras, though they statistically occur more frequently in the auroral zone, do not occur exclusively in this region. Furthermore, the location of the auroral zone moves toward the equator during periods of geomagnetic activity. During times of geomagnetic storms, auroras become visible very far from the so-called auroral zone, and are even

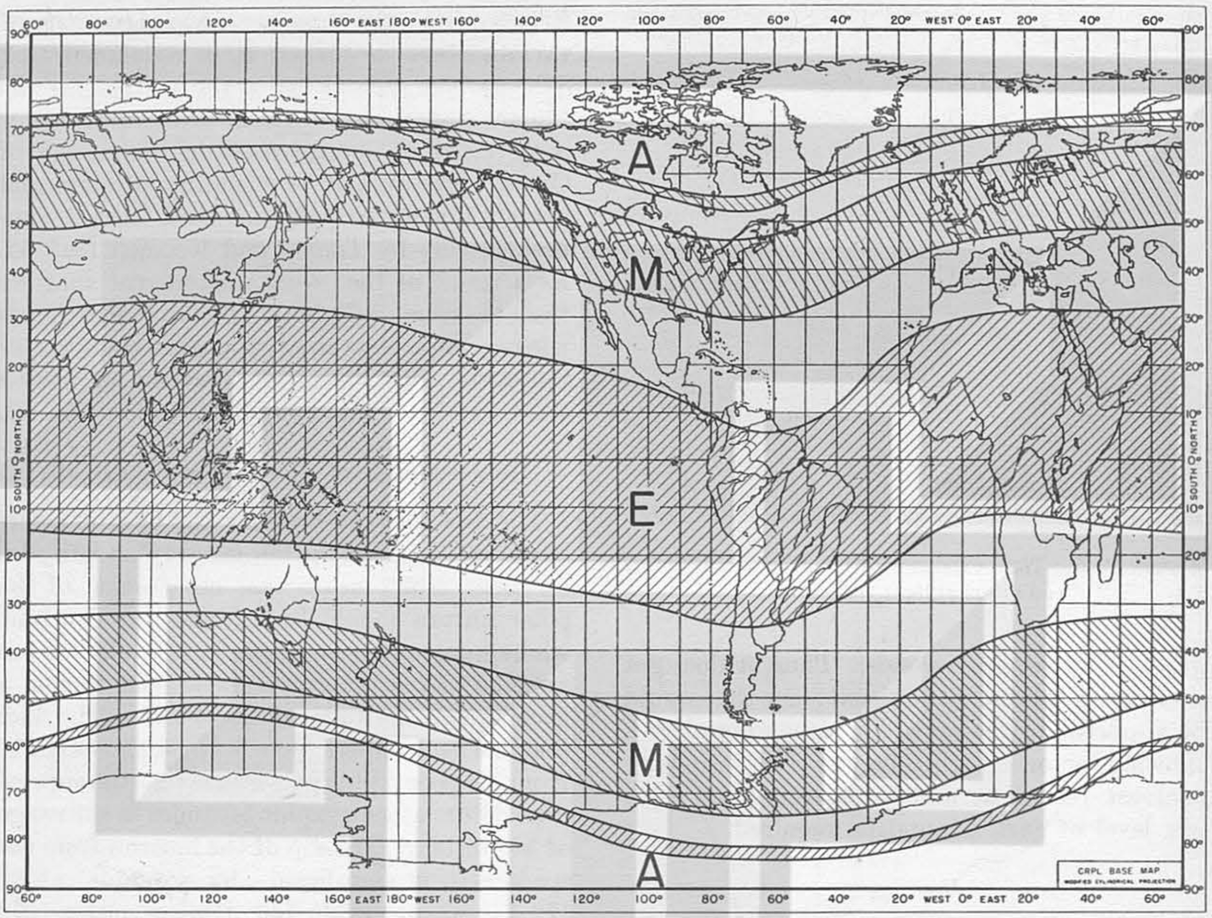


FIGURE 32-6.—Auroral map as seen from earth.

seen in the southern parts of the United States. The significant point in this discussion is that for the Gemini flights the combination of circumstances favors the observation of auroras to the south of the Australia region. The favorable factors for auroral observation are: (1) the apogee is near the southern extreme latitude, thus giving the maximum dip of the horizon; (2) the orbits are such that the spacecraft nights occur at longitudes near the general longitude of Australia; and (3) the southern auroral zone has its most equatorward excursion just south of Australia.

This report includes data from three separate flights in which auroral sightings to the south of Australia were noted by astronauts. During the Gemini IV flight, McDivitt and White saw an aurora in the form of auroral sheets projected against the earth. (See ref. 4, pp. 4 and 5, for a general description of what they saw.) Specifically, on June 4, 1965, at 17:24:37 Greenwich mean time (G.m.t.), at a spacecraft altitude of 151.41 nautical miles, at −31.89° geocentric latitude, −32.06° geodetic latitude, and 104.19° longitude, and with dip-of-horizon of −16.75°, the latitude of the southern horizon is −48.81°, very close to the best observing latitude in this region. Concerning this sighting, Astronaut White notes "the unusual display (June 4, 1965, 17 h. 24 m.) of night airglow combined with some northern-lights-type effect. The airglow looks lit up way out on the horizon." Some "spacecraft nights" later, McDivitt remarks:

I see the same sort of curve of lights like the northern lights except they are below us. I saw them another time. They were great big long lines . . . looks like arcs parallel to direction of flight path, and they extend from just below the airglow in the earth's horizon up a little past the top of the airglow, the same thing I saw the other night except not quite as bright as it was then.

The crew of Gemini V described a similar phenomenon in the same general location. During the 2-week flight of Gemini VII, the crewmen made a sketch of an auroral arc which was well defined between their apparent horizon and the airglow layer. Their sketch is reproduced as figure 32–7.

Meteors

A brief comment on the astronauts' meteor observations made during the early Gemini flights is given in reference 4. That Gemini V had the expectation of seeing a good many meteors can be seen from the Hourly Plots of Meteor Counts for July and August 1965 (fig. 32–8; also see ref. 7). Actually, the August meteors show more than a tenfold increase over the rest of the year. The crew's estimate of the number seen during the Gemini V flight is given in table 32–I. A much smaller number of meteors was observed during the flights of Gemini VII and VI–A (see table 32–I). This was expected, as shown in figure 32–9 (also see ref. 9), since the number of December meteors is greatly reduced as compared with the peak for the year, which occurs in August.

The number of meteors seen by the crew is a function of a number of factors, including the time interval in which they are observing (which may or may not include the actual peak of a shower), the nature of the Gemini window (their approximate angle of view is 50°), and the condition of that window (which will determine the limiting magnitude of the meteors seen). The Gemini VII pilot reported that his window was smudged, probably due to the staging process. Thus, only the bright meteors, within the rather small angle of view afforded by the spacecraft window, would catch the pilot's attention. So it is not surprising that so few meteors were reported during Gemini VII in spite of the pilot's attention to specific observation of them. Observation of meteors during Gemini VI–A was very much a chance

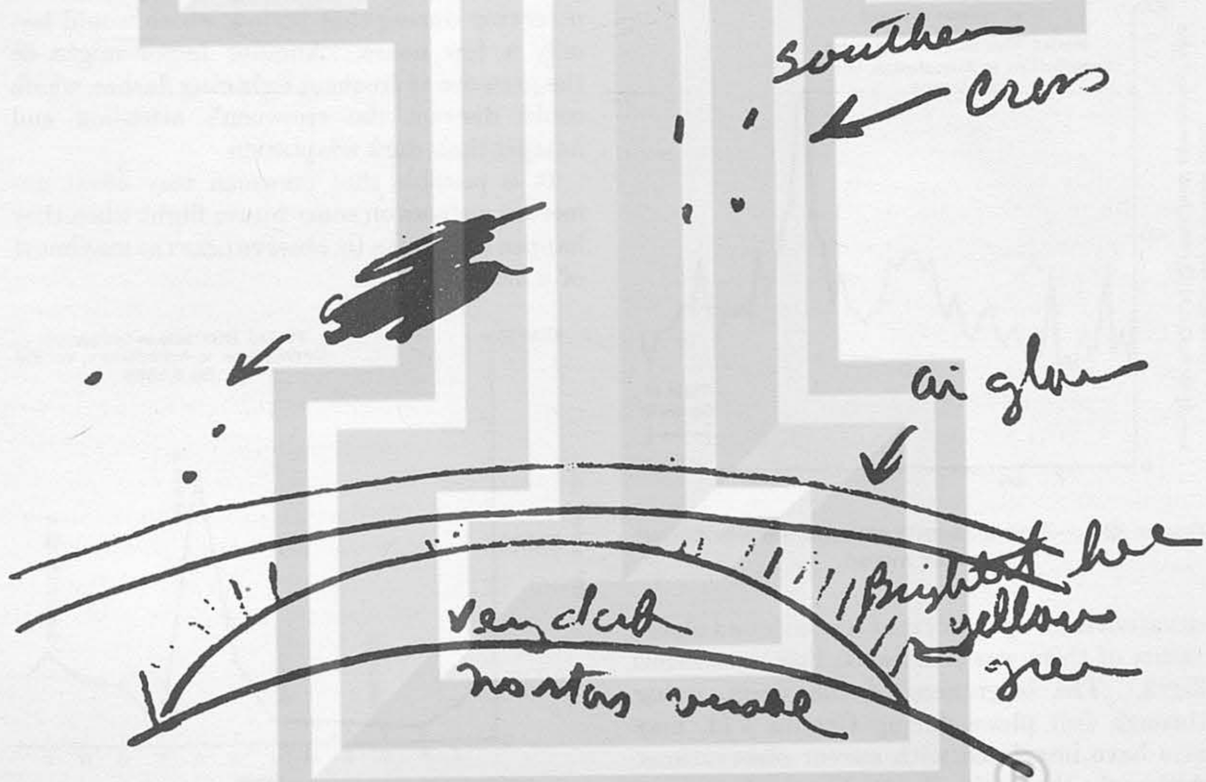


FIGURE 32–7.—Auroral arc as sketched by Gemini VII crewmen.

TABLE 32-I.—*Meteors Observed During Gemini Flights*

Flight no.	Date of flight (1965)	Duration	Phase of moon	Meteor shower [a]	Approximate date of maximum of shower [a]	Count reported by crew
III	Mar. 23	9 hr	Last quarter, Mar. 25	----------	----------	None
IV	June 3–7	4 days	First quarter, June 6	----------	----------	Many (no number given)
V	Aug. 21–28	8 days	Last quarter, Aug. 20	Perseids	Aug. 10 (Aug. 9–14) [b]	Numerous (20/hr estimated) [c]
VII	Dec. 4–18	14 days	First quarter, Dec. 1; last quarter, Dec. 15	Geminids	Dec. 11, 12 (Dec. 9–12)	3 total; [d] 1 in 30-minute observation interval
VI–A	Dec. 15	24 hr	Last quarter, Dec. 15	Geminids	----------	1 fireball

[a] See ref. 8.

[b] See ref. 9.

[c] The times of observation of 5 or more meteors are recorded on the onboard tape. Several of these were noted at the same time as lightning flashes.

[d] From the pilot's description, these were probably Geminids.

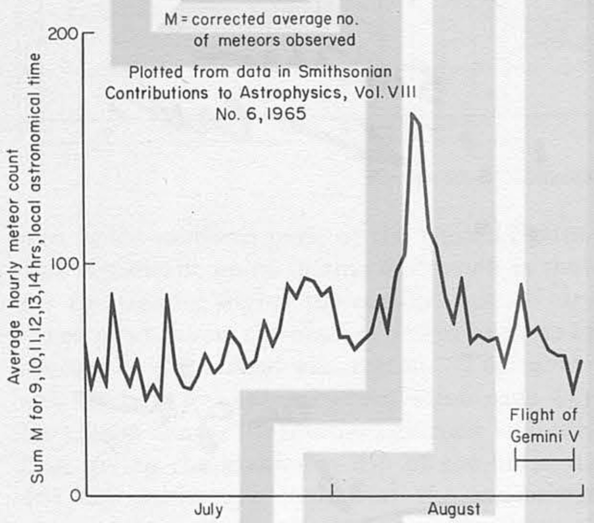


FIGURE 32-8.—Average hourly count of meteors during July and August.

situation since no interval of concentrated observation of them was possible on that rendezvous flight. The brightness of the moon, going through full phase during Gemini VII, may also have interfered with meteor observations. Although the peak of the Geminids meteor shower definitely occurred during the flight of Gemini VII, the crewmen probably were not observing during that period, which would last only a few hours. Another factor might be the presence of frequent lightning flashes, which could distract the crewmen's attention and hamper their dark adaptation.

It is possible that crewmen may count numerous meteors on some future flight when they happen to, or plan to, observe near the maximum of a meteor swarm.

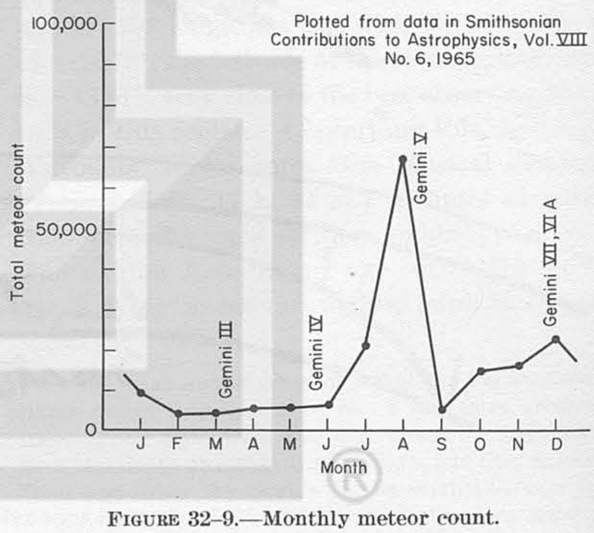


FIGURE 32-9.—Monthly meteor count.

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33. DIM LIGHT PHOTOGRAPHY

By LAWRENCE DUNKELMAN, *Laboratory for Space Sciences, NASA Goddard Space Flight Center, and* ROBERT D. MERCER, *Flight Crew Support Division, NASA Manned Spacecraft Center*

Introduction and Summary

For the Gemini VI and VII missions, plans were made to perform photography (on an opportunity basis) of a variety of dim-light phenomena with existing onboard cameras using "operational" film. Eastman No. 2475 film was selected for the morphological photography of Comet Ikeya-Seki. This work had been intended for Gemini VI as originally scheduled for October 25, 1965, just 5 days after perihelion passage of the comet. This investigation was brought about by a number of factors including the following:

(1) Previous, unaided eye observations by Mercury and Gemini astronauts which suggested the possibility and desirability of recording certain phenomena on film.

(2) An unusual event such as the newly discovered Comet Ikeya-Seki.

(3) The need to obtain additional information on airglow, for example, to assist in interpretation of results from an unmanned satellite, the first of the polar orbiting geophysical observatory series.

(4) The desire to obtain information on night cloud cover to assist in the design of future weather satellites.

(5) The desire to obtain information on the level of the luminance (brightness) of the day sky.

(6) The wish to study the earth's atmosphere by means of twilight limb photography, etc.

Another consideration, particularly in the case of the Gemini VII mission, was that during a 14-day mission, there might be sufficient time to exploit a number of observational possibilities. It was recognized that considerations of the mission requirements, operational procedures, and the scheduled experiments with the attendant fuel and time usage would probably preclude the performance of many of the dim-light photographic tasks. Nevertheless, it was determined that it would be useful to have an onboard checklist of subtasks and written related material that would permit maximum ultilization of the camera equipment and film allocated to the flights, should time and fuel become available. A reproduction of the detailed information written for the astronauts is available from the authors.

Other factors behind this type of investigation included:

(1) A study of the ease with which an observation or an experiment could be synthesized onboard (provided certain basic equipment was available to the crewmembers—in this case a flexible camera, interchangeable lens, a variety of black-and-white and color film, and some optical filters) based on phenomena observed by the crewmembers or transmitted to them from the ground. The information transmitted, in turn, could come either as a result of ground, rocket, or satellite observations, or as a spontaneous need to obtain some knowledge from the spacecraft.

(2) Additional experience which might benefit related experiments such as stellar spectroscopy and airglow photography which are definitely selected for the later Gemini missions.

(3) The further advancement of the acquisition of data on the optical environment of a manned satellite.

(4) The desire to continue to give the crewmen the opportunity to bring back objective information to support and add to their visual observations.

(5) The wish to obtain information to help define future experiments as to design, procedure, scheduling, interference, and complexity.

This report should be considered only as a progress report, inasmuch as at this writing all the onboard voice recordings are not available for study, and there has been insufficient time to analyze the recorded briefings and to identify and analyze the film with a densitometer.

The specific phenomena for possible study and photography during the missions included: (1) twilight scene, (2) night cloud cover, (3) sunlit airglow, (4) day-sky background, (5) night airglow, edge-on, (6) aurorae, (7) meteors, (8) lightning, (9) artificial lighting, (10) galactic survey, (11) zodiacal light and gegenschein, and (12) comets.

Formal briefings and training of the crewmembers for this study were minimal, which was both possible and necessary for several reasons. Except for three narrow-bandpass filters, this study used only onboard equipment, with which the crew were familiar. Even the use of lens filters was not new, since a minus blue haze filter was onboard for use in terrestrial photography. The crewmembers had been exposed to information about dim light phenomena briefly on several occasions during their basic training in astronomy and atmospheric physics. This had been reinforced during discussions and debriefing sessions with previous crewmembers, and Astronaut Schirra had observed some of these phenomena directly during his MA–8 mission. Because this study was approved and inserted into the flight plan at a late date, due to its low priority in a very busy schedule of events, and because the investigators (as well as the crews) did not wish to add a disorganizing influence late in the planning, the investigators chose properly to omit a formal briefing. Instead, the crewmembers were provided with written material and checklists to acquaint them with the specific operational tasks and inflight judgments required to obtain data and to respond quickly to ground requests as opportunities arose during the flight.

Photographs taken and identified at this time (February 6, 1966) included:

(1) Black-and-white as well as color shots of the twilight scene.

(2) A series showing night cloud cover where the illumination was the sum of lunar, airglow, zodiacal, and stellar light.

(3) Lightning.

(4) Airglow, edge-on.

(5) Thrusters.

(6) The Gemini VII spacecraft from Gemini VI–A.

(7) Probably the third stage of a Minuteman rocket and possibly its reentry vehicle.

Many tasks were not performed because of fuel- and weather-related scheduling problems. It is emphasized here that all the approved experiments reported elsewhere were properly accorded higher priority.

Description

A fuller description of all the phenomena listed in the introduction for possible photography has been prepared by the authors (ref. 1). For brevity, only those tasks for which there was an opportunity to photograph from Gemini VI–A or Gemini VII are given here. However, for ready reference and illustration, the checklist placed onboard is reproduced as figure 33–1. The exposures shown were based on an American Standards Association (ASA) value of several thousands for the Eastman 2475 film, using data reported by Hennes and Dunkelman, 1966 (ref. 2).

It is emphasized that the tasks and procedures were related to the approved onboard cameras, which included:

(1) Hasselblad (70-mm film) with 80-mm (f/2.8) lens and 250-mm (f/5.6) telephoto lens.

(2) Movie/sequence Maurer 16-mm camera.

For dim-light photography, faster lenses would have been desirable. Nevertheless, in some cases, it was still considered reasonable to use these relatively slow lenses, with the highest speed film available, for survey purposes.

Results

Reproductions of three photographs, whose analysis has recently begun, are shown on the following pages. Figure 33–2 is a photograph of the Gemini VII spacecraft taken from Gemini VI–A during the rendezvous exercise. Most of the illumination was furnished from the Gemini VI–A docking light, since the moon was in the last quarter and produced an illuminance of only 10 percent of full moonlight. Figure 33–3 is a photograph, from a 140-nautical-mile slant angle, of a Minuteman missile reentering the earth's atmosphere showing the

DIM LIGHT PHOTOGRAPHY

CODING: 1 = HASSELBLAD 2 = 16 MM MAURER
3 = 2475 B & W 4 = SO 217 COLOR
A = 80 MM LENS B = 250 MM LENS
C = F-STOP 2.8 D = F-STOP 5.6
X = 75 MM LENS Y = 1 FPS, 1/50

1.TWILIGHT BANDS: POST-SUNSET OR PRE-SUNRISE

EQUIP		1	2	3	4	5	6
CODE 14B	F	11	5.6	5.6	5.6	5.6	5.6
	T	1/500	1/500	1/125	1/30	1/8	1/2
CODE 24XY	F	32	22	16	11	8	5.6
	T	10	10	10	10	10	10

7	8	9	10
5.6	5.6	5.6	5.6
2	10	30	120
4	2.5		
10	210		

REVERSE ORDER OF SEQUENCE FOR PRE-SUNRISE: HORIZON JUST ABOVE SUNSET IN LOWER LEFT OR RIGHT CORNER

2.NIGHT CLOUD COVER: CODE 13AC, TRACK CLOUDS

CONDITIONS VS TIME	1	2	3	4
NO MOON	8	16	-	-
QUARTER MOON	1/4	1/2	1	2
FULL MOON	1/30	1/15	1/8	1/4

3 SUNLIT AIRGLOW: CODE 13AC

NO	SUBJECT/COND	SET	1	2	3
1	sunset +60 SEC HORIZON SCENE, SET POINT CENTERED IN LOWER PART OF PHOTO	T	1/8	1/8	1/8
		FTR	6300	6225	5300
		-	4	5	6
		T	10	10	10
		FTR	5300	6225	5300
2	SMOST SET/RISE +/-60 SOUTH HZ	(SAME TIME/FILTER SEQUENCE AS NO. 1)			
3	NORTH OR SOUTH HORIZON AT MID NIGHT ±10 MIN	SET	1	2	3
		T	10	10	10
		FTR	6300	6225	5300
4	NMOST SET/RISE +/-60 NORTH HZ	(SAME TIME/FILTER SEQUENCE AS NO. 1)			
5	SUNRISE -60 SEC AT HORIZON	(REVRS TIME/FILTER SEQUENCE AS NO. 1)			

4.DAY SKY BACKGROUND: CODE 13AC, WINDOW SHADED FROM SUN & EARTHSHINE - POINT CAMERA TOWARD SKY, 3 EXP; 5, 30 120 SEC

5.NIGHT AIRGLOW EDGE-ON: CODE 13AC - 5 EXP; 1/2, 1, 2, 4, 8 SEC WITH HORIZON IN FIELD

6.AURORAE: CODE 13AC TWO TYPES OF AURORA

BRIGHT	1/8	1/2	2
DIM	1	4	15

7.METEORS: CODE 13AC

TOTAL COUNT	30	120	300
INDIVIDUAL RECORD	AS REQUIRED		

8.LIGHTING: USE WITH BOTH CODES: 13AC 13BD

TOTAL COUNT	10	30	120	300
INDIVIDUAL RECORD	AS	REQUIRED		

DO WITH METEORS

9.ARTIFICIAL LIGHTING: CODE 13AC, 1/8, 1/2; AND CODE 13BD, 1/4, 1 SEC

10.GALACTIC SURVEY: CODE 13, HOLD +1/2 DEG

SUBJECT/COND	1	2	3	4	5	6	7
ORION OR PEG	80	80	80	80	80	250	250
ASUS, MOON	2.8	2.8	2.8	5.6	5.6	5.6	5.6
45 DEG AWAY	60	120	240	120	240	120	240

CODE AC, EACH EXP 90 SEC, DO EACH ZODIACAL CONSTELLATION TO WITHIN 15° OF SUN

11.ZODIACAL LIGHT & GEGENSCHEIN: CODE 13AC

5-10 MIN INTO DARK

ZODIACAL	1/16	1/4	1	3	5
GEGENSCH	10	30	60	120	-

12.COMET: CODE 13AC OR 13BD IF PHOTOS TAKEN

FOLLOWING LIST OF KEY WORDS/PHRASES AS REF

TIME HACK STAR TRANSITS	GLARE & LIGHTING
ANGULAR MEASUREMENTS	LAYERS/STREAK/THICK-
LOCATE POSITION	NESS/SEPERATION/HUE/
ADJACENT STARS/PLANETS	COLOR/BRIGHTNESS/
ESTIMATE ATTITUDE/RATES	EDGE FEATURES/COUNT.

FIGURE 33-1.—Crew inflight checklist for dim-light study.

FIGURE 33-2.—Gemini VII spacecraft as photographed at night by Gemini VI-A flight crew.

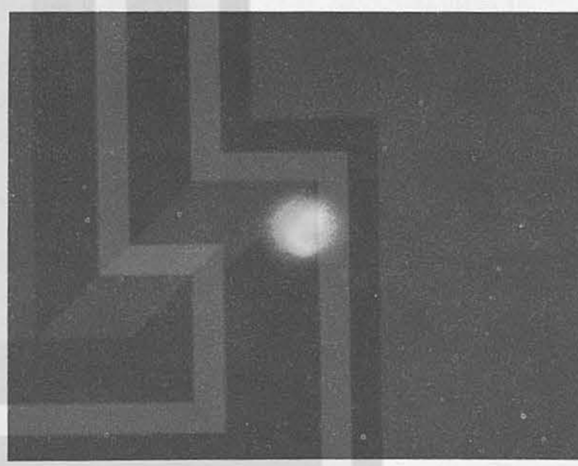

FIGURE 33-3.—Reentering Minuteman missile as photographed by Gemini VII flight crew.

FIGURE 33-4.—Nightglow, moonlit earth and clouds, and lightning in clouds as photographed by Gemini VII flight crew.

glow from the third-stage rocket and possibly its reentry vehicle. Figure 33-4 is one of a series of scenes showing night cloud cover. The exposure was 8 seconds at a lens setting of f/2.8 and was taken when the moon was almost full. The night airglow is seen in the original film as a rather faint but distinctly visible layer. When comparing this photograph with those taken of the night airglow from a rocket (ref. 2), it is difficult to explain the faint layer when taking into account the apertures, time, and film. An analysis is in progress to determine whether the exposure here is effectively less than f/2.8. The bright-appearing cloud just to the right of the center is believed to be caused by lightning.

Certain new experiments, or at least modifications or additions to those already scheduled for later manned flights, were identified. Among these are:

(1) Photographic and spectroscopic studies of the twilight scene in order to study aerosol heights and composition.

(2) Photographic and/or photoelectric luminance (brightness) of the day-sky background (related to the difficulties of seeing stars in the daytime) and otherwise making physical observations during the daytime phase. (As an example, the S-1 experiment planned for Gemini VIII will include at least one exposure to obtain data on the day sky.)

(3) Further studies of night cloud cover.

(4) Planetary spectrophotography.

(5) Photoelectric measurements to support both visual estimates and photographic exposures for phenomena too dim for "standard" exposure meters.

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34. EXPERIMENT S–8/D–13, VISUAL ACUITY AND ASTRONAUT VISIBILITY

By Seibert Q. Duntley, Ph. D., *Director, Visibility Laboratory, Scripps Institution of Oceanography, University of California;* Roswell W. Austin, *Visibility Laboratory, Scripps Institution of Oceanography, University of California;* John H. Taylor, *Visibility Laboratory, Scripps Institution of Oceanography, University of California; and* James L. Harris, *Visibility Laboratory, Scripps Institution of Oceanography, University of California*

Summary

Preflight, inflight, and postflight tests of the visual acuity of the members of the Gemini V and Gemini VII crews showed no statistically significant change in their visual capability. Observations of a prepared and monitored pattern of rectangles made at a ground site near Laredo, Tex., confirmed that the visual performance of the astronauts in space was within the statistical range of their respective preflight thresholds, and that laboratory visual acuity data can be combined with environmental optical data to predict correctly man's limiting visual capability to discriminate small objects on the surface of the earth in daytime.

Introduction

Reports by Mercury astronauts of their sighting small objects on the ground prompted the initiation of a controlled visual acuity experiment which was conducted in both Gemini V and Gemini VII. The first objective of Experiment S–8/D–13 was to measure the visual acuity of the crewmembers before, during, and after long-duration space flights in order to ascertain the effects of a prolonged spacecraft environment. The second objective was to test the use of basic visual acuity data, combined with measured optical properties of ground objects and their natural lighting, as well as of the atmosphere and the spacecraft window, for predicting the flight crew's limiting naked-eye visual capability to discriminate small objects on the surface of the earth in daylight.

Inflight Vision Tests

Inflight Vision Tester

Throughout the flights of Gemini V and Gemini VII, the visual performance of the crewmembers was tested one or more times each day by means of an inflight vision tester. This was a small, self-contained, binocular optical device containing a transilluminated array of 36 high-contrast and low-contrast rectangles. Half of the rectangles were oriented vertically in the field of view, and half were oriented horizontally. Rectangle size, contrast, and orientation were randomized; the presentation was sequential; and the sequences were nonrepetitive. Each rectangle was viewed singly at the center of a 30° adapting field, the apparent luminance of which was 116 foot-lamberts. Both members of the flight crew made forced-choice judgments of the orientation of each rectangle and indicated their responses by punching holes in a record card. Electrical power for illumination within the instrument was derived from the spacecraft.

The space available between the eyes of the astronaut and the sloping inner surface of the spacecraft window, a matter of 8 or 9 inches, were important constraints on the physical size of the instrument. The superior visual performance of all crewmembers, as evidenced by clinical test scores, made it necessary to use great care in alining the instrument with the observer's eyes, since the eyes and not the instrument must set the limit of resolution. In order to achieve this, the permissible tolerance of decentering between a corneal pole and the corresponding optical axis of the eyepiece was less than 0.005 of an inch. This tolerance was met by means of a biteboard equipped with the flight crewmember's dental impression to take advantage of the fixed geometrical relation between his upper teeth and his eyes. Figure 34–1 is a photograph of the inflight vision tester.

Selection of the Test

The choice of test was made only after protracted study. Many interacting requirements were considered. If, for example, the visual capabilities of the astronauts should change during the long-duration flight, it would be of prime importance to measure the change in such a way that man's inflight ability to recognize, classify, and identify landmarks or unknown objects on the ground or in space could be predicted. These higher-order visual discriminations depend upon the quadratic content of the difference images between alternative objects, but virtually all of the conventional patterns used in testing vision yield low-precision information on this important parameter. Thus, the prediction requirement tended to eliminate the use of Snellen letters, Landolt rings, checkerboards, and all forms of detection threshold tests.

The readings must not go off-scale if visual changes should occur during flight. This requirement for a broad range of testing was not readily compatible with the desire to have fine steps within the test and yet have sufficient replication to insure statistically significant results.

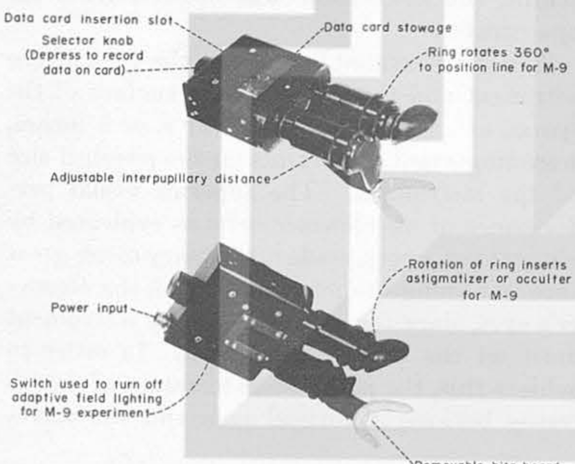

FIGURE 34–1.—Inflight vision tester.

It was also deemed desirable that the pattern chosen for the inflight vision tester should be compatible with that used on the ground where search contamination of the scores must be carefully avoided; this consideration made any conventional detection threshold test undesirable. The pattern on the ground was within sight for at least 2 minutes during all usable passes, but variations due to atmospheric effects, geometrical foreshortening, directional reflectance characteristics, etc., made it necessary to select a test which could be completed in a 20-second period centered about the time of closest approach.

The optimum choice of test proved to be the orientation discrimination of a bar narrow enough to be unresolved in width but long enough to provide for threshold orientation discrimination. The size and apparent contrast of all of the bars used in the test were sufficient to make them readily detectable, but only the larger members of the series were above the threshold of orientation discrimination. These two thresholds are more widely separated for the bar than for any other known test object. The inherent quadratic content of the difference image between orthogonal bars is of greater magnitude than the inherent quadratic content of the bar itself. Interpretation of any changes in the visual performance of the astronauts is, therefore, more generally possible on the basis of orientation discrimination thresholds for the bar than from any other known datum.

Rectangles in the Vision Tester

The rectangles presented for viewing within the inflight vision tester were reproduced photographically on a transparent disk. Two series of rectangles were included, the major series set at a contrast of −1 and the minor series set at about one-fourth of this value. The higher contrast series constituted the primary test and was chosen to simulate the expected range of apparent contrast presented by the ground panels to the eyes of the crewmen in orbit. The series consisted of six sizes of rectangles. The sizes covered a sufficient range to guard against virtually any conceivable change in the visual performance of the astronauts during the long-duration flight. The size intervals were small enough, however, to provide a sufficiently sensitive test.

The stringent requirements imposed by conditions of space flight made it impossible to use as many replications of each rectangle as was desirable from statistical considerations. After much study, it was decided to display each of the six rectangular sizes four times. This compromise produced a sufficient statistical sample to make the sensitivity of the inflight test comparable to that ordinarily achieved with the most common variety of clinical wall chart. This sensitivity corresponds roughly to the ability to separate performance at 20/15 from performance at 20/20. It was judged that this compromise between the sensitivity of test and the range of the variables tested was the proper one for this exploratory investigation.

A secondary test at lower contrast was included as a safeguard against the possibility that visual performance at low contrast might change in some different way. With only 12 rectangles assignable within the inflight vision tester for the low-contrast array, it was decided to use only 3 widely different rectangle sizes, presenting each of these sizes 4 times.

Because of the accelerated launch schedule of Gemini V, it was not possible to use the flight instrument for preflight experiments. These data were, therefore, obtained with the first of the inflight vision testers (serial no. 1), while the last instrument to be constructed (serial no. 5) was put aboard the spacecraft. The two instruments were optically identical except for their 12 low-contrast rectangles, which measured a contrast of −0.332 and −0.233, respectively. In Gemini VII all of the reported data (preflight, inflight, and postflight) were obtained with serial no. 5 tester.

Analysis of Correct Scores in Gemini V

A comparison of the correct scores made by the Gemini V crewmembers on the ground (preflight) and in space (inflight) can be used to ascertain whether their observed visual performance differed in the environments or changed during the 7-day mission. The correct scores from the low-contrast and high-contrast series in the vision tester are shown for both crewmembers in figure 34–2. The results of standard statistical tests applied to these data are shown in tables 34–I through 34–IV.

Comparisons between preflight and inflight data are given in tables 34–I and 34–II. All Student's t tests show no significant difference in means. All Snedecor's F tests show no significant difference in variances at the 0.05 level, with the exception of Cooper's high-contrast comparison, which shows no significant difference at the 0.01 level.

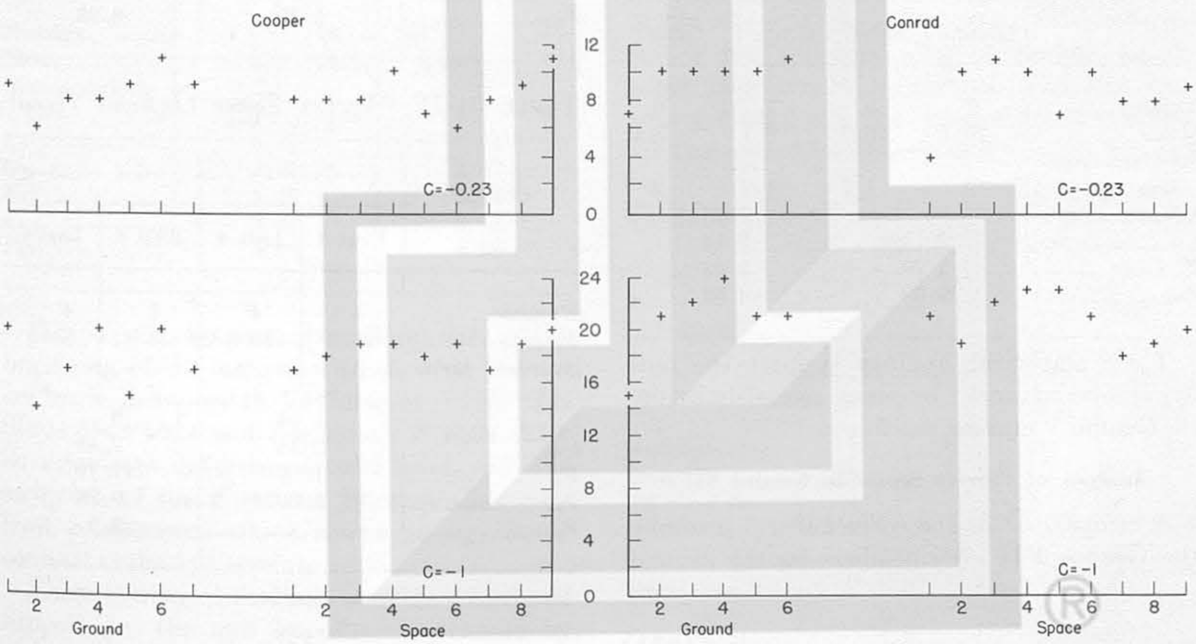

FIGURE 34–2.—Correct vision-tester scores for Gemini V flight crew.

Comparisons between the inflight data at the beginning of the mission with that at the end are made in tables 34–III and 34–IV. All Student's t tests and Snedecor's F tests show no significant differences at 0.05 level, with the exception of the F test on Conrad's low-contrast comparison, which shows no significant contrast at 0.01 level.

TABLE 34–I.—*Vision Tester (Ground Versus Space*

Cooper	$C=-1$		$C=-0.23$	
	Ground	Space	Ground	Space
Number	7	9	7	9
Mean	17.6	18.4	8.6	8.3
Standard deviation	2.3	.96	1.3	1.4
t	0.96		0.31	
$t_{0.05}$	2.14		2.14	
F	6.12		1.02	
$F_{0.05}$	3.58		3.58	
$F_{0.01}$	6.37		----------	

TABLE 34–II.—*Vision Tester (Ground Versus Space)*

Conrad	$C=-1$		$C=-0.23$	
	Ground	Space	Ground	Space
Number	7	9	7	9
Mean	20.7	20.7	9.7	8.6
Standard deviation	2.7	1.7	1.2	2.0
t	0		1.13	
$t_{0.05}$	2.14		2.14	
F	2.79		2.43	
$F_{0.05}$	3.69		4.82	

These statistical findings support the null hypothesis advanced by many scientists before the Gemini V mission was flown.

Analysis of Correct Scores in Gemini VII

A comparison of the correct scores made by the Gemini VII crewmembers on the ground (preflight) and in space (inflight) can be used to ascertain whether their observed visual performance differed in the environments or changed during the 14-day mission. The correct scores from the low-contrast and high-contrast series in the vision tester are shown for both crewmembers in figure 34–3. The results of standard statistical tests applied to these data are shown in tables 34–V through 34–VIII.

Comparisons between preflight and inflight data are given in tables 34–V and 34–VI. All Student's t tests show no significant difference in means. All Snedecor's F tests show no significant difference in variances at the 0.05 level, with the exception of Borman's low-contrast comparison, which shows a weekly significant difference at the 0.01 level.

TABLE 34–III.—*Vision Tester (Inflight Trend)*

Cooper	$C=-1$		$C=-0.23$	
	First 4	Last 4	First 4	Last 4
Number	4	4	4	4
Mean	18.2	18.8	8.5	8.5
Standard deviation	.83	1.1	.87	1.8
t	0.68		0	
$t_{0.05}$	2.45		2.45	
F	1.73		4.33	
$F_{0.05}$	9.28		9.28	

TABLE 34–IV.—*Vision Tester (Inflight Trend)*

Conrad	$C=-1$		$C=-0.23$	
	First 4	Last 4	First 4	Last 4
Number	4	4	4	4
Mean	21.3	19.5	8.8	8.75
Standard deviation	1.5	1.1	2.8	.83
t	1.64		0	
$t_{0.05}$	2.45		2.45	
F	1.96		11.19	
$F_{0.05}$	9.28		9.28	
$F_{0.01}$	----------		29.5	

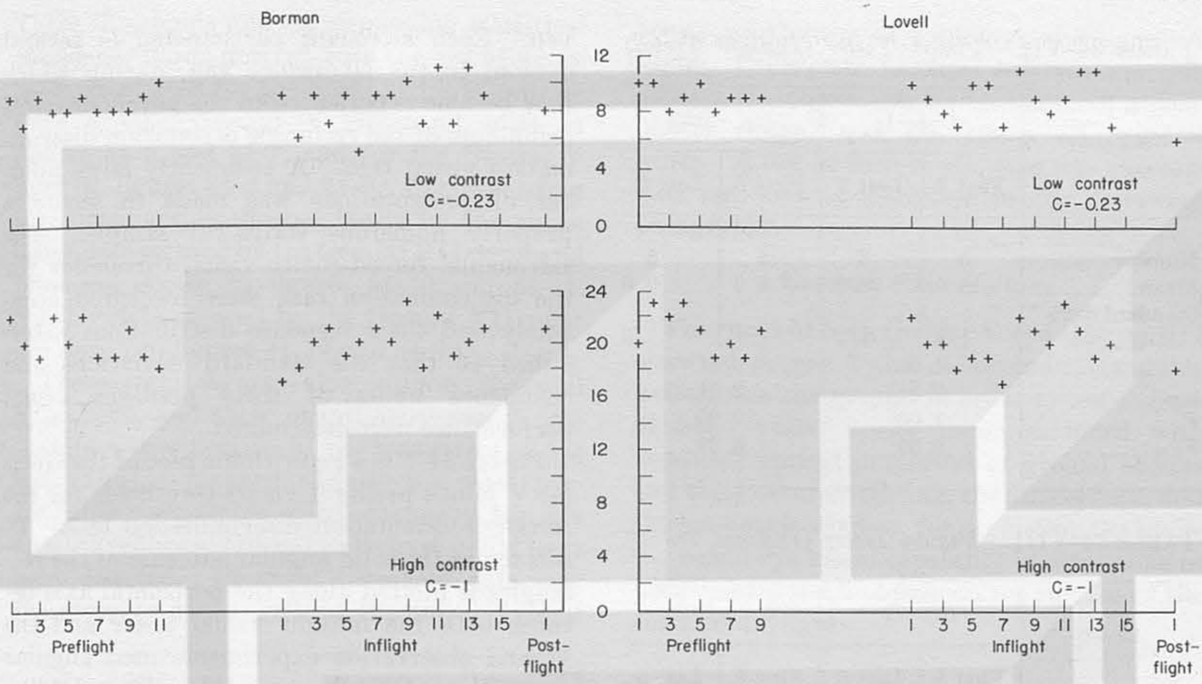

Figure 34-3.—Correct vision-tester scores for Gemini VII flight crew.

Table 34-V.—*Vision Tester (Ground Versus Space)*

Borman	$C=-1$		$C=-0.23$	
	Ground	Space	Ground	Space
Number	11	14	11	14
Mean	20. 0	19. 9	8. 45	8. 4
Standard deviation	1. 3	1. 6	. 78	1. 7
t	0. 12		0. 017	
$t_{0.05}$	2. 07		2. 07	
F	1. 49		4. 74	
$F_{0.05}$	2. 89		2. 89	
$F_{0.01}$	4. 66		4. 66	

Comparisons between the inflight data at the beginning of the mission with those at the end are made in tables 34–VII and 34–VIII. All Student's t tests and Snedecor's F tests show no significant difference at 0.05 level, with the exception of the F test on Borman's low-contrast comparison, which shows no significant contrast at the 0.01 level.

These statistical findings provide additional support for the null hypothesis advanced by many scientists before the Gemini missions were flown. Examination of the sensitivity of the test must be considered next. This topic is treated in the following paragraphs.

Preflight Physiological Baseline

Design of the inflight vision tester, as well as the ground sighting experiments described in subsequent paragraphs and the interpretation of the results from both experiments, required that a preflight physiological baseline be obtained for both crewmembers. For this purpose a NASA van was fitted out as a portable vision research laboratory, moved to the Manned

Table 34-VI.—*Vision Tester (Ground Versus Space)*

Lovell	$C=-1$		$C=-0.23$	
	Ground	Space	Ground	Space
Number	9	14	9	14
Mean	20. 9	20. 0	9. 1	9. 1
Standard deviation	1. 4	1. 6	74	1. 4
t	1. 29		0. 073	
$t_{0.05}$	2. 08		2. 08	
F	1. 17		3. 64	
$F_{0.05}$	3. 26		3. 26	
$F_{0.01}$	5. 62		5. 62	

TABLE 34-VII.—*Vision Tester (Inflight Trend)*

Borman	$C=-1$		$C=-0.23$	
	First 5	Last 5	First 5	Last 5
Number	5	5	5	5
Mean	19.0	20.0	8.0	9.0
Standard deviation	1.4	1.4	1.3	1.8
t	1.00		0.91	
$t_{0.05}$	2.31		2.31	
F	1.00		2.00	
$F_{0.05}$	6.39		6.39	

TABLE 34-VIII.—*Vision Tester (Inflight Trend)*

Lovell	$C=-1$		$C=-0.23$	
	First 5	Last 5	First 5	Last 5
Number	5	5	5	5
Mean	19.8	20.4	8.8	9.2
Standard deviation	1.3	1.5	1.2	1.6
t	0.60		0.40	
$t_{0.05}$	2.31		2.31	
F	1.27		1.88	
$F_{0.05}$	6.39		6.39	

Spacecraft Center at Houston, Tex., and operated by Visibility Laboratory personnel. Figure 34–4 is a cutaway drawing of this research van. The astronauts, seated at the left, viewed rear-screen projections from an automatic projection system located in the opposite end of the van. Each astronaut participated in several sessions in the laboratory van, during which they became experienced in the psychophysical techniques of the rectangle orientation discrimination visual task. A sufficiently large number of presentations was made to secure a properly numerous statistical sample. The astronauts' forced-choice visual thresholds for the discrimination task were measured accurately and their response distributions determined so that the standard deviations and confidence limits of their preflight visual performance were determined.

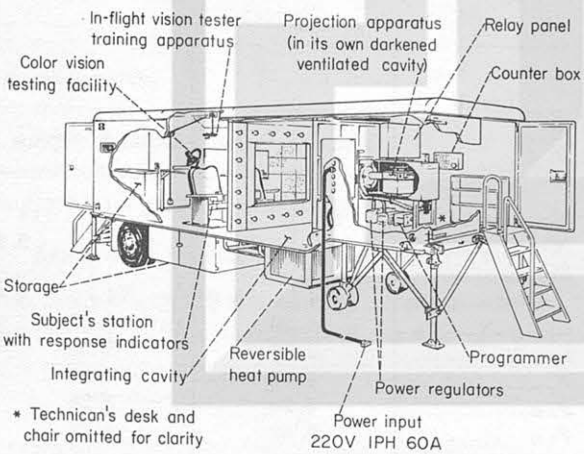

FIGURE 34–4.—Vision research and training van.

Figure 34–5 is a logarithmic plot of the Gemini V pilot's preflight visual thresholds for the rectangle orientation discrimination task. In this figure the solid angular subtense of the rectangles is plotted along the horizontal axis because both the inflight vision tester and the ground observation experiments used angular size as the independent variable. The solid line in this figure represents the forced-choice rectangle orientation threshold of the pilot at the 0.50 probability level. The dashed curves indicate the $-\sigma, +\sigma$, and $+2\sigma$ levels in terms of contrast. The six circled points in the upper row indicate the angular sizes of the high-contrast ($C=-1$) rectangles presented by the inflight vision tester. The three circled points of the middle and lower rows show the angular sizes of the low-contrast rectangles used in the preflight unit (serial no. 1) and the flight unit (serial no. 5), respectively.

The separate discriminations recorded on the record cards in the inflight vision tester can be used to determine a threshold of angular size.

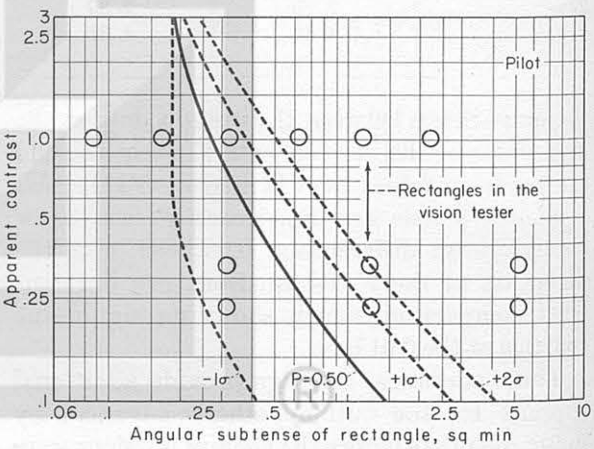

FIGURE 34–5.—Logarithmic plot of preflight visual thresholds.

These thresholds and corresponding statistical confidence limits derived with the aid of figure 34–5 are plotted for the high- and low-contrast tests of the Gemini V command pilot in figures 34–6 and 34–7, and for the Gemini V pilot in figures 34–8 and 34–9. Corresponding thresholds and confidence limits for the vision tester data secured by the Gemini VII command pilot are shown in figures 34–10 and 34–11. Similar data secured by the Gemini VII pilot are shown in figures 34–12 and 34–13.

These eight figures also support the null hypothesis, and their quantitative aspect constitutes a specification of the sensitivity of the test. Thus, as planned, variations in visual performance comparable with a change of one line on a conventional clinical wall chart would have been detected. Preflight threshold data can, therefore, be used to predict the limiting visual acuity capabilities of astronauts during space flight, if adequate physical information concerning the object and its background, atmospheric effects, and the spacecraft window exists. A test of such predictions was also carried out and is described in the following paragraphs.

Ground Observations

The crews of both Gemini V and Gemini VII observed prepared and monitored rectangular patterns on the ground in order to test the use of basic visual acuity data, combined with measured optical properties of ground objects and their natural lighting, the atmosphere, and the spacecraft window, for predicting the limiting naked-eye visual capability of astronauts to discriminate small objects on the surface of the earth in daylight.

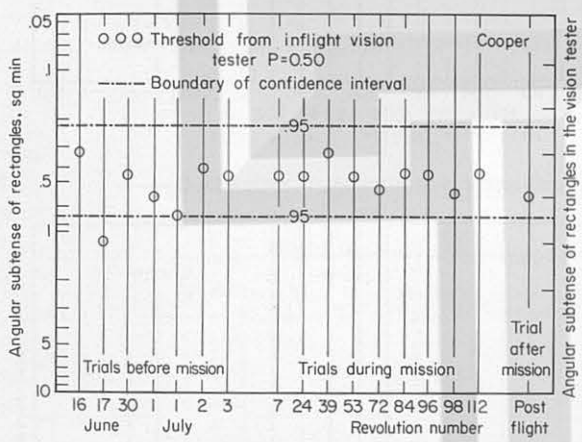

FIGURE 34–6.—Gemini V command pilot's rectangle discrimination thresholds, $C=-1$.

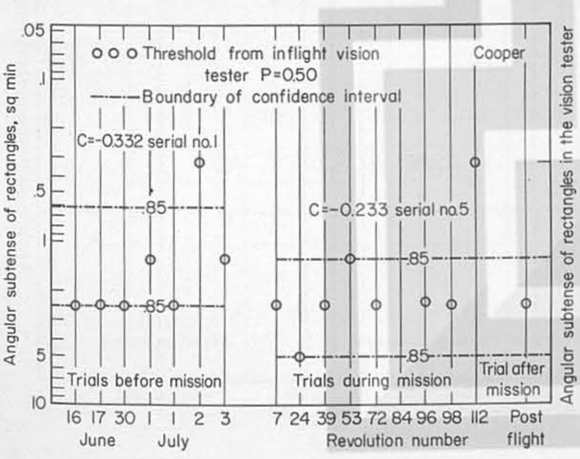

FIGURE 34–7.—Gemini V command pilot's rectangle discrimination thresholds.

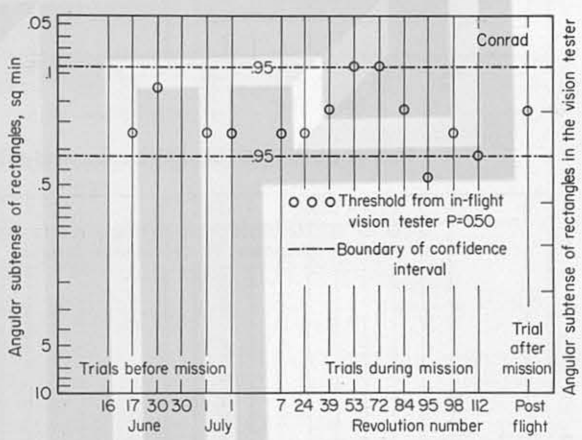

FIGURE 34–8.—Gemini V pilot's rectangle discrimination thresholds, $C=-1$.

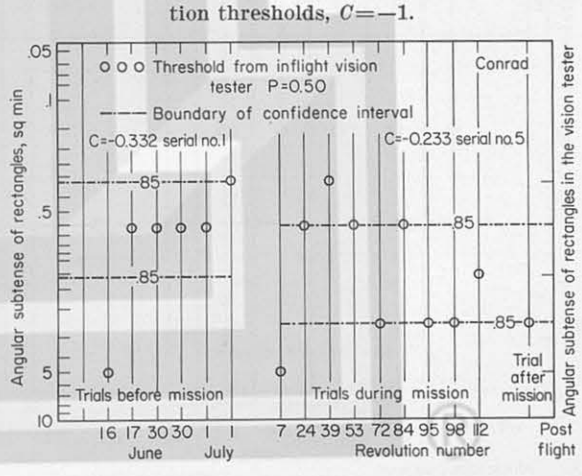

FIGURE 34–9.—Gemini V pilot's rectangle discrimination thresholds.

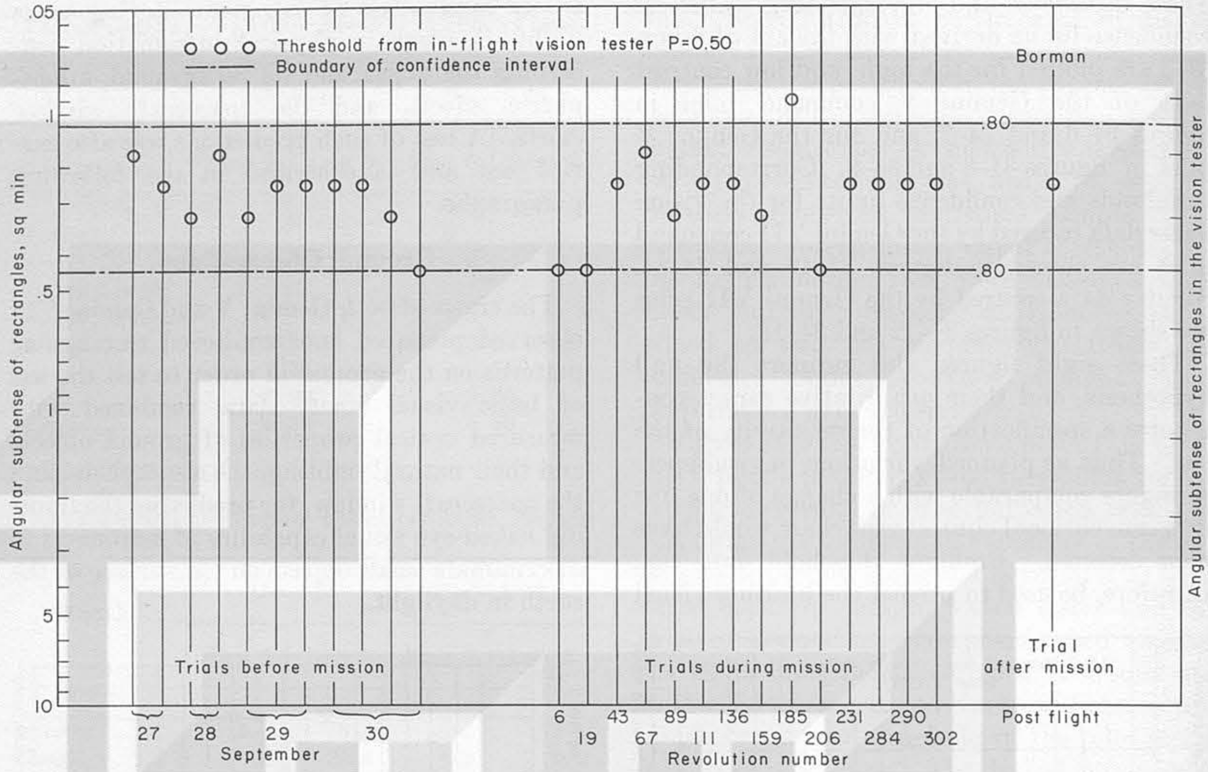

FIGURE 34–10.—Gemini VII command pilot's rectangle discrimination thresholds, $C=-1$.

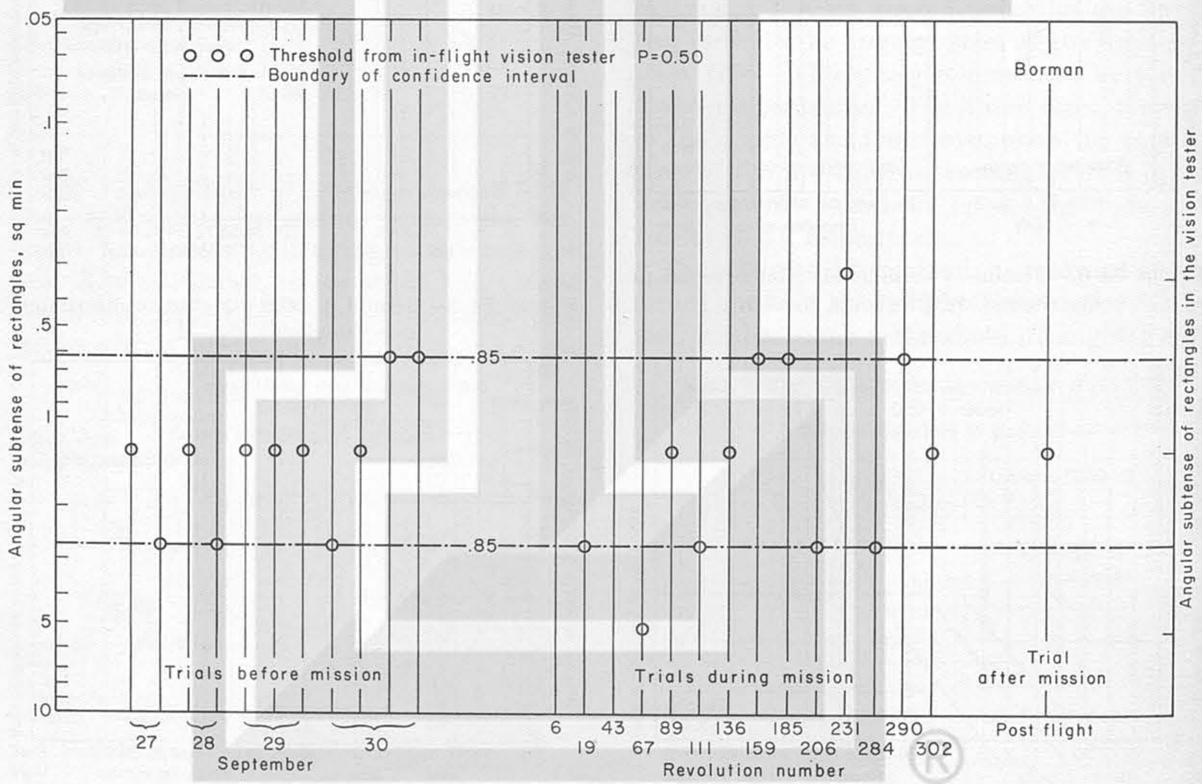

FIGURE 34–11.—Gemini VII command pilot's rectangle discrimination thresholds, $C=-0.233$.

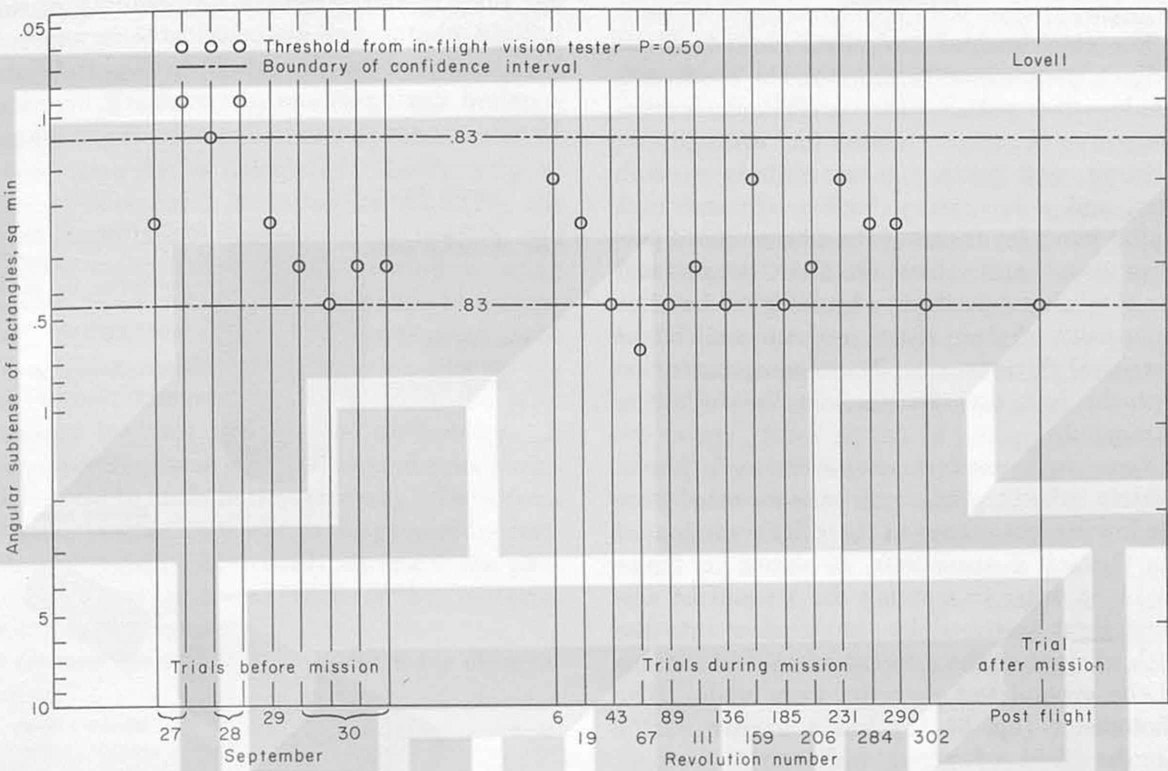

FIGURE 34–12.—Gemini VII pilot's rectangle discrimination thresholds, $C=-1$.

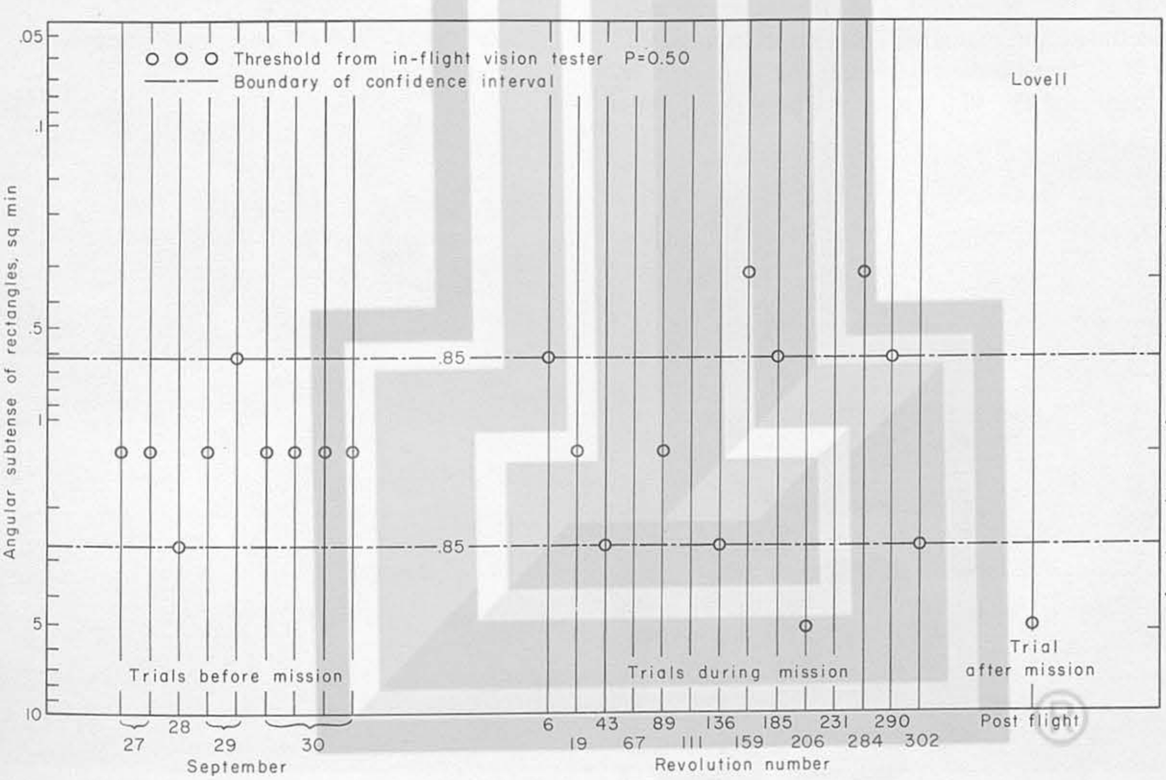

FIGURE 34–13.—Gemini VII pilot's rectangle discrimination thresholds, $C=-0.233$.

Equipment

The experimental equipment consists of an inflight photometer to monitor the spacecraft window, test patterns at two ground observation sites, instrumentation for atmospheric, lighting, and pattern measurements at both sites, and a laboratory facility (housed in a trailer van) for training the astronauts to perform visual acuity threshold measurements and for obtaining a preflight physiological baseline descriptive of their visual performance and its statistical fluctuations. These equipments, except the last, are described in the following paragraphs.

Spacecraft window photometer.—A photoelectric inflight photometer was mounted near the lower right corner of the pilot's window of the Gemini V spacecraft, as shown in figure 34–14, in order to measure the amount of ambient light scattered by the window into the path of sight at the moment when observations of the ground test patterns were made. The photometer (fig. 34–15) had a narrow (1.2°) circular field of view, which was directed through the pilot's window and into the opening of a small black cavity a few inches away outside the window. The photometric scale was linear and extended from approximately 12 to 3000 foot-lamberts. Since the apparent luminance of the black cavity was always much less than 12 foot-lamberts, any reading of the inflight photometer was ascribable to ambient light scattered by the window. Typical data acquired during passes of Gemini V over the Laredo site are shown in figure 34–16. This in-

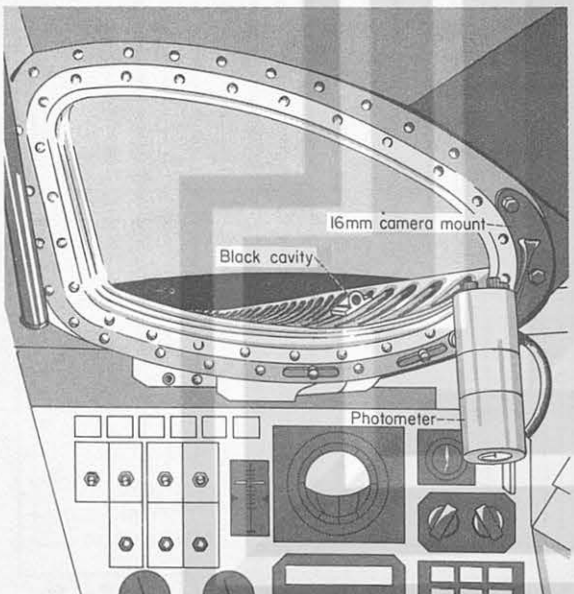

FIGURE 34–14.—Location of inflight photometer.

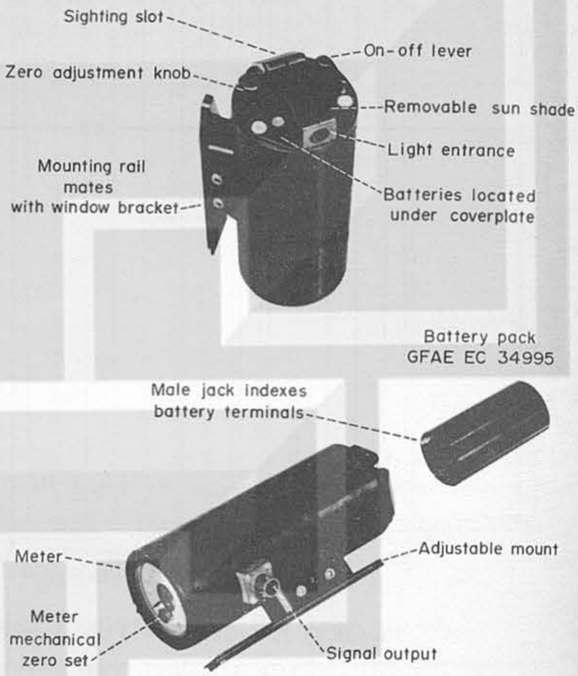

FIGURE 34–15.—Inflight photometer components.

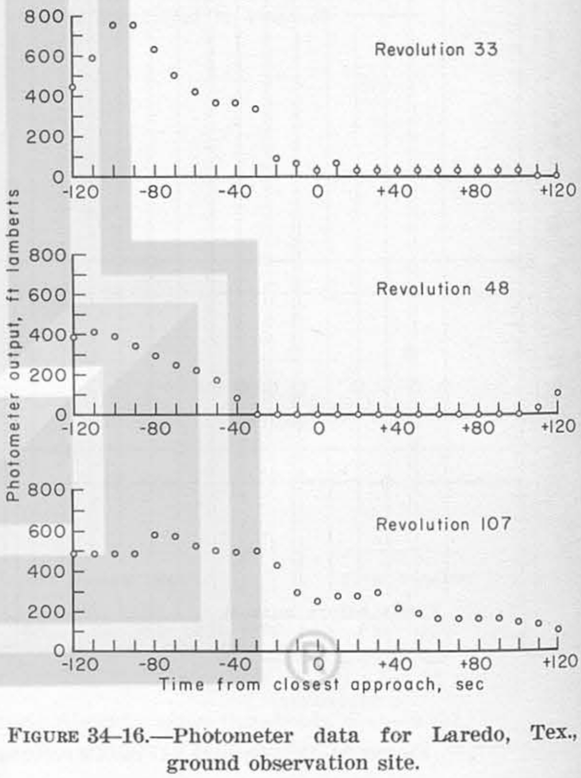

FIGURE 34–16.—Photometer data for Laredo, Tex., ground observation site.

formation, combined with data on the beam transmittance of the window and on the apparent luminance of the background squares in the ground pattern array, enabled the contrast transmittance of the window at the moment of observation to be calculated. Uniformity of the window could be tested by removing the photometer from its positioning bracket and making a handheld scan of the window, using a black region of space in lieu of the black cavity. A direct-reading meter incorporated in the photometer enabled the command pilot to observe the photometer readings while the pilot scanned his own window for uniformity. A corresponding scan of the command pilot's window could be made in the same way. Data from the photometer were sent to the ground by realtime telemetry. Electrical power for the photometer was provided entirely by batteries within the instrument.

Ground observation sites.—Sites for observations by the crew of Gemini V were provided on the Gates Ranch, 40 miles north of Laredo, Tex. (fig. 34–17), and on the Woodleigh Ranch, 90 miles south of Carnarvon, Australia (figs. 34–18 and 34–19). At the Texas site, 12 squares of plowed, graded, and raked soil 2000 by 2000 feet were arranged in a matrix of 4 squares deep and 3 squares wide. White rectangles of Styrofoam-coated wallboard were laid out in each square. Their length decreased in a uniform logarithmic progression from 610 feet in the northwest corner (square number 1) to 152 feet in the southwest corner (square number 12) of the array. Each of the 12 rectangles was oriented in one of four positions (that is, north-south, east-west, or diagonal), and the orientations were random within the series of 12. Advance knowledge of the rectangle orientations was withheld from the flight crew, since their task was to report the orientations. Provision was made for changing the rectangle orienta-

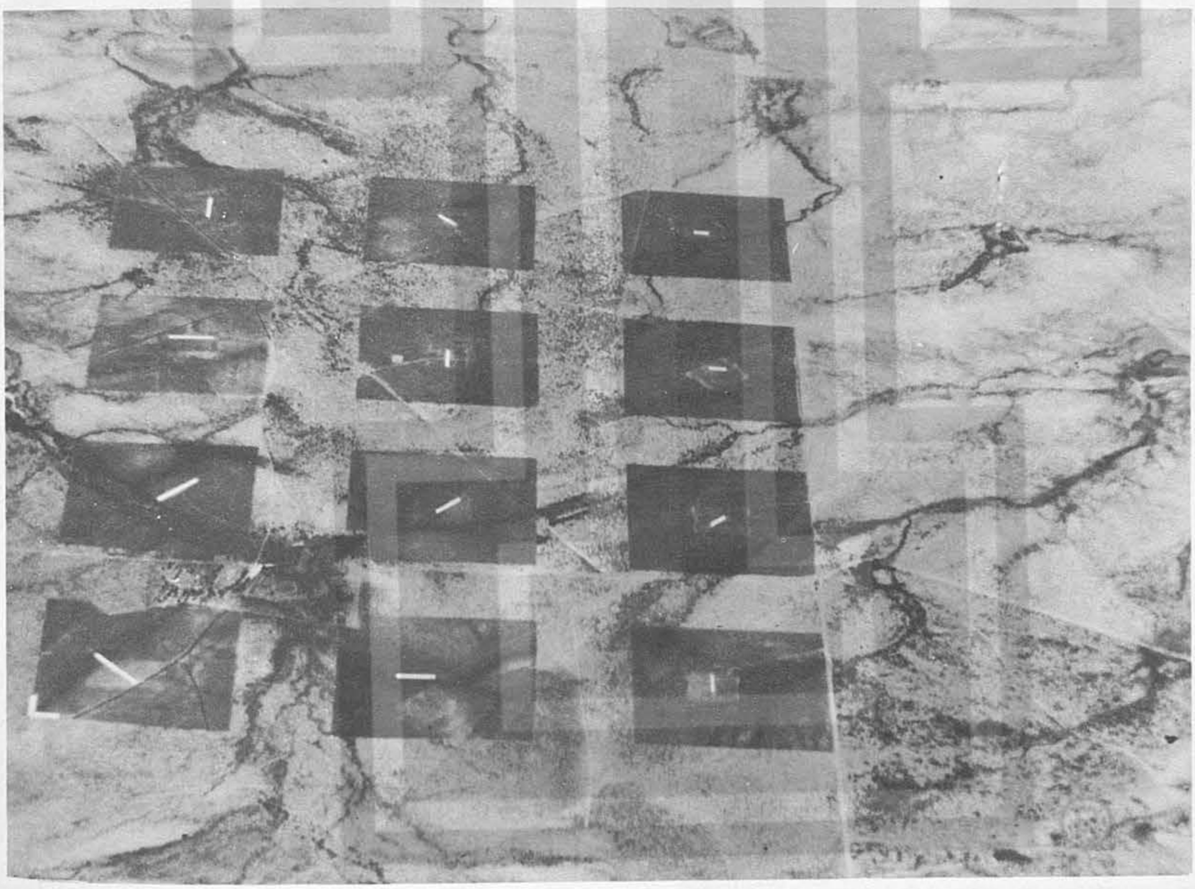

FIGURE 34–17.—Aerial photograph of Gemini V visual acuity experiment ground pattern at Laredo, Tex.

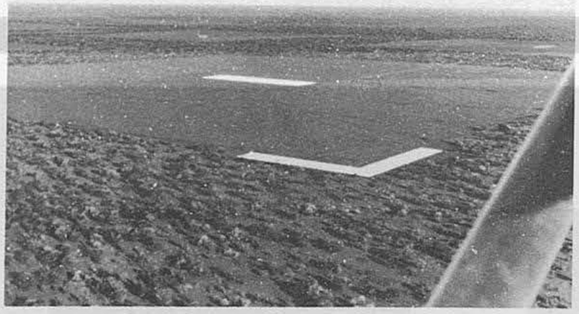

FIGURE 34-18.—Aerial photograph of the Gemini V visual acuity ground observation pattern at Carnarvon, Australia.

tions between passes and for adjusting their size in accordance with anticipated slant range, solar elevation, and the visual performance of the astronauts on preceding passes. The observation site in Australia was somewhat similar to the Texas site, but, inasmuch as no observations occurred there, the specific details are unnecessary in this report.

The Australian ground observation site was not manned during Gemini VII because the afternoon time of launch precluded usable daytime overpasses there until the last day of the mission. The 82.5° launch azimuth used for Gemini VII prevented the use of an otherwise highly desirable ground site in the California desert near the Mexican border. Weather statistics for December made the use of the Texas site appear dubious, but no alternative was available. The afternoon launch made midday passes over this site available on every day of the mission. Experience gained on Gemini V pointed to the need for a more prominent orientation marking. This was provided by placing east-to-west strips of crushed white limestone 26 feet wide and 2000 feet long across the center of each of the four north background squares in the array. Thus, only eight test rectangles were used in a 2 by 4 matrix on the center and south rows of background squares, as shown in figure 34-20. The largest and smallest rectangles were of the same size as those used in Gemini V.

Instrumentation.—Instrumentation at both ground sites consisted of a single tripod-mounted, multipurpose, recording photoelectric

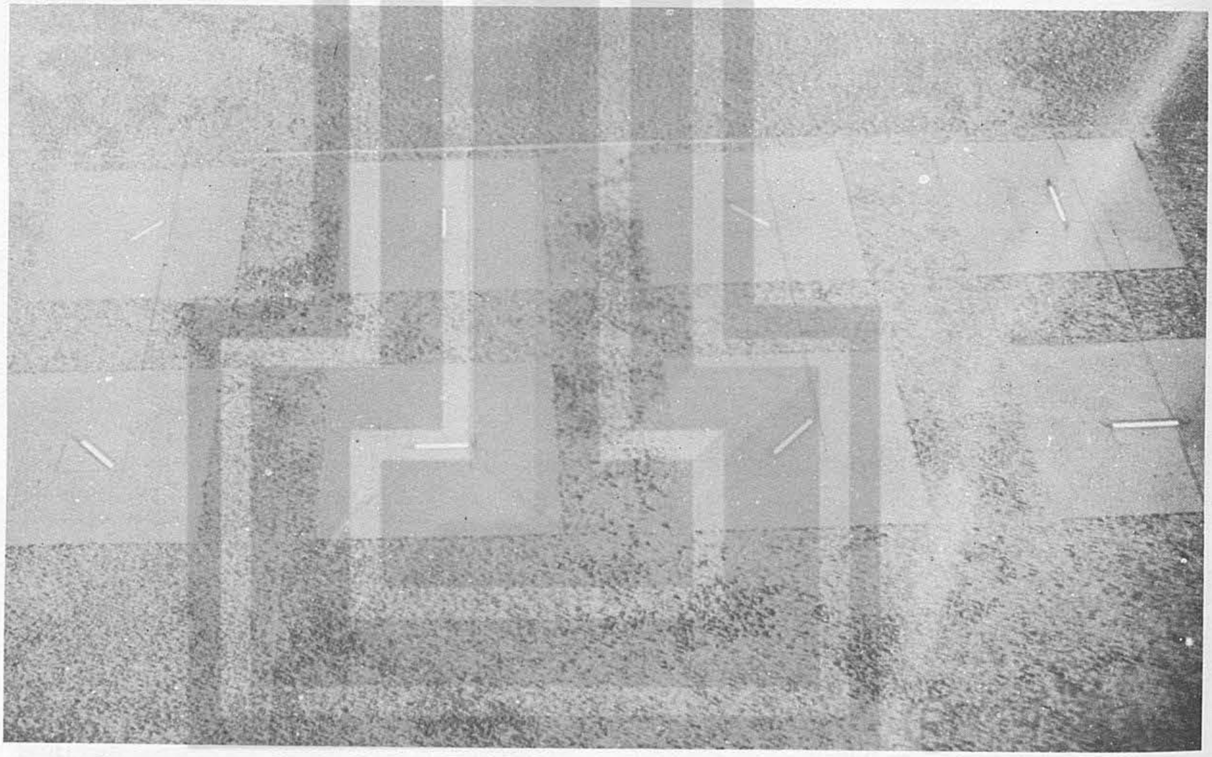

FIGURE 34-19.—Aerial photograph of the Gemini V visual acuity experiment ground pattern at Carnarvon, Australia.

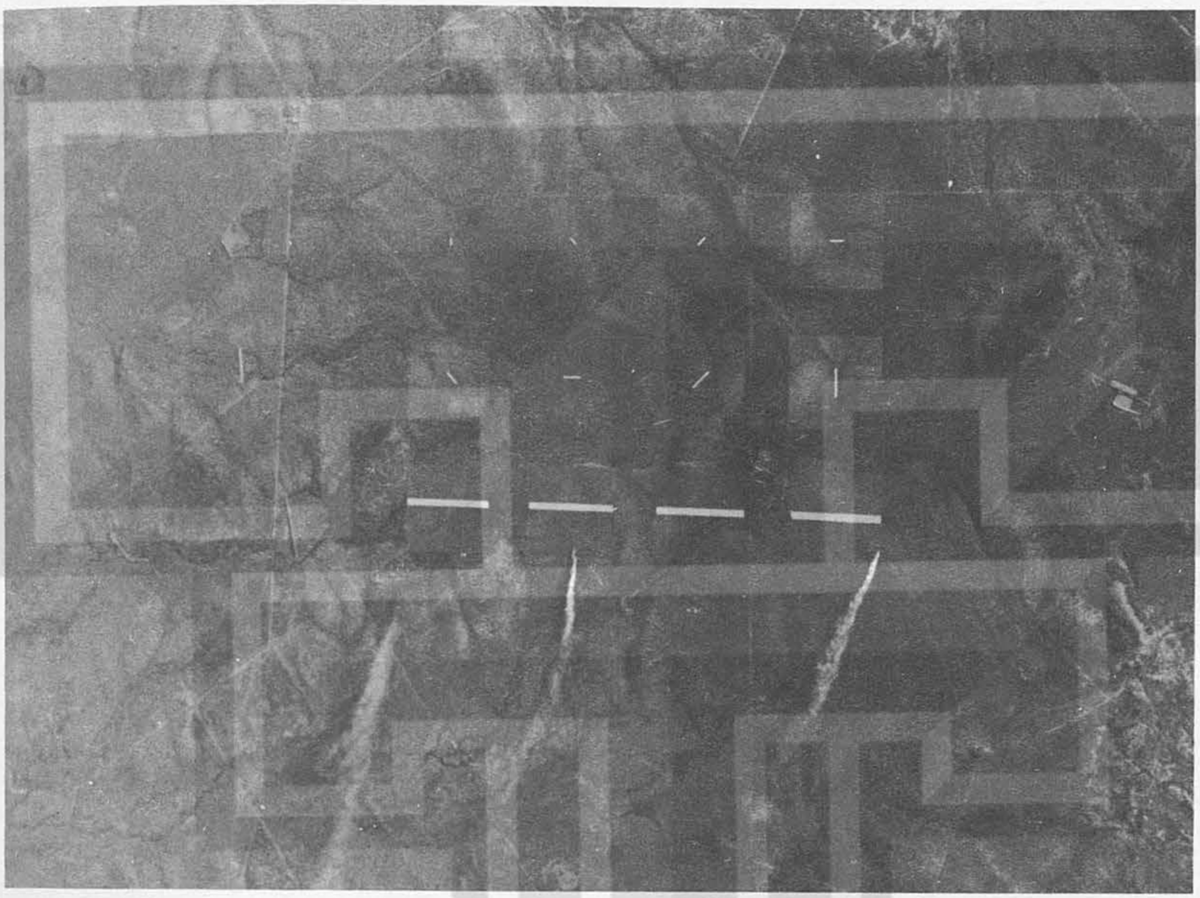

FIGURE 34-20.—Visual acuity experiment ground pattern at Laredo, Tex., as photographed by the Gemini VII flight crew during revolution 17.

photometer (figs. 34-21 and 34-22) capable of obtaining all the data needed to specify the apparent contrast of the pattern as seen from the spacecraft at the moment of observation. The apparent luminance of the background squares needed for evaluation of the contrast loss due to the spacecraft window was also ascertained by this instrument. A 14-foot-high mobile tower, constructed of metal scaffolding and attached to a truck, supported the tripod-mounted photometer high enough above the ground to enable the plowed surface of the background squares to be measured properly. This arrangement is shown in figures 34-23 and 34-24.

Observations in Gemini V

Observation of the Texas ground-pattern site was first attempted on revolution 18, but fuel-cell difficulties which denied the use of the platform were apparently responsible for lack of acquisition of the ground site.

The second scheduled attempt to see the pattern near Laredo was on revolution 33. Acquisition of the site was achieved by the command pilot but not by the pilot, and no readout of rectangle orientation was made.

At the request of the experimenters, the third attempt at Laredo, scheduled originally for revolution 45, was made on revolution 48 in order to secure a higher sun and a shorter slant range. Success was achieved on this pass and is described in the following section.

Unfavorable cloud conditions caused the fourth scheduled observation at the Texas site, on revolution 60, to be scrubbed. Thereafter, lack of thruster control made observation of the ground patterns impossible, although excellent weather conditions prevailed on three scheduled occasions at Laredo (revolutions 75,

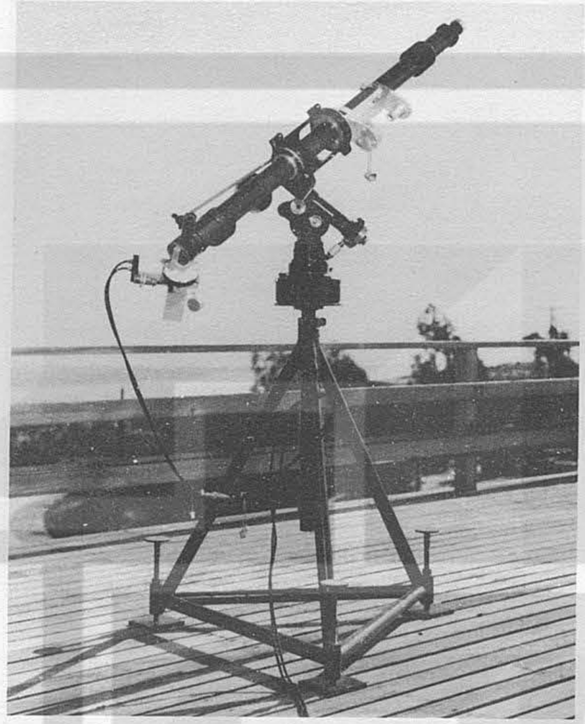

FIGURE 34-21.—Ground-site tripod-mounted photoelectric photometer.

92, and 107) and once at the Australian site (revolution 88). Long-range visual acquisition of the smoke markers used at both sites was reported in each instance, but the drifting spacecraft was not properly oriented near the closest approach to the pattern to enable observations to be made. A fleeting glimpse of the Laredo pattern during drifting flight on revolution 92 enabled it to be photographed successfully with hand cameras. Another fleeting glimpse of the pattern was also reported on revolution 107.

Results of Observations in Gemini V

Quantitative observation of ground markings was achieved only once during Gemini V. This observation occurred during revolution 48 at the ground observation site near Laredo, Tex., at 18:16:14 Greenwich mean time (G.m.t.) on the third day of the flight. Despite early acquisition of the smoke marker by the command pilot and further acquisition by him of the target pattern itself well before the point of closest approach, the pilot could not acquire the markings until the spacecraft had been

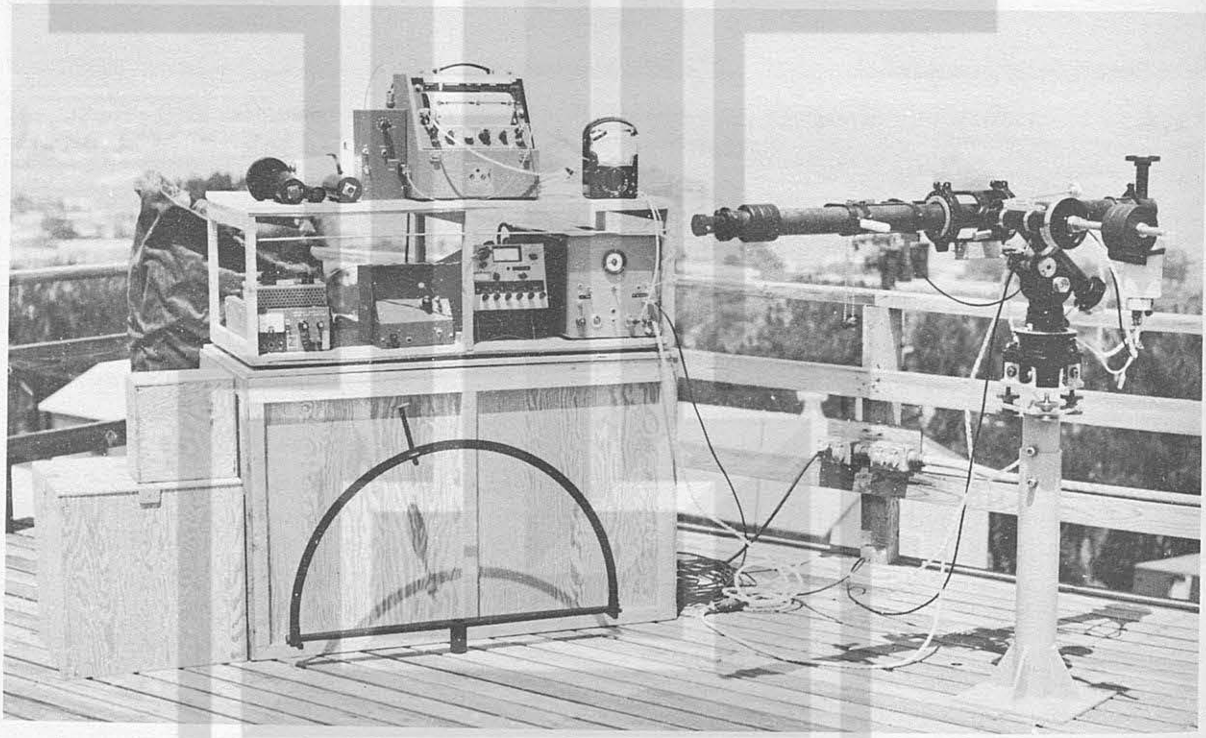

FIGURE 34-22.—Ground-site photoelectric photometer with recording unit.

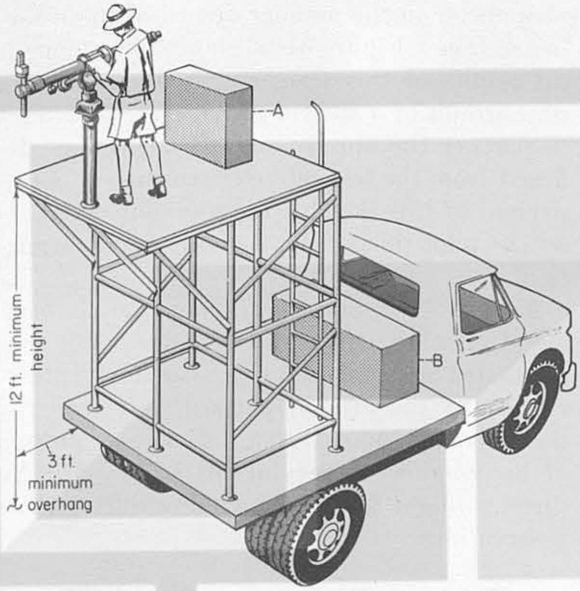

FIGURE 34-23.—Ground-site photoelectric photometer mounted on a truck.

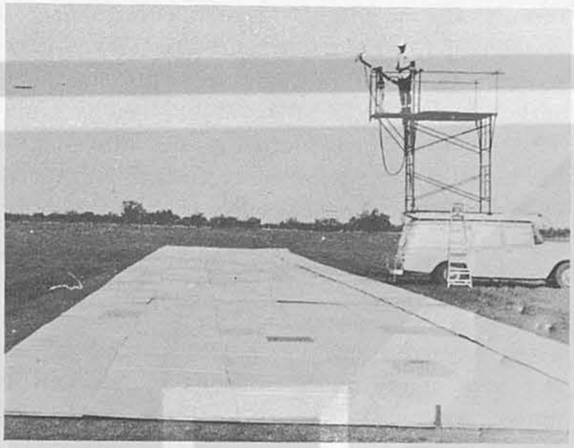

FIGURE 34-24.—Photograph of truck-mounted photoelectric photometer.

turned to eliminate sunlight on his window. Telemetry records from the inflight photometer show that the pilot's window produced a heavy veil of scattered light until the spacecraft was rotated. Elimination of the morning sun on the pilot's window enabled him to make visual contact with the pattern in time to make a quick observation of the orientation of some rectangles. It may be noted that, during approach, the reduction of contrast due to light scattered by the window was more severe than that due to light scattered by the atmosphere.

An ambiguity exists between the transcription of the radio report made at the time of the pass and the written record in the flight log. The writing was made "blind" while the pilot was actually looking at the pattern; it is a diagram drawn in the manner depicted in the Gemini V flight plan, the Mission Operation Plan, the Description of Experiment, and other documents. The orientation of the rectangles in the sixth and seventh squares appears to have been correctly noted. The verbal report given several seconds later correctly records the orientation of the rectangle in the sixth square if it is assumed that the spoken words describe the appearance of the pattern as seen from a position east of the array while going away from the site.

Despite the hurried nature of the only apparently successful quantitative observation of a ground site during Gemini V, there seems to be a reasonable probability that the sighting was a valid indication of the pilot's correctly discriminating the rectangles in the sixth and seventh squares. Since he did not respond to squares 8 through 12, it can only be inferred that his threshold lay at square 6 or higher.

Tentative values of the apparent contrast and angular size of the sixth and seventh rectangles at the Laredo site at the time of the observation are plotted in figure 34-25. The solid line rep-

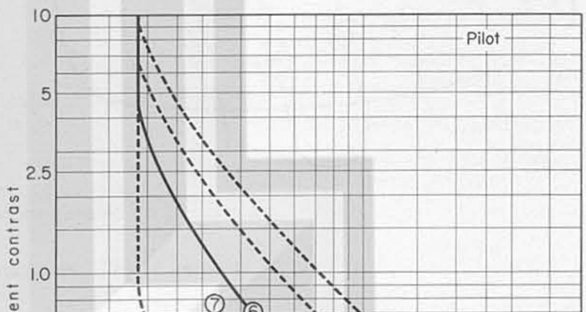

FIGURE 34-25.—Apparent contrast compared with angular size of the sixth and seventh rectangles for revolution 48 of the Gemini V mission.

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resents the preflight visual performance of Astronaut Conrad as measured in the vision research van. The dashed lines represent the 1- and 2-sigma limits of his visual performance. The positions of the plotted points indicate that his visual performance at the time of revolution 48 was within the statistical range of his preflight visual performance.

Observations in Gemini VII

Observations of the Texas ground-pattern site were made on revolutions 16, 17, and 31 under very favorable weather conditions. Heavy clouds blanketed the site throughout the remainder of the mission, however, and no further observations of the site were possible. Contamination of the outer surface of the pilot's window made observation of the ground pattern difficult and the result uncertain. The contamination, which was observed to have occurred during launch, was mapped during revolution 19 by means of a window scan with the inflight photometer in the manner described in an earlier section. Figure 34–26 shows some numerical results of this scan, and figure 34–27 is a photograph of a shaded pencil sketch intended to portray the appearance of the window deduced from the telemetered scan curves. Comparison of this sketch with a similar one made by the pilot during flight shows good correlation.

Figures 34–26 and 34–27 show that the command pilot's window was not measurably contaminated on its inboard side. Successful observations of the ground pattern were made by the command pilot through this clear portion of his window on revolutions 17 and 31. No direct sunlight fell on the window during those observations.

Results of Observations in Gemini VII

The results of observations by the command pilot on revolutions 17 and 31 of Gemini VII are shown in figure 34–28. These observations

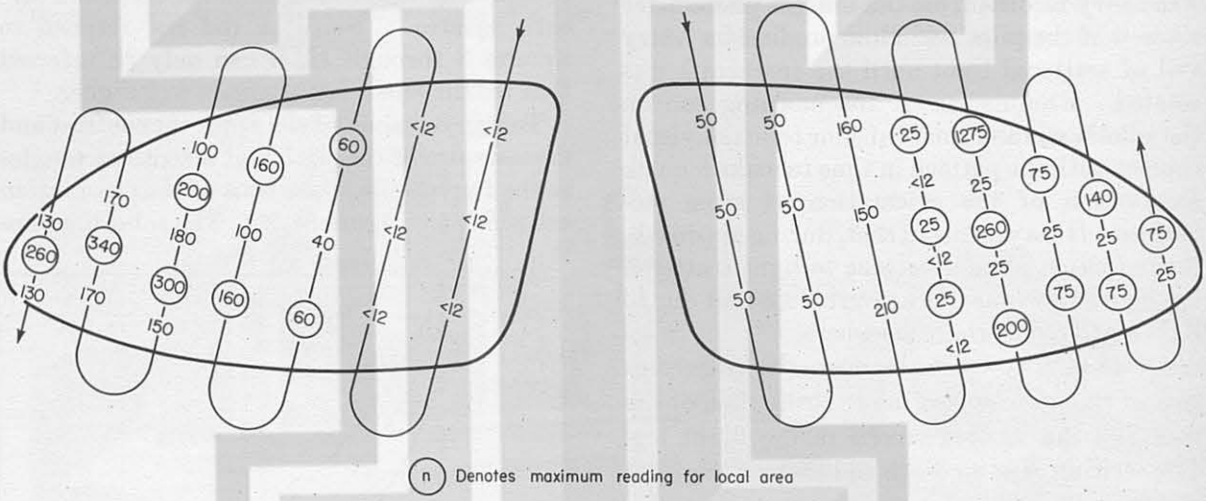

FIGURE 34–26.—Numerical results of window scan.

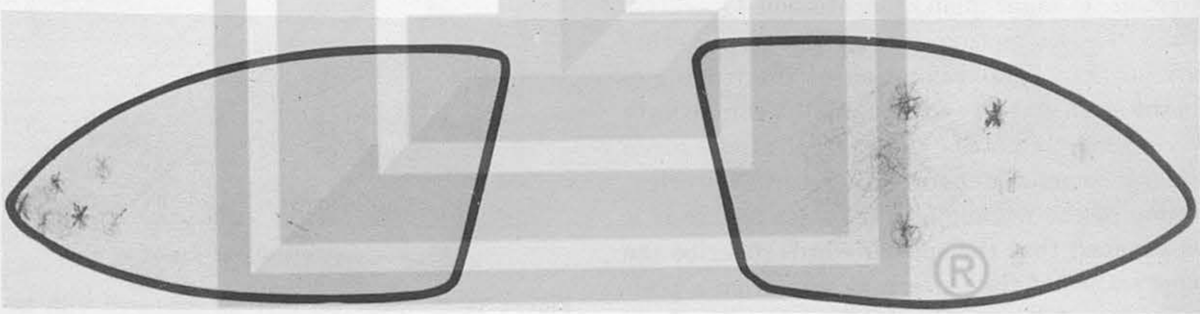

FIGURE 34–27.—Photograph of shaded pencil sketch of window contamination.

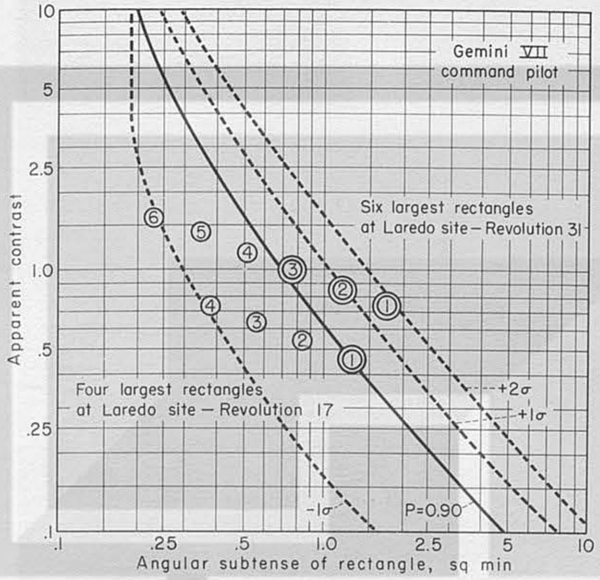

FIGURE 34–28.—Apparent contrast compared with angular size of rectangles.

occurred at 27:04:49 and 49:26:48 ground elapsed time (g.e.t.) on the second and third days of the flight, respectively.

In figure 34–28 the circled points represent the apparent contrast and angular size of the largest rectangles in the ground pattern. Apparent contrast was calculated on the basis of measured directional luminances of the white panels and their backgrounds of plowed soil, of atmospheric optical properties measured in the direction of the path of sight to the point of closest approach, and of a small allowance for contrast loss in the spacecraft window based upon window scan data and readings of the inflight photometer at the time of the two observations. Angular sizes and apparent contrast were both somewhat larger for revolution 31 than for revolution 17 because the slant range was shorter and because the spacecraft passed north of the site, thereby causing the background soil to appear darker, as can be noted by comparing figure 34–20 with figure 34–29. The orientations of those rectangles indicated by double circles were reported correctly, but those represented by single circles were either reported incorrectly or not reported at all.

The solid line in figure 34–28 represents the preflight visual performance of Borman as measured in the vision research van. The dashed lines represent the $-\sigma$, $+\sigma$, and $+2\sigma$ contrast limits of his visual performance. The positions of the plotted points indicate that his visual performance was precisely in accordance with his preflight visual thresholds.

Conclusions

The stated objectives of experiment S–8/D–13 were both achieved successfully. Data from the inflight vision tester show that no change was detected in the visual performance of any of the four astronauts who composed the crews of Gemini V and Gemini VII. Results from observations of the ground site near Laredo, Tex., confirm that the visual performance of the astronauts during space flight was within the statistical range of their preflight visual performance and demonstrate that laboratory visual data can be combined with environmental optical data to predict correctly the limiting visual capability of astronauts to discriminate small objects on the surface of the earth in daylight.

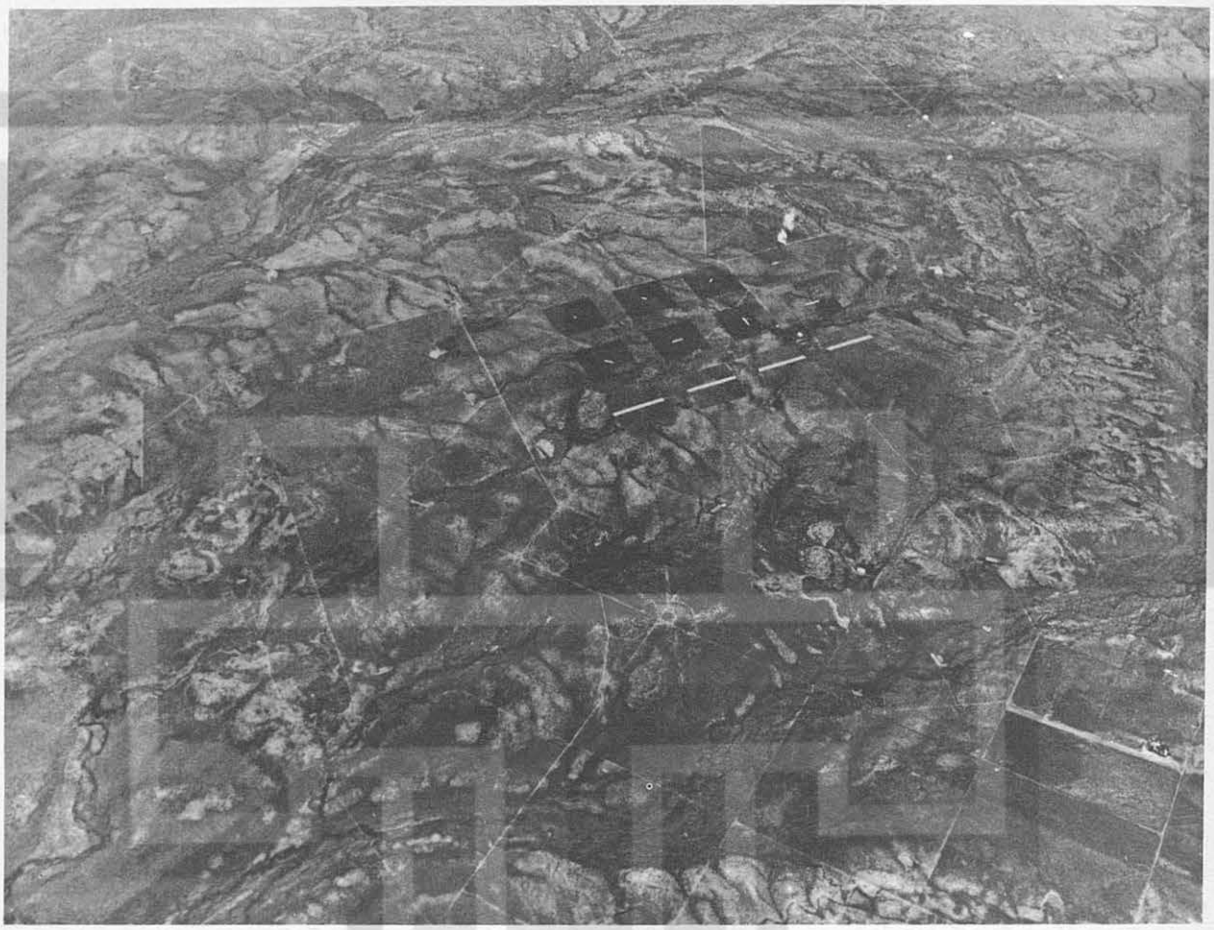

FIGURE 34-29.—Visual acuity experiment ground pattern at Laredo, Tex., as photographed by the Gemini VII flight crew during revolution 31.

35. EXPERIMENT S–5, SYNOPTIC TERRAIN PHOTOGRAPHY

By Paul D. Lowman, Jr., Ph. D., *Laboratory for Theoretical Studies, NASA Goddard Space Flight Center*

Introduction

The S–5 Synoptic Terrain Photography experiment was successfully conducted during the Gemini VI–A and VII missions. The purpose of this report is to summarize briefly the methods and results of the experiment. Interpretation of the large number of pictures obtained will, of course, require considerable time, and a full report is not possible now. As in previous reports, representative pictures from the missions will be presented and described.

Gemini VI–A

The purpose of the S–5 experiment in Gemini VI–A was, as in previous Gemini missions, to obtain high-quality color photographs of selected land and near-shore areas for geologic, geographic, and oceanographic study. The oceanographic study is an expansion of the scope of the experiment undertaken at the request of the Navy Oceanographic Office. The camera, film, and filter (Hasselblad 500C, Planar 80-mm lens, Ektachrome SO–217, and haze filter) were the same as used on previous flights. Camera preparation and loading were done by the Photographic Technology Laboratory, Manned Spacecraft Center, as was preliminary identification of the pictures.

The experiment was very successful, especially in view of the changes in mission objectives made after the experiment was planned. About 60 pictures useful for study were obtained. Areas covered include the southern Sahara Desert, south-central Africa, northwestern Australia, and several islands in the Indian Ocean.

Figure 35–1, one of a continuous series taken during the 15th revolution, shows a portion of central Mali including the Niger River and the vicinity of Tombouctou. The Aouker Basin and part of the southwestern Sahara Desert are visible in the background. The picture furnishes an excellent view of what are probably

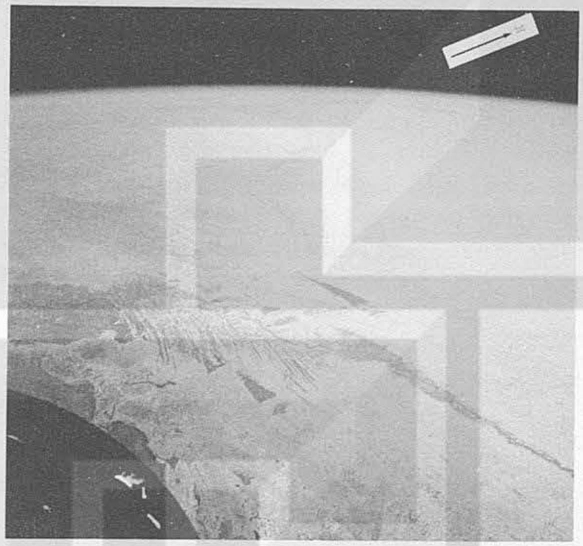

FIGURE 35–1.—Niger River and vicinity of Tombouctou, Mali (view looking northwest).

stabilized sand dunes (foreground), such as sand dunes which are no longer active and have been partly eroded (ref. 1). These dunes probably represent a former extension of the arid conditions which now characterize the northern Sahara. This photograph and others in the series should prove valuable in the study of the relation of the stabilized dunes to active dunes and to bedrock structure.

Figure 35–2 shows the Air ou Azbine, a plateau in Niger. The dark, roughly circular masses are Cenozoic lava flows on sandstones and schists (ref. 2). The crater at the lower left would appear to be of volcanic origin in view of its nearness to lava flows, but Raisz (ref. 2) indicates this area to be capped by sandstone. The picture gives an excellent view of the general geology and structure of the uplift as a whole.

Figure 35–3, one of several extremely clear pictures of this region, was taken over Somalia in the vicinity of the Ras Hafun (the cape at left). The area is underlain by Cenozoic

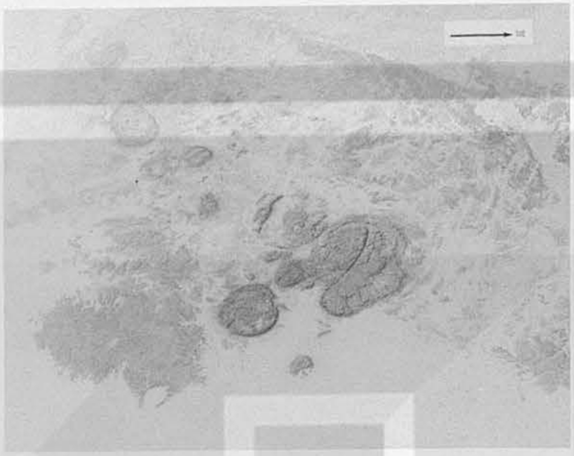

FIGURE 35-2.—Air ou Azbine, volcanic plateau in Niger.

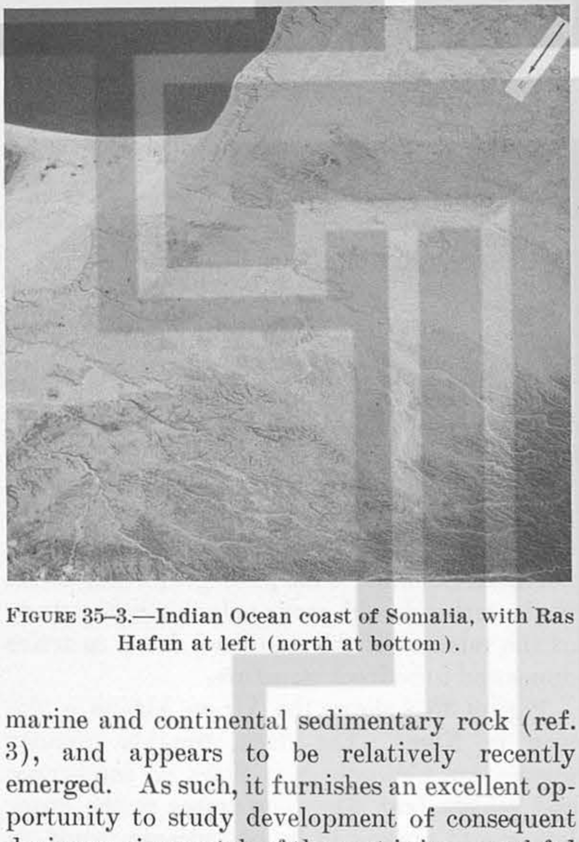

FIGURE 35-3.—Indian Ocean coast of Somalia, with Ras Hafun at left (north at bottom).

marine and continental sedimentary rock (ref. 3), and appears to be relatively recently emerged. As such, it furnishes an excellent opportunity to study development of consequent drainage, since much of the area is in a youthful stage of geomorphic development.

Figure 35-4 shows several lakes in the portion of the Rift Valley south of Addis Ababa, Ethiopia. Considerable structural detail is visible, such as the presumably fracture-controlled drainage on the east side of the Rift Valley. In addition, several areas of volcanic rock can be distinguished. This photograph may be helpful in testing Bucher's suggestion

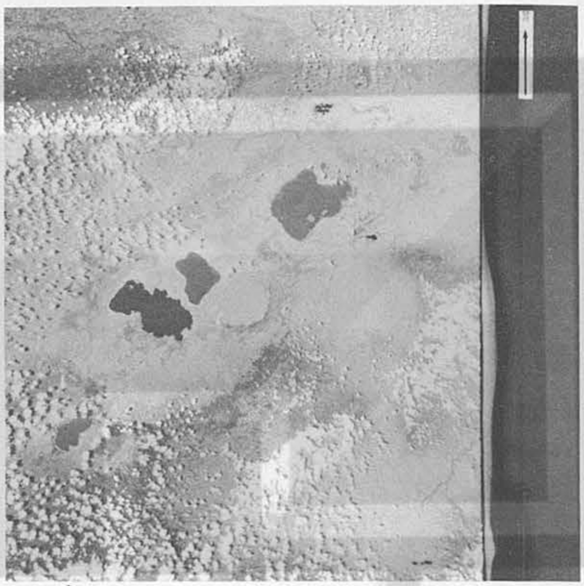

FIGURE 35-4.—Lakes in the Rift Valley, Ethiopia, south of Addis Ababa.

(ref. 4) that vulcanism in the Rift Valley is independent of structure. This area is in any event of great geologic interest and is a prime subject of study during the Upper Mantle Project (ref. 5).

Gemini VII

The scope of the terrain photography experiment (S-5) was considerably expanded for the Gemini VII mission because of the much greater mission length, and the greater amount of film capacity available. Requests had been received for photography of a number of specific areas from Government agencies, such as the U.S. Geological Survey, and from universities, and these were incorporated into the flight plan. The Hasselblad 500C and Ektachrome SO-217 again were the major equipment items, but, in addition, a Zeiss Sonnar 250-mm telephoto lens and Ektachrome infrared, type 8443, film were carried.

The experiment was highly successful. Approximately 250 pictures usable for geologic, geographic, and oceanographic purposes were obtained, covering parts of the United States, Africa, Mexico, South America, Asia, Australia, and various ocean areas. However, two major difficulties hampered the experiment. First, the cloud cover was exceptionally heavy over many of the areas selected. Second, a deposit was left on the spacecraft windows, apparently from second-stage ignition; this deposit seriously degraded a number of the pictures. The large number of usable pictures obtained is a tribute to the skill and perseverance of the crew.

Figure 35–5 is one of a series taken over the southern part of the Arabian peninsula. The series provides partial stereoscopic coverage. The area shown, also photographed during the Gemini IV mission, is the Hadramawt Plateau with the Hadramawt Wadi at lower right. The plateau is underlain by gently dipping marine shales (Geologic Map of the Arabian Peninsula, U.S. Geological Survey, 1963) deeply dissected in a dendritic pattern. Several interesting examples of incipient stream piracy are visible, in which streams cutting headward intersect other streams. (All are, of course, now dry.)

Figure 35–6 was taken over Chad, looking to the southeast over the Tibesti Mountains. This photograph was specifically requested to investigate geologic features discovered on Gemini IV photographs (ref. 6). One of these features is the circular structure at far left center. Although probably an igneous intrusion, such as a laccolith, its similarity to the Richat structures suggests that an impact origin be considered. Another structural feature whose significance is currently unknown is the series of concentric lineaments at far left. These are probably joints emphasized by wind and stream erosion, and may be tensional fractures associated with the epeirogenic uplift of the Tibesti massif. In addition to these structures, considerable detail can be seen in the sedimentary, igneous, and metamorphic rocks of the western Tibestis. The large circular features are calderas, surrounded by extensive rhyolite or ignimbrite deposits (ref. 7).

Figure 35–7, since it was taken with the 250-mm lens, is of considerable interest in evaluating the usefulness of long-focal-length lenses. The area covered is the Tifernine Dunes (ref. 2) in south-central Algeria. Despite the longer focal length, the region included in the picture is about 90 miles from side to side because of the camera tilt. The picture provides a synoptic view of the dune field and its relation to surrounding topography, which should prove valuable in studies of dune formation.

Figure 35–8 shows a portion of the Erg Chech in west-central Algeria, looking to the southeast. The dark ridges at the lower left are the Kahal Tabelbala and Ougarta, folded Paleozoic sandstones, limestones, and schists (ref. 8), separated by the Erg er Raoui, a dune field. Of considerable interest is the variety of dunes in the lower right. At least two major directions of dune chains at high angles to each other are visible, suggesting a possible transition from transverse to longitudinal dunes.

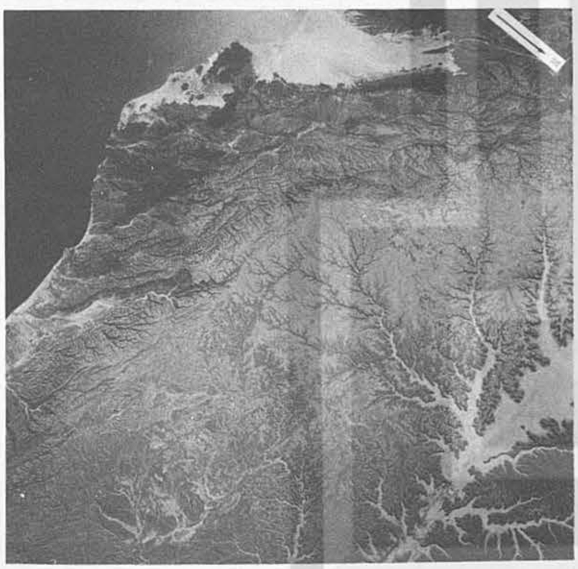

FIGURE 35–5.—Nearly vertical view of the Hadramawt Plateau, south coast of the Arabian Peninsula (north to right).

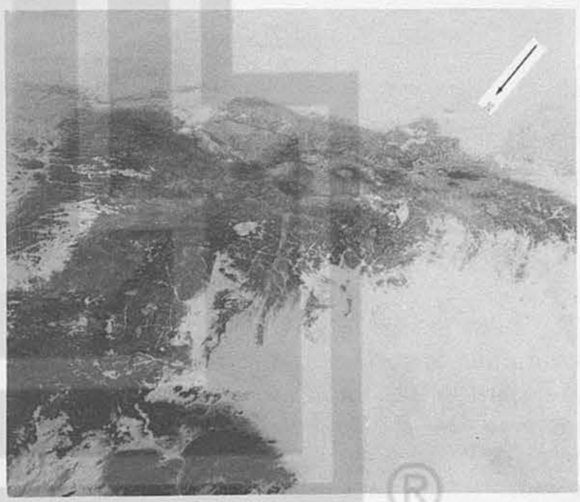

FIGURE 35–6.—Tibesti Mountains, Chad (view looking to southeast).

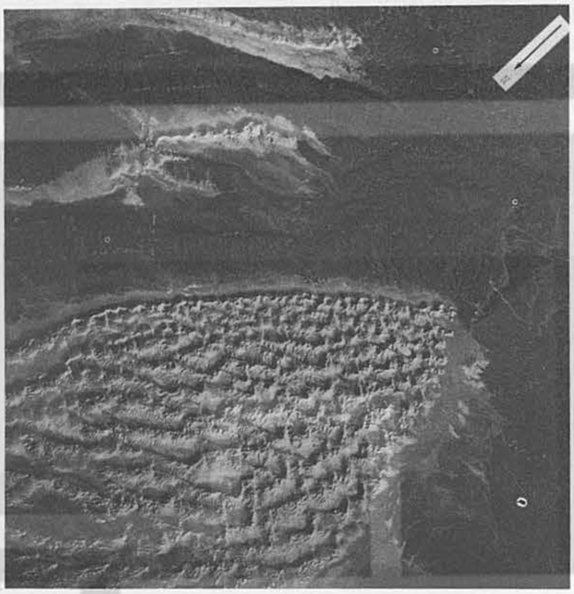

FIGURE 35-7.—Tifernine dune field, Algeria (view looking to southeast).

FIGURE 35-8.—Part of the Erg Chech, Algeria, and the Erg er Raoui (view looking to southeast).

The value of such photographs in the study of sand dune formation and evolution is obvious.

Figure 35-9 is one of several taken with color infrared film, used for the first time in scientific terrain photography on this flight. Despite the obscuration of the window caused by the previously mentioned deposit and the artifacts at right, the picture demonstrates strikingly the

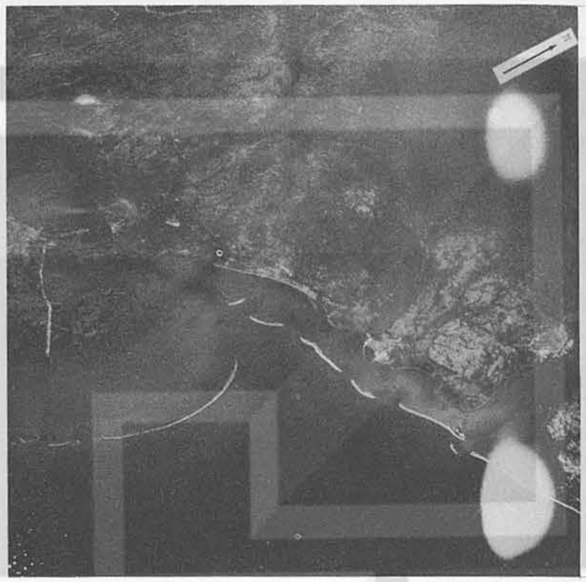

FIGURE 35-9.—Black-and-white of color photograph taken with infrared film over Gulf of Mexico (view looking northwest over Mobile Bay-New Orleans coast).

potential value of this type of film for hyperaltitude photography.

The area shown in figure 35-9 includes the Gulf coast of Alabama, Mississippi, and Louisiana; Mobile Bay is at lower right, and Lake Ponchartrain and New Orleans at far left. The arc at left center is the Chandeleur Island chain. The picture is notable for several reasons. First, the infrared sensitivity provides considerable haze-penetrating ability, as had been expected from the behavior of black-and-white infrared films flown on rockets (ref. 9). This is shown by the fact that highways can be distinguished at slant ranges of about 200 miles (at upper left: probably Interstate 55 and Route 190). Other cultural features include additional highways, the bridge carrying Interstate 59 across the east end of Lake Ponchartrain (the causeway, however, is not visible), and the Mississippi River-Gulf outlet canal (the white line crossing the delta parallel to the left border).

Many color differences can be seen in the Gulf of Mexico and adjoining inland waters. There appears to be considerable correspondence between water color and depth, as suggested in a report being prepared by R. F. Gettys. For example, the dark tonal boundary just above the spacecraft nose (lower left) may outline the 60-fathom contour as shown on Coast and Geodetic Chart 1115. Also, the tone contours just east of the Mississippi Delta at lower left correspond roughly to the depth of water between the delta and Breton Island. However, it is probable that temperature of the water and overlying air influence the color response of this film, and more detailed analysis is needed.

Considerable color detail is visible in land areas. Differences are probably the expression of vegetation rather than soil or geologic units, since the expected color response (for example, red replacing green) is present on the color prints. It is obvious, from this and adjoining pictures, that much more color discrimination is possible with color infrared film than with conventional color film. This fact is of great importance for the application of hyperaltitude photography to range management, forestry, and agriculture, since terrain photography on previous Gemini flights has shown that the color response of conventional color film in green wavelengths is poor, probably due to atmospheric scattering.

Summary

The following results have been achieved during the terrain photography on the Gemini IV and VII missions:

(1) New areas not previously photographed have been covered.

(2) Coverage of previously photographed areas has been extended or improved.

(3) The value of color infrared film in hyperaltitude photography has been demonstrated.

(4) The effectiveness of moderately long focal lengths has been demonstrated.

The experiment on both missions has been highly successful, despite the difficulties encountered.

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36. EXPERIMENT S–6, SYNOPTIC WEATHER PHOTOGRAPHY

By Kenneth M. Nagler, *Chief, Space Operations Support Division, Weather Bureau, Environmental Science Services Administration, and* Stanley D. Soules, *National Environmental Satellite Center, Environmental Science Services Administration*

Summary

The weather photography experiment conducted in the Gemini IV, V, VI–A, and VII missions resulted in a total of nearly 500 high-resolution color photographs showing clouds. Many of these illustrate interesting meterological features on a scale between that obtainable from surface or aircraft views, and that obtainable from operational weather satellites.

Description

The S–6 weather photography experiment represents an effort to get a selection of high-resolution color photographs of interest to the meteorologist.

The pictures obtainable from the altitude of the Gemini flights provide details on a scale between that of views from the ground or aircraft and that from weather satellites. When the Gemini photographs are taken approximately vertically, every cloud is plainly visible over an area approximately 100 miles square. At oblique angles, much larger areas can be seen in considerable detail. Such views are illustrative of, and can assist in, the explanation of various meteorological phenomena. Also, they are an aid in the interpretation of meteorological satellite views, which are sometimes imperfectly understood.

The equipment for the experiment has been relatively simple. It consists of the Hasselblad camera (Model 500C, modified by NASA) with a haze filter on the standard Zeiss Planar 80-mm f/2.8 lens. The film (70-mm) has been for the most part Ektachrome MS (SO–217), although one roll of Anscochrome D–50 film was used on the Gemini V flight. Also, the infrared Ektachrome film used on Gemini VII primarily for other purposes yielded some meteorologically interesting pictures.

The procedures for conducting the experiment were essentially the same on the four missions. Well in advance of the flights, a number of meteorologists (primarily from the National Environmental Satellite Center and the Weather Bureau) were questioned as to the types of cloud systems they would like to see, and as to what particular geographical areas were of interest. Several months before each flight, the aims of the experiment were discussed in detail with the flight crew. A number of specific types of clouds were suggested as possibilities for viewing on each mission.

The mission plans were arranged so that the pilots could devote part of their time to cloud photography over the preselected areas. On the day preceding each launch, the pilots were briefed on interesting features likely to be seen on their mission. During the mission, areas of interest were selected from time to time from weather analyses and from Tiros pictures. When operationally feasible, this information was communicated to the crew from the Manned Spacecraft Center at Houston, Tex., in time for them to locate and to photograph the clouds in question, provided this did not interfere with their other duties. So long as fuel was available for changing the attitude of the spacecraft for this purpose, the pilots were able to search for the desired subjects. Otherwise, they could take pictures only of those scenes which happened to come into view.

Results

In all, close to 500 high-quality pictures containing clouds or other meteorologically significant information were taken by the crews on Gemini IV, V, VI–A, and VII missions. Many of the aims of the experiment were realized; naturally, with the variety and the infrequent occurrence of some weather systems, and with the crew's other activities and constraints, some meteorological aims were not realized.

The results of the Gemini IV and Gemini V missions have been discussed previously by Nagler and Soules (refs. 1, 2, and 3).

Before mentioning specific features of interest, it should be pointed out that many views, while not scientifically significant, do illustrate cloud systems of many types in color and with excellent resolution. These make a valuable library for educational and illustrative purposes. Some of the categories of meteorologically interesting views obtained on these Gemini flights are described below.

Organized Convective Activities

In all of the flights there were views illustrating cloud fields which resulted from organized convection under a variety of meteorological conditions. These included the cumulus cloud streets, long lines of cumulus clouds parallel to the windflow, as illustrated in figure 36–1. Also, some scenes show a broad pattern of branching cumulus streets. Another type of convection pattern, occurring when there is little shear throughout the cloud layer, is the cellular pattern. In these patterns, sometimes the rising motion, as indicated by the presence of clouds, is in the center of the cells with descending motion near the edges, as in figure 36–2; and sometimes the circulation is in the opposite sense.

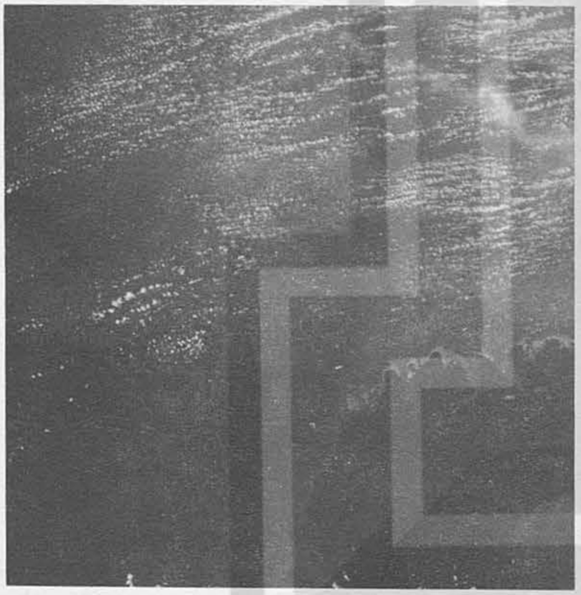

FIGURE 36–1.—Typical cumulus cloud streets in the South Atlantic Ocean near the mouth of the Para River, Brazil. Photographed by Gemini VII flight crew at 19:53 G.m.t., December 12, 1965.

Eddy Motions

Vortices induced by air flowing past islands or coastal prominences have also been photographed on the Gemini flights. Figure 36–3 shows a vortex of the latter type. Views of such eddies on successive passes, to show how they move and change, were not obtained and remain a goal for future missions.

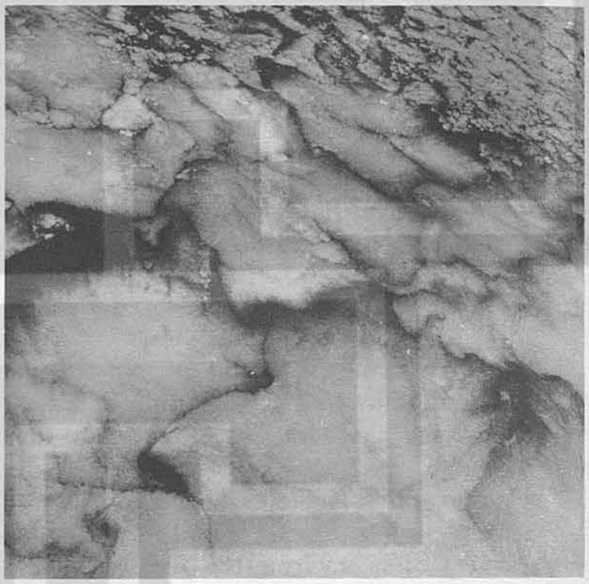

FIGURE 36–2.—Cellular cloud patterns over the Central North Pacific Ocean, showing small vortices along the boundaries. Photographed by Gemini IV flight crew at 22:29 G.m.t., June 4, 1965.

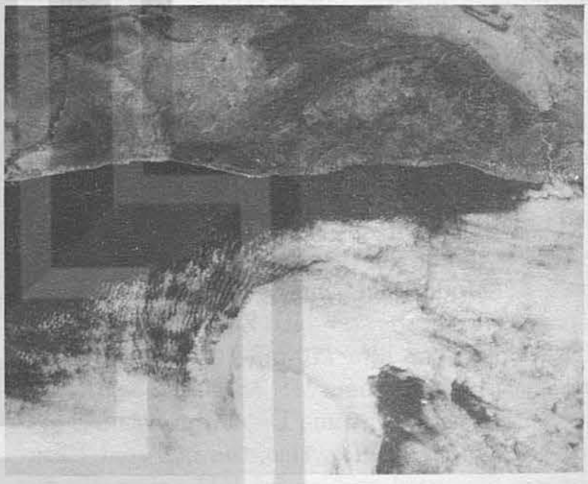

FIGURE 36–3.—Vortex in stratocumulus clouds off Morocco, induced by strong northeasterly winds flowing past Cape Rhir just north of this scene. Photographed by Gemini V flight crew at 10:25 G.m.t., August 26, 1965.

Tropical Storms

Views of tropical storms are naturally of interest to the meteorologist. A number of such views were obtained, ranging from small incipient disturbances to mature storms.

Daytime Cloudiness Over Land

Many of the pictures illustrate, as do many meteorological satellite pictures, the nature of cumulus clouds over land areas during the daytime. Of particular interest in this regard are the views of Florida (figs. 36–4, 36–5, and 36–6) obtained on three successive passes approximately 90 minutes apart. These show the changes and movements of such clouds.

Cirrus Clouds Relative to Other Cloud Decks

Sometimes on meteorological satellite views the determination as to whether the clouds present are high (cirrus) or lower (altostratus or stratus) clouds is a difficult one. The suggestion is often present that dark areas on such pictures may be shadows of cirrus clouds on lower decks. Sometimes, by their orientation, the long dark lines present give an indication of the direction of the winds at the cirrus level, since cirrus clouds in the strong wind core of the upper troposphere (jetstream) frequently occur in long bands parallel to the winds. In the Gemini VI–A and VII flights, several examples of such cirrus shadows on lower clouds were obtained, one of which is shown in figure 36–7.

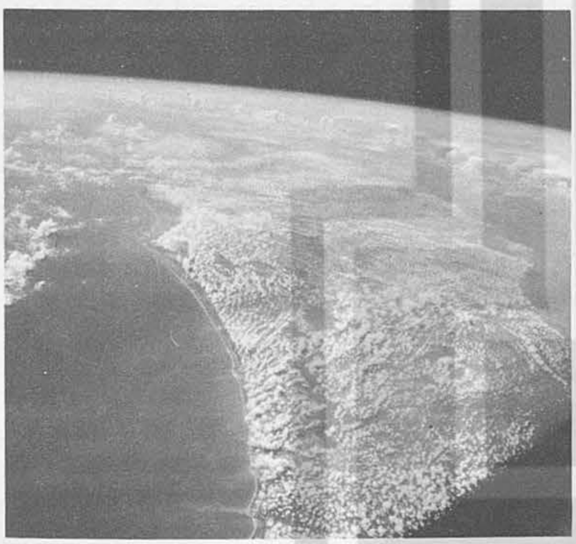

FIGURE 36–4.—View of Florida showing cumulus clouds over the land, the first of three views of this area taken on successive passes. Photographed by Gemini V flight crew at 15:31 G.m.t., August 22, 1965.

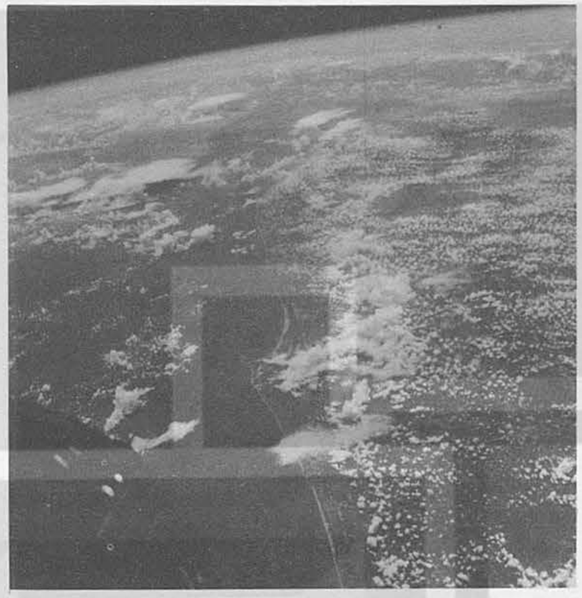

FIGURE 36–5.—Florida, the second of three views of this area, showing increased cumulus cloud development along a line just inland from the east coast. Photographed by Gemini V flight crew at 17:07 G.m.t., August 22, 1965.

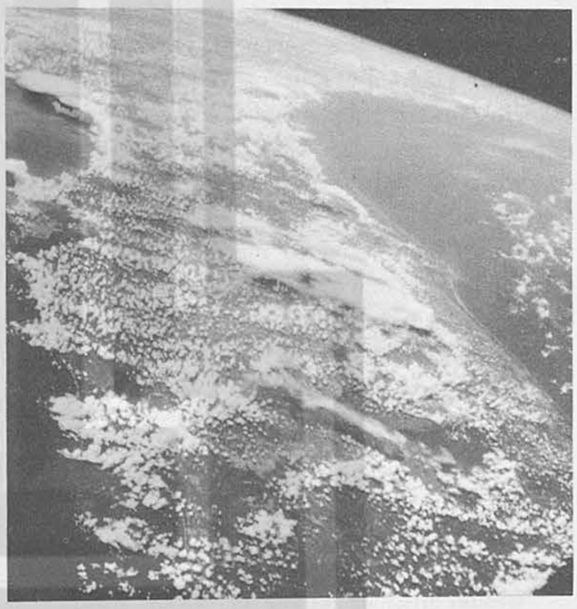

FIGURE 36–6.—Florida, the third of three views taken on successive passes showing that the cumulus activity had developed to the cumulonimbus (thunderstorm) stage just inland in the Cape Kennedy area. Photographed by Gemini V flight crew at 18:38 G.m.t., August 22, 1965.

FIGURE 36-7.—Cirrus shadows on lower cloud layers, over the North Atlantic Ocean. Photographed by Gemini VI flight crew at 10:38 G.m.t., December 16, 1965.

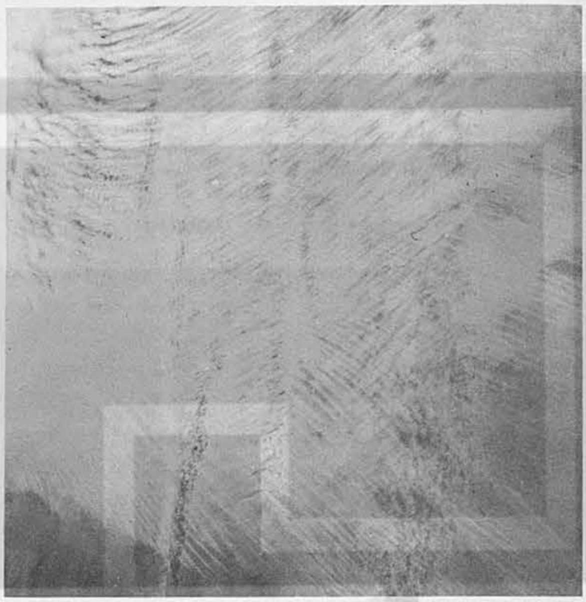

FIGURE 36-8.—Seif dunes in the northwestern Sudan, with a banded cloud structure above, one of a number of views of dune formations taken on the Gemini flights. Photographed by Gemini VII flight crew at 12:02 G.m.t., December 11, 1965.

Other Phenomena

Pictures of features other than clouds, often obtained from the S-5 synoptic terrain photography experiment which uses the same camera and film as S-6, sometimes are of interest in meteorology and related fields. For example, smoke from forest fires or from industrial sources may indicate the low-level wind direction and may yield quantitative information on the stability of the lower atmosphere. Sand dunes of various types are of interest to those working on the relationship between winds and deposition patterns. One of many dune scenes is shown in figure 36-8. Similarly, the configuration of bottom sand in some shallow water areas can be related to motions in the ocean. Figure 36-9 is one of several views of the ocean bottom in the Bahama Islands area. Also, the differences in the reflectivity of wet and dry soils can be related to the occurrence of recent rainfall (ref. 4). Figure 36-10 shows the dark area resulting from heavy rains in the previous 24 hours.

Conclusion

In conclusion, through the skill of the crews of various Gemini missions, and the assistance of many NASA individuals working in the experiments program, a great many excellent, useful pictures of the earth's weather systems have been obtained; however, weather systems are extremely variable, and there remain a number of interesting views or combinations of views which it is hoped will be obtained on future manned space flights over regions of the earth, both within and outside the equatorial zone.

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2. NAGLER, K. M.; AND SOULES, S. D.: Cloud Photography From the Gemini 4 Spaceflight. Bulletin of the American Meteorological Society, vol. 46, no. 9, September 1965.
3. NAGLER, K. M.; AND SOULES, S. D.: Experiment S-6, Weather Photography. Manned Space-Flight Experiments Interim Report, Gemini V Mission, NASA, Washington, D.C., January 1966.
4. HOPE, J. R.: Path of Heavy Rainfall Photographed From Space. Bulletin of the American Meteorological Society, May 1966.

FIGURE 36–9.—Great Exuma Island in the Bahamas, showing the bottom configuration in the shallow water areas. Photographed by Gemini V flight crew at 18:39 G.m.t., August 22, 1965.

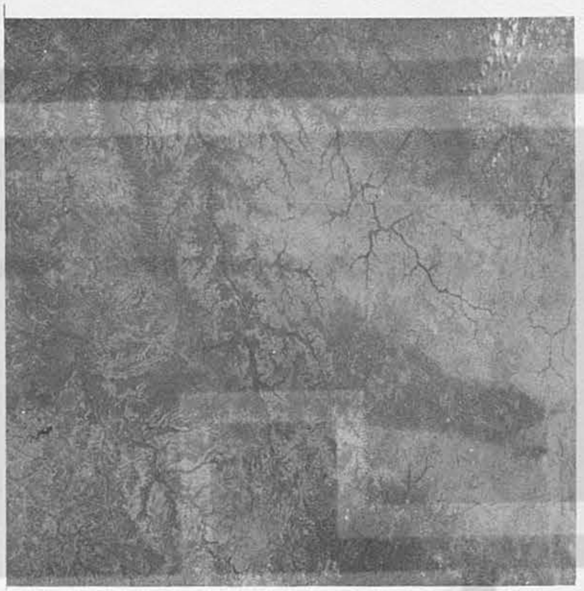


FIGURE 36–10.—Terrain shading in central Texas, caused by heavy rainfall the previous day. The highway prominent in the upper left corner connects Odessa and Midland. The stream in the center of the picture is the North Concho River along San Angelo. Photographed by Gemini IV flight crew at 17:46 G.m.t., June 5, 1965.

37. EXPERIMENTS MSC-2 AND MSC-3, PROTON/ELECTRON SPECTROMETER AND TRI-AXIS MAGNETOMETER

By JAMES R. MARBACH, *Advanced Spacecraft Technology Division, NASA Manned Spacecraft Center, and* WILLIAM D. WOMACK, *Advanced Spacecraft Technology Division, NASA Manned Spacecraft Center*

Introduction

Experiments MSC-2 and MSC-3 were the first of a continuing series of measurements of particles and fields conducted by the Radiation and Fields Branch at the Manned Spacecraft Center (MSC) in support of its shield verification and dose prediction program for all manned spacecraft. The simultaneous measurement of the external radiation environment and the radiation dose received by the flight crew throughout a space mission serves to evaluate and perfect calculational techniques, whereby the dose to be received by the crew on any given mission can be estimated prior to that mission.

Instrumentation

The specific function of the MSC-2 and MSC-3 instrumentation was to respectively provide an accurate picture of the proton and electron intensities and energies, and the direction and magnitude of the earth's magnetic field during selected portions of the Gemini IV and Gemini VII missions. The MSC-3 experiment was actually flown in support of MSC-2 to provide the instantaneous direction of the earth's magnetic field relative to the spectrometer. This information was needed in the reduction of MSC-2 data since the particle intensities encountered are strongly directional with respect to the magnetic field. The Gemini IV mission employed a pulse height analyzer with plastic scintillator in an anticoincidence arrangement for the proton/electron measurement. Internal gain shifting techniques provided alternate measurements of the proton and electron environment every 13 seconds. The instrument monitored electrons of $0.4<E<8$ MeV and protons of $25<E<80$ MeV at fluxes between 0 and 3×10^5 particles/cm²-sec. The MSC-3 experiment on Gemini IV utilized a tri-axial flux gate magnetometer to detect the direction and amplitude of the earth's magnetic field over the range of 0 to 60 000 gammas.

The Gemini VII spectrometer utilized the same pulse height analyzer technique as on Gemini IV except the anticoincidence scintillator was replaced with a thin dE/dx plastic wafer over the instrument entrance aperture. This modification allowed the measurement of protons of $5<E<18$ MeV instead of $25<E<80$ MeV. The electron range and flux-handling capability were the same as those on Gemini IV, and again protons and electrons were measured alternately in time. The Gemini VII magnetometer was identical to that on Gemini IV. Figures 37-1 through 37-5 show the instruments as employed on both spacecraft.

Gemini IV Data

Both experiments were operated at the same time throughout the Gemini mission and were scheduled for turn-on during passes that provided maximum coverage through the South

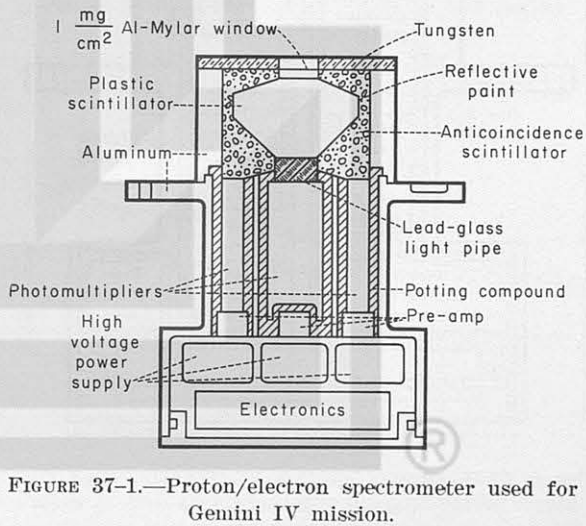


FIGURE 37-1.—Proton/electron spectrometer used for Gemini IV mission.

218-556 O—66——24

Anomaly Region between South America and Africa. This region (bounded approximately by 30° E and 60° W longitude and 15° S and 55° S latitude) is the only portion of the spacecraft trajectory that presents any significant proton and electron intensities.

Figure 37–6 is an intensity time history for a typical pass through the anomaly. This particular revolution has been converted to true omnidirectional flux and shows a peak counting

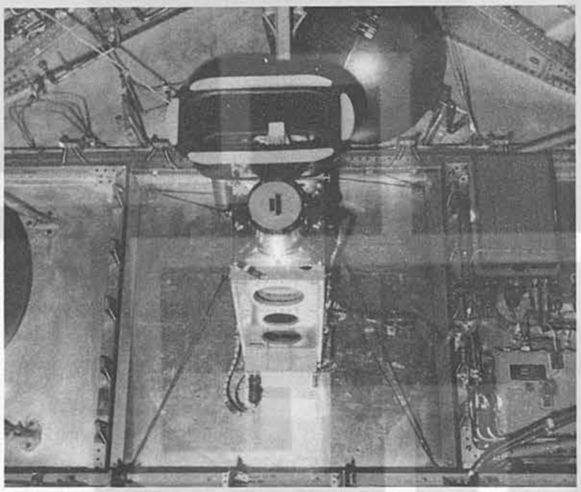


FIGURE 37–2.—Location of proton/electron spectrometer in Gemini IV spacecraft adapter assembly.

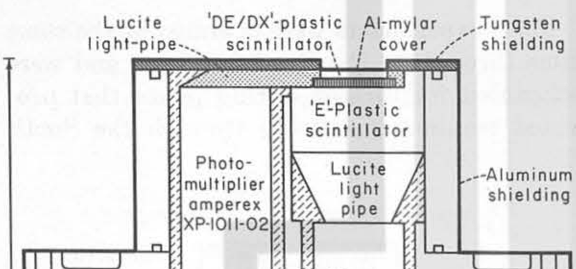


FIGURE 37–3.—Proton/electron spectrometer used for Gemini VII mission.

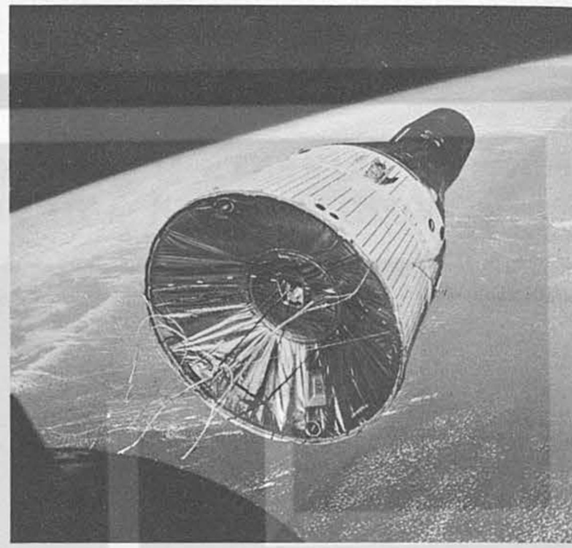


FIGURE 37–4.—Location of proton/electron spectrometer in Gemini VII spacecraft.

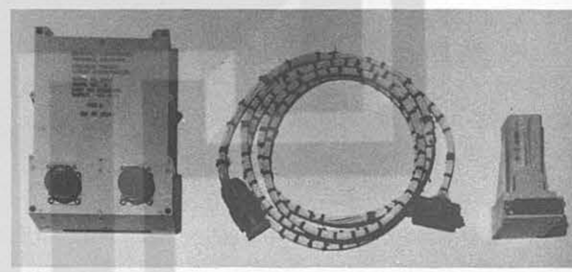


FIGURE 37–5.—Magnetometer used for Gemini IV and VII missions.

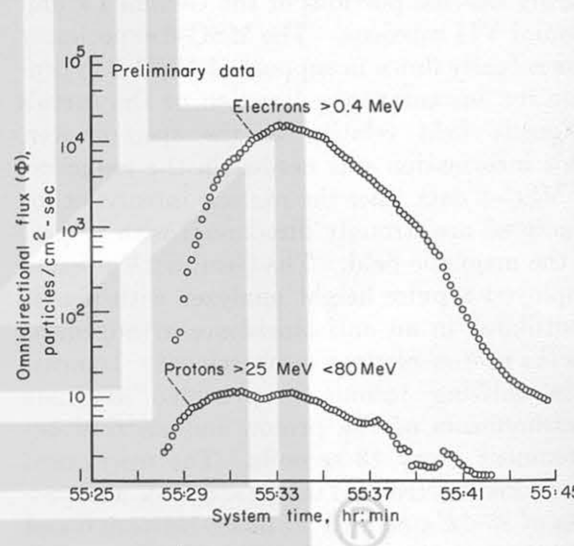


FIGURE 37–6.—Flux compared with time for revolution 36 of Gemini IV mission.

rate of about 10^4 electrons/cm^2-sec and 10 protons/cm^2-sec. Peak counting rates encountered never exceeded about 6×10^4 for electrons and 10^2 for protons. Figure 37–7 shows characteristic electron spectra observed through one anomaly pass. As is evident in the figure, the spectrum changes significantly through the anomaly. Figure 37–8 depicts the proton spectrum for the same pass. The change in shape here is much more subtle.

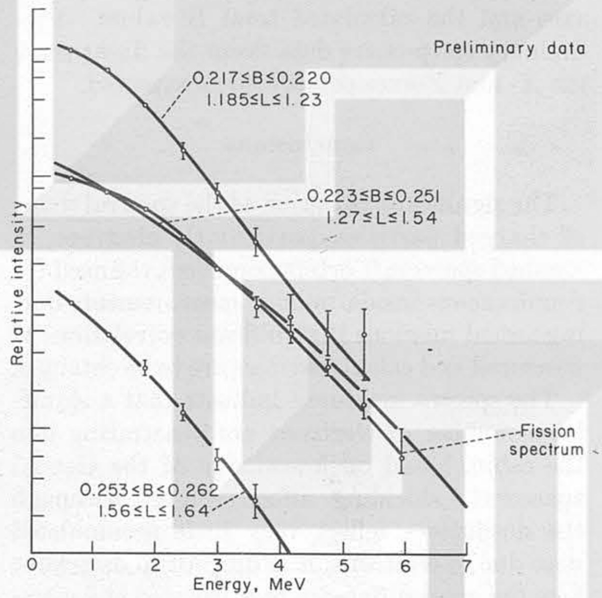


FIGURE 37–7.—Characteristic electron spectra for revolution 36 of Gemini IV mission.

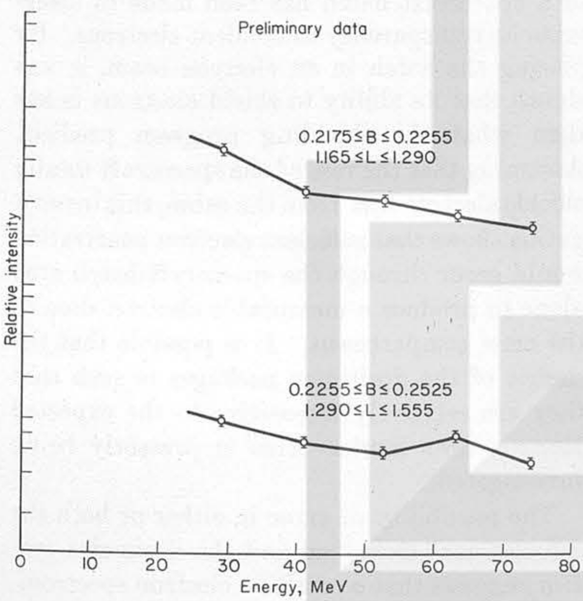


FIGURE 37–8.—Characteristic proton spectra for revolution 36 of Gemini IV mission.

Figure 37–9 is a plot of magnetometer data that were typical throughout most of the mission. The strongly varying direction of the field lines, with respect to the spacecraft during revolutions 7 and 22, was due almost entirely to the tumbling motion of the spacecraft, which was free to drift in pitch, roll, and yaw throughout most of the mission. Revolution 51 is a pass during which the pilot held pitch, roll, and yaw as close to zero as possible. Figure 37–10 shows the total field strength measured during revolution 51 as compared with the theoretical values predicted for this region using the computer technique of McIlwain. The difference is attributed to small errors in the measurement due to stray magnetic fields from the spacecraft. In order to check this assumption, the total field intensity values, as predicted by McIlwain, were assumed to be correct, and the three axes were appropriately corrected so that the measured total field agreed with the predicted values. These corrected values are also plotted in figure 37–10. Figure 37–11 is a plot of the total field direction as

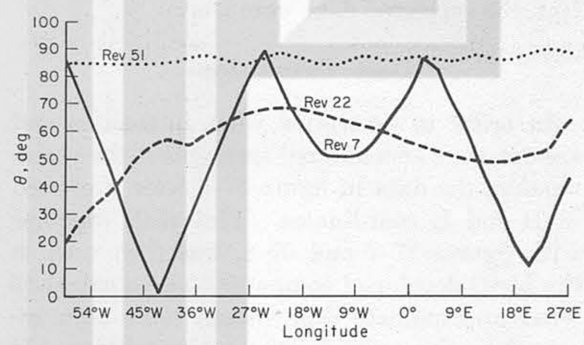


FIGURE 37–9.—Direction of magnetic field during Gemini IV mission.

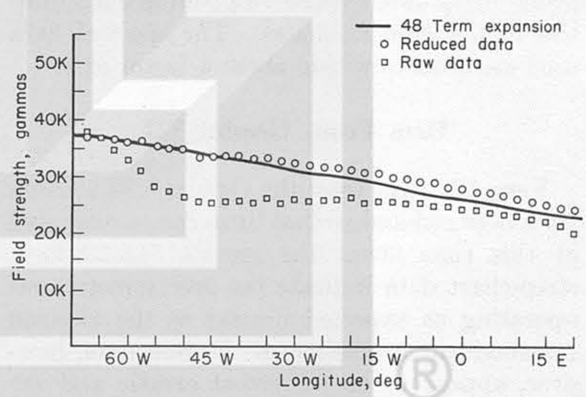


FIGURE 37–10.—Field strength measured during revolution 51 of Gemini IV mission.

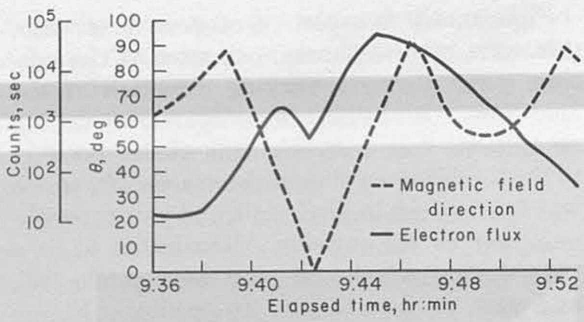


FIGURE 37–11.—Correlation of Experiment MSC–2 and Experiment MSC–3 data for revolution 7 of Gemini IV mission.

measured on revolution 7 with the correction included. The point where the spacecraft Z-axis is approximately parallel with the magnetic field correlates nicely with an observed dip in charged particle intensity as observed by the MSC–2 spectrometer. Since the flux incident on the spectrometer is at a minimum whenever the Z-axis of the spacecraft is alined with the magnetic field, this dip would be expected if, in fact, the corrected data were true.

Dose Calculations

In order to determine what intensities and spectra were encountered throughout the entire mission, the data in figure 37–6 were replotted in B and L coordinates. This plot, together with figures 37–7 and 37–8, was then used in the MSC-developed computer code to calculate what approximate dose should have been received by the crew for the entire mission. It should be noted that the B, L plots are based on one revolution only and, thus, provide only preliminary data with corresponding uncertainties in the dose estimates. The spectral data used are good to within about a factor of 2.

Data From Gemini VII

Very few data from the Gemini VII mission have been reduced so that little can be discussed at this time about the results. Quick-look, strip-chart data indicate the spectrometer was operating as expected insofar as the electron measurement is concerned. Proton data, however, appear to be somewhat erratic and are suspected, but a detailed analysis of more data is needed to determine if a true difficulty developed during the launch or orbit phase of the mission.

Several days prior to the Gemini VII launch, the magnetometer Z-axis detector was observed to have failed. Replacement of the sensor would have caused a slippage in the launch date, and it was decided that, based on the apparent reliability of the McIlwain total intensity values (as determined on Gemini IV), the needed directional data could be obtained using only two axes and the calculated total B values. Preliminary strip-chart data from the flight show the X- and Y-axes performed as expected.

Conclusions

The significant variation of the spectral shape of charged particles, particularly electrons, in manned spacecraft orbits points out the need for simultaneous inside/outside measurements during actual missions if significant correlations of measured and calculated dose are to be obtained.

The spectra measured indicate that a significant number of electrons are penetrating into the cabin, based on knowledge of the Gemini spacecraft shielding effectiveness. Although the dosimeters reflect very little accumulated dose due to electrons, it is difficult to determine how the gross difference in calculated and measured dose can be due entirely to inadequacies in the shielding calculations. A preliminary study of a spacecraft hatch has been made to determine its transparency to incident electrons. By placing the hatch in an electron beam, it was shown that its ability to shield electrons is less than what the shielding program predicts. Assuming that the rest of the spacecraft totally shields electron flux from the cabin, this investigation shows that sufficient electron penetration would occur through the spacecraft hatch area alone to produce a measurable electron dose in the crew compartment. It is possible that the design of the dosimeter packages is such that they are relatively insensitive to the expected electron dose levels. This is presently being investigated.

The possibility of error in either or both the calculational technique and the dosimeter system suggests that a sensitive electron spectrometer inside the spacecraft cabin would provide very valuable data. An effort is presently under-way at MSC to modify the bremsstrahlung spectrometer experiment equipment (MSC–7), which is now scheduled for a later Gemini mission, to detect both electron flux as well as secondary X-rays. This technique and the associated results will be discussed in the experiment symposia following the flights in which the equipment is installed.

38. EXPERIMENT D4/D7, CELESTIAL RADIOMETRY AND SPACE-OBJECT RADIOMETRY

By Burden Brentnall, *Air Force Systems Command Field Office, NASA Manned Spacecraft Center*

Summary

The study of the spectral irradiance of natural phenomena and manmade objects has been of increasing interest in recent years both to the scientific community and to the Department of Defense. The purpose of the Air Force D4/D7 experiment has been to obtain accurate measurements from space of emitted and reflected radiance from a comprehensive collection of subjects. The determination of threshold sensitivity values in absolute numbers, and the separation and correlation of specific targets with various backgrounds have been prime objectives.

This report is intended to provide a description of the equipment used on Gemini V and VII and its operations, and a discussion of the measurements made. Results will be discussed generally on a quantitative basis.

Experiment Description

Two interferometer spectrometers and a multichannel spectroradiometer were used as the sensing instruments in this experiment. The selection of the instruments and the particular detectors in the instruments was based upon the spectral bands to be investigated in each flight (fig. 38–1) and the nature of the intended measurements. The instrument characteristics (field of view and resolution, for example) were a compromise among optimization for a particular type of measurement, a need for a broad selection of spectral information, and the performance and other influencing characteristics of the spacecraft.

Since the D4/D7 experiment equipment is contained in several units, it will be reviewed first by component and then integrally as an experimental system aboard the Gemini space-

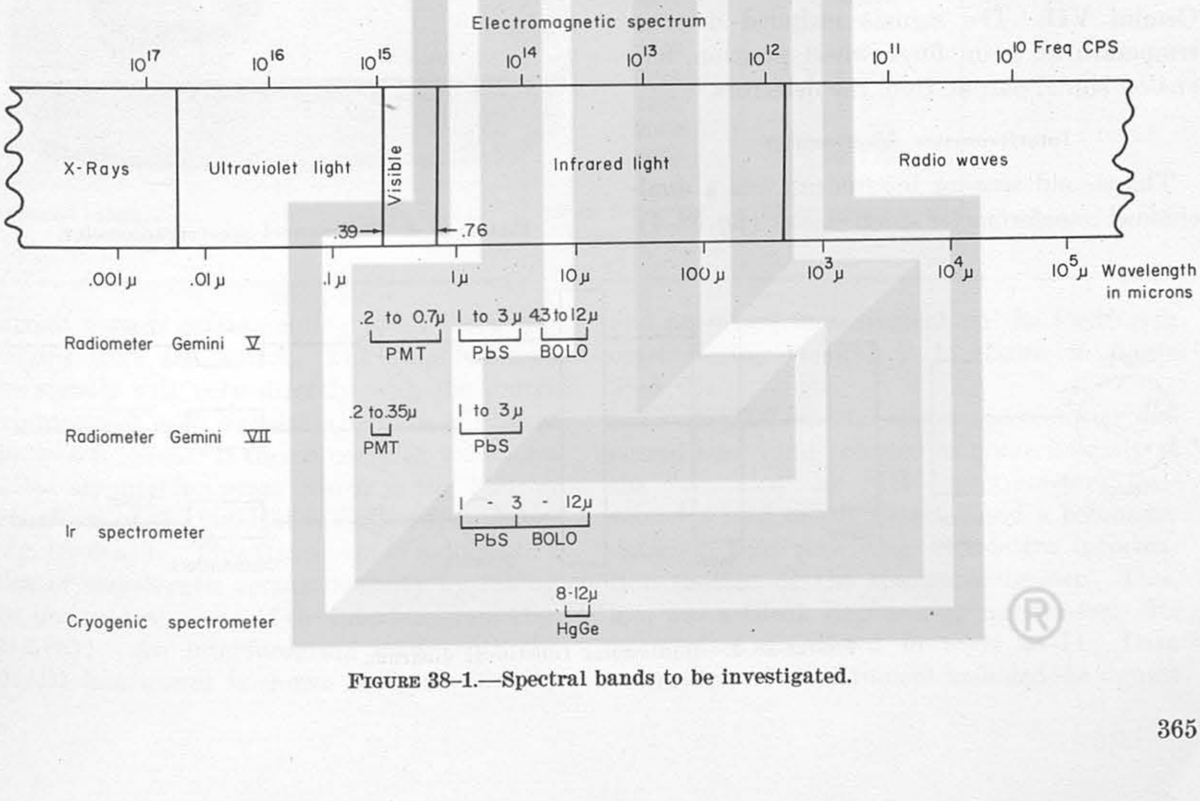


Figure 38–1.—Spectral bands to be investigated.

craft. After the system has been defined, operational aspects will be discussed.

D4/D7 Flight Equipment

Radiometer

One of the three measuring instruments used in this experiment was a multichannel, direct-current spectroradiometer. In this radiometer (fig. 38–2), the impinging energy is focused by the collecting optics, mechanically chopped and filtered to obtain specific bands of interest, and then received by the three detectors. The detector signals are then amplified and demodulated. The resultant signals are a function of energy intensity in a given spectral band.

The D4/D7 radiometer (fig. 38–3) was made by Block Engineering Associates, Cambridge, Mass. The radiometer instrument parameters for each flight are presented in table 38–I.

As a result of reviewing the Gemini V flight data, a decision was made to modify the Gemini VII radiometer to incorporate a more sensitive ultraviolet (UV) photomultiplier tube. An ASCOP 541F–05M tube was installed in place of the IP 28 flown on Gemini V, and the bolometer detector was eliminated to make room for the larger photomultiplier tube.

Thirteen signals were provided from the radiometer on Gemini V; 11 were provided on Gemini VII. The signals included detector temperatures, gain, filter wheel position, and analog signal output from the detectors.

Interferometer Spectrometer

The second sensing instrument was a dual-channel interferometer spectrometer (fig. 38–4). The interferometer section was patterned after the Michelson interferometer (fig. 38–5).

The beam splitter splits the optical path, sending part of the beam to the movable mirror M_1 and the other part to a fixed mirror M_2. As a result of the optical path changeability, the waves returning from the mirrors may be in phase (additive) or may be out of phase to some degree and have a canceling effect. The total effect is to produce cyclic reinforcement or interference with the wave amplitude at the detector at any given frequency. The frequency at the detector of this alternate cancellation and reinforcement is a function of the particular spectral energy wavelength λ, the optical retardation B of the mirror, and the time required to move the mirror (scan time) T. Thus,

$$F_\lambda = \frac{B}{\lambda T}$$

The detector puts out an alternating-current signal which is the sum of the alternating-

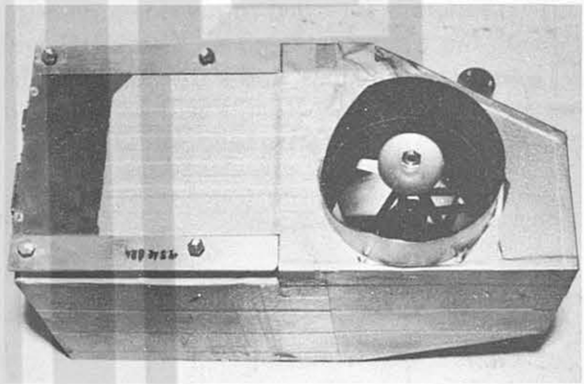


FIGURE 38–3.—Trichannel spectroradiometer.

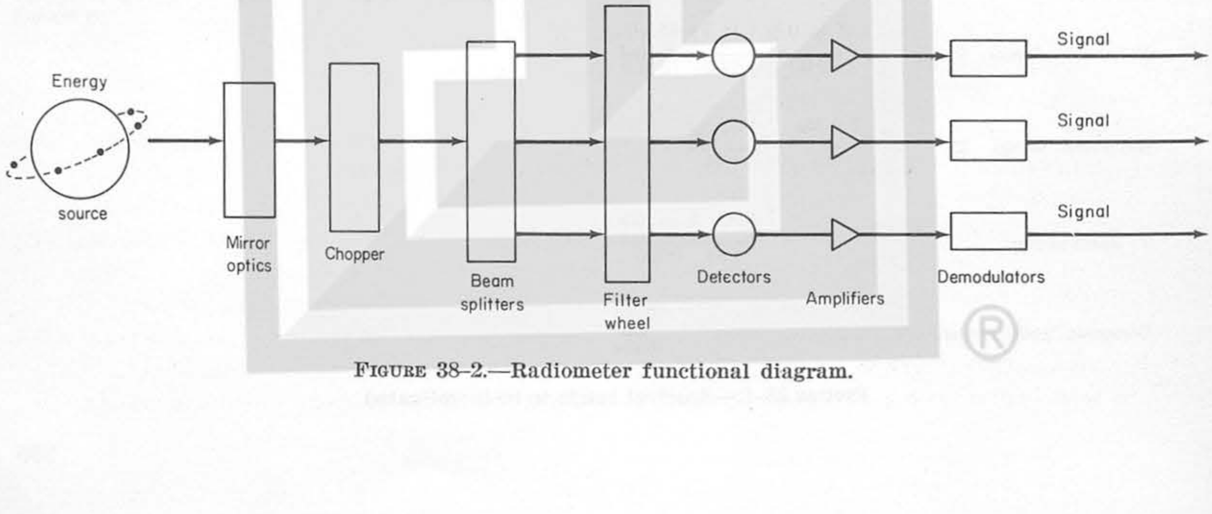


FIGURE 38–2.—Radiometer functional diagram.

TABLE 38–I.—*Radiometer Instrument Parameters*

Weight	17. 5 lb		
Power input	14 watts		
Field of view	2°		
Optics	4 in. Cassegrain		
Detectors, Gemini V	Photomultiplier tube (IP 28)	Lead sulfide	Bolometer
Spectral band, μ	0. 2–0. 6	1. 0–3. 0	4–15
Nominal filter width, μ	0. 03	0. 1	0. 3
Filters used, μ	0. 22 . 24 . 26 . 28 . 30 . 35 . 40 . 50 . 60	1. 053 1. 242 1. 380 1. 555 1. 870 2. 200 2. 820	4. 30 4. 45 6. 00 8. 0 9. 6 15. 0
Dynamic range	10^5 in 4 discrete steps	10^3 log compressed	10^3 log compressed
Detectors, Gemini VII	Photomultiplier tube (ASCOP 541 F–05M)	Lead sulfide	
Spectral band, μ	0. 2–0. 35	1. 0–3. 0	
Nominal filter width, μ	0. 03	0. 1	
Filters used, μ	0. 2200 . 2400 . 2500 2600 . 2800 . 2811 . 2862 . 3000 . 3060	1. 053 1. 242 1. 380 1. 555 1. 870 1. 9000 2. 200 2. 725 2. 775 2. 825	
Dynamic range	10^5 in 4 discrete steps	10^3 log compressed	

current signals corresponding to all the wavelengths from the source. The amplitudes of the signals will vary directly with the source brightness at each wavelength. The output of the interferometer is then a complex waveform called an interferogram which is the Fourier transform of the incident radiation frequencies (fig. 38–6(a)). This transform is reduced to a plot of wavelength versus intensity by taking the inverse transform of the interferogram (fig. 38–6(b)). An interferogram made with the D4/D7 instrument is shown in figure 38–6(c) and an actual measurement on the California coast during Gemini V is shown in figure 38–6(d).

The D4/D7 interferometer spectrometer discussed here (and referred to nontechnically as the "uncooled" or "IR" spectrometer) contained a lead sulfide detector and a bolometer detector, thus providing correlative information to that of the spectroradiometer. This, too, was a Block Engineering instrument. Its parameters are listed in table 38–II. Data output from the instrument included the signals

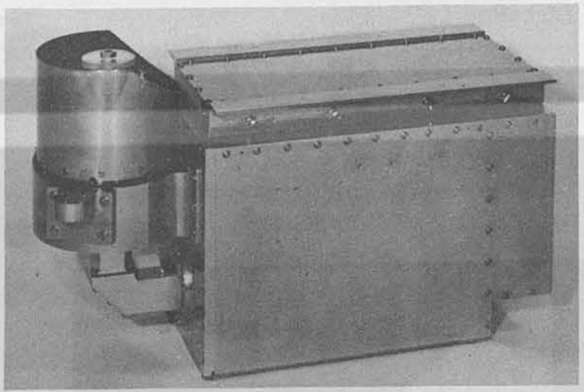


FIGURE 38-4.—Dual-channel interferometer spectrometer.

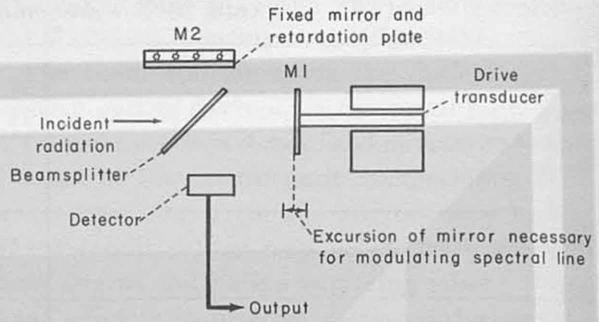
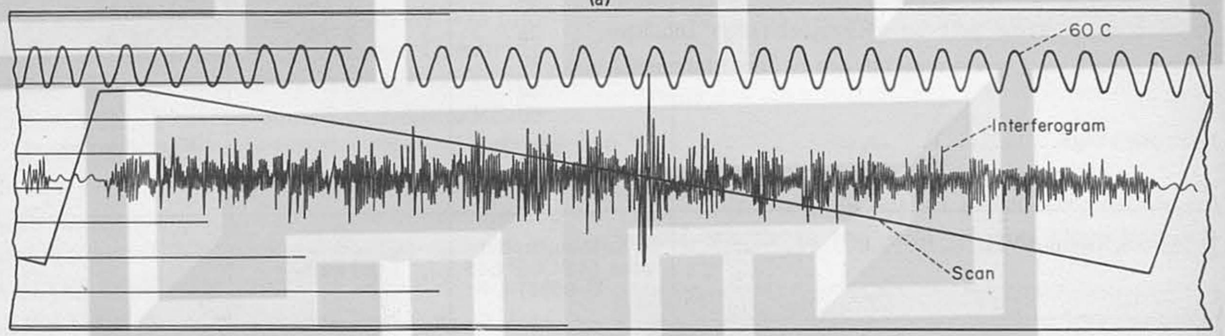


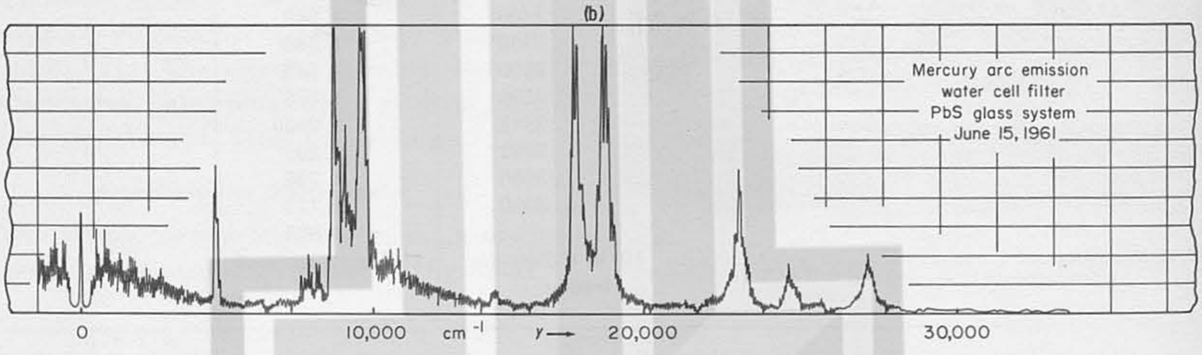
FIGURE 38-5.—Schematic of Michelson interferometer.

(a)



(*a*) Representation of an interferogram.
FIGURE 38-6.—Interferometer measurements.

(b)



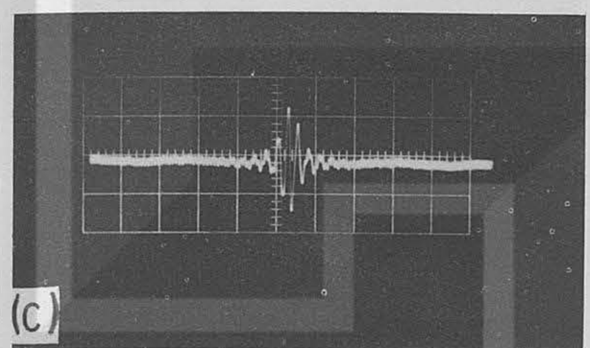
(*b*) Representation of an interferogram reduced to a spectrum.
FIGURE 38-6.—Continued.

from the two detectors, gain settings, detector temperatures, and automatic calibration source data. Lead-sulfide signal data were handled on a data channel-sharing basis with the detector output from the cryogenic spectrometer.

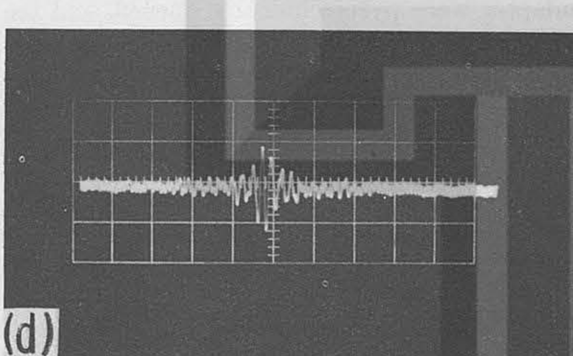
Cryogenic Interferometer Spectrometer

The cryogenic interferometer spectrometer is similar in operation to the IR spectrometer, although dissimilar in appearance (fig. 38-7). The principal difference is that the highly sensitive detector must be cryogenically cooled to make measurements in the region of interest (8 to 12 microns). The cooling is accomplished by immersing a well containing the detector, optics, and some of the electronics in liquid neon.

The cryogenic subsystem was made for Block Engineering by AiResearch Division of Garrett Corp. It was an open-cycle, subcritical, cryogenic cooling system which maintained the instrument well at a temperature of −397° F for a period of approximately 14 hours. Figure 38–8 shows an X-ray view of the cryogenic tank and instrument well. The parameters for the instrument are listed in table 38–III.



(*c*) Spectrometer interferogram, 2100° C calibration source.
FIGURE 38–6.—Continued.



(*d*) IR spectrometer interferogram during the Gemini V flight (California coastal land).
FIGURE 38–6.—Concluded.

TABLE 38–II.—*Parameters of the IR Spectrometer*

Weight	18.5 lb
Power input	8 watts
Field of view	2°
Optics	4 in. Cassegrain

Detectors	Lead sulfide	Bolometer
Spectral band, μ	1–3	3–15
Dynamic range	10^3 automatic gain changing	10^3 automatic gain changing

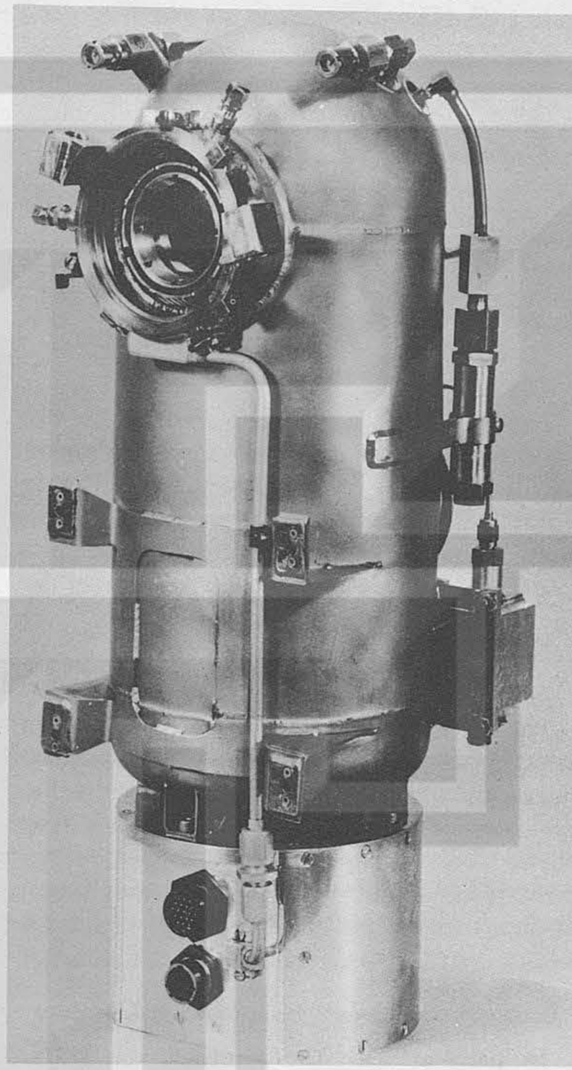


FIGURE 38–7.—Cryogenic interferometer spectrometer.

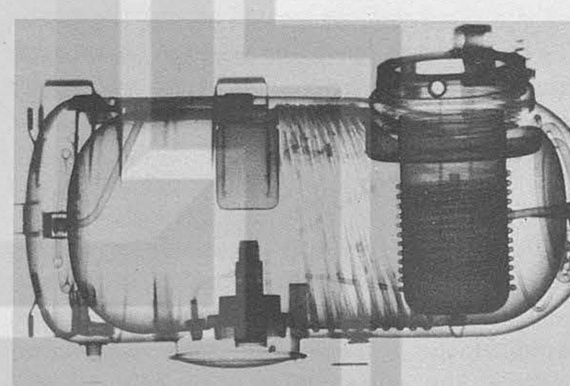


FIGURE 38–8.—X-ray view of cryogenic interferometer spectrometer.

TABLE 38-III.—*Parameters of the Cryogenic Interferometer Spectrometer*

Weight (with neon)	33.5 lb.
Power input	6 watts
Field of view	2°
Optics	4 in. Cassegrain
Detector	Mercury-doped germanium
Spectral band	8 to 12 microns
Dynamic range	10^3 automatic gain changing
Coolant	Liquid neon

Electronics Unit

The electronics unit used in conjunction with the three sensing devices contained the various circuits necessary for the experiment. The circuitry includes an electronic commutator, filter motor logic, variable control oscillators, mixer amplifier, clock pulse generator, and other secondary electronic circuitry.

Recorder Transport and Electronics

The D4/D7 experiment tape recorder was separated into two modules: the tape transport and the recorder electronics. This was done so that the recorder would fit into the available space on the Gemini reentry vehicle. The recorder provided 56 minutes of tape for three channels of data. It was not capable of dump, and data were stored and retrieved with the spacecraft.

Frequency-Modulation Transmitter and Antenna

In parallel with the recorder, the D4/D7 transmitter provided three channels of real-time frequency-modulated (FM) data to selected ground stations located around the earth. The transmitter, operating through an antenna extended from the pilot's side of the spacecraft, transmitted 2 watts on an assigned ultrahigh frequency.

Control Panel

The majority of the switches associated with the experiment were located on the pilot's main console (fig. 38-9). Additional functions were provided by a meter and some sequencing switches.

D4/D7 Experiment System

The experiment system consisting of the foregoing components was mounted in Gemini V

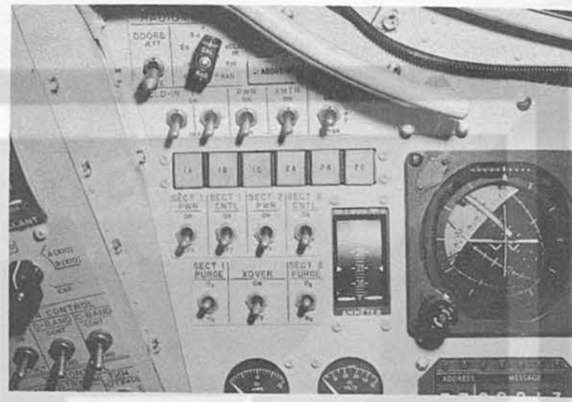


FIGURE 38-9.—Instrument panel for Experiment D4/D7.

and VII as shown in figure 38-10. The radiometer and spectrometers were mounted in the Gemini retroadapter section on swingout arms. After the spacecraft was in orbit, doors in the adapter were pyrotechnically opened, and the three sensing units swung through the openings into boresight alinement with the spacecraft optical sight. After the sensing units had been erected, the spacecraft was pointed at the desired area for measurement. Figure 38-11 shows the Gemini VII with the instruments extended. Gemini V was similar in appearance.

The data from the radiometer were telemetered through the spacecraft pulse code modulation (PCM) system. The data from the spectrometers were telemetered through the transmitter or routed to the recorder, or both were accomplished, if desired.

D4/D7 Mission Plan

The desired objectives for the D4/D7 measurements included the following:

	Microns
Earth backgrounds	0.2 to 12
Sky backgrounds	0.2 to 12
Sky-to-horizon spectral calibrations	8 to 12
Rocket exhaust plumes	0.2 to 3
Natural space phenomena (stars, moon, sun)	0.2 to 12
Manmade objects in space	0.2 to 12
Weather phenomena (clouds, storms, lightning)	0.2 to 10
Equatorial nadir-to-horizon spectral calibrations	8 to 10

Since the lifetime of the cryogenic neon in the cooled spectrometer was limited to 14 hours, 5

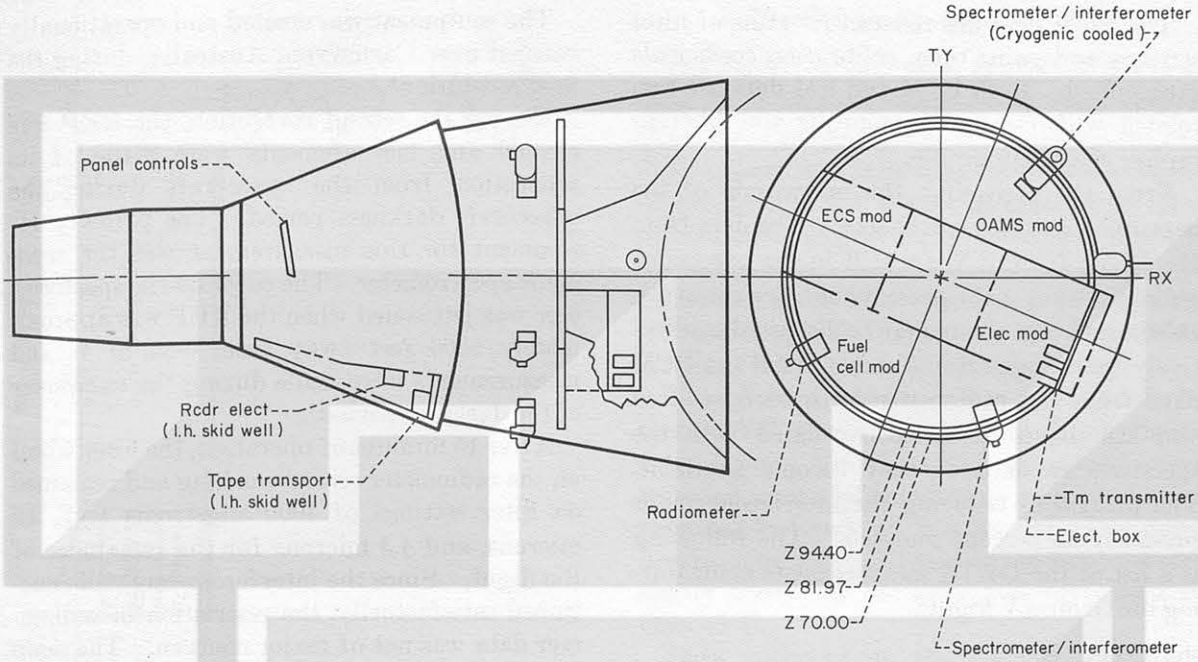


FIGURE 38–10.—Location of Experiment D4/D7 equipment in spacecraft.

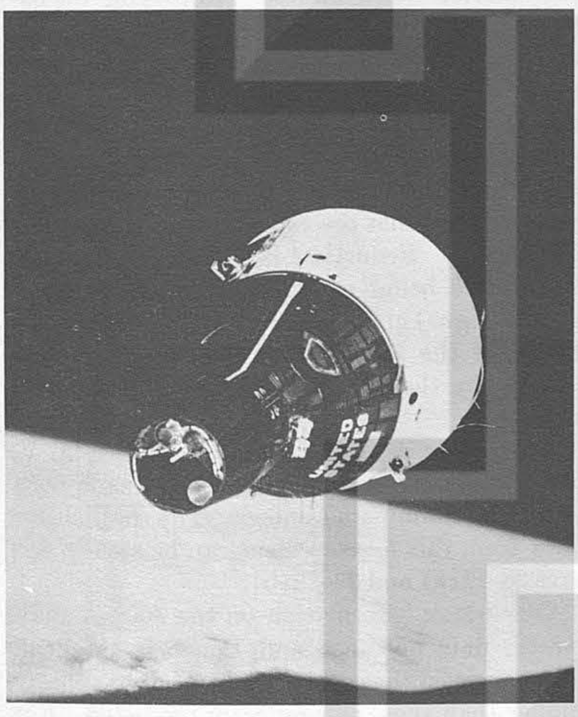


FIGURE 38–11.—Cryogenic spectrometer and radiometer erected on Gemini VII spacecraft.

of which would be spent on the launch pad, the measurements requiring the use of the cooled spectrometer were planned for the first few revolutions. The rocket-plume measurements were planned for those revolutions which brought the spacecraft closest to the firing site, yet as early or late in the day as feasible to minimize background radiation. The sun measurement was planned to be the final measurement, since calibration of the detectors might be affected. The remainder of the measurements, requiring real-time updating, were interspersed throughout the flight.

Results From Gemini V

Approximately 3 hours 10 minutes of D4/D7 data were gathered during the Gemini V flight. Twenty-one separate measurements were made, covering 30 designated subjects. The PCM and FM transmitted data amounted to 125 000 feet of magnetic tape.

Processing the data requires a great amount of time. The interferometer data must be run through a wave analyzer or a high-speed computer. The wave analyzer integrates 35 interferograms and gives the results in the form of Fourier coefficients in approximately 30 minutes. The computer takes about 2 hours to perform the transform on one interferogram. Over 10 000 interfercgrams were made during the Gemini V flight.

The PCM data are reduced in terms of filter settings and gain; then, calibration coefficients are applied. Both PCM and FM data are correlated with crewman comments and photography, where applicable.

From the foregoing, the magnitude of the data-reduction task can be seen. The data from D4/D7 on Gemini V are still in the process of reduction and, at the present time, are not available in sufficient amounts to be discussed qualitatively to any significant extent. All the PCM data from the radiometer have been reduced and are presently being correlated with the spectrometer data as they become available. The process of reducing the interferograms is presently 35 percent complete. The following is a list of the D4/D7 measurements made during the Gemini V flight:

Revolution	Location	Measurement
1	Carnarvon, Australia.	Operational readiness check of cryogenic spectrometer
2	Africa-Australia	Rendezvous evaluation pod (REP) measurements during darkness
14	Australia	Night water and night land measurements
16	Africa	Mountains and land with vegetation
16	Malagasy	Night water and night land measurements
16	Australia	Star measurement, Vega
16	Australia	Equipment alinement check
17	Australia	Moon irradiance measurement
31	Africa	Cloud blanket sweep, nadir-to-horizon
31/32	Florida	Land with vegetation
45	Australia	Night void-sky measurement
47	Australia	Zodiacal light
47	Australia	Star measurement, Deneb
47	California	Minuteman missile launch
51	Hawaii	Island measurement
61	New Mexico	Rocket sled firing
62	California	Minuteman missile launch
74	Africa	Water, land, mountains, desert
88	Africa	Desert
89	Africa	Mountains
103	Australia	Horizon-to-nadir scan

The equipment was erected and operationally verified over Carnarvon, Australia, during the first revolution.

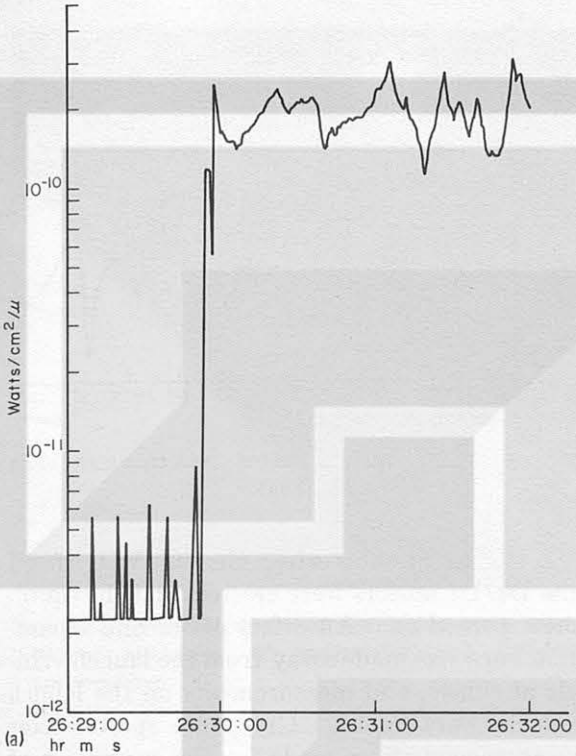
During the second revolution, the REP was ejected and measurements were made of its separation from the spacecraft during the spacecraft darkness period. The primary instrument for this measurement was the cryogenic spectrometer. The cover on the spectrometer was jettisoned when the REP was approximately 2500 feet away from Gemini V, and measurements were made during the remainder of the darkness period.

After 15 minutes of operation, the filter wheel on the radiometer ceased working and remained on filter settings of 4000 angstroms (Å), 2.2 microns, and 4.3 microns for the remainder of the flight. Since the interferometers still functioned satisfactorily, the restriction in radiometer data was not of major concern. The main loss of data was in the UV region—not covered by the spectrometers—where only the 4000 Å information was available. In playing the onboard D4/D7 recorder after its retrieval, it was discovered that no REP measurement data were recorded on the tape. This limited the information from the cryogenic spectrometer to the FM data received during the pass over Carnarvon. Review of the interferograms made at Carnarvon indicates that the signal was well above the noise level. Reduction is in process, and attempts are being made to separate the background signal and spacecraft radiance from the signal of the REP. This task is made more difficult by the lack of data from the onboard recorder.

Due to the date of the launch of Gemini V, the moon measurements had to be made on a partially illuminated moon. The radiometer data from this measurement can be seen in figures 38–12(a) and 38–12(b).

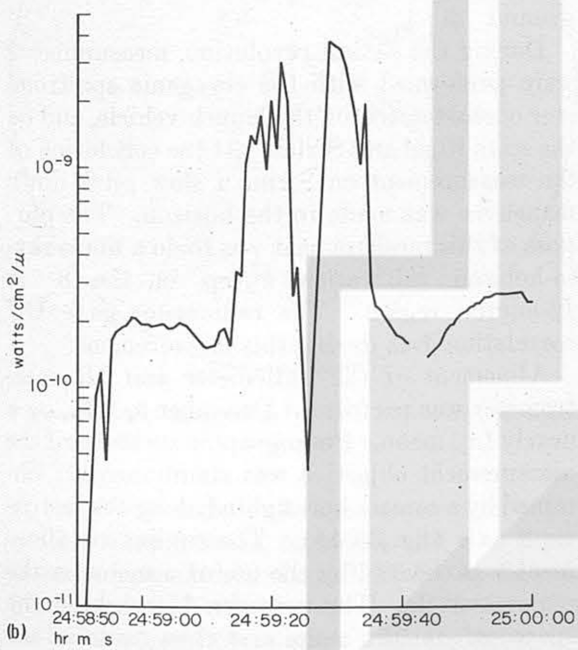
Quick-look information on the 4000 Å radiometer data on Vega and Deneb is excellent. The values on that spectrum band were slightly higher than those theoretically predicted. For example, the value for Vega was 1.2×10^{-11} watts per square centimeter per micron at 4000 Å.

An example of the IR spectrometer data can be seen in figure 38–13. This shows the return at 1.88 microns on the California land background.



(*a*) Moon measurements made during revolution 17, Gemini V mission.

FIGURE 38-12.—Radiometer data from moon measurements (4000 Å).



(*b*) Moon measurements made during alinement check, revolution 16 of Gemini V mission.

FIGURE 38-12.—Concluded.

Results From Gemini VII

The D4/D7 results from Gemini V did have some effect on the experiment on Gemini VII. Since there were only 4 months between the two flights, there was little time for data evaluation inputs to use for design modification. One modification, as previously noted, was made to the radiometer. Another modification, a switch guard on the recorder switch, was added to the instrument panel. Otherwise the experiment system was identical for both spacecraft.

The planned measurements to be made by Gemini VII were affected by the data gathered from Gemini V. Certain measurements were repeated where information in addition to that provided by Gemini V was desired. New measurements were added, based on the demonstrated ability shown by the crew and equipment on Gemini V.

Data gathered on the Gemini VII flight totaled 3 hours 11 minutes, which was almost the same as the amount gathered on Gemini V. There were 36 separate D4/D7 measurements made of 42 designated subjects.

The following is a list of the measurements made during the Gemini VII flight:

Revolution	Location	Measurement
1	Africa-Malagasy	Launch vehicle measurement and cooled spectrometer alinement check
1	Malagasy	Launch vehicle background measurement
1	Malagasy-Australia.	Launch vehicle measurement
2	Ascension	Void space measurement
2	Ascension	Star measurement—Rigel with cryogenic spectrometer
2	Ascension	Launch vehicle measurement
2	South Atlantic	Star measurement—Sirius with cryogenic spectrometer
2	Malagasy	Night sky-earth horizon calibration sweep with cooled spectrometer
6	Malagasy	Cryogenic lifetime check

Revolution	Location	Measurement
6	Hawaii	Cryogenic lifetime check
7	Hawaii	Cryogenic lifetime check
8	Ascension	Cryogenic lifetime check
15	Malagasy	Radiometer and IR spectrometer alinement check on nearly full moon
30	Malagasy	Star measurements—Betelgeuse and Rigel without cryogenic instrument
31	Florida	Polaris launch
32	Ascension	Milky Way
32	North America	Earth background—coastal, mountains, desert, land with vegetation
45	North America	Earth background—water, mountains, plains, coastal regions correlated with IR color-film photographs
49	Malagasy	Night airglow
49	Malagasy	Large fire on earth at night
59	Malagasy	Full moon measurement
59	Australia	Night land, water, cloud reflectance with full moon
59	Australia	Lightning at night
74	Africa	Cloud blanket sweep with camera correlation
75	Africa	Lightning at night
76	Ascension	Horizon-to-nadir scan
88	Africa	Desert
89	Malagasy	Celestial measurement—Venus
104	Australia	Night land and water
117/118	Florida	Gemini VI–A abort
148	New Mexico	Rocket sled firing
149	Pacific	Night measurement of Minuteman reentry
161/162	Florida	Gemini VI–A climb to orbit
166	Hawaii	Gemini VI–A station keeping
169	South America	Gemini VI–A separation burn
193	Texas	Sun measurement

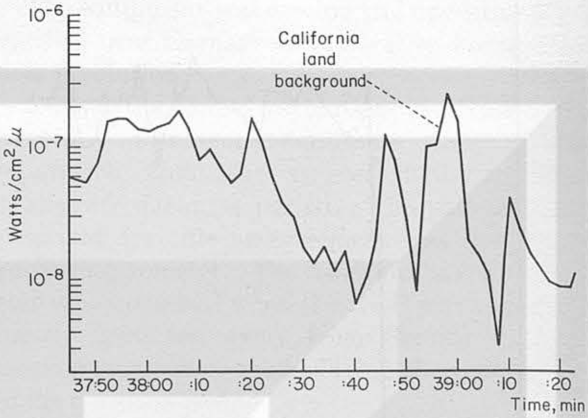


FIGURE 38–13.—Interferometer spectrometer data (1.88μ).

Nineteen minutes after Gemini VII lift-off the D4/D7 sensors were erected, and the equipment turned on. An 8-feet-per-second separation burn was made away from the launch vehicle at sunset, and measurements on the launch vehicle were begun. Cryogenic spectrometer measurements were made for the remainder of the night cycle as the spacecraft separated from the launch vehicle. Periodically during this period, launch vehicle background measurements were made, and, at one point, the launch vehicle was measured against a moon background.

During the second revolution, measurements were performed with the cryogenic spectrometer on void space, on the launch vehicle, and on the stars Rigel and Sirius. At the conclusion of the measurement on Sirius a slow pitch-down maneuver was made to the horizon. The purpose of this measurement was to do a night sky-to-horizon calibration sweep in the 8- to 12-micron region. The radiometer gave UV correlation data during this measurement.

Alinement of the radiometer and IR spectrometer was performed December 5, 1965, on a nearly full moon. Photographic coverage of the measurement objective was simultaneously obtained by a camera boresighted along the instrument axis (fig. 38–14). The equipment alinement was checked by the use of a meter in the center console. The crewmen boresighted the spacecraft on the moon and then made minor excursions in pitch and yaw to locate the aiming point for optimum signal return (fig. 38–15). This accounts for the dips in the curves seen on

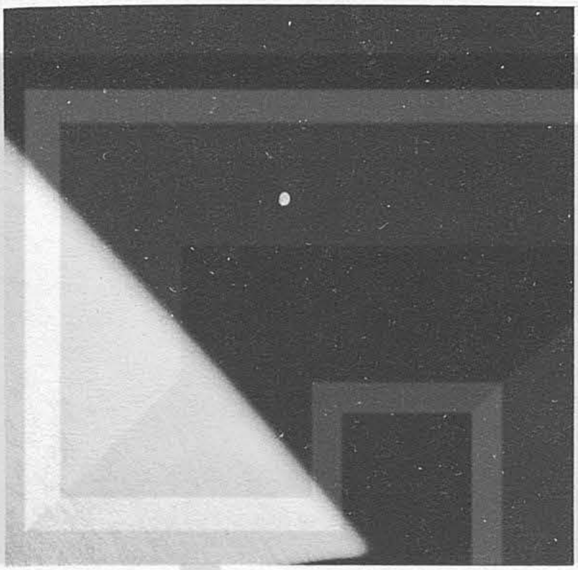


FIGURE 38-14.—Photograph of nearly full moon taken during alinement of radiometer and infrared spectrometer.

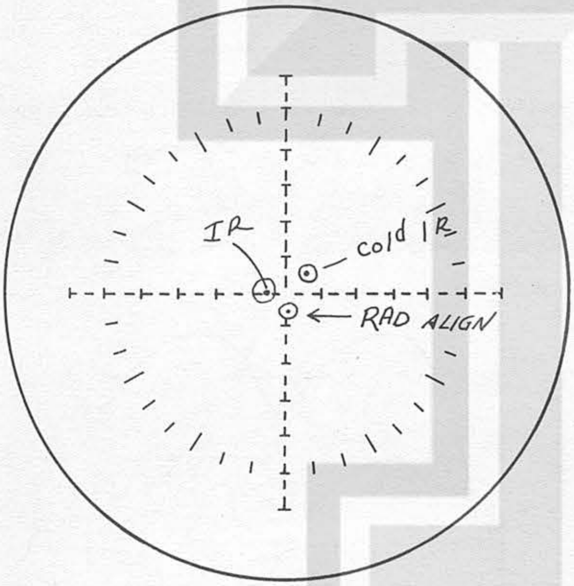


FIGURE 38-15.—Alinement pattern (as noted in flight logbook).

figures 38-16 and 38-17. The values of moon irradiance from 2000Å to 3060Å and 1 to 3 microns as measured by the radiometer on December 5 are shown in figures 38-18 and 38-19. The data show good correlation with the other instruments and with the measurements made at the full moon on December 8. As an illustration, a plot of the lead sulfide channel readings taken December 5 on the radiometer is compared with the lead sulfide channel readings on the IR spectrometer made on December 8 (fig. 38-20). The values taken on December 8 are slightly higher than those taken on December 5, as would be expected. Figure 38-21 shows the flight measurements from Gemini V on a predicted 25-day moon curve and those for Gemini VII against a full moon curve.

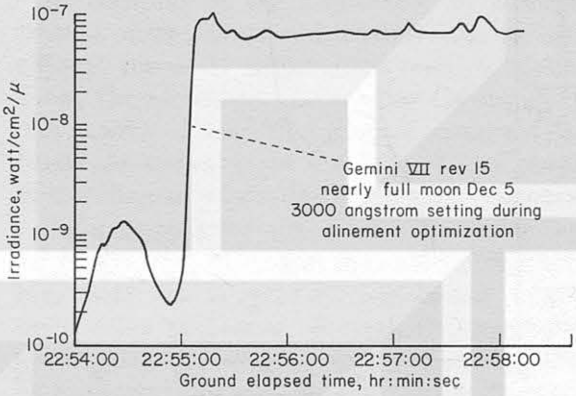


FIGURE 38-16.—Moon irradiance during alinement optimization (3000 angstrom setting).

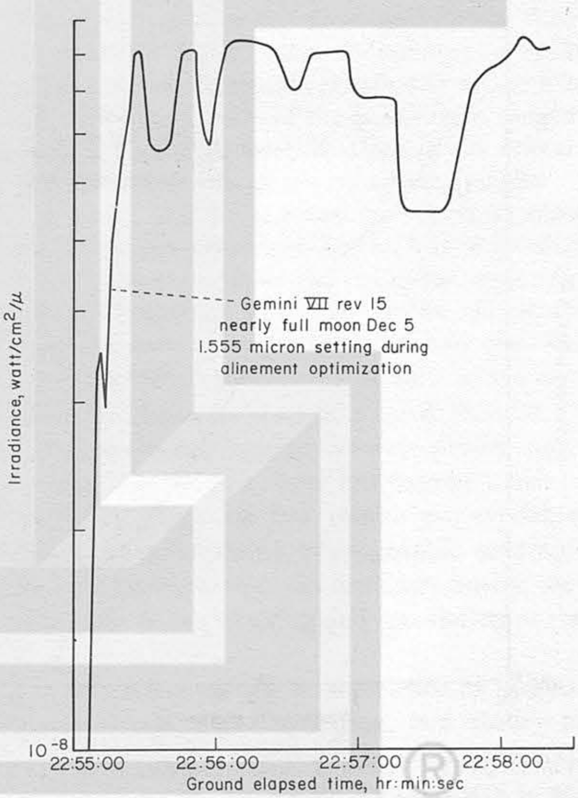


FIGURE 37-17.—Moon irradiance during alinement optimization (1.555 micron setting).

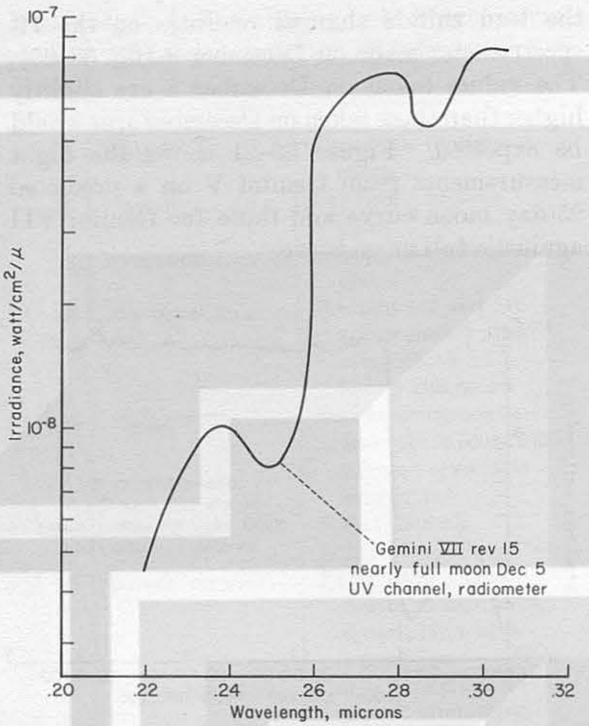


FIGURE 38-18.—Values of moon irradiance from 2000 to 3060 angstroms.

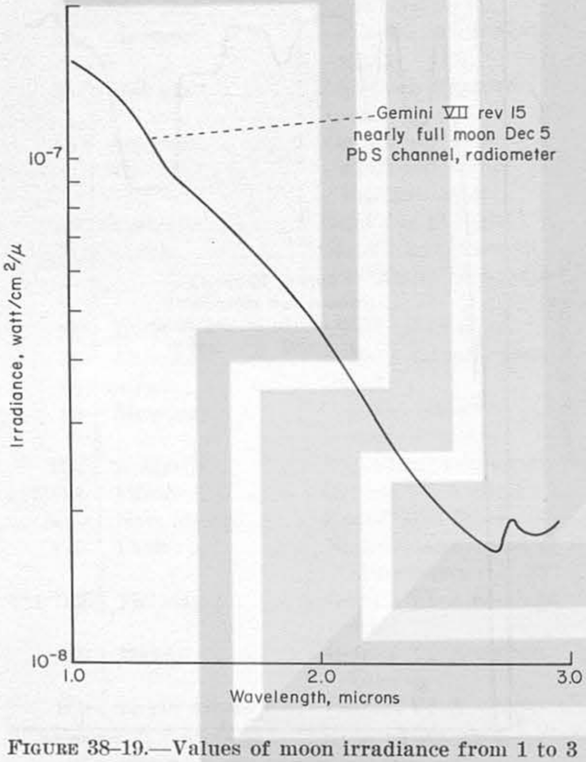


FIGURE 38-19.—Values of moon irradiance from 1 to 3 microns.

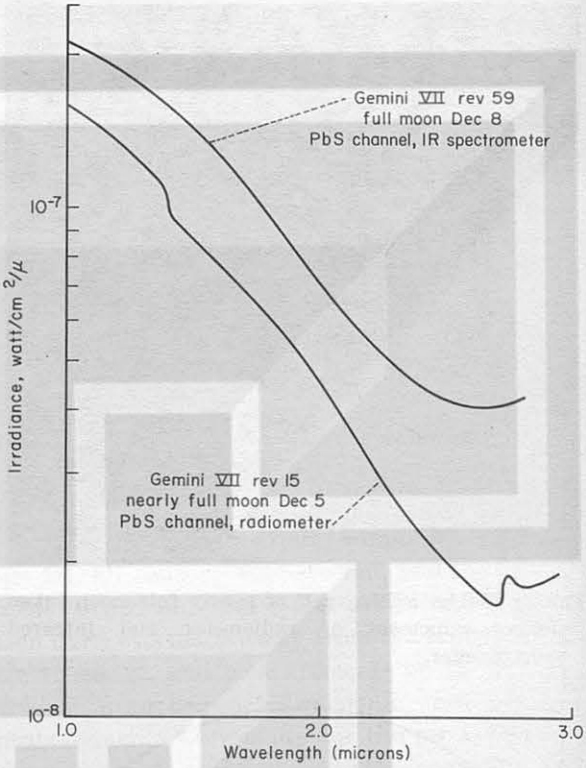


FIGURE 38-20.—Comparison of PbS channel readings on December 5 and December 8, 1965.

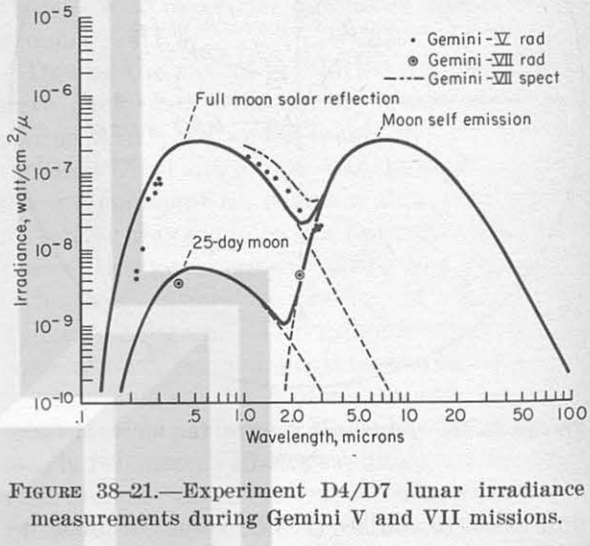


FIGURE 38-21.—Experiment D4/D7 lunar irradiance measurements during Gemini V and VII missions.

Throughout the measurements, a high degree of photograph and voice correlation was maintained. Figure 38-22 is a picture of a cloud bank measured during the cloud blanket sweep over Africa. Figure 38-23 is a photograph, made with IR film, of the Gulf coast during a D4/D7 land/water measurement. Photographic coverage was also accomplished during the Polaris launch, airglow measurement, Gemini VI–A retrograde maneuver, rocket sled run, and horizon-to-nadir calibration.

During the flight all of the sensing equipment functioned perfectly. The experiment recorder operated intermittently during the first two revolutions and operated satisfactorily thereafter. The recorder difficulty caused no serious loss of data, however, since vital parts of the

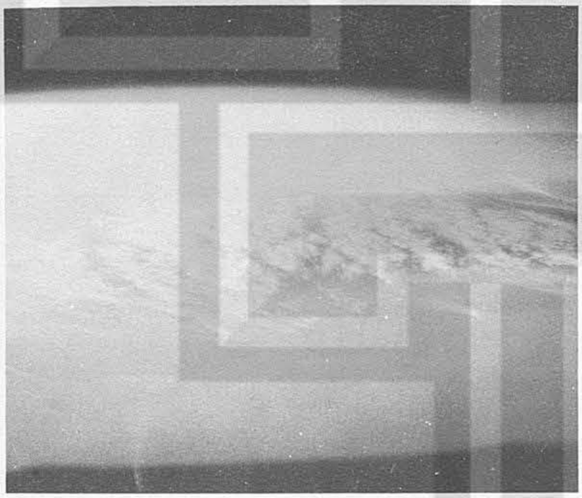


FIGURE 38–22.—Cloud formation photographed during infrared cloud blanket sweep.

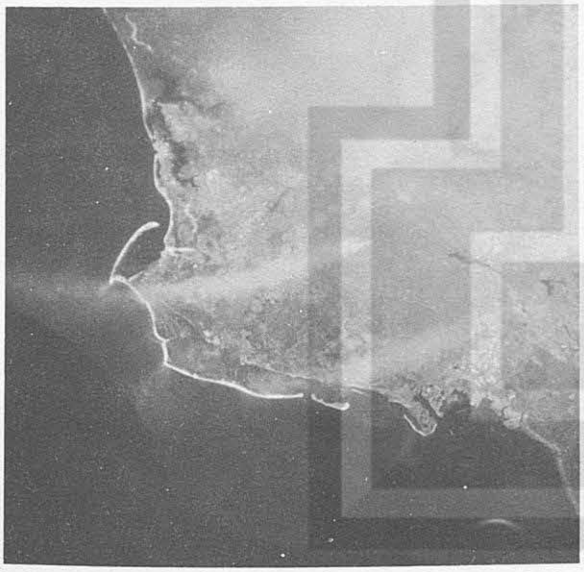


FIGURE 38–23.—Photograph of Gulf Coast taken during Experiment D4/D7 background measurements.

measurements were scheduled over experiment ground receiving stations. The transmitter worked well throughout the flight.

Crewman performance during the flight was outstanding. In addition to performing all scheduled measurements, several targets of opportunity (for example, a ground fire and lightning) were measured on the crewman's initiative.

In addition to the acquisition of a large amount of significant radiometric data, several adjunct pieces of information were obtained. First, the alinement check after Gemini VII was in orbit showed that ground alinement between the optical sight and D4/D7 equipment in the adapter was valid within 0.5°. Concern had been expressed that alinement under 1-g conditions and shifting at the heat shield interface with the adapter during launch might cause some problems. Second, the cryogenic lifetime for the cooled spectrometer—nominally 14 to 15 hours under quiescent 1-g conditions—was essentially unchanged by subjection to launch environment and then zero-g conditions. The system was a subcritical, open-cycle, liquid-neon system in a fixed-wall Dewar flask. It operated for 8 hours 50 minutes in space after 5 hours of ground operation awaiting lift-off. Globularization of the neon due to weightlessness caused no perturbations in the operating characteristics of the cryogenic system.

Finally, it is to be noted that frost or snow can be seen in pictures of Gemini VII in roughly an oval pattern aft of the cryogenic spectrometer. This frost was still on the spacecraft some 10 days after the cryogen had been depleted, which is interesting in view of the sublimation characteristics of a hard vacuum.

In conclusion, because the data processing is so slow and because there has been so much to correlate, there are few results yet available. The voice annotations, photographic coverage, and debriefing comments are contributing significantly to the meaning and correlation of the data.

Man's contributions in the choice of targets, mode of equipment operation, and ability to track selectively with the spacecraft have been unique in giving the flexibility necessary to accomplish such a diverse group of radiometric measurements.

B

MEDICAL SCIENCE EXPERIMENTS

39. EXPERIMENT M–1, CARDIOVASCULAR CONDITIONING

By Lawrence F. Dietlein, M.D., *Assistant Chief for Medical Support, Crew Systems Division, NASA Manned Spacecraft Center; and* William V. Judy, *Crew Systems Division, NASA Manned Spacecraft Center*

Introduction

Ground baseline studies in support of Experiment M–1 indicated that leg cuffs alone, when inflated to 70 to 75 millimeters of mercury for 2 out of every 6 minutes, provided protection against cardiovascular "deconditioning" which was occasioned by 6 hours of water immersion (ref. 1). Four healthy, male subjects were immersed in water to neck level for a 6-hour period on two separate occasions, 2 days apart. Figures 39–1, 39–2, 39–3, and 39–4 indicate that 6 hours of water immersion resulted in cardiovascular "deconditioning," as evidenced by cardioacceleration in excess of that observed during the control tilt and by the occurrence of syncope in two of the four subjects. The tilt responses following the second period of immersion, during which leg cuffs were utilized, revealed that a definite protective effect was achieved. Cardioacceleration was less pronounced, and no syncope occurred.

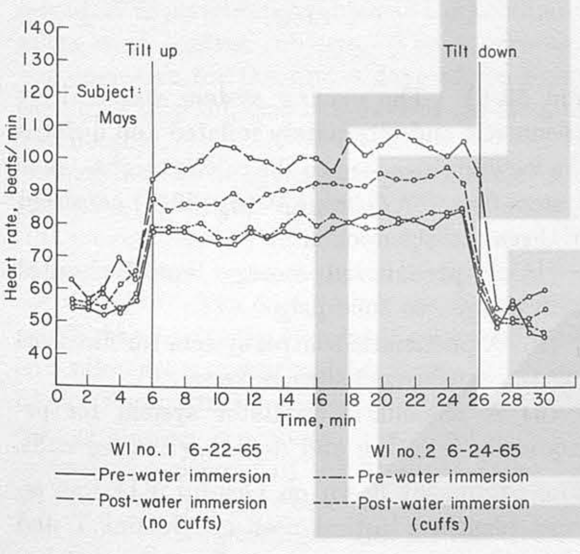


Figure 39–1.—Six-hour water immersion studies, first subject.

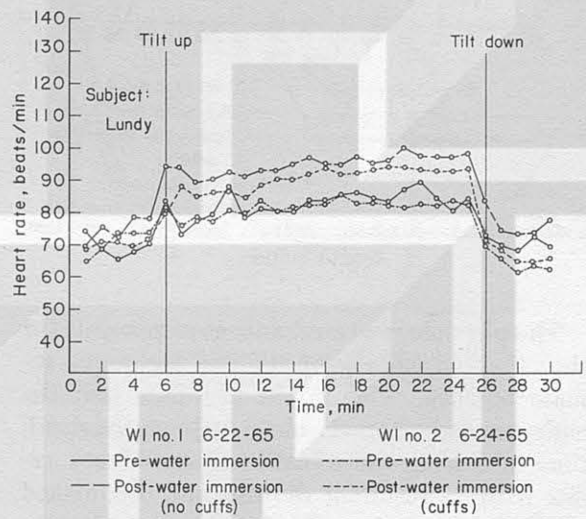


Figure 39–2.—Six-hour water immersion studies, second subject.

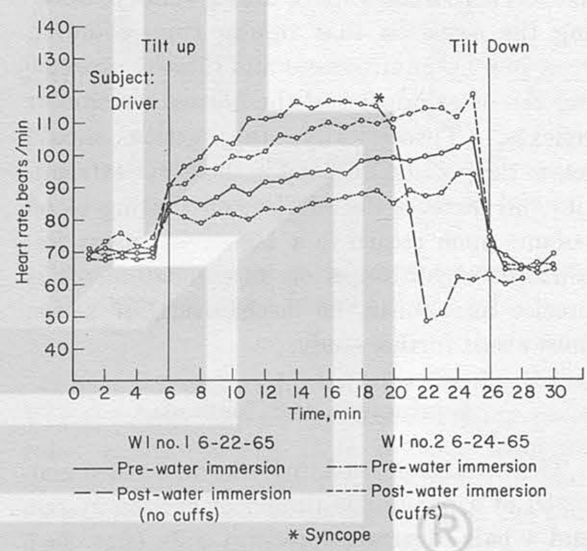


Figure 39–3.—Six-hour water immersion studies, third subject.

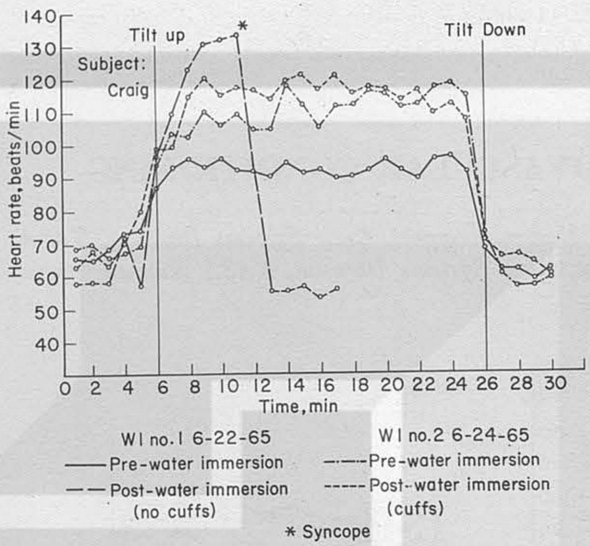


FIGURE 39-4.—Six-hour water immersion studies, fourth subject.

The physiological mechanisms responsible for the observed efficacy of the cuff technique remain obscure. One might postulate that the cuffs prevent thoracic blood volume overload, thus inhibiting the so-called Gauer-Henry reflex with its resultant diuresis and diminished effective circulating blood volume. Alternatively, or perhaps additionally, one might postulate that the cuffs induce an intermittent artificial hydrostatic gradient (by increasing venous pressure distal to the cuffs during inflation) across the walls of the leg veins, mimicking the situation that results from standing erect in a 1-g environment and thereby preventing the deterioration of the normal venomotor reflexes. Theoretically, this action should lessen the pooling of blood in the lower extremities and increase the effective circulating blood volume upon return to a 1-g environment following weightlessness or its simulation. The precise mechanism, or mechanisms, of action must await further study.

Equipment and Methods

The equipment used in Experiment M-1 consisted of a pneumatic timing or cycling system and a pair of venous pressure cuffs (figs. 39-5 and 39-6).

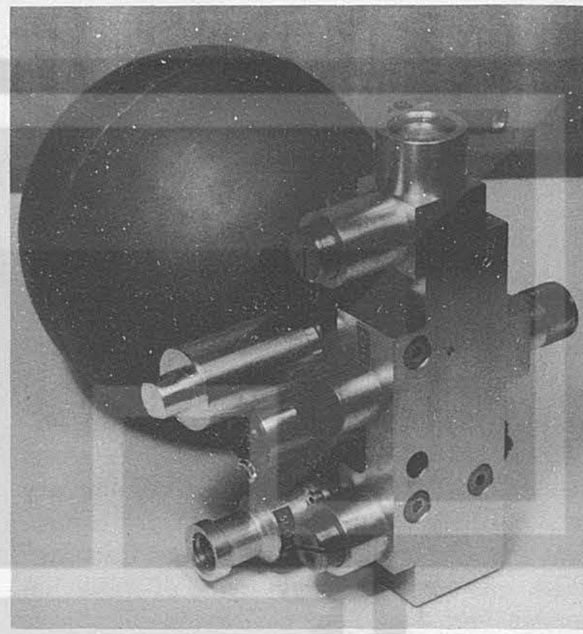


FIGURE 39-5.—Cardiovascular reflex conditioning system.

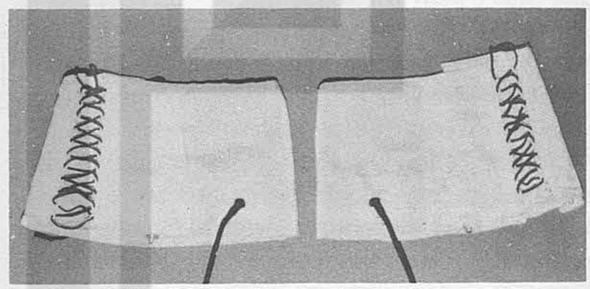


FIGURE 39-6.—Cardiovascular conditioning pneumatic cuffs.

The cycling system was entirely pneumatic and alternately inflated and deflated the leg cuffs attached to the pilot's thighs. The system flown on Gemini V (fig. 39-7) consisted of three basic components:

(1) A pressurized storage vessel charged with oxygen to 3500 psig.

(2) A pneumatic control system for monitoring the pressurized storage vessel.

(3) A pneumatic oscillator system for periodically inflating and deflating the leg cuffs.

The equipment flown on Gemini VII was almost identical to that used on Gemini V and was supplied with oxygen pressure from the spacecraft environmental control system. The pneumatic venous pressure cuffs were formfitted to the proximal thigh area of the pilot. The cuffs consisted essentially of a 3- by 6-inch bladder enclosed in a soft nonstretchable fabric. The bladder portion of each cuff was positioned on the dorsomedial aspect of each thigh. The lateral surface of the cuffs consisted of a lace adjuster to insure proper fit.

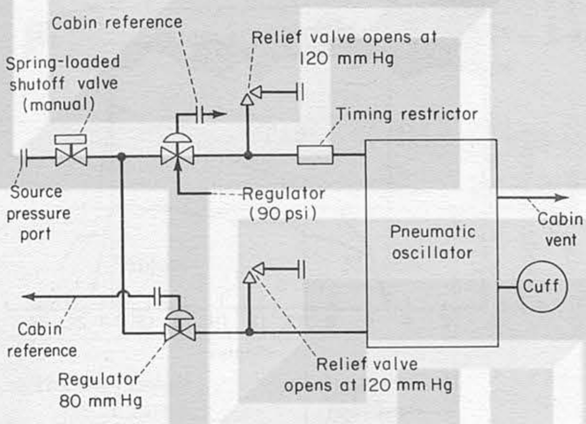


FIGURE 39-7.—Schematic diagram of cardiovascular reflex conditioner.

Results

The Cardiovascular Conditioning Experiment (M-1) was flown on the Gemini V and VII missions. The pilots for these missions served as experimental subjects; the command pilots were control subjects. The experiment was operative for the first 4 days of the 8-day Gemini V mission, and 13.5 days of the Gemini VII mission.

Prior to these missions, each crewmember was given a series of tilt-table tests. These control tilts are summarized in table 39-I, the numerical values indicated being mean values for the three control tilts. The results of six consecutive postflight tilts for the Gemini V command pilot and pilot are summarized in figures 39-8 and 39-9. Figure 39-10 summarizes the heart-rate change during the initial postflight tilt expressed as a percent of the preflight value for all the Gemini flights to date. The results of four consecutive postflight tilts for the Gemini VII command pilot are indicated in figures 39-11 through 39-14, and for the Gemini VII pilot in figures 39-15 through 39-18. Figure 39-19 summarizes the Gemini VII tilt-table data.

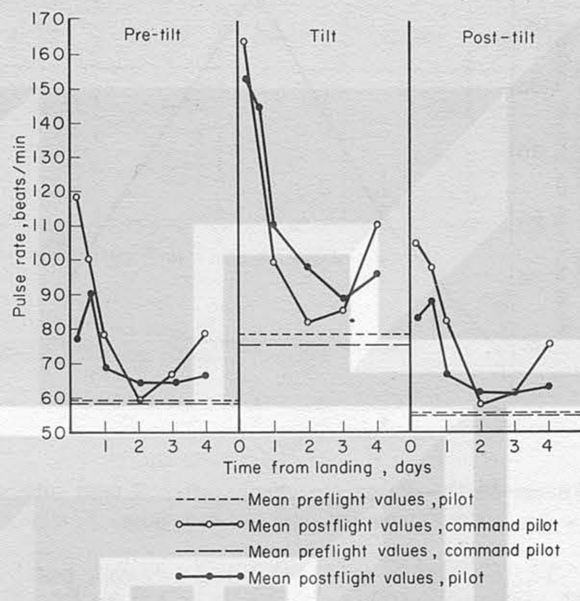


FIGURE 39-8.—Summary of pulse rate during tilt-table studies of Gemini V flight crew.

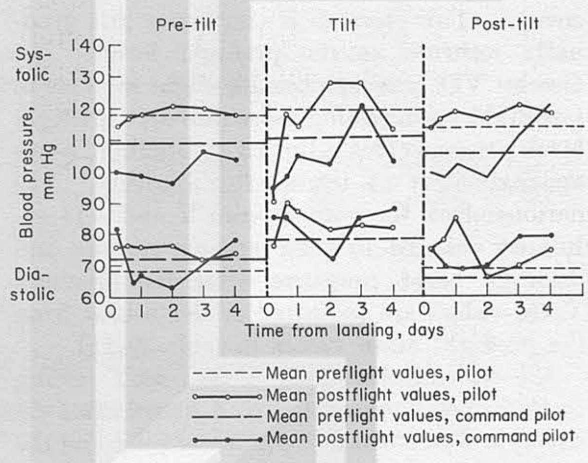


FIGURE 39-9.—Summary of blood pressure during tilt-table studies for Gemini V flight crew.

The crewmembers for both the Gemini V and VII missions exhibited increased resting pulse rates during the first 12 to 24 hours after recovery. Resting pulse rate changes for both crews are indicated as deviations from the pre-flight mean values in table 39-II.

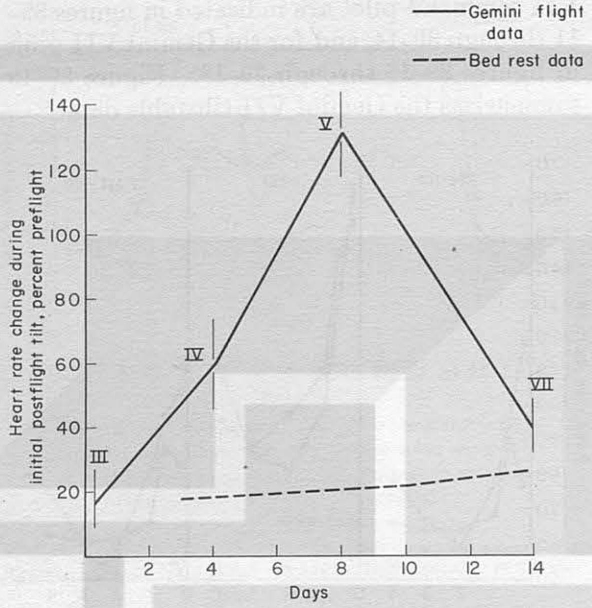


FIGURE 39-10.—Pulse-rate change after Gemini missions compared with bed-rest data.

The Gemini V crew exhibited a higher postflight mean resting pulse rate than did the Gemini VII crew, with a maximal difference of 12-fold (pilot's) occurring 2 to 4 hours after recovery. This elevated resting pulse rate gradually returned to the preflight levels. The Gemini VII crew exhibited a slight increase in postflight mean resting pulse rate over preflight levels; these values returned to preflight levels approximately 24 hours after recovery. The crewmembers for both Gemini V and VII exhibited changes in their resting systolic and diastolic blood pressures after the missions. These values are indicated as deviations from the preflight mean values in table 39-III.

All crewmembers had a decreased resting systolic blood pressure 2 to 4 hours after recovery. The Gemini V command pilot and the

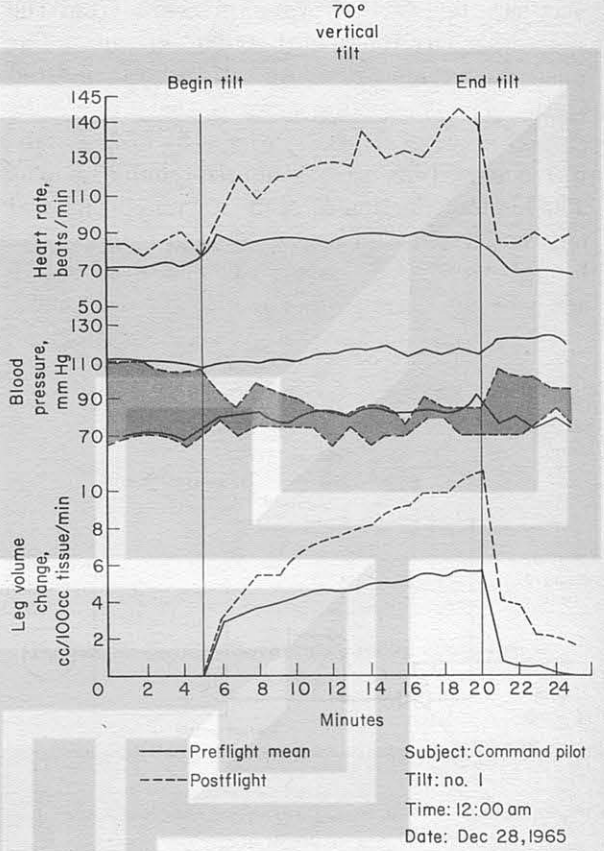


FIGURE 39-11.—Data from first tilt-table study of Gemini VII command pilot.

Gemini VII pilot maintained a lower-than-preflight systolic pressure throughout the postflight test period. All crewmembers exhibited a decreased resting diastolic blood pressure during each postflight tilt test except during the first and last tilts for the Gemini V command pilot, and during the second tilt for the Gemini VII pilot. Daily changes in resting blood pressures are indicated in figures 39-9 and 39-19 as deviations from the preflight mean values.

TABLE 39-I.—*Summary of Tilt-Table Tests*

Subject	Mission	Pretilt		70° vertical tilt			Posttilt		
		Pulse rate	Blood pressure	Pulse rate	Blood pressure	Δ leg volume, percent	Pulse rate	Blood pressure	Δ leg volume, percent
Command pilot	V	58	109/72	75	111/79	+3. 0	55	108/62	+0. 3
	VII	59	117/68	78	120/79	+2. 7	56	115/64	+. 2
Pilot	V	73	110/72	87	114/81	+4. 5	70	113/76	+. 4
	VII	72	131/75	84	126/84	+4. 4	70	123/73	+. 5

TABLE 39-II.—*Change in Mean Resting Heart Rate*

[Data in beats per minute [a]]

Subject	Mission	Hours after recovery					
		2-4	8-12	24-30	48-56	72-80	90-104
Command pilot	V	+21	+32	+10	+6	+6	+9
	VII	+10	+8	−2	−1	----------	----------
Pilot	V	+59	+41	+18	0	+12	+19
	VII	+4	+9	+5	−5	----------	----------

[a] Positive values are above the preflight mean; negative values are below the preflight mean.

TABLE 39-III.—*Change in Mean Resting Blood Pressure*

[Data in mm of mercury [a]]

Subject	Mission	Hours after recovery											
		2-4 [b]		8-12 [b]		24-30 [b]		48-56 [b]		72-80 [b]		96-104 [b]	
Command pilot	V	−9	+10	−10	−8	−10	−3	−13	−9	−3	−3	−5	+6
	VII	−3	−3	+11	+9	+2	−3	+5	−5	-----	-----	-----	-----
Pilot	V	−3	−8	0	−9	+1	−8	+4	−9	+3	−3	+1	−6
	VII	−8	−4	−7	−2	−4	−4	−14	−5	-----	-----	-----	-----

[a] Positive values are above the preflight mean; negative values are below the preflight mean.
[b] Left value is systolic; right value is diastolic.

During the postflight tilts, all the Gemini V and VII crewmembers exhibited increased pulse rates. Highest rates were observed during the tilts performed 2 to 4 hours after recovery. Pulse rate increases over preflight mean values for each postflight tilt are indicated in table 39-IV.

TABLE 39-IV.—*Change in Mean Tilt Heart Rate*

[Data in beats per minute [a]]

Subject	Mission	Hours after recovery					
		2-4	8-12	24-30	48-56	72-80	90-104
Command pilot	V	+79	+69	+35	+14	+13	+21
	VII	+40	+19	+2	+4	----------	----------
Pilot	V	+86	+55	+21	+4	+11	+32
	VII	+28	+33	+34	+2	----------	----------

[a] Positive values are above the preflight mean; negative values are below the preflight mean.

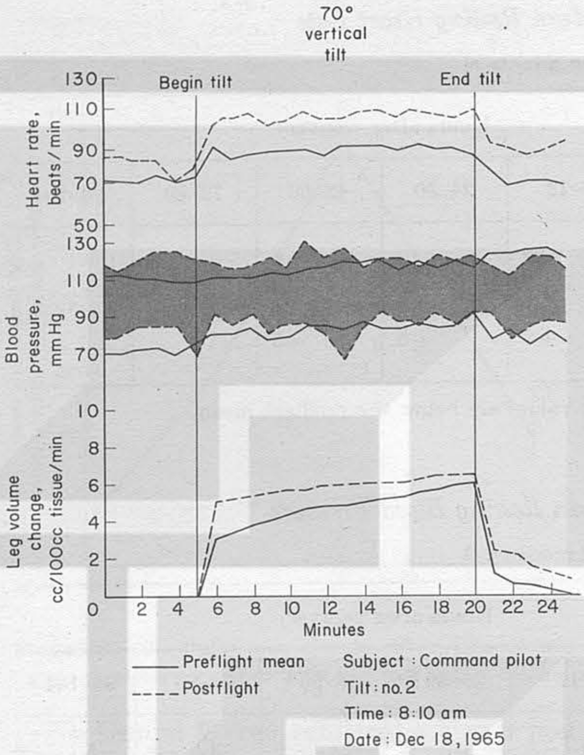


FIGURE 39-12.—Data from second tilt-table study of Gemini VII command pilot.

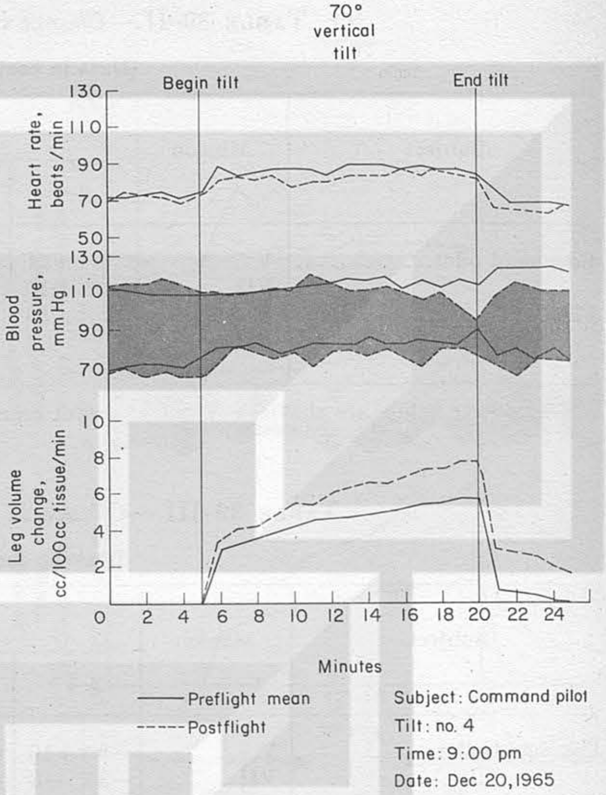


FIGURE 39-14.—Data from fourth tilt-table study of Gemini VII command pilot.

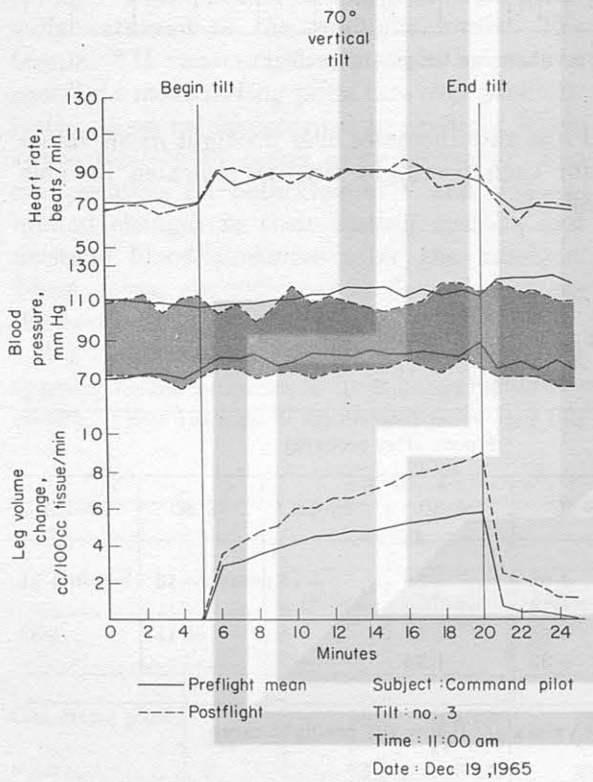


FIGURE 39-13.—Data from third tilt-table study of Gemini VII command pilot.

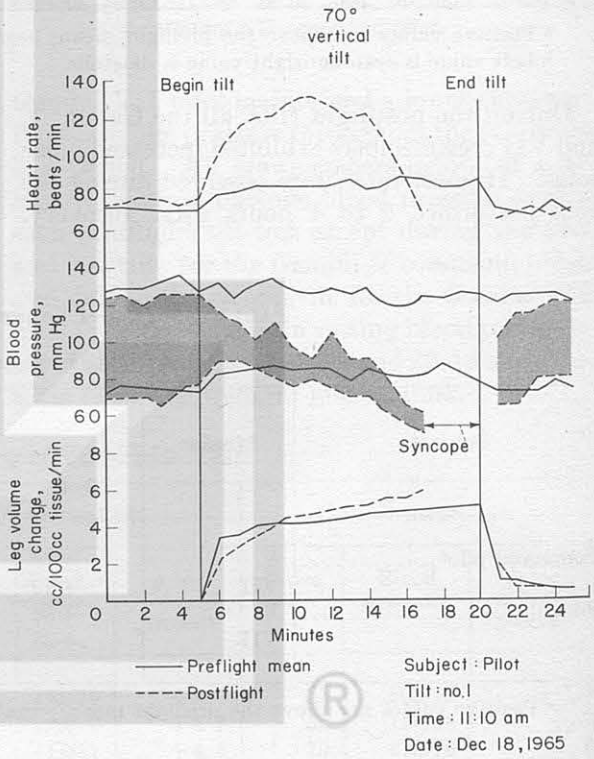


FIGURE 39-13.—Data from third tilt-table study of Gemini VII pilot.

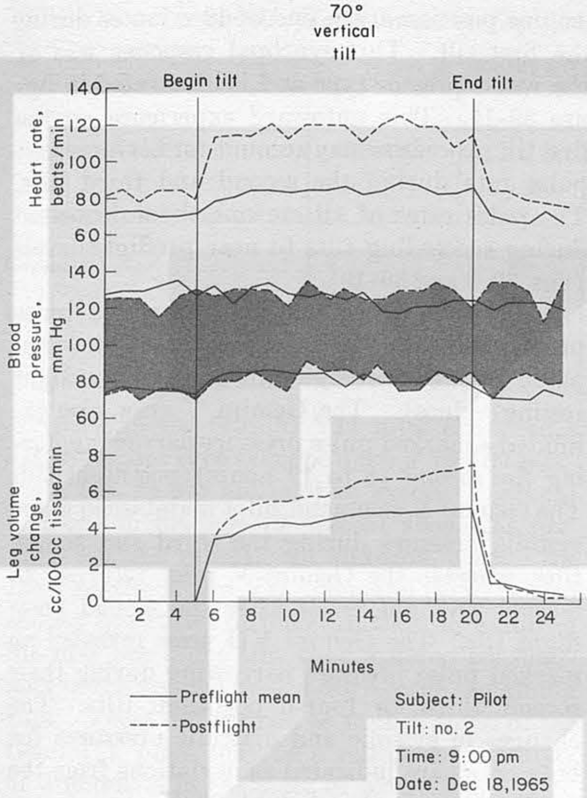


FIGURE 39-16.—Data from second tilt-table study of Gemini VII pilot.

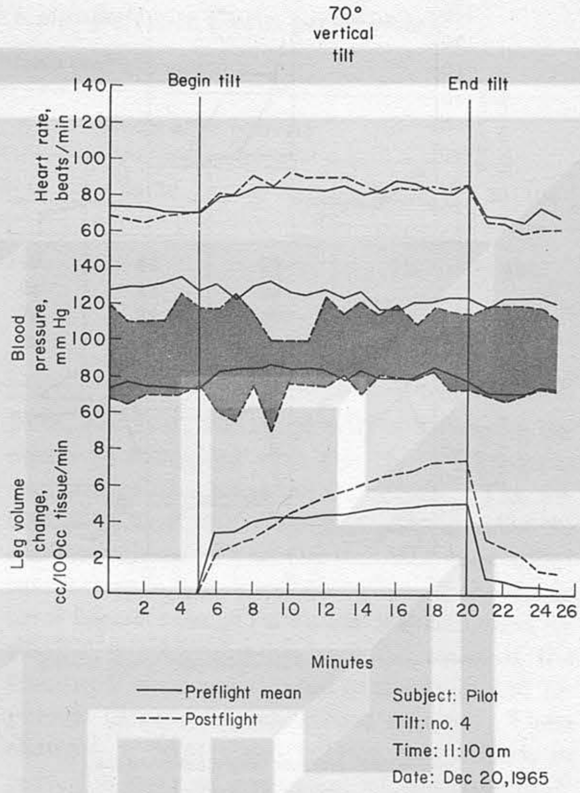


FIGURE 39-18.—Data from fourth tilt-table study of Gemini VII pilot.

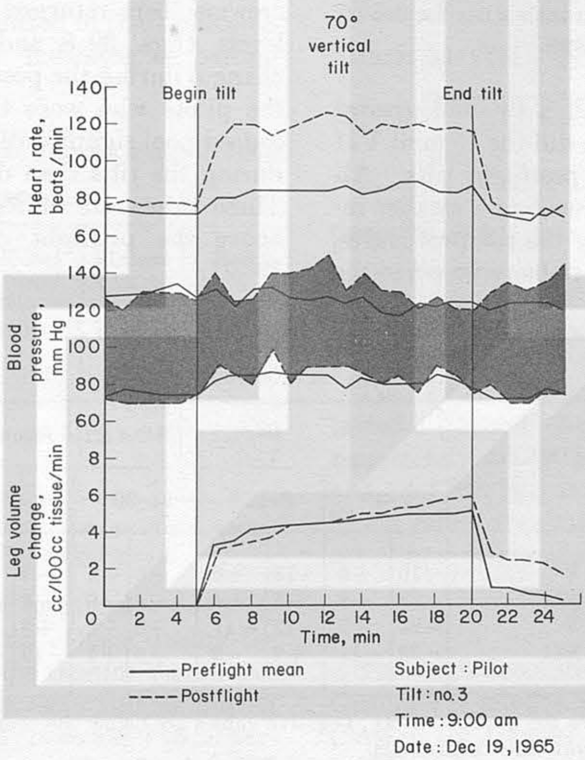


FIGURE 39-17.—Data from third tilt-table study of Gemini VII pilot.

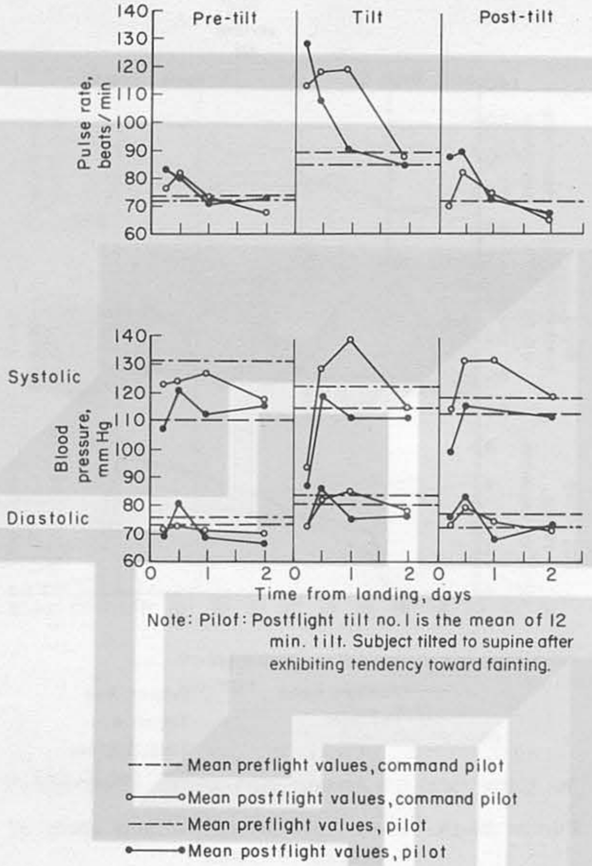


FIGURE 39-19.—Summary of tilt-table study for Gemini VII flight crew.

The Gemini V crew had a twofold greater increase in pulse rate than did the Gemini VII crew during the first two postflight tilts. Although the Gemini VII crew had a smaller increase in pulse rate during the tilt procedures, the Gemini VII pilot had to be returned to the supine position at the end of 12 minutes during the first tilt. This syncopal response was of the vasodepressor type and is illustrated in figure 39-15. This untoward experience on the first tilt procedure may account for his increased pulse rate during the second and third tilts. The pulse rates of all crewmembers decreased during succeeding tilts to near preflight levels (figs. 39-8 and 39-19).

All crewmembers exhibited narrowed pulse pressures during the first postflight tilt (compared with the preflight tilt and the postflight resting values). The Gemini V crew also exhibited a marked pulse pressure narrowing during the second (8 to 12 hours) postflight tilt. The Gemini V command pilot maintained a low systolic pressure during the third and fourth tilts, whereas the Gemini V pilot returned to normal preflight levels after the second postflight tilt. The Gemini VII crew revealed no marked pulse pressure narrowing during their second, third, or fourth postflight tilts. The changes in systolic and diastolic pressures for both crews are indicated as deviations from the preflight mean values in table 39-V.

During the postflight recovery phase, the blood pressure values for the Gemini V and VII crewmembers returned to near pretilt resting levels (figs. 39-8 and 39-19). Leg volume changes during the postflight tilts indicate that the pilots who wore the pneumatic cuffs did indeed pool significantly less blood in their legs during the tilts than did the command pilots. These values are indicated at percent increase above the preflight control values in table 39-VI.

TABLE 39-V.—*Changes in Mean Tilt Blood Pressure*

[Data in mm of mercury [a]]

Subject	Mission	Hours after recovery											
		2-4 [b]		8-12 [b]		24-30 [b]		48-56 [b]		72-80 [b]		96-104 [b]	
Command pilot	V	−16	+6	−13	+6	−6	+2	−9	−7	+11	+7	−8	+9
	VII	−27	−8	+5	+4	−3	−6	−4	−5	-----	-----	-----	---
Pilot	V	−20	−3	−12	+11	+6	+9	+8	+2	+8	+4	+7	+3
	VII	−33	−11	+2	−2	+6	+1	−12	−11	-----	-----	-----	---

[a] Positive values are above the preflight mean; negative values are below the preflight mean.
[b] Left value is systolic; right value is diastolic.

TABLE 39-VI.—*Change in Leg Blood Volume (cc/100cc Tissue per Minute)*

[Data in percent change above preflight mean]

Subject	Mission	Hours after recovery					
		2–4	8–12	24–30	48–56	72–80	96–104
Command pilot	V	89	149	44	73	78	111
	VII	71	31	47	33	----------	----------
Pilot	V	87	73	25	57	117	97
	VII	2	36	9	15	----------	----------

Although the Gemini VII pilot exhibited a vasodepressor type syncope during his first postflight tilt, he did not pool an excessive amount of blood in his legs (2 percent above the preflight control value). In addition, despite the fact that the V and VII command pilots pooled similar quantities of blood in their legs during the first postflight tilt, they differed considerably in the volume pooled during the remaining tilts. These differences, as well as those of the Gemini V pilot, may be a reflection primarily of differences in the state of hydration.

Changes in total blood volume, plasma volume, and red cell mass were determined before and after flight. Radioactive isotope (I^{125}, Cr^{51}) techniques were utilized in these measurements. The results are indicated as percent changes in table 39-VII.

TABLE 39-VII.—*Change in Intravascular Volume*

[Data in percent [a]]

Subject	Mission	Total blood volume	Plasma volume	Red cell mass
Command pilot	V	−13	−8	−20
	VII	0	+15	−19
Pilot	V	−12	−4	−20
	VII	0	+4	−7

[a] Positive values are above the preflight mean; negative values are below the preflight mean.

The Gemini VII crew sustained a 4- to 15-percent increase in plasma volume during the 14-day mission, whereas the Gemini V crew lost 4 to 8 percent of their plasma volume during the 8-day mission. Both crews lost 7 to 20 percent of their red cell mass. The Gemini VII pilot, however, sustained only a 7-percent decrease as compared with the 19- to 20-percent decrease of the other crewmembers. The decrease in red cell mass and the increase in plasma volume of the Gemini VII crew offset each other to give a net zero-percent change in total blood volume, whereas the reduction in plasma volume and the red cell mass of the Gemini V crew contributed to the measured 13-percent decrease in total blood volume. These changes in total blood volume may reflect, in part, the state of hydration of the Gemini V crew, but this is not true in the case of the Gemini VII crew. The postflight changes in body weight are indicated in table 39-VIII.

TABLE 39-VIII.—*Nude Body Weight Changes*

[Negative values indicate weight loss]

Subject	Mission	Pounds
Command pilot	V	−7.5
	VII	−10.0
Pilot	V	−8.5
	VII	−6.5

The Gemini V command pilot and pilot sustained a 7.5- and 8.5-pound loss in body weight, respectively. The Gemini VII command pilot and pilot lost 10.0 and 6.5 pounds, respectively. These values are similar to those observed after previous missions of shorter duration.

Discussion

The flight conditions operative during the Gemini VII mission were notably different from those of the Gemini V flight. These variables or differences were of sufficient magnitude that a comparison of the M–1 results on the two missions is difficult, if not impossible. Gemini VII was decidedly different from previous Gemini flights in that the Gemini VII crew did not wear their suits during an extensive portion of the 14-day flight. Their food and water intake was more nearly optimal than in previous flights; this assured better hydration and electrolyte balance, and the Gemini VII exercise regimen was more rigorous than that utilized on previous flights. These variables, in addition to the usual individual variability always present, preclude any direct comparison of M–1 results on the two missions. This is particularly true since the pulsatile cuffs were operative during only the first half of the 8-day Gemini V mission. The Gemini VII pilot's physiological measurements should be compared only with those of the command pilot who served as the "control" subject.

It is indeed true that the postflight physiological responses of the Gemini VII crew were vastly different from, and generally improved over, those observed in the Gemini V crew. It is difficult, however, to determine which of the previously mentioned variables were responsible for the observed improvement. This improvement is perhaps best shown in figure 39–8, which depicts the change in heart rate during the initial postflight tilts expressed as a percentage change with respect to the preflight value. The responses of the Gemini VII crew were far superior to the responses observed in the Gemini IV and V crews, and they were very nearly comparable to the response following 14 days of recumbency.

Additional comparisons between the Gemini VII and V crews may be summarized as follows:

(1) The Gemini VII crew exhibited less increase in postflight mean resting pulse rate (4 and 10 beats per minute versus 21 and 59 beats per minute).

(2) The Gemini VII crew exhibited signs of orthostatic intolerance for only 24 hours postflight; the Gemini V crew exhibited these signs for 24 to 48 hours.

(3) The Gemini VII crew pooled less blood in their lower extremities during all postflight tilts.

(4) The Gemini VII crew exhibited less pronounced changes in intravascular fluid volumes in the postflight period as shown in the following:

(a) Total blood volume: 0 percent versus 13 percent

(b) Plasma volume: +15 percent and +4 percent versus −8 percent and −4 percent.

(c) Red cell mass: −19 percent and −7 percent versus −20 percent and −20 percent.

(5) The Gemini VII crew lost 10.0 pounds (command pilot) and 6.5 pounds (pilot) during their flight, while the Gemini V crew lost 7.5 and 8.5 pounds, respectively.

(6) The Gemini VII crew regained less body weight during the first 24 hours postflight (40 percent and 25 percent versus 50 percent).

The physiological findings in the Gemini V crew have been previously reported (ref. 2) and will only be summarized here.

(1) The pilot's resting pulse rate and blood pressure returned to preflight resting levels within 48 hours after recovery; the command pilot required a somewhat longer period.

(2) The pilot's pulse pressure narrowed during tilt and at rest was less pronounced than that of the command pilot.

(3) The pilot's plasma volume decreased 4 percent, and the command pilot's decreased 8 percent.

(4) The pilot's body weight loss was 7.5 pounds; the command pilot's was 8.5 pounds.

(5) The pooling of blood in the legs of the pilot was generally less than that observed in the command pilot.

The observed differences between the Gemini V command pilot and pilot probably reflect only individual variability and cannot be construed as demonstrating any protective effect of the pulsatile thigh cuffs. The Gemini V tilt data are summarized in figures 39–9 and 39–10.

Tilt-table data are graphically presented in figures 39–11 through 39–14 for the command pilot and in figures 39–15 through 39–18 for the pilot. All the Gemini VII tilt data are summarized in figure 39–19. During the first postflight tilt, the pilot exhibited signs of vasodepressor syncope; the procedure was interrupted, and the pilot was returned to the supine position. This episode occurred despite the fact that there was no evidence of increased pooling of blood in the lower extremities. In subsequent tilts, the pilot exhibited no further signs of syncope or impending syncope. It is of significance that this episode of syncope occurred despite the fact that the measured blood volume of both crewmembers was unchanged from preflight levels.

It would seem possible that this syncopal episode was the result of sudden vasodilitation with pooling of blood in the splanchnic area, diminished venous return, diminished cardiac output, and decline in cerebral bloodflow.

As previously mentioned, there was no diminution in the total blood volume of either crewmember after the mission. The pilot's plasma volume increased 4 percent; the command pilot's increased 15 percent. The pilot's red cell mass decreased 7 percent; the command pilot's, 19 percent. The pilot lost 6.5 pounds (nude body weight) during the mission and replaced 25 percent of this loss during the first 24 hours after recovery. The command pilot lost 10.0 pounds and replaced 40 percent of this value within the first 24 hours following recovery.

The pilot's subsequent tilts revealed a moderate cardioacceleration during tilts 2 and 3, with normal pulse pressure and insignificant pooling of blood in the lower extremities (figs. 39–16, 39–17, and 39–18). The command pilot exhibited moderate cardioacceleration, marked narrowing of the pulse pressure, and increased pooling of blood in the lower extremities during the initial postflight tilt. Subsequent tilts revealed a rather rapid return to normal of heart rate and pulse pressure, but a greater tendency to pool blood in the legs than was observed in the pilot.

Conclusions

On the basis of the preflight and postflight data, it must be concluded that the pulsatile cuffs were not effective in lessening postflight orthostatic intolerance. This conclusion is based not on the occurrence of syncope during the pilot's first tilt, but rather on the higher heart rates observed during subsequent tilts, as compared with the control subject. It is well established that syncope in itself is a poor indicator of the extent or degree of cardiovascular deconditioning.

The pulsatile cuffs appeared to be effective in lessening the degree of postflight pooling of blood in the lower extremities as judged by the strain gage technique.

References

1. VOGT, F. B.: Effect of Extremity Cuff-Tourniquets on Tilt-Table Tolerance After Water Immersion. Aerospace Medicine, vol. 36, May 1965, pp. 442–446.

2. DIETLEIN, L. F.; AND JUDY, W. V.: Experiment M–1, Cardiovascular Conditioning. Manned Space-Flight Experiments Interim Report, Gemini V Mission, Washington, D.C., January 1966.

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40. EXPERIMENT M-3, INFLIGHT EXERCISE—WORK TOLERANCE

By LAWRENCE F. DIETLEIN, M.D., *Assistant Chief for Medical Support, Crew Systems Division, NASA Manned Spacecraft Center; and* RITA M. RAPP, *Crew Systems Division, NASA Manned Spacecraft Center*

Summary

The response of the cardiovascular system to a quantified workload is an index of the general physical condition of an individual. Utilizing mild exercise as a provocative stimulus, no significant decrement in the physical condition of either of the Gemini VII crewmembers was apparent. The rate of return of the pulse rate to preexercise levels, following inflight exercise periods, was essentially the same as that observed during preflight baseline studies.

Objective

The objective of Experiment M-3 was the day-to-day evaluation of the general physical condition of the flight crew with increasing time under space flight conditions. The basis of this evaluation was the response of the cardiovascular system (pulse rate) to a calibrated workload.

Equipment

The exercise device (figs. 40-1 and 40-2) consisted of a pair of rubber bungee cords attached to a nylon handle at one end and to a nylon foot strap at the other. A stainless-steel stop cable limited the stretch length of the rubber bungee cords and fixed the isotonic workload of each pull. The device could be utilized to exercise the lower extremities by holding the feet stationary and pulling on the handle. Flight bioinstrumentation (fig. 40-3) was utilized to obtain pulse rate, blood pressure, and respiration rate. These data were recorded on the onboard biomedical magnetic tape recorder and simultaneously telemetered to the ground monitoring stations for real-time evaluation.

Procedure

The device used in Gemini VII required 70 pounds of force to stretch the rubber bungee cords maximally through an excursion of 12

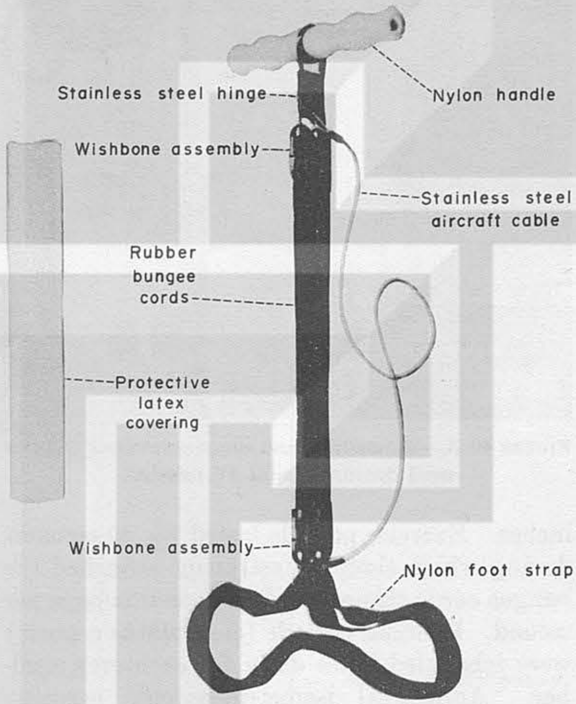

FIGURE 40-1.—Inflight exerciser major components.

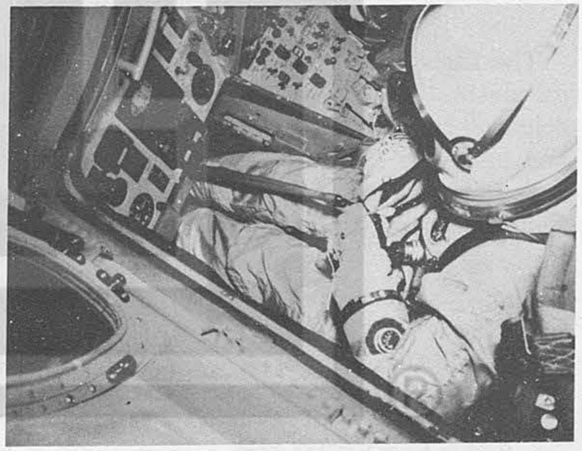

FIGURE 40-2.—Inflight exerciser in use.