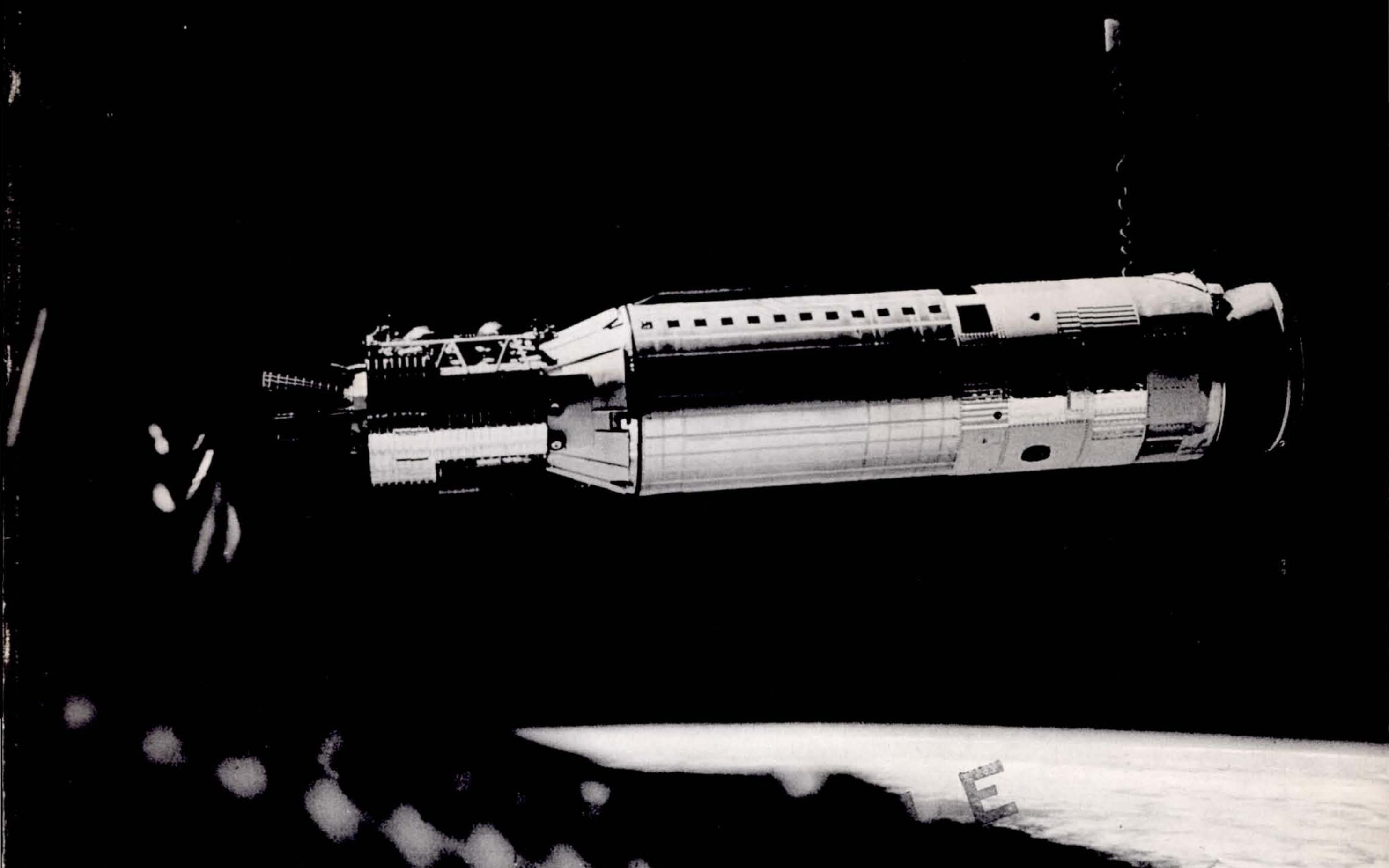
NASA SP 138

GEMINI SUMMARY CONFERENCE



February 1-2, 1967 Manned Spacecraft Center Houston, Texas

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEMINI SPACECRAFT FLIGHT HISTORY

MISSION	DESCRIPTION	LAUNCH DATE	MAJOR ACCOMPLISHMENTS
Gemini I	Unmanned 64 orbits Qualification	Apr. 8, 1964	Demonstrated structural integrity, and launch vehicle systems performance.
Gemini II	Unmanned Suborbital Qualification	Jan. 19, 1965	Demonstrated spacecraft systems performance.
Gemini III	Manned 3 orbits Qualification	Mar. 23, 1965	Demonstrated manned qualification of the Gemini spacecraft.
Gemini IV	Manned 4 days Long duration	June 3, 1965	Demonstrated spacecraft systems performance and crew capability for 4 days in space, and demonstrated extravehicular activity.
Gemini V	Manned 8 days Long duration	Aug. 21, 1965	Demonstrated long-duration flight, demonstrated rendezvous radar capability, and rendezvous maneuvers.
Gemini VI	Manned 2 days Rendezvous (Canceled after failure of Gemini Agena Target Vehicle)	Oct. 25, 1965	Demonstrated dual countdown procedures (Gemini Atlas-Agena Target Vehicle and Gemini Launch Vehicle/spacecraft), and flight performance of the Target Launch Vehicle and flight readiness of the Gemini Agena Target Vehicle secondary propulsion system.
Gemini VII	Manned 14 days Long duration	Dec. 4, 1965	Demonstrated 2-week duration flight and station keeping with Gemini Launch Vehicle Stage II, evaluated shirt-sleeve environment, acted as the rendezvous target for Spacecraft 6, and demonstrated controlled reentry to within 7 miles of planned landing point.
Gemini VI-A	Manned 1 day Rendezvous	Dec. 15, 1965	Demonstrated on-time launch procedures, closed-loop rendezvous capability, station-keeping technique with Spacecraft 7.

(Continued inside back cover)

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Scientific and Technical Information Division
OFFICE OF TECHNOLOGY UTILIZATION 1967
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

FOREWORD

The Gemini Summary Conference was held on February 1 and 2, 1967, at the NASA Manned Spacecraft Center, Houston, Tex. The conference emphasized the highlights of the Gemini Program and especially the flight results of the last five missions. This report contains the 21 technical papers presented at the conference as well as an introduction by George E. Mueller and concluding remarks by George M. Low.

The technical papers are divided into five sections: the first describes the rendezvous, docking, and tethered-vehicle operations involving the spacecraft and a target vehicle; the second presents various aspects of extravehicular activity; the third concerns the operational support of the missions; the fourth covers the experiments conducted during the missions; and the fifth compares the astronaut flight and simulation experiences and relates the Gemini results to the Apollo Program.

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1. INTRODUCTION

By GEORGE E. MUELLER, *Associate Administrator for Manned Space Flight, NASA*

The Gemini Program is over. The papers in this report summarizing the program were prepared by some of the people who contributed to the overall success. In each case, the authors were actual participants and provide a cross section of what may be called the Gemini team. As is true in any undertaking of this magnitude, involving many diverse organizations and literally thousands of people, a vital element of the Gemini success may be traced to teamwork. In the purest definition of the word, wherein individual interests and opinions are subordinate to the unity and efficiency of the group, the Gemini team has truly excelled.

Much has already been written concerning the Gemini achievements, and many of the achievements are presented again in greater depth within this report. By way of introduction, and to set the stage for the following papers, a few words are necessary to assess the achievements in the context of the goals of the national manned space-flight program. Only in this way is it possible to evaluate the significance of the Gemini accomplishments.

The Gemini Program was undertaken for the purpose of advancing the United States manned space-flight capabilities during the period between Mercury and Apollo. Simply stated, the Gemini objectives were to conduct the development and test program necessary to (1) demonstrate the feasibility of long-duration space flight for at least that period required to complete a lunar landing mission; (2) perfect the techniques and procedures for achieving rendezvous and docking of two spacecraft in orbit; (3) achieve precisely controlled reentry and landing capability; (4) establish capability in extravehicular activity; and (5) achieve the less obvious, but no less significant, flight and ground crew proficiency in manned space flight. The very successful flight program of the United States has provided vivid demonstration of the achievements in each of these objective areas.

The long-duration flight objective of Gemini was achieved with the successful completion of Gemini VII in December 1965. The progressive buildup of flight duration from 4 days with Gemini IV, to 8 days with Gemini V and 14 days with Gemini VII, has removed all doubts, and there were many, of the capability of the flight crews and spacecraft to function satisfactorily for a period equal to that needed to reach the lunar surface and return. Further, this aspect of Gemini provides high confidence in flight-crew ability to perform satisfactorily on much longer missions. The long-duration flights have also provided greater insight into, and appreciation of, the vital role played by the astronauts, the value of flexibility in mission planning and execution, and the excellent capability of the manned space-flight control system. As originally conceived, the Gemini Program called for completion of the long-duration flights with Gemini VII, which was accomplished on schedule.

One of the more dramatic achievements has been the successful development of a variety of techniques for the in-orbit rendezvous of two manned spacecraft. The preparation for this most complex facet of Gemini missions was more time consuming than any other. That it was performed with such perfection is a distinct tribute to the Gemini team that made it possible: the spacecraft and launch-vehicle developers and builders, the checkout and launch teams, the flight crews and their training support, and the mission-planning and mission-control people.

The ability to accomplish a rendezvous in space is fundamental to the success of Apollo, and rendezvous was a primary mission objective on each mission after Gemini VII. Ten rendezvous were completed and seven different rendezvous modes or techniques were employed. Nine different dockings of a spacecraft with a target vehicle were achieved. Eleven different astronauts gained rendezvous experience in this most important objective. Several of the rendezvous were designed to simulate some facet of an Apollo rendezvous requirement. The principal focus of the rendezvous activities was, however, designed to verify theoretical determinations over a wide spectrum. Gemini developed a broad base of knowledge and experience in orbital rendezvous and this base will pay generous dividends in years to come.

A related accomplishment of singular importance to future manned space-flight programs was the experience gained in performing docked maneuvers using the target-vehicle propulsion system. This is a striking example of Gemini pioneering activities—the assembly and maneuvering of two orbiting space vehicles.

The first attempt at extravehicular activity during Gemini IV was believed successful, and although difficulties were encountered with extravehicular activity during Gemini IX–A, X, and XI, the objective was achieved with resounding success on Gemini XII. This in itself is indicative of the Gemini Program in that lessons learned during the flight program were vigorously applied to subsequent missions. The extravehicular activity on Gemini XII was, indeed, the result of all that had been learned on the earlier missions.

The first rendezvous and docking mission, although temporarily thwarted by the Gemini VI target-vehicle failure, was accomplished with great success during the Gemini VII/VI–A mission. This mission also demonstrated the operational proficiency achieved by the program. The term "operational proficiency" as applied to Gemini achievements means far more than just the acceleration of production rates and compressing of launch schedules. In addition and perhaps more importantly, operational proficiency means the ability to respond to the unexpected, to prepare and execute alternate and contingency plans, and to maintain flexibility while not slackening the drive toward the objective. Time and again Gemini responded to such a situation in a manner that can only be described as outstanding.

A few comments are in order on what the Gemini accomplishments mean in terms of value to other programs. There is almost no facet of Gemini that does not contribute in some way to the Apollo Program. Aside from the actual proof testing of such items as the manned space-flight control center, the manned space-flight communications net, the development and perfection of recovery techniques, the training of the astronauts, and many others which apply directly, the Gemini Program has provided a high level of confidence in the ability to accomplish the Apollo Program objectives before the end of this decade. The Apollo task is much easier now, due to the outstanding performance and accomplishments of the Gemini team.

Similarly, the Apollo Applications Program has been inspired in large part by the Gemini experiments program, which has sparked the imagination of the scientific community. In addition to the contributions to Apollo hardware development which provide the basis for the Apollo Applications Program, it has been discovered, or rather proved, that man in space can serve many extremely useful and important functions. These functions have been referred to as technological fallout, but it is perhaps more accurate to identify them as accomplishments—that is, accomplishments deliberately sought and achieved by the combined hard labor of many thousands of people. Some of these people have reviewed their work in this report.

The Manned Orbiting Laboratory Program has been undertaken by the Department of Defense for the purpose of applying manned space-flight technology to national defense and is making significant use of the

Gemini accomplishments. This may be considered as a partial repayment for the marvelous support that NASA has received and continues to receive from the DOD. The success of the NASA programs is in no small measure due to the direct participation of the DOD in all phases of the manned space-flight program. This support has been, and will continue to be, invaluable.

The combined Government/industry/university team that makes up the manned space-flight program totals about 240 000 people. In addition, thousands more are employed in NASA unmanned space efforts, and in programs of the Department of Defense, the Department of Commerce, the Atomic Energy Commission, and other agencies involved in total national space endeavors. These people, in acquiring new scientific knowledge, developing new techniques, and working on new problems with goals ever enlarged by the magnitude of their task, form the living, growing capability of this Nation for space exploration.

For the last quarter century, this Nation has been experiencing a technological revolution. Cooperative efforts on the part of the Government, the universities, the scientific community, and industry have been the prime movers. This cooperation has provided tremendous capability for technological research and development which is available now and which will continue to grow to meet national requirements of the future. The influence of this technological progress and prowess is, and has been, a deciding factor in keeping the peace. Preeminence in this field is an important instrument in international relations and vitally influences this country's dealings with other nations involving peace and freedom in the world. Political realities which can neither be wished away nor ignored make the capability to explore space a matter of strategic importance as well as a challenge to the scientific and engineering ingenuity of man. This Nation can no more afford to falter in space than it can in any earthly pursuit on which the security and future of the Nation and the world depend.

The space effort is really a research and development competition, a competition for technological preeminence which demands and creates the quest for excellence.

The Mercury program, which laid the groundwork for Gemini and the rest of this Nation's manned space-flight activity, appears at this point relatively modest. However, Mercury accomplishments at the time were as significant to national objectives as the Gemini accomplishments are today and as those that are planned for Apollo in the years ahead.

That these programs have been, and will be, conducted in complete openness with an international, real-time audience makes them all the more effective. In this environment, the degree of perfection achieved is even more meaningful. Each person involved can take richly deserved pride in what has been accomplished. Using past experience as a foundation, the exploration of space must continue to advance. The American public will not permit otherwise, or better yet, history will not permit otherwise.

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2. SUMMARY OF RENDEZVOUS OPERATIONS

By W. BERNARD EVANS, *Office of Vehicles and Missions, Gemini Program Office, NASA Manned Spacecraft Center; and* MARVIN R. CZARNIK, *Dynamics Group Engineer, McDonnell Aircraft Corp.*

Introduction

One of the major objectives of the Gemini Program was to develop and to demonstrate techniques for the rendezvous and docking of space vehicles. This objective is of vital importance since rendezvous and docking is mandatory for success in many future manned space-flight programs. For example, lunar orbital rendezvous has been selected as the primary mode for the Apollo lunar-landing mission which requires one rendezvous and two dockings. Other programs requiring rendezvous are planetary missions, manned space stations, and unmanned satellite inspection and repair missions.

During the Gemini Program, the following types of rendezvous techniques were evaluated: fourth orbit ($M = 4$), third orbit ($M = 3$), first orbit ($M = 1$), optical rendezvous, rendezvous from above, stable orbit rendezvous, and optical dual rendezvous. These techniques were used successfully in the completion of 10 rendezvous operations (table 2–I). A major factor in achieving success during these operations can be attributed to the implementation of an extensive analysis, simulation, and training program leading first to the Gemini VI–A rendezvous mission, and subsequently to more complex missions. During the Gemini III mission, the spacecraft propulsion system and the guidance and control system were evaluated. On the Gemini IV mission, a plan was developed and an attempt was made to station keep and rendezvous with the spent second stage of the launch vehicle. During Gemini V, a phantom rendezvous and a spacecraft radar-to-ground transponder tracking test were performed. The phantom rendezvous involved a series of maneuvers based upon ground tracking and computations, and precisely duplicated the maneuver sequence and procedures planned for the midcourse phase of the Gemini VI–A mission.

TABLE 2–I.—*Mission Summary*

Gemini mission	Type of rendezvous
VI–A	Fourth orbit ($M = 4$)
VIII	Fourth orbit ($M = 4$)
IX–A	Third orbit ($M = 3$)
	Optical re-rendezvous
	Re-rendezvous from above
X	Fourth orbit ($M = 4$)
	Optical dual
XI	First orbit ($M = 1$)
	Stable orbit
XII	Third orbit ($M = 3$)

Sufficient data were obtained from the spacecraft radar tracking test during the Gemini V mission to adequately flight-qualify the radar for the Gemini VI–A flight. Even though the rendezvous operations planned for the first three manned Gemini flights were not all successful, they were extremely valuable to the program since they provided flight experience and indicated areas requiring further analysis, simulation, and training.

On December 15, 1965, the Gemini VI–A crew, using the Gemini VII spacecraft as the target vehicle, completed the first space rendezvous operation. Although this mission did not include a docking, it was successful and after lift-off proceeded almost precisely as planned. On the following mission, the Gemini VIII crew successfully performed the first rendezvous and docking with a Gemini Agena Target Vehicle. Subsequent, more complex,

rendezvous operations were successfully performed during the Gemini IX-A, X, XI, and XII missions. These successes have provided confidence in the ability to accomplish such operations. However, rendezvous must still be recognized as a highly precise operation that is rather unforgiving of errors which occur during the final approach, details of which will be discussed in this paper.

Review of Rendezvous Operations Development

An explanation of rendezvous can be greatly simplified by a description of the relative-motion concept. Figure 2–1 shows a coordinate system centered on the target vehicle in a circular orbit with the X– and Y–axes in the target orbital plane. The Y–axis rotates with the target vehicle and is positive radially upward; the X–axis is curvilinear and positive opposite the direction of motion. The out-of-plane parameter is the Z–axis, which completes the right-hand coordinate system. The motion of the spacecraft with respect to this reference is illustrated in figure 2–2.

Figure 2–2(*a*) shows the spacecraft in a lower circular orbit. It should be noted that

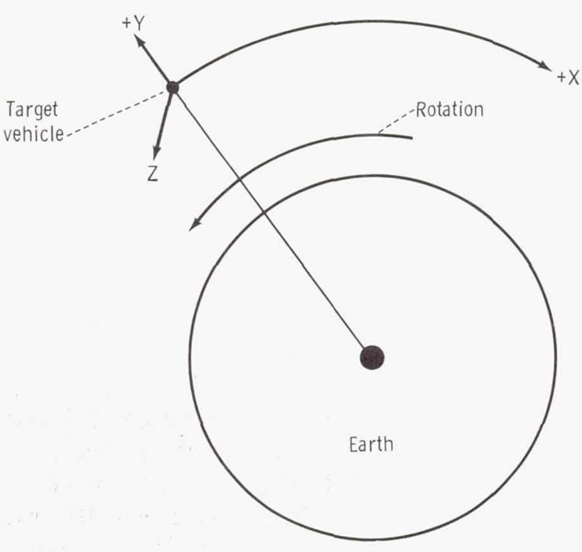


FIGURE 2–1.—Target-centered coordinate system.

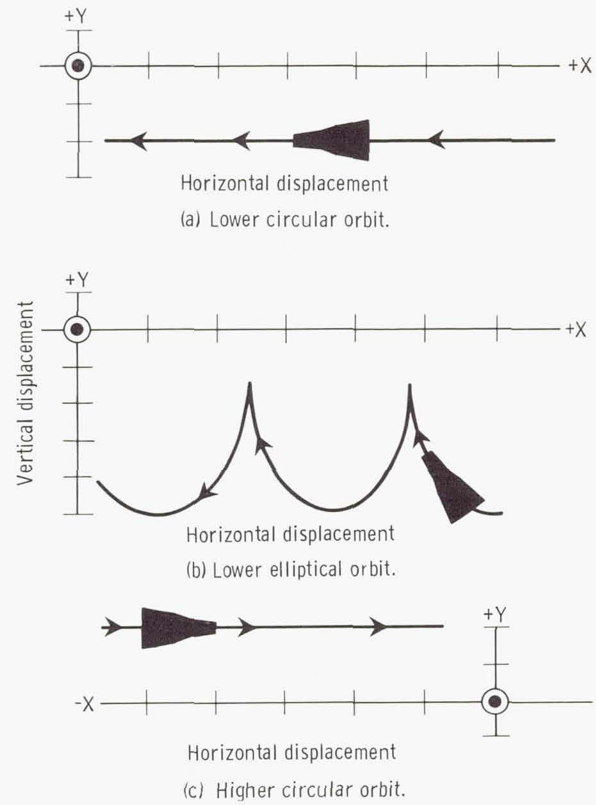


FIGURE 2–2.—Motion relative to a target-centered coordinate system.

the radial displacement Y is constant while the trailing displacement X decreases with time, since the spacecraft in the lower orbit has a higher angular rate. Figure 2–2(*b*) shows a lower elliptical orbit. As can be expected, this orbit has a catchup rate; however, the radial displacement also changes, with the low points representing perigees, and the high points, apogees. Figure 2–2(*c*) illustrates a spacecraft in a circular orbit higher than the target orbit. The radial distance is constant, as in the case of the lower circular orbit; however, in this case the trailing displacement changes since the target now has the higher angular rate. The following paragraphs use this coordinate system in describing the Gemini rendezvous operations.

The development of the operational rendezvous missions required extensive analyses as previously described in reference 1. For

Gemini VI, many concepts were evaluated and three were selected as candidates for the Gemini VI mission. The first was the tangential concept which included the tangential approach of the spacecraft to the target vehicle following four orbits of ground-controlled midcourse maneuvers. The second concept had a similar catchup sequence, except that the final midcourse maneuver established a coelliptical approach trajectory, and the spacecraft closed-loop guidance system was then used to establish a collision course. A third concept featured rendezvous at first spacecraft apogee. Following a tangential approach of the spacecraft to the target, the spacecraft would be inserted on a collision course with the target, and the spacecraft closed-loop system would be used to correct insertion dispersions.

After the three concepts had been selected, analyses were performed to determine the concept best suited for the Gemini VI mission. In June 1964, prior to the flight of Gemini II, the coelliptical rendezvous concept was selected for the Gemini VI mission.

Description of Initial Rendezvous Operations

Gemini VI-A, VIII, and X

Figures 2-3 and 2-4 present typical relative trajectory plots of the fourth-orbit rendezvous conducted on Gemini VI-A, VIII, and X. On each mission, the spacecraft was inserted into an orbit essentially coplanar with the target vehicle. The first orbit was left free of rendezvous maneuvers to allow the crew sufficient time to verify satisfactory spacecraft operation. A number of midcourse corrections were performed before completing the rendezvous during the fourth spacecraft orbit near the end of the fourth darkness period. At the first spacecraft perigee, an apogee height-adjust maneuver N_H was performed to correct for in-plane insertion dispersions. At the second apogee, a phase-adjust maneuver N_{C1} was performed to raise the perigee, thus providing the catchup rate required for proper phasing of the terminal-phase initiation near the fourth darkness entry. An out-of-plane correction

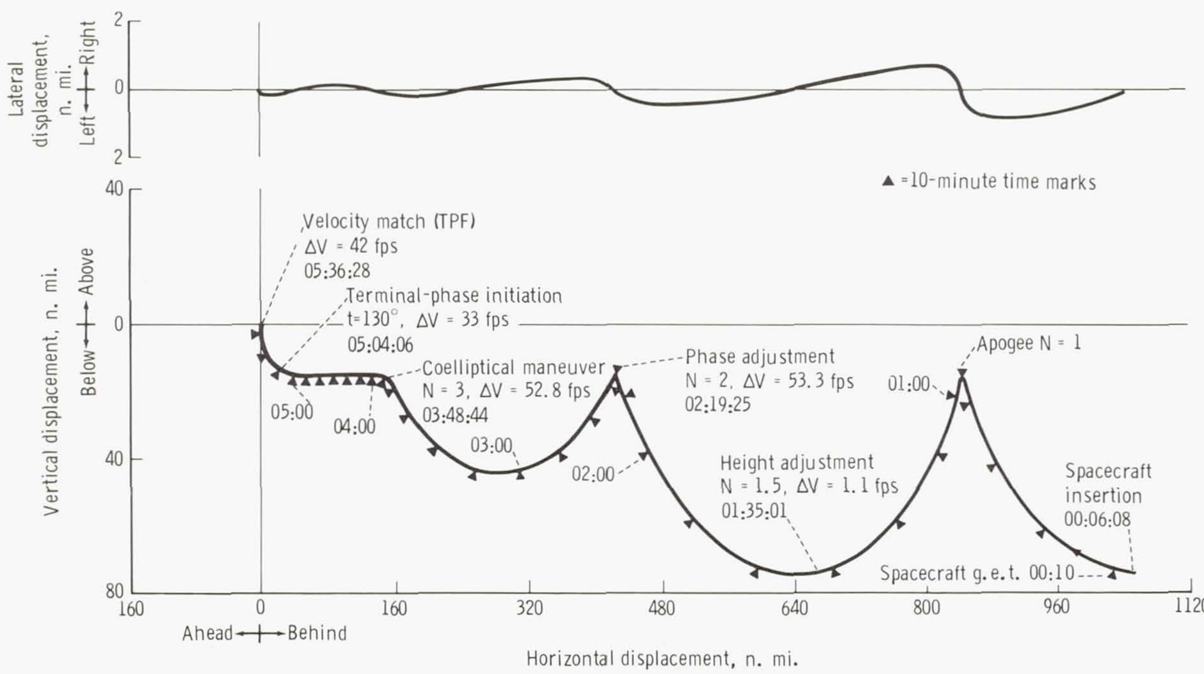


FIGURE 2-3.—Typical relative trajectory of spacecraft from insertion to rendezvous in target-vehicle curvilinear coordinate system. Gemini VI-A, VIII, and X missions.

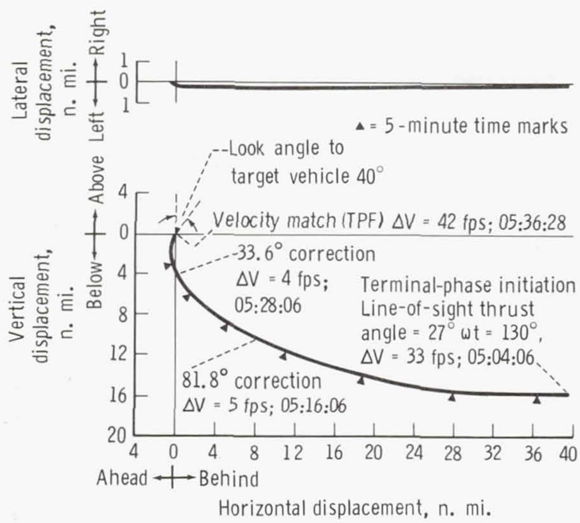


FIGURE 2-4.—Typical relative trajectory of spacecraft from terminal-phase initiation to rendezvous in target-vehicle curvilinear coordinate system. Gemini VI-A, VIII, and X missions.

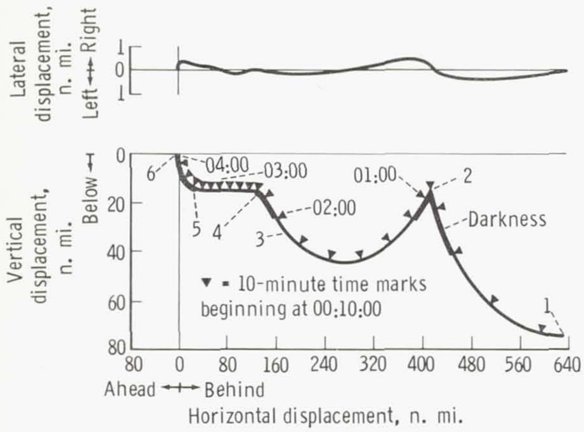
P_C was applied at the nodal crossing after the second apogee to correct out-of-plane insertion dispersions. At the third spacecraft apogee, a coelliptical maneuver N_{SR} was performed to produce a constant altitude differential of 15 nautical miles. The onboard system then provided solutions for the terminal-phase-initiation (TPI) maneuver, which would occur when the line-of-sight elevation angle reached the nominal value of 27°. Two vernier corrections followed at 12-minute intervals. Finally, braking (terminal-phase finalization (TPF)) and line-of-sight rate control were effected by a manual operation based upon radar and visual data.

The transfer trajectory was selected to satisfy several of the mission requirements in the area of onboard procedures. First, in order to provide a backup reference direction for the terminal-phase-initiation maneuver in case of a guidance-system failure, the maneuver had to be performed along the line of sight to the target. The second requirement was a low terminal line-of-sight angular rate and a low closing rate. Finally, the terminal-phase-initiation point had to be below and behind the target vehicle; and the final approach, from below and ahead of the target vehicle, in order to optimize the lighting. These factors were evaluated, and a 130° transfer was selected.

The selection of the nominal coelliptical differential altitude of 15 nautical miles was based upon a tradeoff between two considerations. First, the range to the target at the terminal-phase-initiation point had to be small enough to assure visual acquisition. Second, a large differential altitude was required to minimize the effect of insertion dispersions and catchup maneuver errors on the location of the terminal-phase-initiation point. For example, a differential altitude of 15 nautical miles resulted in a 3-sigma dispersion of ±8 minutes in the timing of the terminal-phase-initiation maneuver. Early error analysis indicated a ±15-minute variation in terminal-phase-initiation timing for a differential altitude of 7 nautical miles. Flight experience demonstrated that the launch vehicle and spacecraft guidance systems accuracies, crew procedures, and ground-tracking accuracy were better than had been expected; as a result, the altitude differential was reduced to 5 and 7 nautical miles in the later rendezvous operations.

Gemini IX–A and XII

A second primary rendezvous technique was utilized on Gemini IX–A and XII (figs. 2–5 and 2–6). This technique resulted in rendezvous in the third spacecraft orbit near the end of the third spacecraft darkness period. A phase-adjust maneuver N_{C_1} was performed at first spacecraft apogee to provide the correct phasing at the second apogee. Approximately three-fourths of an orbit later, the first of a set of two maneuvers was performed: a combination phasing, height-adjust, and out-of-plane correction. The first maneuver N_{CC}, combined with the following coelliptical maneuver, provided a fixed rendezvous time with minimum propellant usage. The out-of-plane portion of the first maneuver established a node at the following coelliptical maneuver point. The coelliptical maneuver N_{SR} eliminated the out-of-plane



1. Spacecraft insertion; 00:06:21
2. Phase adjustment N = 1, ΔV = 53.4 fps; 00:59:39
3. Corrective combination N = 1.75, ΔV = 0.8 fps; 01:57:00
4. Coelliptical maneuver N = 2, ΔV = 52.7 fps; 02:20:32
5. Terminal-phase initiation ΔV = 32.4 fps; 03:27:07, ωt = 130°
6. Velocity match (TPF) ΔV = 41.6 fps; 03:59:52

FIGURE 2-5.—Typical relative trajectory. Gemini IX-A and XII missions.

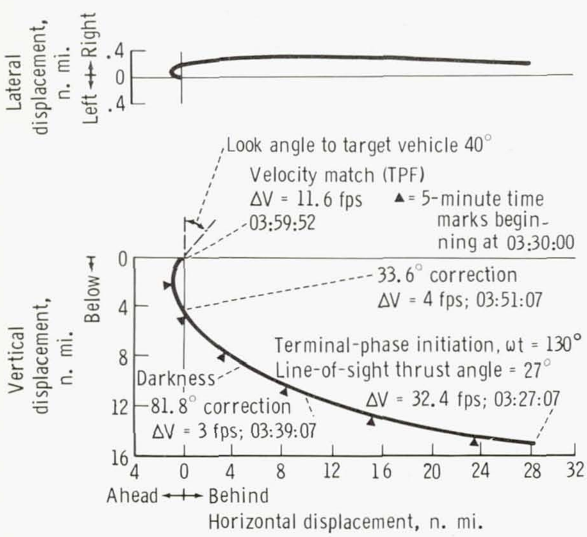


FIGURE 2-6.—Typical relative trajectory, terminal phase. Gemini IX-A and XII missions.

motion and established coelliptical orbits with an altitude differential that varied within certain limits. The terminal phase of this technique was the same as the fourth-orbit technique, except that procedural changes were necessary to accommodate the variable altitude differential.

Gemini XI

The third primary rendezvous conducted during the program was the first-orbit technique used for Gemini XI (figs. 2-7 and 2-8). The limited time available to conduct the first-orbit rendezvous prohibited the multicorrection catchup phase and coelliptical approach used on other missions. Instead, a correction was made at spacecraft insertion to remove out-of-plane motion and to adjust

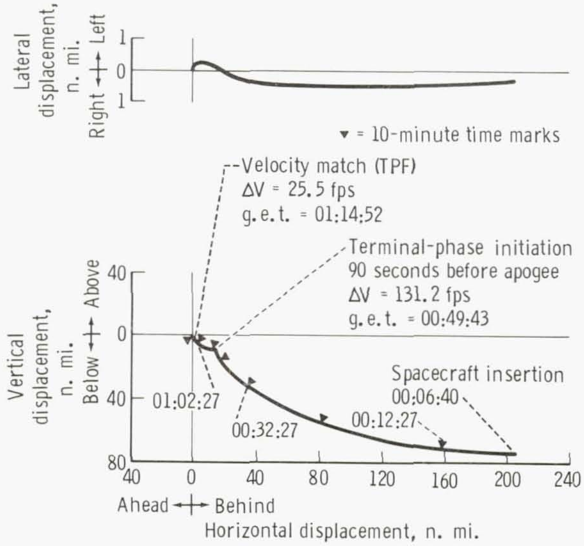


FIGURE 2-7.—Relative trajectory. Gemini XI mission.

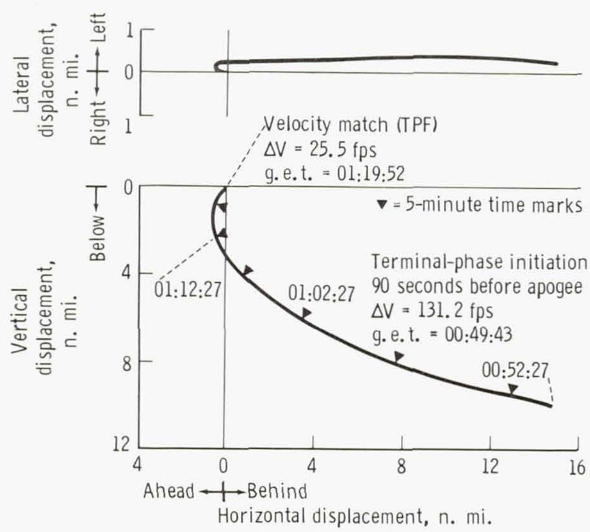


FIGURE 2-8.—Relative trajectory, terminal phase. Gemini XI mission.

apogee height and phasing. This correction was based upon onboard navigation information obtained from the spacecraft guidance system. At 90° after insertion, a second out-of-plane correction, also based upon onboard information, was performed. Terminal-phase initiation occurred just prior to first spacecraft apogee with the spacecraft 10 nautical miles below and 15 nautical miles behind the target vehicle. A 120° transfer was used with two vernier corrections at 12-minute intervals after the terminal-phase initiation. After a manual braking and line-of-sight phase, rendezvous was completed within the first orbit.

Description of Re-Rendezvous and Dual Rendezvous Operations

The first of three re-rendezvous techniques was an optical rendezvous from an equiperiod orbit and was conducted on the Gemini IX–A mission (fig. 2–9). The purpose of this rendezvous was to evaluate the optical rendezvous procedures, and particularly the terminal-phase lighting, required for the dual rendezvous scheduled for Gemini X. An upward radial velocity change was used to separate the spacecraft from the target vehicle into an equiperiod orbit. Approximately one-half orbit after separation, a correction

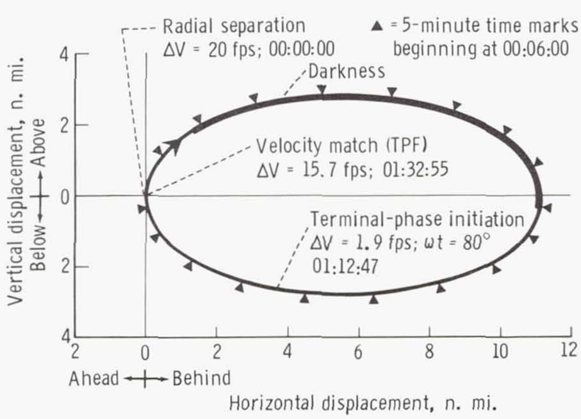


FIGURE 2–9.—Relative trajectory of spacecraft for (equiperiod) re-rendezvous in target vehicle curvilinear coordinate system. Gemini IX–A mission.

was applied based upon the time the line of sight to the target vehicle crossed the local horizontal. The time and the magnitude of the terminal-phase-initiation maneuver were determined from visual angle observations, and an 80° transfer was initiated when the Sun was nearly overhead. Two vernier corrections also based upon visual angle measurements were applied, and rendezvous occurred just prior to sunset. It was a requirement that the spacecraft be in a station-keeping mode prior to entering darkness with a passive target.

A second re-rendezvous technique (figs. 2–10 and 2–11) was developed to evaluate a terminal-phase condition with an Earth background. Two midcourse maneuvers were used to insert the spacecraft into a coelliptical orbit 7.5 nautical miles above the target vehicle. Except for a reversal in approach direction, the terminal phase was identical to that employed on the earlier coelliptical approach from below. Experience gained during this rendezvous indicates that the probability of success would be very low in case of a radar guidance system failure because of the extremely poor target visibility.

During the Gemini XI mission, a third re-rendezvous exercise was performed. This rendezvous was ground controlled except that the terminal braking and line-of-sight control phases were performed by the crew using visual observations (no radar). After the initial separation maneuver, the spacecraft was in a nearly circular orbit at the same altitude as the target vehicle, but with a trailing displacement of approximately 25 nautical miles. Since the relative motion of the vehicles in this configuration was approximately zero, the rendezvous was referred to as a stable-orbit rendezvous (fig. 2–12). A ground-computed maneuver was performed which placed the spacecraft on a trajectory to intercept the target vehicle in 292° of target orbital travel. With 34° of orbital travel remaining, a second and final ground-computed maneuver was applied. The rendezvous was then completed by the flight crew using visual cues. The terminal-phase portion of

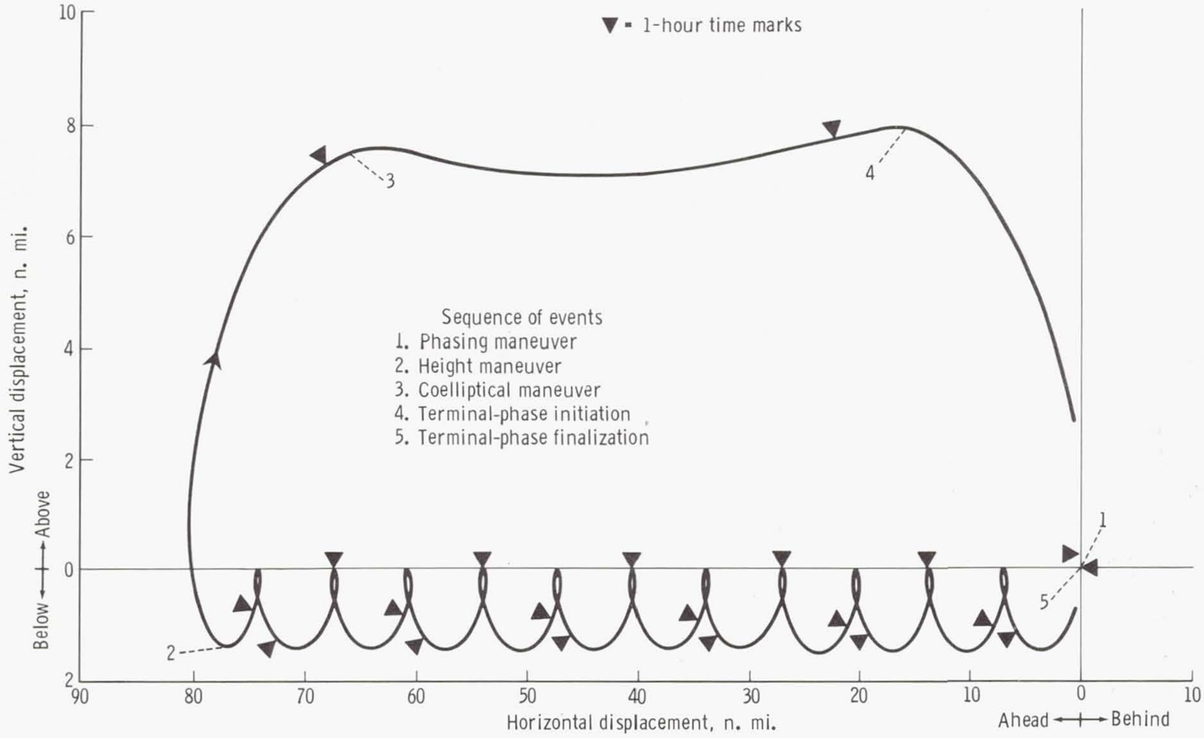


FIGURE 2-10.—Relative trajectory profile for re-rendezvous from above. Gemini IX-A mission.

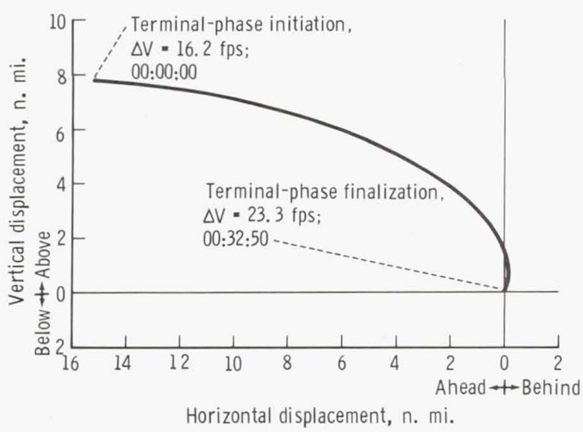


FIGURE 2-11.—Relative trajectory re-rendezvous from above. Gemini IX-A mission.

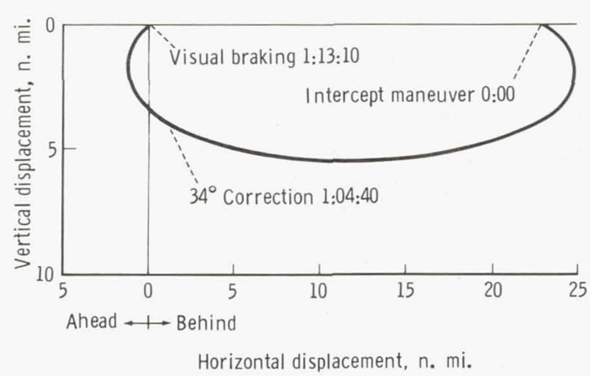


FIGURE 2-12.—Gemini XI stable orbit re-rendezvous.

this rendezvous had the same characteristics as the tangential concept previously described. Theoretically, the propellant required is small when compared with the coelliptical approach; however, with minor dispersions at the intercept maneuver point, the lighting conditions, approach angles, and propellant consumption for the braking phase can vary widely. The reason is that, for most cases, the spacecraft will end up approaching the target from above, resulting in poor target visibility. This type of rendezvous generated considerable interest in its application to certain rendezvous operations, particularly where a highly precise ground-tracking system is used to provide

the terminal-phase maneuvers. The commitment to conduct such a rendezvous reflected the confidence that was established during Gemini in the capabilities of the ground-tracking, computation, and control facilities.

In addition to the primary and re-rendezvous missions, a dual rendezvous was performed by the Gemini X crew. The target vehicle launched during the Gemini VIII mission was left in orbit and was the passive target for the dual operation. One problem encountered during the development of the Gemini X mission was obtaining precise state vectors for the passive target vehicle, and making accurate predictions far enough in advance to find acceptable launch windows. Because of the inaccuracies in drag prediction, it was necessary for launch date, lift-off time, and catchup sequence to be flexible. The catchup sequence included a series of maneuvers by the docked Gemini X spacecraft and Gemini X target vehicle for gross catchup, and another series of maneuvers by the undocked spacecraft for fine catchup. The capability for large changes in altitude during the gross catchup sequence allowed an acceptable wide variation in the initial-phase angle. The terminal approach was coelliptical with an altitude differential of 7 nautical miles; the terminal-phase guidance employed was the same as for the optical rendezvous conducted on Gemini IX–A.

Rendezvous Considerations and Flight Results

In developing the rendezvous missions, many factors were considered, primarily launch procedures, system requirements, and crew procedures.

Launch Procedures

Development of the launch procedures required extensive analyses to define methods of controlling out-of-plane displacement, establishing launch-window length, and developing a countdown method.

Selecting a target orbit inclination slightly above the latitude of the launch site makes the out-of-plane displacement relatively small for a long period of time (fig. 2–13). By varying the launch azimuth so that the spacecraft would be inserted parallel to the target-vehicle orbital plane, the out-of-plane displacement of the launch site at the time of launch becomes the maximum out-of-plane displacement between the two orbit planes. The out-of-plane displacement could also be minimized by using the variable launch-azimuth technique with guidance in yaw during second-stage powered flight. This is accomplished by biasing the launch azimuth of the spacecraft so that the launch azimuth is at an optimum angle directed toward the target-vehicle orbital plane (fig. 2–14). As a result, the out-of-plane distance would be reduced prior to the initiation of closed-loop guidance during the second-stage flight. This technique would effectively use the launch-vehicle performance capability to control the out-of-plane displacement. Sufficient performance capability existed in the Gemini Launch Vehicle to control the out-of-plane displacement to within ±0.55° (table 2–II). The maximum allowable wedge angle of ±0.55° was not needed on any of the rendezvous missions. By selecting an inclination of

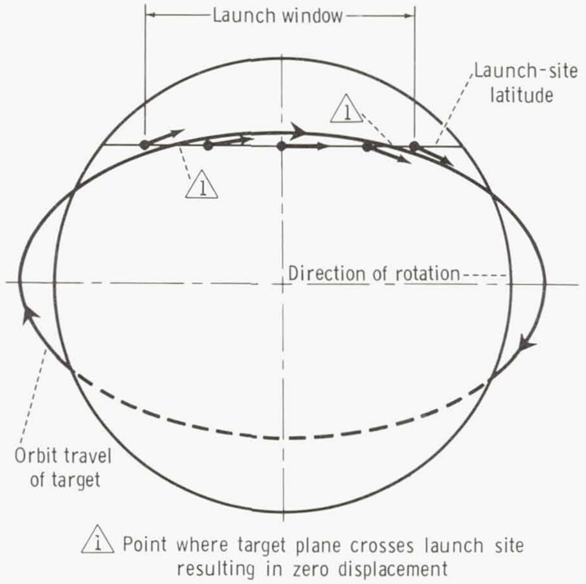


FIGURE 2–13.—Variable azimuth launch technique.

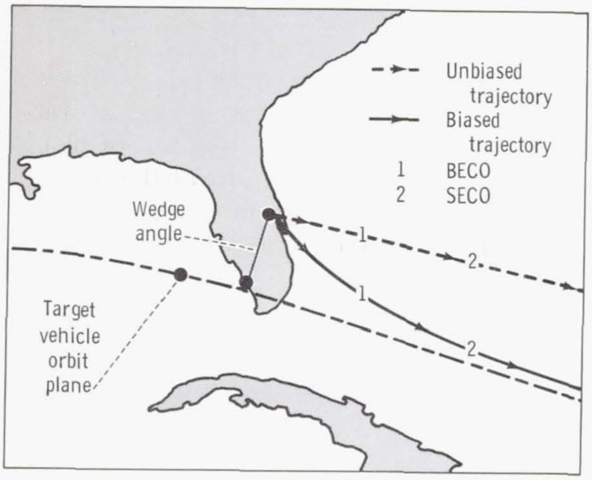


FIGURE 2–14.—Typical Gemini rendezvous launch. Biased launch azimuth and Stage II yaw steering.

TABLE 2–II—*Yaw Steering Summary*

Gemini mission	Targeted out-of-plane displacement, deg
VI–A	0.20
VIII	–.21
IX–A	–.50
X	–.077
XI	–.131
XII	–.16

28.87°, 0.53° above the launch-site latitude, and by using a variable launch-azimuth technique, the out-of-plane displacement could be controlled to within 0.53° for 135 minutes.

During the early planning phases of the Gemini Program, a relatively large launch window (table 2–III) was considered mandatory; however, later experience indicated that reliable countdown procedures could be developed, and it is now the general opinion that large launch windows are not required. Since Gemini V, the launches have either been essentially on time, or the launch has been scrubbed. By suitable planning, minor launch delays can be easily absorbed in the count, and if major problems occur, large launch-window lengths are not particularly helpful. An on-time launch capability provides a tremendous potential in planning operational rendezvous missions and indicates

TABLE 2–III.—*Gemini Launch Performance*

Mission	Launch attempts	Launch date	Launch-time deviation
I	1	Apr. 8, 1964	On time
II	2	Jan. 19, 1965	–4 min
III	1	Mar. 23, 1965	–24 min
IV	1	June 3, 1965	–16 min
V	2	Aug. 21, 1965	On time
VI	1	([a])	—
VI–A	2	Dec. 15, 1965	On time
VII	1	Dec. 4, 1965	On time
VIII	2	Mar. 16, 1966	On time
IX	1	([b])	—
IX–A	2	June 3, 1966	On time
X	1	July 18, 1966	On time
XI	3	Sept. 12, 1966	On time
XII	3	Nov. 11, 1966	On time

[a] Target-vehicle failure.
[b] Target launch-vehicle failure.

that rendezvous operations, booster performance permitting, are operationally feasible at any orbital inclination.

Initial analyses of countdown methods indicated that the highest probability of mission success could be achieved by simultaneously counting down both vehicles. Even though simultaneous countdowns have been used extensively in Gemini, nothing in the results clearly indicates that this is a necessity.

Systems Requirements

A primary consideration in the development of the rendezvous operations was the area of systems requirements. The requirements for the systems design were based upon design-reference missions. As the designs became established, however, the operational missions were developed to exploit the systems capabilities, and, of course, the missions were ultimately limited by the systems capabilities. For example, a desired objective during the Gemini XII mission planning was to complete a rendezvous during the second orbit ($M=2$). Accomplishing this objective within acceptable dispersions would have required a trajectory cor-

rection based on radar range at a point outside the spacecraft radar-range capability. As a result, the second-apogee rendezvous plan was eliminated.

Crew Procedures

Further requirements were imposed to achieve workable crew procedures. The major requirements in this area were the following:

(1) Sufficient time for the crew to complete the necessary activities

(2) Approach trajectories which are reasonably insensitive to insertion dispersion and to errors in midcourse maneuvers

(3) Lighting conditions which are compatible with backup procedures

(4) Low terminal-approach velocities and line-of-sight angular rates

(5) Backup procedures for guidance-systems failures

The requirement to allow sufficient time for crew procedures had an effect on several of the Gemini missions. For example, the first orbits of the Gemini VI–A and VIII missions were free of rendezvous maneuvers, allowing the crew sufficient time to verify the satisfactory operation of all spacecraft systems. The Gemini X primary rendezvous was changed from a third-orbit to a fourth-orbit rendezvous to allow the crew sufficient time to conduct the heavy procedural workload required by the star-horizon onboard orbit determination.

The second procedural requirement, approach trajectories which are reasonably insensitive to insertion dispersion and errors in midcourse maneuvers, was also important in the development of the fourth-orbit rendezvous. An objective was to develop a mission which could effect a near-nominal terminal-approach trajectory notwithstanding insertion dispersions, spacecraft equipment degradation, or ground tracking and computation errors. This objective established the need for the development of backup terminal-phase procedures in the event of a guidance-component failure.

The need for lighting conditions (fig. 2–15) compatible with backup procedures affected all the rendezvous missions. The desired lighting situation for an active target was that the crew (1) see the target by reflected sunlight prior to and at terminal-phase initiation, (2) see the target acquisition lights against a star background during the terminal transfer, and (3) see the target by reflected sunlight for docking after exit from darkness. This lighting situation enabled the crew to maintain target visibility throughout the terminal-rendezvous operations, and established the capability for making inertial line-of-sight angle measurements in the event of a guidance platform failure. The lighting requirement was a factor in selecting the location of the terminal-phase-initiation point, the central angle of the transfer, and the terminal-approach angle. The desirable lighting conditions for rendezvous with an active target were different than for rendezvous with a passive target (fig. 2–16). Since a passive target would not

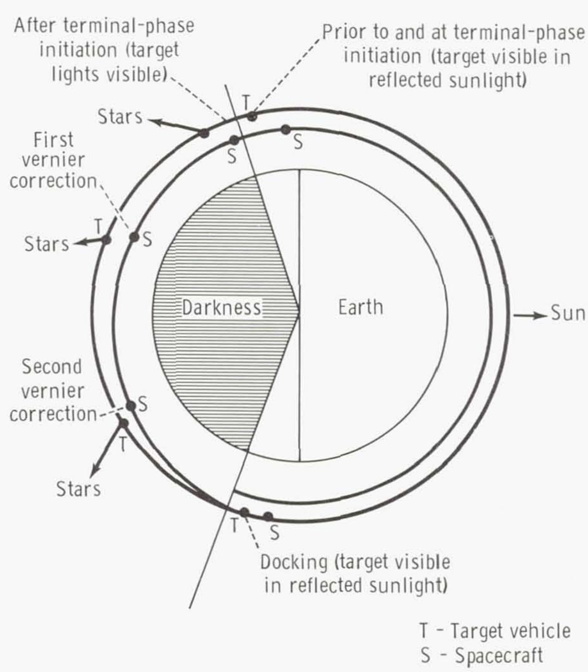


FIGURE 2–15.—Desired lighting situation for primary rendezvous.

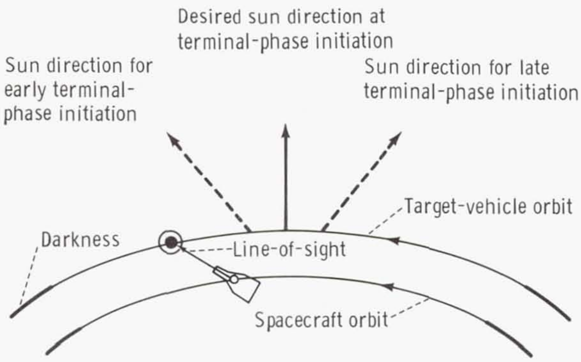


FIGURE 2-16.—Desired lighting situation for passive rendezvous.

be visible in darkness, the terminal-phase portion of the Gemini X dual optical rendezvous was conducted entirely in daylight. The desired terminal-phase initiation occurred near the midpoint of the daylight period. Earlier initiations would have placed the sunline too near the line of sight to the target, thereby obscuring target visibility. Later initiations would not have allowed adequate time in daylight for completing the rendezvous. Gemini experience has shown that lighting is not a major constraint for an active rendezvous provided the spacecraft guidance system does not fail during the terminal approach; but lighting is a major constraint for an optical rendezvous.

The fourth requirement was that the terminal trajectory allow a low terminal-approach velocity and low line-of-sight angular rate. The requirement was important in selecting the trajectory parameters for the coelliptical and the first-orbit rendezvous plans. The 130° transfer utilized on several of the missions was chosen primarily because of the low line-of-sight angular rate near intercept. The biased apogee approach was selected for Gemini XI because the direct tangential approach would have resulted in a high closing velocity.

Throughout the Gemini Program, there was a question of the level of effort to be applied to the development of backup procedures to accommodate guidance-system failures. During the Gemini XI first-orbit rendezvous mission, a problem with the radar system developed just prior to the final terminal-phase midcourse correction. Even though a backup solution for this maneuver was computed and applied, rendezvous could have been accomplished without the correction, since the correction required in this particular instance was small (2 ft/sec). However, on Gemini XII, a failure of a primary guidance-system component required the use of the backup procedures. The radar system failed prior to the terminal-phase-initiation maneuver on this mission, and backup procedures were employed throughout the terminal phase to complete the rendezvous.

The terminal phase of a rendezvous operation involves precision maneuvers and careful control of closing and line-of-sight rates. Table 2–IV compares fuel expenditures encountered during terminal-phase operations with the theoretical minimum. A considerable variation exists between the ratio of actual-to-minimum propellant for various types of terminal-phase conditions, and also for different flights using the same or similar terminal-phase conditions. This variation reflects the critical nature of the task, in that fairly small velocity vector errors can cascade to high propellant consumption or failure to complete the rendezvous. The braking operation is particularly critical. Braking too soon will increase line-of-sight control requirements, and require more time to control the spacecraft during the closing sequence.

An additional comparison of rendezvous performance is shown in table 2–V where the actual terminal-phase vernier corrections are compared with the preflight minimal predicted. This comparison provides an especially good measure of guidance-system performance, since the maneuvers were nominally very small and became large only with degradation of guidance-system performance or with control difficulties.

A number of terminal-phase rendezvous operations were satisfactorily completed during the Gemini Program by using optical

TABLE 2–IV.—*Rendezvous Propellant Usage*

Gemini mission	Type of rendezvous	Conditions at start of terminal phase	Propellant usage, lb		
			Actual	Minimum	Ratio
VI–A	$M=4$	Coelliptic: $\Delta h=15$ n. mi. $\Delta X=25$ n. mi.	130	81	1.60
VIII	$M=4$	Coelliptic: $\Delta h=15$ n. mi. $\Delta X=25$ n. mi.	160	79	2.02
IX–A	$M=3$	Coelliptic: $\Delta h=12$ n. mi. $\Delta X=22$ n. mi.	113	68	1.66
IX–A	Optical	$\Delta h=2.5$ n. mi. $\Delta X=3.5$ n. mi.	61	20	3.05
IX–A	From above	$\Delta h=-7.5$ n. mi. $\Delta X=-10$ n. mi.	137	39	3.51
X	$M=4$	Coelliptic: $\Delta h=15$ n. mi. $\Delta X=30$ n. mi.	360	84	4.28
X	Optical dual	Coelliptic: $\Delta h=7$ n. mi. $\Delta X=12$ n. mi.	180	73	2.46
XI	$M=1$	Spacecraft at apogee of 87/151 orbit: $\Delta h=10$ n. mi. $\Delta X=15$ n. mi.	290	191	1.52
XI	Stable orbit	$\Delta h=0$ n. mi. $\Delta X=25$ n. mi.	87	31	2.81
XII	$M=3$	Coelliptic: $\Delta h=10$ n. mi. $\Delta X=20$ n. mi.	112	55	2.04

TABLE 2–V.—*Vernier Correction Solutions for Primary Rendezvous*

Gemini mission	Actual correction, ft/sec		Nominal correction, ft/sec	
	First	Second	First	Second
VI–A	11	7	1	2
VIII	15	9	1	0
IX–A	1	3	2	3
X	20	23	2	3
XI	6	2	0	2
XII	2	5	2	3

techniques alone (no closed-loop radar-computer operation). Optical rendezvous requires careful control of lighting conditions, and a stabilized reference such as an inertial platform is highly desirable. During simulations, rendezvous have been effected without platform information; however, the probability of success is relatively low.

Concluding Remarks

The rendezvous operations conducted on Gemini have demonstrated that rendezvous is operationally feasible with an active or a passive target. It has also been demonstrated that the operation can be performed using only onboard guidance information after lift-off; using only ground-supplied information; or by using a combination of onboard and ground-supplied information.

Reference

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SPACE ORBITAL MANEUVERING

3. GROUND CONTROL AND MONITORING OF RENDEZVOUS

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Summary

This paper discusses the ground control and monitoring function performed in support of the Gemini rendezvous missions. Included are discussions of the support philosophy adopted for Gemini; the resulting influence upon mission design; and comparisons between predicted and actual flight results.

Introduction

The concepts adopted for the ground support of Gemini were in keeping with the basic mission-design criterion of maximizing the probability of achieving rendezvous. A flexible ground system was developed to permit the flight-control team to react to anomalous situations routinely, while still preserving standardized conditions for the terminal-phase rendezvous. Since the possibility existed for a multitude of anomalous situations, a real-time mission-planning capability was implemented in the Mission Control Center—Houston. This capability consisted of computer-driven displays which permitted the flight controllers to assess current conditions, and to select a maneuver sequence compatible with mission constraints. In effect, the role of the flight controllers was to provide a series of midcourse maneuvers which achieved a particular relative separation and velocity between the spacecraft and the target vehicle. Following the final midcourse maneuver, the role changed more to monitoring the onboard-computed intercept maneuver and the final terminal-phase operations. The following discussion will compare, from a ground-support standpoint, the primary rendezvous missions as well as the re-rendezvous operations which may be conducted during a flight.

Gemini Rendezvous Missions

The ground support of a rendezvous mission was planned so that all information that the flight crew would nominally request, plus additional backup information, would be available at an optimum time in the flight plan. Once the basic mission plan was developed, a large number of final details had to be refined in simulations of the mission with the actual flight-crew personnel. The primary maneuver updates from the Mission Control Center—Houston had to be scheduled at a time that would afford maximum radar tracking history in the mission computers at the Manned Spacecraft Center, Houston. The Gemini rendezvous missions were separated into two distinct mission phases, the midcourse maneuver and the terminal rendezvous. For the midcourse phase, the flight-control team was the primary source for the maneuver computations. The purpose of these maneuvers was to effect a rendezvous between the spacecraft and a point in space that would result in the desired spacecraft displacement and velocity with respect to the target vehicle. To accomplish this, pre-established maneuver points were selected so that the propellant requirements for this mission phase were minimized, and sufficient network tracking was available for maneuver updates. Of course, the first rendezvous mission, Gemini VI–A, had the most uncertain conditions. Consequently, for this mission, a

plan was selected which afforded rendezvous in the fourth spacecraft revolution with the following salient features:

(1) The Gemini Launch Vehicle was targeted to provide the desired altitude differential between the target and spacecraft orbits at spacecraft apogee. Also, a dogleg launch trajectory was flown in order to insert the spacecraft into the plane of the target orbit.

(2) The first spacecraft orbit was free of rendezvous activity so the crew could make the necessary systems checks, and the ground controllers could determine the precise spacecraft orbit.

(3) Preestablished maneuver points were selected to account for expected dispersions in lift-off time and spacecraft insertion conditions.

(4) The site chosen to update a maneuver had acquisition so that adequate time remained for the crew to orient the spacecraft to the maneuver attitude.

The midcourse maneuver sequence can be seen in figure 3–1. Tracking during the first revolution indicated that the altitude differential at spacecraft apogee exceeded the acceptable tolerance; thus, the initial midcourse translation was a height adjustment performed at spacecraft perigee near the end of the first revolution. The second midcourse maneuver was a phase adjustment which occurred at the second spacecraft apogee. Out-of-plane errors were removed with a maneuver at the common node following the second apogee. Subsequent radar-tracking information indicated the need for an additional adjustment to the altitude differential at spacecraft apogee. This maneuver was performed at perigee near the end of the second revolution. The final midcourse translation was a coelliptic maneuver performed at the third apogee. The purpose of this maneuver was to place the spacecraft orbit at a constant altitude difference below the target-vehicle orbit. The same basic mission plan was also successfully used on Gemini VIII. For the Gemini IX–A mission, the midcourse-maneuver sequence had the additional requirement to more nearly duplicate the Apollo time line and midcourse phase planned for the lunar rendezvous operations. This led to rendezvous in the third spacecraft revolution with a somewhat different maneuver sequence (fig. 3–2). The phase-adjustment maneuver was performed at the first spacecraft apogee. Since the phasing maneuver was based upon a minimal amount of tracking, a second midcourse maneuver designed to achieve phasing, height, and plane requirements was scheduled in the second revolution. The location of this maneuver was

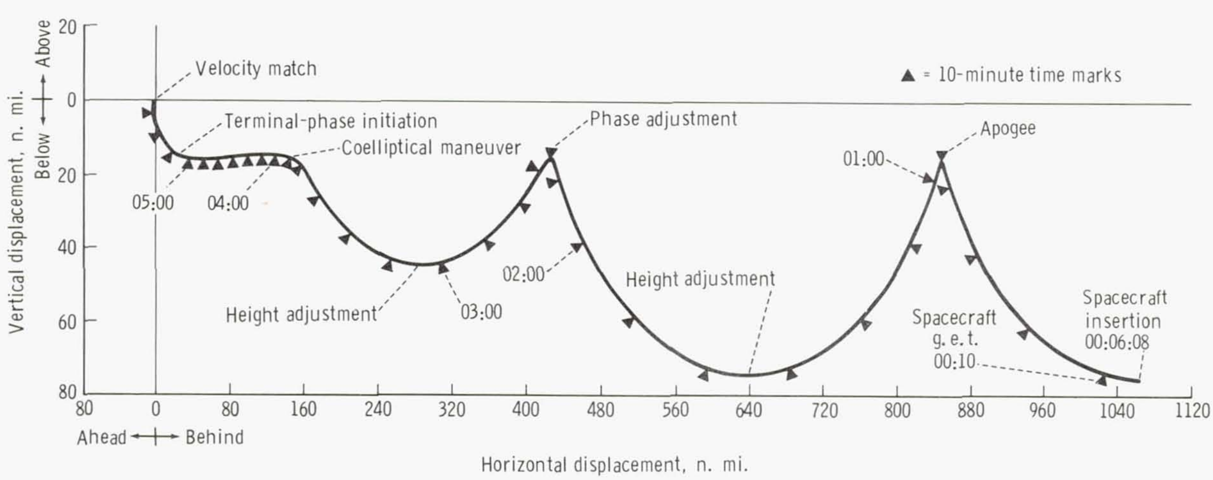

FIGURE 3–1.—Relative trajectory of spacecraft from insertion to three-revolution rendezvous in target-centered curvilinear coordinate system.

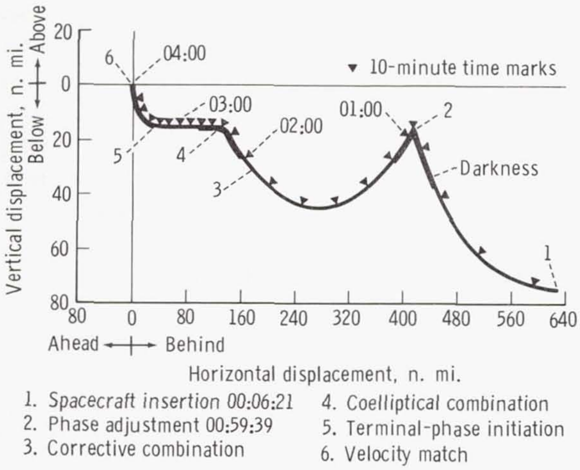

FIGURE 3–2.—Relative trajectory of spacecraft from insertion to two-revolution rendezvous in target-centered curvilinear coordinate system.

selected to afford a maximum amount of tracking over the continental U.S. stations. The final maneuver in this sequence provided a constant altitude differential between the two orbits, and also placed the Gemini spacecraft in the plane of the target vehicle.

The initial rendezvous maneuver sequence utilized on Gemini X was identical to that of Gemini VI–A. However, the ground controllers had the additional tasks of evaluating onboard maneuver calculations based upon star measurements and upon the Inertial Guidance System ascent vector; and of giving a go—no-go decision on these solutions based upon retaining acceptable terminal-phase conditions. The flight plan also included a rendezvous between the spacecraft and the passive target vehicle, which had been launched during the Gemini VIII mission and then placed in a higher parking orbit. This plan created an additional complexity, as compared with the earlier rendezvous missions, and necessitated an on-time launch for both the target vehicle and the spacecraft. Table 3–I shows the variation during the 4-month period preceding flight in lift-off time required of the Gemini X target vehicle, as well as the required apogee altitude for dual rendezvous phasing. After the crew completed the initial docking with the Gemini X target vehicle, they initiated midcourse maneuvers (fig. 3–3) to achieve desired conditions for the terminal phase of rendezvous with the passive Gemini VIII target vehicle. The Gemini X target-vehicle propulsion system was used to perform these maneuvers while the spacecraft and target vehicle were docked; the spacecraft propulsion system was used after undocking.

TABLE 3–I.—*Dual Rendezvous Planning*

Gemini VIII target-vehicle vector [a]	Gemini X target-vehicle launch time, Greenwich mean time, hr:min:sec	Required apogee, n. mi.
3/19/66	3:40:58	225
3/30/66	3:40:54	245
4/25/66	3:37:30	470
5/16/66	3:37:30	400
6/ 9/66	3:46:30	390
5/24/66	3:41:55	360
6/20/66	3:40:26	420
7/18/66	3:39:46	409

[a] Column shows dates when the passive Gemini VIII target vehicle was in proper position for lift-off of the Gemini X mission to accomplish dual rendezvous.

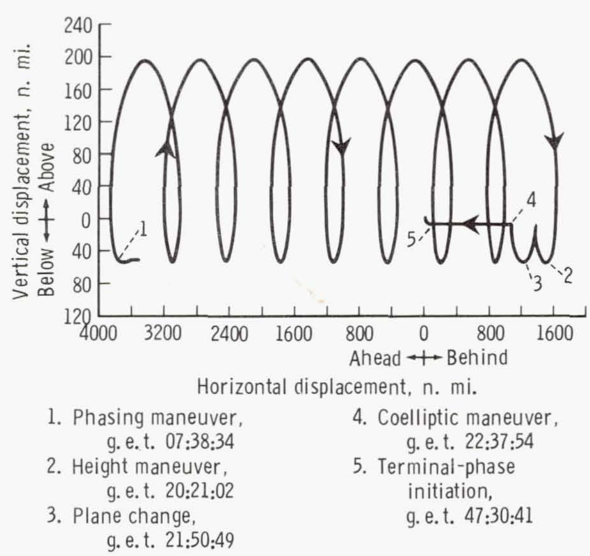

FIGURE 3–3.—Relative trajectory of Gemini X dual rendezvous in target-centered curvilinear coordinate system.

The ground support of the first-orbit rendezvous during the Gemini XI mission (fig. 3–4) was approached in a considerably different manner than during prior rendezvous missions. The only midcourse maneuver scheduled was a plane-change maneuver to account for insertion dispersions. The location of this maneuver was approximately a quarter of a spacecraft revolution after insertion. The major role of the flight controllers for this mission was to evalute the predicted relative conditions at the time of the terminal intercept maneuver, and to give a go—no-go decision for the first-orbit rendezvous. The basis for the go—no-go decision was dependent on the resultant propellant cost for the terminal-phase operations, and on the relative conditions which would preclude the use of onboard backup charts required in the event of degraded systems performance. In addition to providing a go—no-go decision, a contingency maneuver plan was computed in the event that the decision was no-go. This plan was based upon rendezvous in the third revolution.

For the Gemini XII initial rendezvous, the midcourse maneuver sequence was identical to that of the Gemini IX–A mission. The additional complexity involved for this mission included ground evaluation of the onboard-computed plane-change maneuver and the final maneuver to establish the constant altitude differential.

Following the final midcourse maneuver update, the ground provided a backup terminal-phase-initiate maneuver to serve as a comparison between the onboard closed-loop and backup solutions. In addition, supplemental information, such as the variation in altitude differential, was passed to the crew.

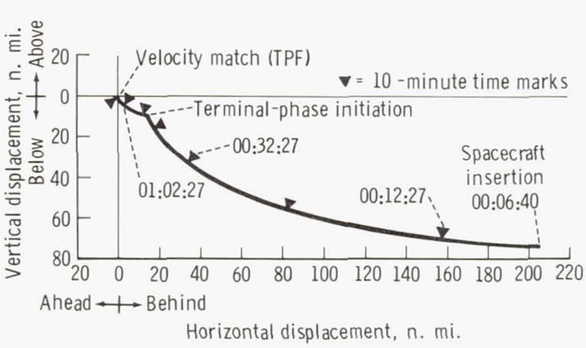

FIGURE 3–4.—Relative trajectory of Gemini XI from insertion to rendezvous in target-vehicle curvilinear coordinate system.

Re-Rendezvous Operations

Three re-rendezvous operations were included in the Gemini Program to increase the rendezvous experience. These exercises investigated such factors as variation in lighting and terminal-approach conditions. The equiperiod re-rendezvous of the Gemini IX–A mission was used to study proposed lighting conditions for the dual rendezvous of Gemini X. The second re-rendezvous of Gemini IX–A investigated a terminal approach from ahead and above the target vehicle in support of future Apollo rendezvous operations. The re-rendezvous of Gemini XI was a totally different technique from any previously flown. The spacecraft was given phasing maneuvers from the ground such that no relative phase rate existed between the two vehicles prior to the intercept maneuver. In this configuration, the spacecraft trailed the target vehicle by approximately 25 nautical miles in the same orbit (fig. 3–5). The vehicles remained in this configuration for approximately 12 hours, at which time a ground-computed intercept maneuver was applied, with the final terminal-phase control performed visually by the crew. This technique was flown to compare the propellant cost with that required for long-term, close-range station keeping.

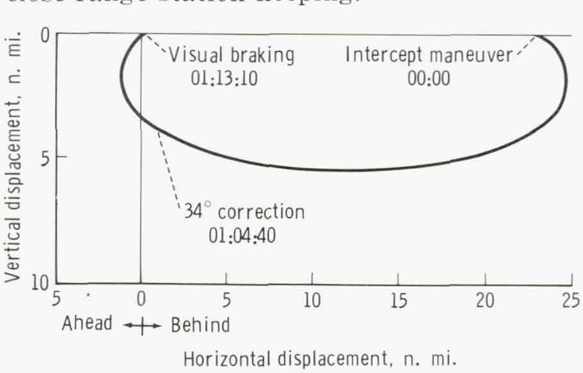

FIGURE 3–5.—Gemini XI stable orbit re-rendezvous.

Flight Results

The effectiveness of the ground-computed midcourse maneuvers can best be evaluated by the propellant required for midcourse maneuvers, and how accurately the conditions for terminal-phase initiation were met. As shown in table 3–II, the lighting conditions obtained were within desired limits; above-nominal midcourse propellant usage was largely due to dispersions in insertion conditions. The variation in altitude differential following the coelliptic maneuver was well within the limits for the use of onboard backup charts on all flights. The ground-computed terminal-phase solutions were consistently in very close agreement with both onboard solutions for all missions.

Gemini Agena Target Vehicle

Prior to spacecraft launch and subsequent rendezvous operations, the Gemini Agena Target Vehicle was monitored and evaluated to insure proper configuration for use as a passive target. Of prime concern, other than total electrical failure, was the verification of insertion into the proper orbit. Any significant error in insertion would require correction by a plane-change maneuver from the target-vehicle propulsion system.

Upon achieving a nominal insertion, complete checkout of vehicle performance and attitude conditioning was accomplished by the target-vehicle flight controllers. This normally consisted of correcting the memory system and configuring the target docking equipment for the rendezvous by real-time commands. The target vehicle was further commanded to an orientation of —90° from the flight path (docking adapter to the north) in order to present a larger target to the spacecraft radar system and to provide a larger target for visual acquisition in sunlight exposure.

From target-vehicle lift-off to spacecraft rendezvous, three major parameters were evaluated to assure a safe target. The propellant-tank differential pressure was of prime concern because a reversal pressure would cause the loss of the target vehicle. The battery temperature was continuously evaluated to predict a rate of change, since the target would be lost if the temperature became excessive. The Attitude Control System pressure was evaluated to assure a nonleak condition which would provide adequate control to preclude vehicle instability and associated unsuitability for docking.

Conclusion

Effective ground support and control has been demonstrated in the successful accomplishment of the rendezvous missions of the Gemini Program. Of key importance in this success was the flexible real-time planning capability which afforded the necessary response to a variety of mission situations.

TABLE 3–II.—*Rendezvous Midcourse Phase Summary*

Gemini mission	Velocity		Variation in terminal-phase initiation time, min [a]	Variation in altitude differential, n. mi.
	Nominal, ft/sec	Actual, ft/sec		
VI–A	117	159	2.1	1.1
VIII	117	150	9.7	1.2
IX–A	126	173	−1.2	.2
X	120	141	−2.2	.9
XI	30	44	.3	—
XII	135	167	5.0	1.3

[a] Positive values indicate late terminal-phase initiations.

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4. ONBOARD OPERATIONS FOR RENDEZVOUS

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Introduction

An overall plan for onboard rendezvous operations for the Gemini missions was developed in parallel with the mission plan. The purpose of this plan was to make optimum use of crew time in orbit to maximize the probability of a successful rendezvous. The evolution of the plan began with a preliminary time line of events based upon the known guidance-equipment requirements and upon the estimated crew timing. A preliminary set of flight charts was developed to aid the crew with primary and backup procedures and to establish a backup guidance capability. These charts, which consisted of a few simple graphs and tabulation sheets, enabled the crew to calculate accurate solutions for the terminal maneuvers even with an inoperative guidance-equipment component. As such, the charts significantly contributed to the probability of mission success. Following the development of the charts, an engineering evaluation was conducted on a realistic man-in-the-loop simulation. During this evaluation, the procedures and charts were subjected to the expected equipment errors and trajectory dispersions, and revisions were made as necessary to improve effectiveness. The resulting plan was presented to the flight crew; the charts were evaluated during a period of training on the simulator. The crew spent several weeks training on both the primary procedures and on the various failure modes.

General Rendezvous Operations

The operation of the guidance system for rendezvous was divided into primary, monitoring, and backup procedures. Primary procedures were the crew tasks necessary to define and execute any given maneuver. Monitoring and backup procedures were used to assess the operation of the system and to complete the mission in contingency situations.

Primary Procedures

The spacecraft onboard operations were broadly categorized into insertion corrections, midcourse or catchup-phase corrections, terminal-phase closed-loop corrections, and braking and line-of-sight control. Since these basic operations were common to most missions, each category is described first as it applies to a general rendezvous mission. Then, the rendezvous operations on specific missions are discussed.

Insertion corrections.—An insertion correction based upon onboard navigation information was computed and displayed to the crew by the Insertion Velocity Adjust Routine (IVAR). This correction was designed to achieve the planned apogee altitude and to eliminate the out-of-plane velocity. Although providing a very early opportunity to reduce trajectory dispersions, the correction could possibly include significant navigation errors; therefore, the application of the maneuver was not always advantageous. For missions with relatively long catchup times, it was usually preferable to omit the correction, or to apply only the in-plane component and then use the ground-tracking information that was available later to determine a more accurate correction. Conversely, when an early rendezvous was desired, both components of the correction were applied,

and a third component was manually computed and applied. This third component was a radial correction based upon a computer readout of downrange travel, and was designed to correct the phasing at first apogee. One of the procedural problems related to the insertion correction was a method for avoiding recontact with the launch vehicle after separation and for applying the Insertion Velocity Adjust Routine maneuver. The problem was resolved by prohibiting a certain band of velocity changes most likely to result in recontact, and by establishing visual contact with the launch vehicle before making retrograde corrections.

Midcourse phase.—The onboard operations required for the catchup phase of a rendezvous mission basically consisted of determining and applying the midcourse maneuvers. Other onboard operations during this phase were routine procedures such as platform alinements and system checks. For most of the rendezvous missions, the midcourse maneuvers were computed by the ground complex and transmitted to the spacecraft. The crew tasks in this case consisted only of achieving the correct attitude and of applying the thrust at the proper time. A typical sequence of catchup maneuvers is shown in figure 4–1.

To demonstrate an onboard navigation capability, the Gemini X mission procedures required the flight crew to compute catchup maneuvers using the onboard orbit determination and prediction capability. The same basic maneuvers were computed as on the earlier four-orbit rendezvous mission, except

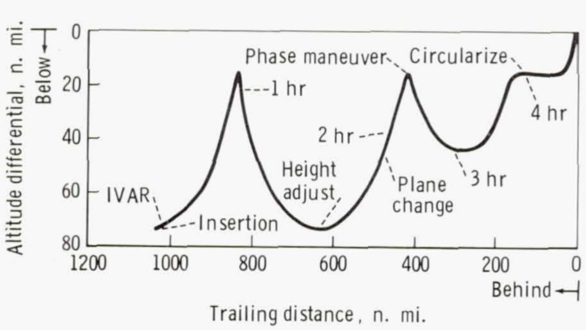

FIGURE 4–1.—Typical midcourse maneuvers.

that the height-adjust maneuver usually performed at second perigee was replaced by an insertion correction. The crew procedures for onboard determination of the midcourse maneuvers involved a sequence of computer and sextant usage. The first maneuver was made at insertion. After this correction, an auxiliary tape memory module containing the mathematical flow for the orbit determination, navigation, and prediction modes of operation was entered into the onboard computer. First, the orbit determination mode was selected and initialized, and a series of star measurements was made and entered into the computer. After processing these data, the computer produced an updated state vector which was used in the orbit prediction mode to predict the spacecraft velocity at the following maneuver point, and the position at the following apogee if no maneuver was made. With the aid of the flight charts, this information was used to predict the desired velocity at the next maneuver point—thus the velocity change. The other maneuvers were determined in a similar manner, and all of the solutions were compared with the corresponding ground computer values. If the differences were within the bounds established before flight, the onboard-determined maneuvers would be applied; if not, the ground-supplied maneuvers would be applied.

Several problems arose in connection with these procedures. For example, a group of star-to-horizon angle measurements from an earlier mission indicated that the apparent altitude of the Earth horizon changed with time, possibly as a result of varying moonlight conditions. These variations were large enough to have a significant effect on the maneuver solutions, and a series of measurements was required to calibrate the horizon. A second problem was the definition of a measurement schedule for orbit determination. The timing, as well as the type and the direction, of the measurements had to be established. Studies revealed that the measurements should be spaced over two darkness periods, and that a variety of directions should be used. The selected schedule con-

sisted of four in-plane and two out-of-plane measurements, but the crew timing requirements and the inaccuracy of the resulting out-of-plane orbit determination led to the decision to use dummy out-of-plane measurements. The effect was that the out-of-plane component of the vector was not updated.

Terminal phase.—The terminal-phase rendezvous operations employed the onboard computer in conjunction with the inertial platform and radar. In the rendezvous mode, the computer gathered radar and platform data, and operated on the data in the sequence outlined in figure 4–2. Initially, data were sampled and stored at a crew-optional fixed-time interval; both 60 and 100 seconds were used. After sufficient data had been stored, an estimate of the total velocity change required for a two-impulse rendezvous transfer was computed and displayed to the crew. The estimate was updated with each succeeding data point for use as an aid in determining the best point to initiate the transfer. The crew initiated the maneuver sequence by depressing the START COMP button on the instrument panel. At this time, the velocity change (in components along the three body axes) for terminal-phase initiation was displayed to the crew, along with the proper attitude for application of the thrust. The maneuver was achieved when the command pilot depressed the maneuver controller until the displayed velocity change counted down to zero. Since equipment and application errors could produce significant dispersions in the resulting transfer trajectory, vernier corrections to the transfer were computed at regular intervals and displayed to the crew. The time of the transfer and the number of vernier corrections were mission-planning options. Generally, based on a trajectory that would result in an intercept in 130° of orbit travel ($\omega t = 130°$), a transfer time of about 30 minutes was selected with two vernier corrections.

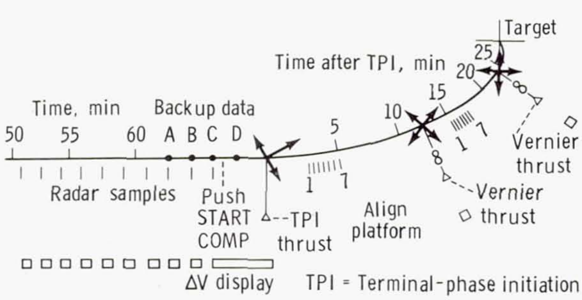

FIGURE 4–2.—Terminal-phase computer sequence.

Braking and line-of-sight control phase.—The braking and line-of-sight control phase which followed the final vernier correction was manually controlled. Simply stated, line-of-sight rate control was achieved by determining the direction of the rate and thrusting normal to the line of sight to null this rate. The direction of the motion could be determined by either of two methods. The first method was to fix the attitude of the target vehicle with respect to a body-fixed reticle. When movement was apparent, thrust was applied radially in the direction of motion. The second method, which could be employed when stars were not visible, made use of the Flight Director Attitude Indicators in an inertial mode. After the command pilot had boresighted on the target, the pilot entered a logic choice into the computer which centered the flight director indicator needles and subsequently deflected them proportionately to spacecraft inertial-attitude changes. The command pilot was then able to hold the attitude that would keep the needles centered, and to observe the target drift with the optical sight. Nulling the target motion was then accomplished in the same manner as the first method.

Monitoring and Backup Techniques

One important crew function during rendezvous was to monitor the performance of the guidance system to assure that the translational maneuvers were accurately computed and applied. Monitoring can be defined as the assessment of guidance-systems operation to the extent necessary for detection and identification of performance degradation in sufficient time for corrective action. During rendezvous, monitoring was accomplished by

sampling basic flight data at specified points in the trajectory, and by calculating with the aid of charts and graphs a solution to each maneuver for comparison with the closed-loop and/or ground solution.

Backup charts.—The data used for monitoring and backup are shown in table 4–I. The use of sensor information varied, depending upon the maneuver to be calculated. A typical case was illustrated by the terminal-phase initiation procedure. The spacecraft attitude was maintained in zero roll and boresighted on the target using the optical sight. This alined the X-axis to the target line of sight. The radar and platform data could then be used to calculate velocity increments ΔV along and normal to the target line of sight. The ΔV along the line of sight was obtained in terms of relative range rate $\dot{R}$ by the equation

$$\Delta \dot{R} = \dot{R}_{REQ} - \dot{R}_{ACT}$$

where

$\Delta \dot{R}$ was the increment in velocity along the target line of sight required to transfer to the desired intercept trajectory

$\dot{R}_{REQ}$ was the range rate of the desired trajectory at the point of data sampling immediately prior to terminal-phase initiation, and was defined by target elevation angle and range for the type trajectory desired

R_{ACT} was the actual range rate at the point of data sampling immediately prior to terminal-phase initiation

A typical terminal-phase trajectory is one which intercepts in 130° of target orbit travel. Figure 4–3 shows the relationship of $\dot{R}_{REQ}$ at terminal-phase initiation with pitch angle θ and range for this transfer. The relationship is nearly independent of the target orbit; thus, figure 4–3 is valid for altitudes within 20 nautical miles of the nominal.

TABLE 4–I.—*Monitoring Data*

Data	Units	Sensor	Display	
			Prime	Backup
Range	0.01 n. mi.	Radar	Manual data unit	Analog gage
Range rate	ft/sec	Radar	Manual data unit	Analog gage
Pitch angle	0.1°	Inertial measuring unit.	Manual data unit	Flight director attitude indicator, stars
Yaw angle	0.1°	Inertial measuring unit.	Manual data unit	Flight director attitude indicator, stars
Roll angle	0.1°	Inertial measuring unit.	Manual data unit	Flight director attitude indicator, stars
Target boresight	0.1°	Optical sight	Visual	—
		Radar	—	Flight director indicators

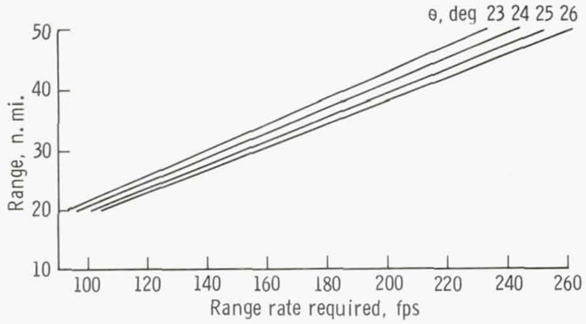

FIGURE 4-3.—Terminal-phase initiation range rate.

The ΔV in-plane, normal to the line-of-sight increment in velocity, defined in terms of line-of-sight angular rate $\dot{\theta}$ and range R by the equation

$$\Delta V_N = (\dot{\theta}_{REQ} - \dot{\theta}_{ACT})R$$

where

ΔV_N was the in-plane, normal to the line-of-sight increment in velocity required to transfer to the desired intercept trajectory

$\dot{\theta}_{REQ}$ was the in-plane line-of-sight angular rate of the desired trajectory at the point of data sampling immediately prior to terminal-phase initiation, and was defined by target elevation for the trajectory desired

$\dot{\theta}_{ACT}$ was the actual line-of-sight rate at the data sampling point immediately prior to terminal-phase initiation

R was range to the target at the measurement point

Since $\dot{\theta}$ could not be measured directly with sufficient accuracy, an increment in θ over a measured time interval was used.

$$\Delta V_N = \left(\dot{\theta}_{REQ} - \frac{\theta_2 - \theta_1}{\Delta t_{12}}\right)R$$

where

θ_1 and θ_2 were target elevation at the beginning and end of the measuring interval, respectively

Δt_{12} was the measurement time interval

For use in flight, the equations for $\Delta\dot{R}$ and ΔV_N were mechanized graphically (fig. 4-4). This chart was part of the onboard data package for Gemini IX-A. The technique used throughout the Gemini Program was to initiate terminal-phase initiation at a reference target elevation angle. This provided a standardized terminal phase in terms of elevation and approach conditions. Crew procedures approaching terminal-phase initiation were to track the target and observe the increase in elevation angle. Pertinent data were recorded on logging sheets at each interval as samples were taken by the computer for the computation of the closed-loop solution for terminal-phase initiation. The reference elevation angle which keyed the terminal-phase initiation sequence was 21.4° for most rendezvous. As the elevation angle approached 21.4°, certain samples were utilized for the terminal-phase initiation monitoring and backup solutions. The significant data points were labeled *A*, *B*, *C*, and *D*, and are defined as follows:

A = Data point immediately prior to 21.4° target elevation

B = First data point after 21.4°; first used to calculate the backup solution

C = Next data point after B; used to initiate the closed-loop sequence for terminal-phase initiation

D = Next point after C; provided the final data for the backup solutions for terminal-phase initiation

Figure 4-4 illustrates the sequence for obtaining a backup solution to terminal-phase initiation. Range and pitch angles were recorded each 100 seconds until θ exceeded 21.4°. This angle was designated point *B* and recorded. After the next sampling point *C*, the START COMP button was depressed to initiate the closed-loop sequence for terminal-phase initiation. Range, range rate, and pitch angle for the second point beyond *B*, point *D*, completed the information needed to calculate the backup solution. The procedures for obtaining the backup solution are as follows:

(1) Boresight on target

(2) Monitor θ, R, and $\dot{R}$ every minute

(3) When $\theta \geq 21.4°$, record data for point *B* on terminal-phase initiation chart

(4) Push START COMP button after next data point

(5) Record data at point *D*

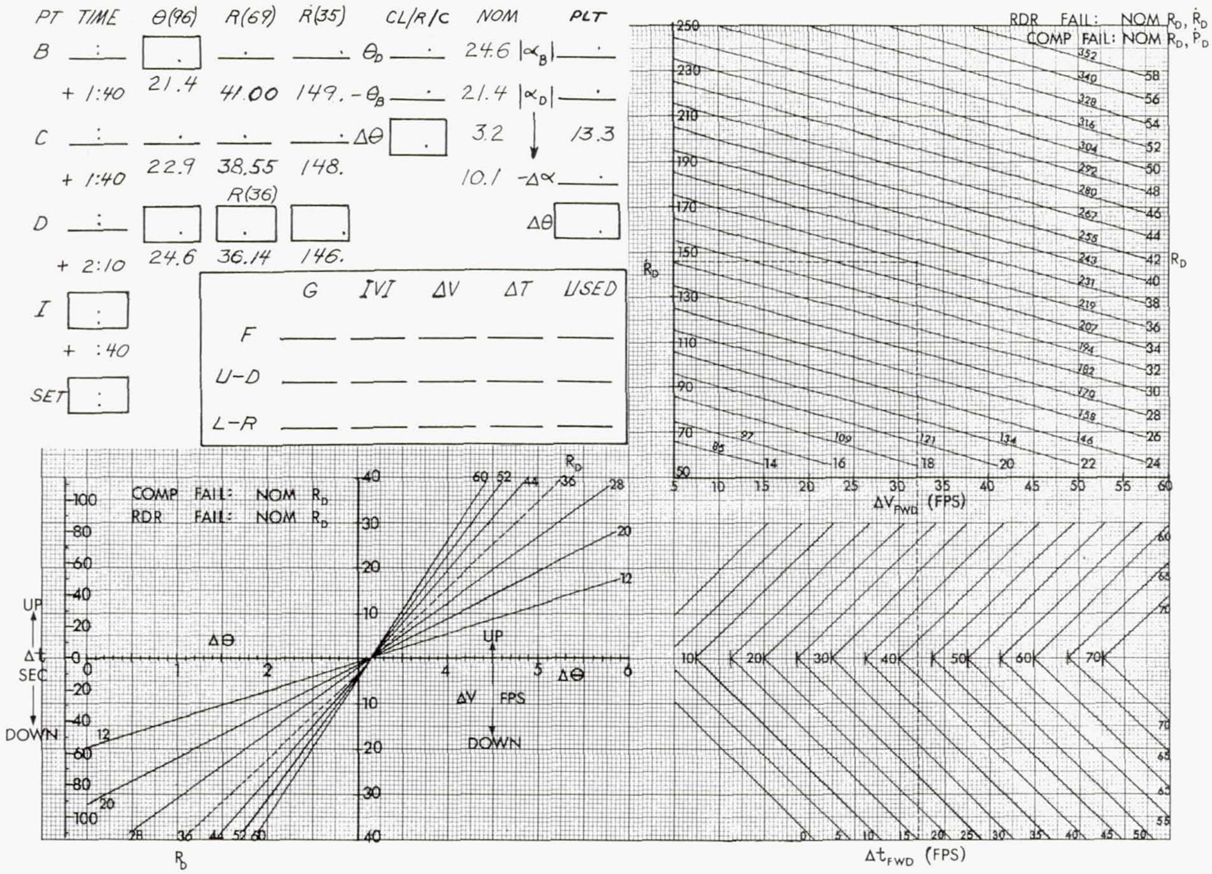

FIGURE 4–4.—Terminal-phase initiation.

(6) Enter terminal-phase initiation chart to calculate $\Delta\dot{R}$, ΔV_N, and terminal-phase initiation time

(7) Compare ΔR and ΔV_N with closed loop and Manned Space Flight Network

A similar technique was used for midcourse corrections except that measurements were triggered on time after terminal-phase initiation rather than on pitch angle.

Failure modes.—Throughout the Gemini Program, manual techniques were utilized wherever practical to maximize the probability of mission success. Thus, the crew was prepared at all times to continue the mission with degraded or failed systems components. This required frequent reference to monitoring data and substitution of alternate sources when failures occurred. The different situations that could exist for all possible combinations of partial and complete failures were too numerous to permit specific training for each. Therefore, procedures were developed only for total failure of each of the three major guidance system components: radar, computer, and platform. Partial failures were then handled by utilizing whatever valid data were available from the degraded component.

For total failure of any guidance component, the closed-loop solution would no longer be available. In this case, it was necessary to rely on the ground or backup solution obtained by alternate methods. For all failures, procedures were designed to obtain a maneuver solution in components along and normal to the target line of sight. Table 4–II summarizes the sensors used for the significant failures. For radar failures, a redundant source of range information was not avail-

TABLE 4–II.—*Failure Modes*

Failure	Forward/aft, ΔV source	Up/down, ΔV source
None	Closed-loop guidance	Closed-loop guidance
Radar	Manned Space Flight Network or nominal	Manual data unit, θ, $\Delta\theta$
Computer	Analog gage, R, $\dot{R}$	Flight director attitude indicator, θ, $\Delta\theta$
Inertial measuring unit	Manual data unit, R, $\dot{R}$	Sextant nominal, θ, stars $\Delta\theta$

able and only up/down maneuvers could usually be calculated on board. One exception was the first-orbit rendezvous on Gemini XI where a terminal-phase initiation correction along the line of sight could be based on the insertion vector obtainable from the Inertial Guidance System. The computer failure case would not cause loss of information in either axis, but would result in less accurate maneuvers because the readout on the Flight Director Attitude Indicator and radar analog gage was less accurate than from the computer readout.

In training, the platform failure proved the most difficult to resolve because accurate attitude angles could not be obtained late in the terminal phase. Fortunately, this failure was not encountered in flight. On most missions subsequent to Gemini VI–A, a handheld sextant was provided for determining time of arrival at terminal-phase initiation in case the Inertial Measuring Unit had failed. The time could be determined by noting the time when the angle between the target and horizon lines of sight corresponded to the planned pitch angle at point *B*. For the platform failure case, the up/down velocity increment for terminal-phase initiation and vernier corrections could be calculated from the change of the target line-of-sight angle as measured against the star background. At the start of an incremental angle measuring interval, the reticle pattern of the optical sight would be fixed against the star background with the target at the top of the reticle. During the measuring interval, the pilot would attempt to maintain the attitude relative to the stars. At the end of the measurement time, noting the position of the target on the reticle provided the delta angle needed for calculating the up/down incremental velocity.

Mission Results

During the Gemini Program, a total of 10 rendezvous was accomplished (table 4–III), providing as broad a spectrum of terminal-phase conditions as possible. On several missions more than one rendezvous was performed. This allowed a rapid development of the rendezvous technology, including problems, tradeoffs, and solutions. The guidance and navigation system proved versatile, as rendezvous plans were shuffled within weeks of launch, and as lessons learned on each mission were incorporated on the next. Since the rendezvous plans and procedures were functions of mission objectives, each type of rendezvous and its characteristics are treated separately in the following paragraphs.

Rendezvous in the Second, Third, and Fourth Orbits

The terminal phase of many of the Gemini mission rendezvous followed a set pattern:

(1) Approach to terminal-phase initiation through a nominally circular catchup orbit, below and behind the target

(2) Time of terminal-phase initiation determined approximately by phasing maneuvers prior to the circular catchup orbit, then fixed precisely by observation of target elevation above the local horizontal

(3) The intercept orbit traveled 130° central angle not including braking

TABLE 4–III.—*Gemini Rendezvous Summary*

Mission	Target	Approach	Separation altitude, n. mi.	Orbit travel, deg
VI–A	Gemini VII spacecraft	Below	15	130
VIII	Gemini VIII target vehicle	Below	15	130
IX–A: Initial rendezvous	Augmented target docking adapter.	Below	12.5	130
No. 1 re–rendezvous		Equiperiod	0	80
No. 2 re–rendezvous		Above	7.5	130
X: Initial rendezvous	Gemini X target vehicle	Below	15	130
Re–rendezvous	Gemini VIII target vehicle	Below	5	80
XI: Initial rendezvous	Gemini XI target vehicle	Below	10	120
Re–rendezvous		Stable orbit	0	292
XII	Gemini XII target vehicle	Below	10	130

(4) Two vernier corrections at fixed times after terminal-phase initiation
(5) An approach from below and slightly ahead of the target through a series of braking maneuvers at fixed ranges along an inertially fixed line

The major variables available for mission planning purposes can be summarized as follows:

(1) Time of terminal-phase initiation
(2) Target elevation angle at terminal-phase initiation
(3) Orbit travel between terminal-phase initiation and terminal-phase finalization
(4) Time between vernier corrections
(5) Braking schedule
(6) Altitude differential between target and spacecraft

The time of terminal-phase initiation was grossly controlled by lift-off time and by phasing maneuvers prior to the circular catchup orbit, with phasing maneuvers determined on the ground. Primary considerations in establishing a time for the terminal-phase initiation were number of phasing orbits desired and sunlight conditions. Three phasing orbits were required for the early flights of Gemini VI–A and VIII. As ground and onboard operations evolved, the number was decreased to two for the later flights, Gemini IX–A and XII. A further decrease in total time to rendezvous required modification of terminal-phase procedures on Gemini XI. Terminal-phase lighting tradeoffs centered around the following:

(1) Target visibility at terminal-phase initiation in reflected sunlight
(2) Availability of stars during braking phase to aid line-of-sight control
(3) Approach to docking in sunlight

These considerations placed the terminal-phase initiation time near sunset with midcourse corrections and line-of-sight control during the night period.

Figure 4–5 depicts the lighting conditions for the typical rendezvous from below the target vehicle. Elevation angles of the target

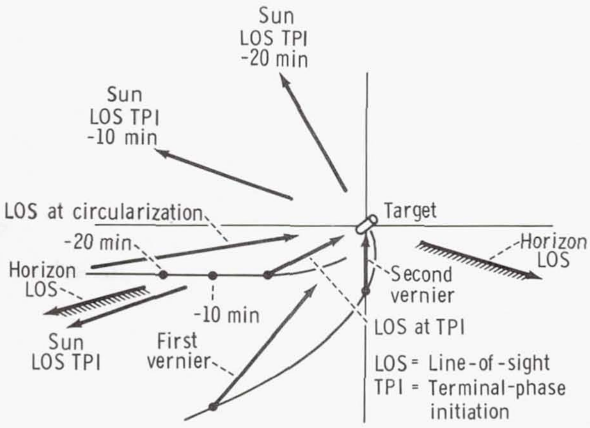

FIGURE 4–5.—Terminal-phase lighting conditions.

vehicle and Sun are shown. With the longitudinal axis of the target vehicle controlled to 90° out of plane, the target vehicle was easily visible in reflected sunlight during the time period when the critical measurements for terminal-phase initiation were made. Thus, the flashing acquisition lights were not relied upon for visual sighting at the longer ranges. As the terminal phase progressed, the Sun elevation and the target line of sight rotated counterclockwise (fig. 4–5). After sunset, motion of the target vehicle in relation to the stars provided confidence in the trajectory status. After the last vernier correction, the star field was also useful for maintaining the collision course. With the terminal-phase initiation near sunset, the spacecraft would pass the last braking gate at a range of 3000 feet at sunrise. The target, in perspective, indicated approach angle and closing velocity.

Careful selection of the orbital travel from terminal-phase initiation to terminal-phase finalization and the target elevation at terminal-phase initiation provided an approach that had a line-of-sight angular rate of nearly zero and terminal-phase initiation maneuver along the line of sight. The small line-of-sight drift rate after the last vernier correction assisted the crew in maintaining a simple and efficient collision course which helped to minimize propellant usage. The spacecraft roll axis was boresighted on the target throughout the terminal phase. Selecting a trajectory for which the terminal-phase initiation angle coincided with the target elevation angle allowed the maneuver to be performed nominally along the roll axis with no attitude deviation. Dispersions in the catchup orbit and guidance system errors appeared at terminal-phase initiation as maneuver components normal to the line of sight, and as deviations from the planned forward impulse. Table 4–IV summarizes the terminal-phase initiation and the midcourse maneuvers for

TABLE 4–IV.—*Terminal-Phase Maneuver Summary*

Mission	Closed-loop guidance and applied maneuvers[a]									
	Terminal-phase initiation, fps				1st vernier, fps			2d vernier, fps		
	Nominal, forward	Actual, forward	Up, down	Right, left	Forward, aft	Up, down	Right, left	Forward, aft	Up, down	Right, left
VI–A	32	31	4U	1R	7F	7U	5L	4F	3U	6R
VIII	32	25	3U	8R	12F	6U	1R	4F	7U	3R
IX–A	27	(27)	(1U)	(2R)	2A	2U	3R	3F	2D	0R
		26	8U	4R						
X	32	41	(0U)	(0L)	15A	(14D)	1R	(0F)	25D	5R
			1U	16L		22D		1F		
XII	22	(22)	(0U)	(0R)	(0F)	(2U)	(0R)	(5A)	(1D)	(0R)

[a] Parentheses indicate applied maneuvers when different from closed-loop solutions.

the Gemini IV, VIII, IX–A, X, and XII missions. The times of vernier corrections were selected to be compatible with crew loading and the anticipated accuracy of the guidance system. Vernier corrections 12 and 24 minutes after terminal-phase initiation allowed sufficient time for crew activities, such as system monitoring and platform alinement where necessary, but were close enough to prevent appreciable trajectory divergence.

The relatively low deceleration capability of the Gemini spacecraft (approximately 1 ft/sec^2) dictated that closing velocity be reduced in several stages to enable the crew to devote proper attention to line-of-sight control. Early training simulations indicated that braking to a maximum closing rate of 40 ft/sec at a range of 2.5 nautical miles, and then down to 5 to 10 ft/sec at a range of 0.5 nautical mile, represented a simple and efficient schedule.

The separation altitude selection was a tradeoff between total propellant and sensitivity of time of arrival at terminal-phase initiation to dispersions in the catchup orbit. As previously discussed, there were advantages to certain sunlighting conditions during the terminal phase; and for a given error in the catchup orbit, the dispersion in arrival time decreased as separation altitude increased. However, propellant requirements for the terminal phase increased in proportion to differential altitude. (An altitude differential of 15 nautical miles was selected for Gemini VI–A.) As knowledge of lighting conditions was gained, and as the capability for ground tracking evolved, the altitude differential was varied (table 4–III).

Rendezvous in the First Orbit

The first-orbit rendezvous accomplished during the Gemini XI mission was more demanding of onboard operations than previous rendezvous missions. The previous missions utilized several orbits of ground tracking and computation to eliminate the effects of insertion dispersions on the terminal-approach trajectory. Because of the very short time available for the first-orbit rendezvous mission, the multiorbit midcourse corrections and circular catchup orbit could not be used. As a result, the flight plan included onboard operations capable of absorbing the expected insertion dispersions in a relatively short time. The trajectory plan selected for the first-orbit rendezvous had a terminal approach similar to the approach employed on the coelliptical rendezvous missions. However, it appeared that insertion dispersions would radically affect this approach as shown in figure 4–6. Terminal-phase initiation occurred near the first spacecraft apogee with a 120° central angle of transfer.

In providing a capability for absorbing the insertion dispersions, several procedural methods were required which were not employed on previous missions. At insertion, the horizontal and out-of-plane velocity changes were planned as usual. These corrections, however, did not remove the trailing displacement error at first spacecraft apogee resulting from downrange and flight-path angle errors at insertion. This error could have had a serious effect on the terminal-approach trajectory; to reduce the error, the pilot read (from the computer) the navigated downrange angle traveled at insertion. From this angle, a required value of altitude rate was determined and compared with the

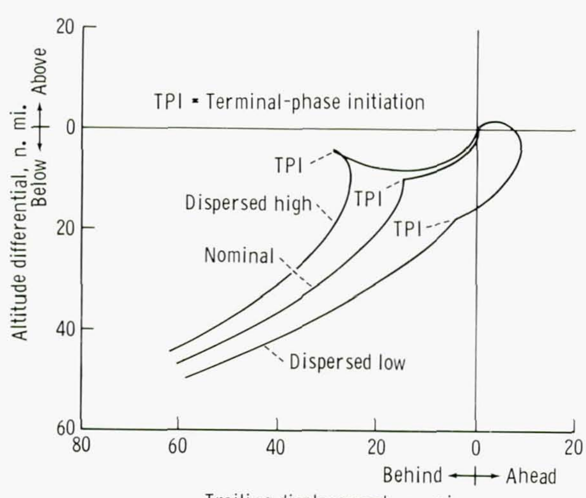

FIGURE 4–6.—First-orbit rendezvous trajectory.

actual altitude rate read from the computer. The velocity difference was applied along the local vertical to achieve an altitude rate resulting in the desired trailing displacement at the terminal-phase initiation point. Although this correction required split-second timing on the part of the crew, it was very effective.

The second onboard-computed maneuver was an out-of-plane correction to be performed 90° after insertion. Since the maneuver at insertion was to eliminate the out-of-plane velocity at that point, the node occurred 90° of orbit travel later. By observing the out-of-plane displacement at insertion, the pilot computed the required maneuver. At the expected time of the node, the correction was applied.

Although the primary procedures for the terminal phase of the first-orbit rendezvous were similar to the procedures for previous rendezvous missions, the effect on the larger terminal-phase dispersions had a significant impact on the design of the backup and the monitoring procedures. The backup procedures utilized measurements of range and line-of-sight angle changes over a fixed time interval. These measurements were used with flight charts to determine the velocity changes and the relative position of the spacecraft at the time of the terminal-phase initiation maneuver. Gemini XI was the first mission to utilize a backup capability for an out-of-plane correction at terminal-phase initiation. The correction reduced the dispersions caused by navigation errors during the earlier corrections.

Two vernier corrections were scheduled at 12-minute intervals during the terminal transfer. The backup computation of these maneuvers was significantly different than for previous missions because the variation from the planned position of the spacecraft at terminal-phase initiation was taken into account. For example, with a radar failure, the earlier charts assumed a planned range in computing the correction instead of using a predicted range based upon the actual spacecraft position at terminal-phase initiation. The use of predicted values provided better accuracy for large dispersions. Table 4–V is a summary of the maneuvers for the first-orbit rendezvous.

Rendezvous From Above the Target Vehicle

A re-rendezvous was conducted on the Gemini IX–A mission to simulate the trajectory of a Lunar Module following abort during powered descent. The trajectory was similar to that utilized on the fourth-orbit rendezvous mission except that the spacecraft approached the target from ahead and above. The procedures for rendezvous from above were very similar to the procedures for a fourth-orbit rendezvous; the only significant differences were in the backup measurements used in the event of a platform failure. Since the spacecraft approached the target from above, there was no star background during the terminal phase. As a result, the hand-held sextant would have been used to make angle measurements with respect to the Earth horizon. These measurements, like those with respect to the star background, required visual acquisition of the target.

A significant lesson was learned from the rendezvous from above; the terminal-phase

TABLE 4–V.—*Gemini XI Rendezvous Maneuvers*

Insertion Velocity Adjust Routine ΔV, fps	Plane change ΔV, fps	Terminal-phase initiation ΔV, fps	1st vernier ΔV, fps	2d vernier ΔV, fps
39 forward	0	140 forward	1 forward	1 forward
5 down	0	27 down	4 up	3 up
1 left	3 left	5 left	4 right	11 right

lighting conditions were more critical than for rendezvous from below. During the early Gemini IX–A mission planning, it was decided that terminal-phase initiation should occur after sunset so that the flashing lights on the target vehicle could be used for visually acquiring the vehicle against the dark Earth background. It was believed that sunset was preferable to an early morning terminal-phase initiation, with acquisition using reflected sunlight (over-the-shoulder lighting) because of the bright Earth background. However, during the Gemini IX–A flight, the nose shroud on the target vehicle (Augmented Target Docking Adapter) did not completely separate, and it was believed that the acquisition lights located in the shroud region might not be visible. The time of terminal-phase initiation was then changed from after darkness to early morning to permit reflected light viewing. Actually, the target was not visible at long range against the bright Earth background, and could not be tracked visually until the range had decreased to 3 nautical miles. If the radar had failed during this exercise, terminal-phase corrections would not have been possible. Furthermore, the rapidly moving terrain background made control of the line of sight more difficult than with a star field or even with a dark Earth. This experience demonstrated the importance of terminal-phase lighting, and pointed out the value of the flashing acquisition lights as a backup to the radar for target tracking. A summary of the terminal-phase maneuvers for the rendezvous from above is shown in table 4–VI.

TABLE 4–VI.—*Terminal-Phase Maneuvers for Rendezvous from Above*

Terminal-phase initiation ΔV, fps	1st vernier ΔV, fps	2d vernier ΔV, fps
19 forward 4 down 2 left	4 aft 1 up 5 left	2 forward 10 down 7 right

Rendezvous With a Passive Target

After the initial rendezvous on Gemini X, an exercise was undertaken to intercept the passive target vehicle that had been in orbit since the Gemini VIII mission. This rendezvous with a completely passive target presented several unique problems, and was more demanding of the crew than any other terminal phase. For the exercise, there was no closed-loop guidance and no radar or acquisition lights; the terminal-phase maneuvers had to be based on backup charts and observation of the target in reflected sunlight. Approximately 27 minutes of favorable lighting time were available in each orbit (from about spacecraft noon until sunset), and the entire terminal phase, including arrival dispersions, braking, and stabilizing position for formation flight through the night period, had to take place within about 108° of orbit travel. Position was maintained after darkness using the docking light on the spacecraft as a source of illumination. The light had a cone angle of about 6° and was effective up to a distance of 300 feet. The short period of visibility indicated that orbit travel between the initiation and the finalization of the terminal phase would have to be reduced considerably from the 130° used on previous rendezvous. An orbit travel of 80° and a differential altitude of 7 nautical miles were selected. The terminal-phase trajectory is shown in figure 4–7. This combination had several advantages in addition to a

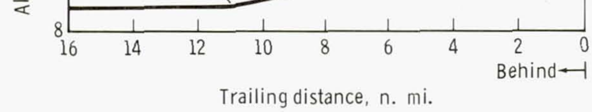

FIGURE 4–7.—Passive target rendezvous trajectory.

short terminal phase. The 80° orbit travel intercept was a relatively high-energy transfer trajectory and, therefore, was less sensitive to initial-condition dispersions and errors in maneuvers. This was particularly significant because no vernier corrections could be calculated along the line of sight without radar information. Second, the reduced differential altitude assisted visual acquisition and, combined with the 80° terminal phase, resulted in closing rates about the same level as the 130° intercept with 15-nautical-mile separation. Thus, similar braking schedules could be used on both rendezvous planned for the mission. The time factor was extremely critical during the braking maneuver; at sunset, all visual contact would suddenly be lost beyond the range of the docking light. Because of the time-critical nature of the exercise, the flight charts included the capability to perform terminal-phase initiation for a range of elevation angles covering a time period of 10 minutes on either side of the nominal. The plan was based upon the nominal elevation angle being used if terminal-phase initiation occurred between visual acquisition and 25 minutes before sunset. A solution was sent from the ground in case visual acquisition occurred too late for an onboard solution.

Stable Orbit Rendezvous

During the Gemini XI flight, a small posigrade separation maneuver was made, followed later by a retrograde maneuver of the same magnitude. The purpose of these ground-computed maneuvers was to establish a trailing position about 25 nautical miles behind the target vehicle and in the same orbit. This location enabled the crew to perform experiments and to sleep while maintaining a position for a simple, economical re-rendezvous. Since the re-rendezvous was initiated from a point in equilibrium relative to the target, the plan was called the Stable Orbit Plan. The maneuver to transfer from the stable orbit to an intercept trajectory was sent from the ground, and was based on the ground track of the spacecraft during the crew sleep period. A terminal-phase trajectory covering 292° was selected, resulting in an elevation time history identical to the familiar 130° transfer. Thus, the backup charts from a previous mission could be used for trajectory monitoring. The radar was not operative during this exercise; therefore, onboard corrections along the line of sight were not possible. However, an up/down vernier correction of zero was calculated, which agreed with the up/down component of the ground solution. The ground-computed maneuver was applied, and braking was accomplished while tracking the target vehicle in reflected sunlight.

Conclusions

The Gemini experience has led to a number of significant conclusions with respect to onboard rendezvous operations.

(1) The extensive participation of the flight crew in rendezvous operations is feasible. They are capable of directing the primary operations of the guidance system and of performing certain phases of the mission without the guidance system. In addition, they can detect and identify system malfunctions and take action to assure the success of the mission.

(2) The crew can monitor the performance of the guidance and navigation system, and determine and accomplish all rendezvous maneuvers with the following basic flight information: (*a*) range to the target, (*b*) range rate, (*c*) body-attitude angles measured from horizontal in-plane references, and (*d*) means for tracking the target (visual or radar).

(3) Flight charts can be developed which provide the crew with the ability to compute solutions for the terminal maneuvers in spite of an inoperative guidance-equipment component. These charts can be made simple to use and can provide accuracies comparable to the primary system.

(4) The onboard operations can be simplified by the proper selection of approach tra-

jectories and lighting conditions. A terminal approach is desirable, which is insensitive to trajectory dispersions and equipment errors. The lighting conditions determine the visibility of the target vehicle and the star background, thus affecting backup procedures.

(5) Visibility through the spacecraft window is an important consideration in terminal-phase rendezvous operations. Visual tracking of the target is a backup to the radar, and the star background is a valuable aid for maintaining a collision course in the braking phase.

(6) A comprehensive program of procedural planning, evaluation, and training is necessary to the success of the mission. Man-in-the-loop simulation is an important part of crew training.

5. OPERATIONAL CHARACTERISTICS OF THE DOCKED CONFIGURATION

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Introduction

In addition to a successful rendezvous between the Gemini spacecraft and the target vehicle, one of the primary objectives of the Gemini Program was to accomplish a docking maneuver to join the two vehicles as a single spacecraft configuration. The next objective was to evaluate the characteristics of the control system on each vehicle in controlling the combined vehicle. A further goal was the use of the Primary Propulsion System of the target vehicle to enlarge the manned spacecraft maneuvering capability. These objectives were all determined feasible, and this paper will describe the implementation of the plan and the achievement of the successful results.

Development of the Docking System

The initial effort in the development of the Gemini docking system was the evaluation of the numerous classical concepts and also of the designs generated during the various studies (fig. 5–1). Each concept raised new questions which had to be studied and resolved. Should the vehicles come together on a collision course or a noncollision course? Should the front end or aft end of the spacecraft be joined to the target vehicle? What differential velocities, mismatch angles, and distances should be considered? How could structural continuity, capable of withstanding orbital maneuvering dynamics, be achieved? How should the propulsion system on the target vehicle be controlled? How could positive separation of the spacecraft from the target vehicle be guaranteed? How could remotely actuated structural attachments be provided on the spacecraft without disturbing the reentry heat-protection configuration?

By systematic evaluation, it was concluded that the docking maneuver must be made with the spacecraft facing the target vehicle, so that the flight crew could adequately control the differential impact velocities and attitudes. This was not the best configuration for orbital maneuvering because of the backward acceleration of the crew, and because the structural arrangement was stress limited in the middle. However, these consid-

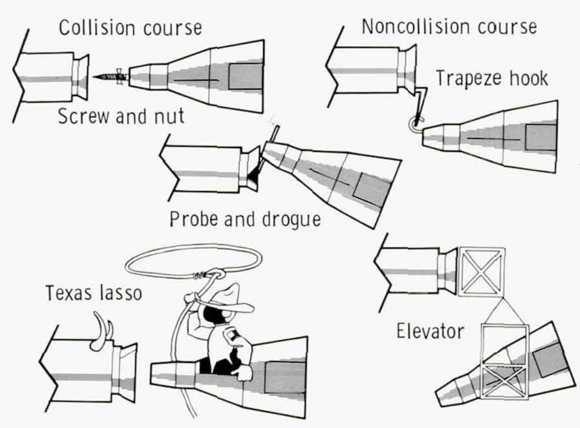

FIGURE 5–1.—Gemini docking concepts.

erations were secondary when compared with the advantage gained by providing a full view of the target vehicle prior to and after docking. With this advantage, impact velocities and attitudes became reasonable values and were determined through simulation exercises. Also, implementation of all target-vehicle control and status display and electrical disconnects was simplified; however, the structural mechanical attachment was somewhat more complicated because of limited bending stiffness.

The evolution from concept to design and the analysis of results from further simulations resulted in the following design criteria: closing velocity of 1.5 ft/sec, angular misalinement of 10°, and centerline displacement of 1 foot with the requirement for multiple docking capability.

Target Docking Adapter

A general arrangement of the selected configuration is shown in figure 5–2. The selected collision-course maneuver was similar to a jet pilot's experience in refueling operations, was the simplest design approach, and was acceptable from a control and safety standpoint. For similar reasons, the probe and drogue design was chosen and a docking bar was installed to provide the indexing feature. The electrical and the primary mechanical power devices were installed on the target vehicle because this vehicle was less weight critical than was the spacecraft.

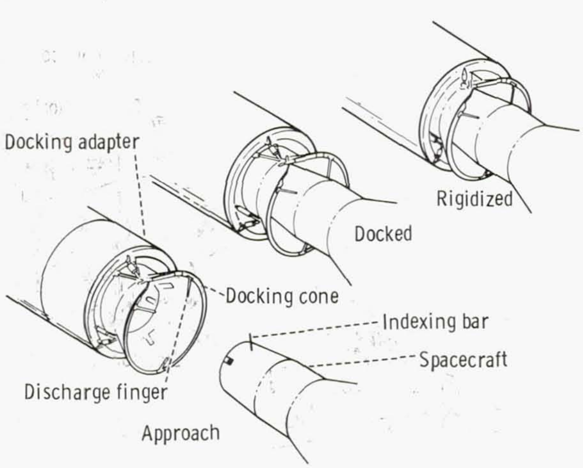

FIGURE 5–2.—Docking and rigidizing sequence.

The prime contractor for the spacecraft was selected to manufacture the docking adapter to be mounted on the target vehicle. An interface plane was chosen so that the adapter contained all equipment directly associated with docking. Only electric power, telemetry data, and command system signals crossed the interface. A simple butt joint, consisting of mating skin-former angles and tension bolts, provided easy attachment of the docking adapter to the target vehicle.

The final docking approach (fig. 5–2) was entirely visual, with the target vehicle powered up and stabilized. Visual cues were provided to indicate the status of the target vehicle for nighttime as well as daylight docking. Docking was accomplished when three latches in the target-vehicle docking cone engaged corresponding fittings on the spacecraft. Engagement of the latches completed a circuit that automatically secured the cone against the rigid structure; this was the rigidized mode. Undocking was the reverse of this procedure, with provisions for emergency undocking furnished by pyrotechnic devices which would dislodge the three spacecraft fittings.

Figure 5–3 shows some of the major components of the Target Docking Adapter. Seven dampers were clustered at three locations and damped relative motion in all three axes; they also returned the cone to the ready configuration. A small electric motor provided the power to retract the cone by means of a torsion cable drive to three-gear motors which operated the overcenter bellcrank and linkage devices. Final motion caused the latches to close down on the spacecraft fittings, effecting a rigid connection. Undocking was simply a reversal of this sequence. Some of the other major components were the target-vehicle status display indicators, acquisition lights, and spiral and dipole antennas.

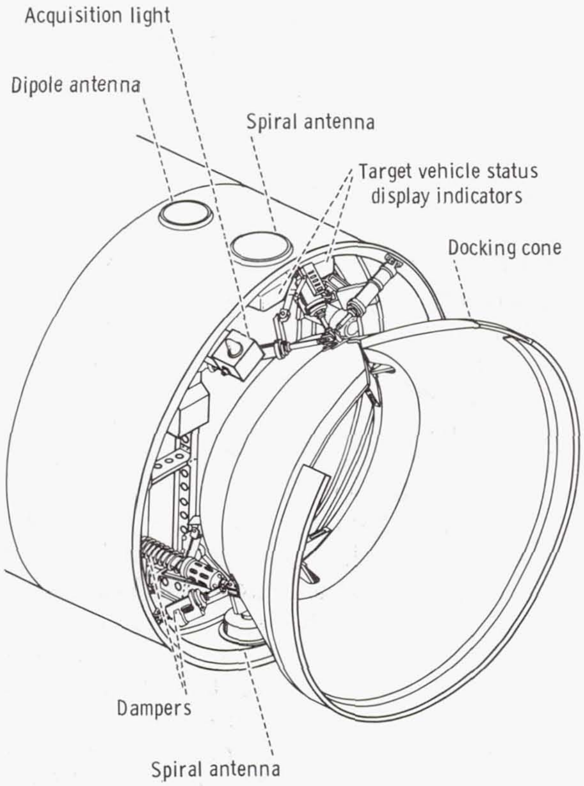

FIGURE 5-3.—Target Docking Adapter assembly.

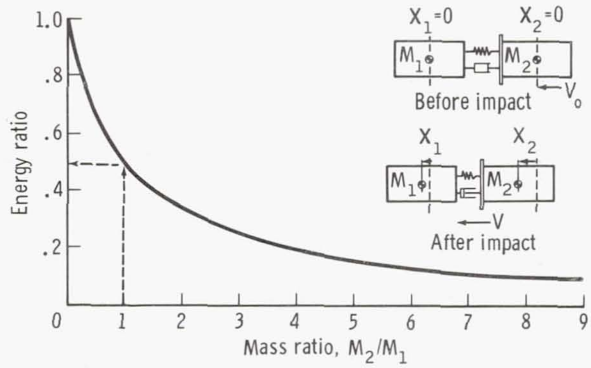

FIGURE 5-4.—Two-degree-of-freedom energy requirements.

Characteristics of the Docking System

The basic characteristics of the docking system were determined with a simple 2-degree-of-freedom model (fig. 5-4). By applying the conservation of momentum and energy laws, the energy absorbed by the docking system to provide for an inelastic impact is shown to be

$$T = \frac{1}{1+M_2/M_1} T_0 \quad (1)$$

where

$$T_0 = \frac{1}{2} M_2 V_0^2$$

and V_0 is the initial relative velocity between vehicles, M_2 is the spacecraft mass, and M_1 is the target-vehicle mass. Roughly, the ratio of masses for spacecraft and target vehicle is 1; therefore, about half of the kinetic energy associated with the relative motion of the vehicles must be absorbed. For a typical closing velocity of 0.5 ft/sec, the system would absorb only about 15 ft-lb of energy.

The 2-degree-of-freedom model also determined the type of shock absorbers that should be used. The following design objectives were utilized: (1) minimum peak load, (2) minimum rebound characteristics, (3) reusability, and (4) maximum reliability. Consequently, the longitudinal members consisted of a spring for reusability and reliability, and of an orifice damper in parallel. The spring and the instroke orifice sizes were matched to produce minimum peak load on the instroke. On the outstroke, the damper fluid was metered through a much smaller orifice which minimized rebound. Since the longitudinal springs were sufficient to return the docking cone to the extended position, springs were not necessary in the lateral members.

After the basic design of the shock absorber had been determined, the analytical study was extended to include all the 8 degrees of freedom of a pitch-plane rigid-body system, consistent with the constraint of the spacecraft being in contact with the target-vehicle docking cone. The 8 degrees of freedom included the following:

(1) Target-vehicle horizontal translation, vertical translation, and pitch

(2) Docking-cone horizontal translation, vertical translation, and pitch

(3) Spacecraft pitch and translation along the surface of the docking cone

Initially, no control-system effects were included. This model permitted detailed investigation of the forces and motions which occurred during free docking.

Figure 5–5 presents a set of typical response parameters plotted against time for the case of the spacecraft impacting the docking cone with a horizontal relative-velocity component of 1.5 ft/sec and a vertical relative-velocity component of 0.5 ft/sec, the design-limit velocities. The initial point of impact at time 0 is near the leading edge of the top inner surface of the docking cone, 26 inches along the docking-cone surface from the latch plane. The motion of the spacecraft leading edge down the cone surface to the latch plane is represented by the curve labeled *D*. The force *F* between vehicles varies from a peak of nearly 300 pounds for this case, to a small grazing value after about 0.4 second. The figure also shows the inertial angular rates produced by *F* for each vehicle; these rates were initially zero. At about 1.5 seconds the spacecraft reaches the base of the docking cone, and the mathematical model no longer applies. The impact essentially has 2-degree-of-freedom characteristics after this point. The damper strokes are not shown on the figure but are available from the program. The maximum single-point contact load between the vehicles was determined to be approximately 800 pounds, and occurred when the spacecraft impacted on the bottom side of the docking cone approximately 1 foot from the latch plane.

Figure 5–6 shows the effect of having the stabilization systems of both vehicles on during docking. This case has the same initial conditions as the previous case when the stabilization systems were off. The main difference in vehicle response between the two cases is that the spacecraft attitude rate is now reduced to the 0.2 deg/sec deadband level instead of maintaining the 3.5 deg/sec level shown in figure 5–5. The target vehicle, on the other hand, acquires a slightly higher attitude rate with the systems on. The higher rate occurs because the spacecraft system is the more powerful and, in stabilizing the spacecraft, it overpowers the stabilization attempts of the target-vehicle system. Consequently, by the time the spacecraft reaches the latch plane, larger angular eccentricities between the vehicles result with the stabilization systems on rather than off and assuming the same errors at initial contact. This becomes less important when the ease with which the pilot can control initial errors in

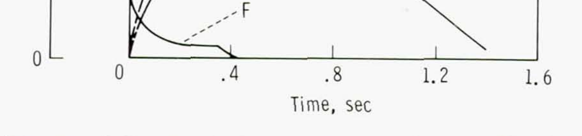

FIGURE 5–5.—Typical response with stabilization systems off. Initial conditions: horizontal velocity = 1.5 ft/sec; vertical velocity = 0.5 ft/sec; *D* = distance traveled by spacecraft leading edge along the docking cone; Θ_G = spacecraft inertial angular rate; Θ_A = target-vehicle inertial angular rate; *F* = force between the spacecraft and target vehicle.

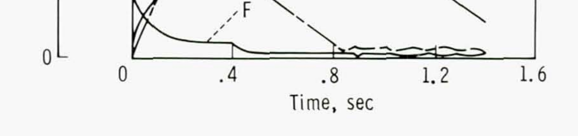

FIGURE 5–6.—Typical response with stabilization systems on. Initial conditions: horizontal velocity = 1.5 ft/sec; vertical velocity = 0.5 ft/sec; *D* = distance traveled by spacecraft leading edge along the docking cone; Θ_G = spacecraft inertial angular rate; Θ_A = target-vehicle inertial angular rate; *F* = force between the spacecraft and target vehicle.

the stabilized mode is compared with the unstabilized mode. Simulator training showed better pilot control when docking in the spacecraft rate-damping mode (the stabilized case) than in the direct mode (the unstabilized case).

While the 8-degree-of-freedom study was being made, a docking test was conducted with a ¼-scale dynamic model. The objectives were to confirm the design of the docking system by providing the following information:

(1) Stability of the shock-absorbing modes

(2) Maximum loads in shock-absorbing system components

(3) Time histories of the accelerations of each vehicle in all rigid-body 6 degrees of freedom

(4) Angular and linear misalinement limiting values for latching the two vehicles

(5) Adequacy of the proposed spring and damper characteristics of the shock-absorbing system

(6) Adequacy of the mathematical model used in the analytical studies

Each vehicle was represented by a ¼-scale model with a rigid-body mass and moment-of-inertia simulation. Other scale factors used in designing the models are listed in table 5–I.

The kinematics of the model's shock-attenuation system closely duplicated the kinematics of the full-scale system, and the springs and dampers were dynamically scaled. The docking-cone surface was coated with the same dry-film lubricant planned for use on the full-scale system; similarly, the leading edge of the Rendezvous and Recovery Section of the spacecraft model was covered with a layer of fiber glass.

Each model was supported at the center of gravity by a low-friction gimbal device suspended by a 30-foot cable from a zero spring-rate mechanism. The device provided each model with the rigid-body 6 degrees of freedom required for simulating the orbital condition.

TABLE 5–I.—*Docking Model Scale Factors*

Parameter	Scale factor, model/prototype
Assigned:	
Length	1/4
Time	1/4
Mass	1/100
Derived:	
Velocity	1/1
Acceleration	4/1
Spring rate	4/25
Kinetic friction	1/25
Preload force	1/25
Moment of inertia	1/1600
Angular velocity	4/1
Angular acceleration	16/1
Velocity-squared damp constant.	1/25

The tests confirmed the docking-system design in every aspect. The 8-degree-of-freedom analytical model was verified. This was desirable before the equations of motion were extended to include the stabilization systems of the vehicles, since a model test with active stabilization systems was not practical. The test indicated that angular eccentricities between the vehicles of about 5° at the latch plane would permit automatic latch.

The final development test of the docking system was a full-scale test using a Target Docking Adapter and a spacecraft Rendezvous and Recovery Section of the normal production configurations. The test setup was similar to the ¼-scale test except that zero spring-rate suspension mechanisms were not used. Each vehicle was suspended as a simple pendulum 57 feet in length, the maximum working height available. Also, the Target Docking Adapter contained an operational rigidizing mechanism which automatically actuated when all three docking-cone latches engaged the spacecraft. All systems performed satisfactorily during the test and favorably agreed with previous analytical and ¼-scale-model studies.

Design Considerations for Maneuvering the Docked Vehicle

During maneuvers, the critical loading condition on the docked vehicle was the bending moment at the spacecraft/target-vehicle latch joint. Two separate conditions produced design-limit loads. The first was the target-vehicle Primary Propulsion System engine performing a hard-over gimbal motion and remaining in the hard-over position. This malfunction produced the maximum bending moment at the latch joint, 117 500 inch-pounds. The bending moment, combined with the associated axial load of 11 000 pounds due to engine thrust, defined the design-limit load for the compression load paths of the docking-adapter structure and also for some stringer structure in the spacecraft Rendezvous and Recovery Section.

The second design condition resulted from terminating the Primary Propulsion System thrust at various times after initiation of the hard-over movement, and then determining the thrust termination time that yielded maximum bending at the latch joint with thrust completely terminated. The maximum bending moment (97 000 inch-pounds) with no accompanying axial load defined the design-limit load for the tension linkages in the mooring structure.

Using the test setup shown in figure 5–7, the Target Docking Adapter and the spacecraft Rendezvous and Recovery Section were qualified for ultimate load levels corresponding to the limit loads previously described. Instead of the usual 1.36 factor of safety for defining ultimate loads from limit loads, a factor of 1.5 was employed to account for the possible use of heavier spacecraft later in the Gemini Program.

A bending moment was applied in increments from 10 percent to ultimate about the horizontal axis, so that the bottom docking latch was placed in tension; no axial load was applied. The loading qualified the tension linkages in the docking-adapter mooring structure.

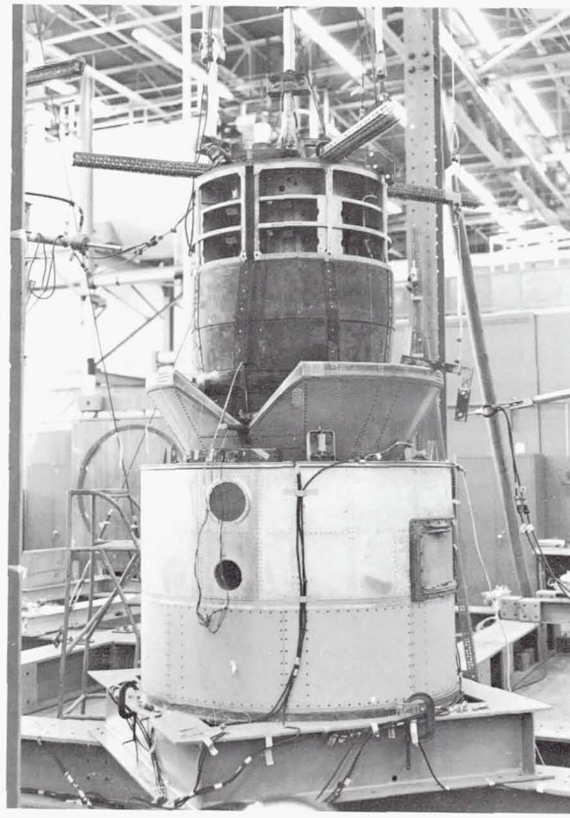

FIGURE 5–7.—Maneuvering loads qualification test.

Starting from zero loading, limit axial and shear loads were applied. Limit bending moment was applied, in increments of 10 percent, about the horizontal axis to place the bottom docking fitting in compression. The axial and shear loads were then increased to ultimate levels. Finally, the bending moment was increased to failure. Failure, in the form of buckling of two stringers adjacent to the bottom docking fitting on the spacecraft Rendezvous and Recovery Section, occurred at 227 percent of limit bending moment. This loading qualified the compression load paths of the Target Docking Adapter and the Rendezvous and Recovery Section.

Considering that the Gemini spacecraft would be a rather awkward payload for an Agena, it was reasonable to expect that the original Agena control system might be unsatisfactory. Based upon an initial estimate of 5 cycles per second for the first body bend-

ing frequency of the moored configuration, stability studies indicated that an inadequate gain margin existed in this mode. The Agena autopilot system was modified by adding a 5-cycle-per-second attenuation filter to the electrical compensation networks. Later estimates, however, indicated that the actual first bending frequency was considerably lower than the estimated 5 cycles per second and was closer to 3 cycles per second. This seriously affected the performance of the newly designed control system.

As shown in figure 5–8, the new control system failed to provide a minimum desirable gain margin of 6-dB and 25° phase margin in the dominant rigid-body mode for the applicable damping values of the first bending mode of the system. As computed here, gain margin is 10 times the common logarithm of the ratio of the upper critical gain to the lower; that is, a ratio of 4 gives 6 dB. The upper critical gain corresponded to instability of the first bending mode, and the lower gain corresponded to rigid-body instability. The dashed portions of the figure are extrapolated values obtained from the actual damping regime that was studied. To improve the gain margin available, the control system was modified by altering the configuration of the lead-lag network to accommodate the 3-cycle-per-second first bending frequency. The gain margins were significantly increased.

To determine the structural dynamic characteristics of the docked configuration, a

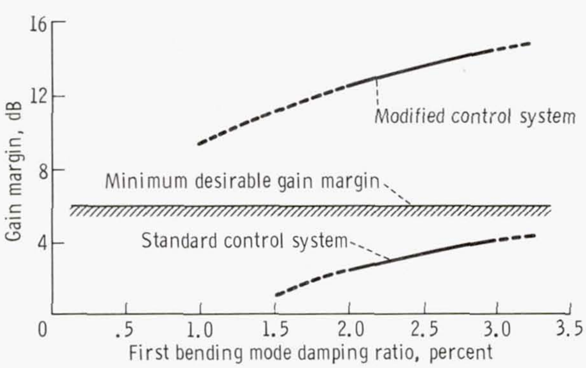

FIGURE 5–8.—Primary Propulsion System stability study.

ground vibration test was conducted using the test setup shown in figure 5–9. The spacecraft was moored to a Target Docking Adapter bolted to a target-vehicle forward auxiliary rack that was cantilevered from the laboratory floor. Data from this cantilevered configuration were then related to the actual spacecraft/target-vehicle free-free configuration, which could not be conveniently simulated in the laboratory. Various axial load and docking-adapter bending-moment conditions were simulated to correspond with inputs from the target-vehicle Primary Propulsion System. The data of primary importance were those needed in the Primary Propulsion System stability study—minimum first bending-mode frequency and damping, and maximum cross-axis coupling. The minimum first free-free bending-mode frequency was determined to be 3.3 cycles per second. The damping ratio (C/C_c) of the first mode varied considerably with test conditions from

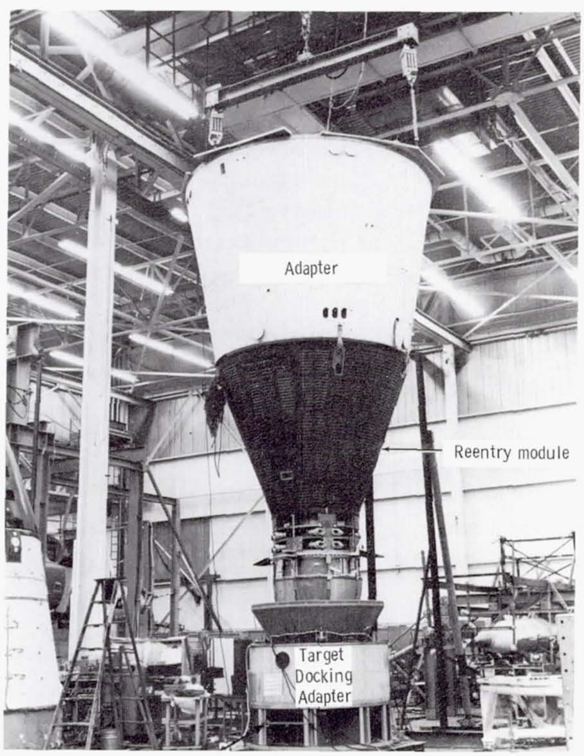

FIGURE 5–9.—Moored configuration ground vibration test.

a minimum of nearly 3 percent to a maximum of almost 5 percent. A minimum damping ratio of 2.34 percent was used in the study to account for possible high-temperature effects on the docking-adapter dampers. The cross-axis response in the test configuration was frequently 50 percent of the in-axis response, indicating that spring coupling coefficients of 3 to 6 percent should be included in the stability study equations of motion. Inclusion of the spring coupling effect in the study showed it to be only slightly destabilizing; this effect is included in figure 5–8.

Inflight Bending-Mode Test

When it became apparent that the original Agena control system was going to perform marginally during the docked Primary Propulsion System firings, a simple test was devised to determine inflight values of the first bending-mode frequency, damping, and cross-axis coupling. Determination of these parameters under actual flight conditions would have increased the confidence in the gain margins for this system (fig. 5–8). When the decision was made to replace the standard control system with a modified system, the inflight bending-mode test was retained in the flight plan as a final check on the docked configuration structural parameters.

The test was performed during the Gemini X mission. After the spacecraft and target vehicle were docked and rigidized, the command pilot fired a pair of spacecraft pitch-plane attitude thrusters for 3 seconds; this was immediately followed by a 3-second firing of the opposing pair of pitch-plane thrusters. The procedure produced three separate sets of vibrational motions for the first bending mode of the vehicles. Each set contained about 10 cycles. The same procedure was repeated in the yaw plane of the docked vehicles. Accelerometers having full-scale values of 0.02g were located in the spacecraft adapter section to sense the vibrations. The accelerometer signals were transmitted through the spacecraft telemetry system to a ground network station. The network station relayed the signals, in real time, to the Manned Spacecraft Center where the data were evaluated prior to the first firing of the target-vehicle Primary Propulsion System.

Table 5–II compares the inflight test data with corresponding data from the cantilever ground test. The first bending-mode frequency was 4 cycles per second and was about 10 percent higher than the frequency indicated from the ground test at corresponding amplitudes of vibration. Due to the thrusters firing, the moored vehicle was bent through an angle of 1 minute at the docking-adapter latch. The observed damping ratios varied from approximately 4.5 to 6.5 percent and were considerably higher than the ground-test value of about 3 percent. The differences could have been caused by low temperatures that sharply increased the contribution of the dampers to the total damping of the first bending mode. The temperature of the dampers was unknown. Cross-axis coupling was evident and was approximately the same level as indicated in the ground test. Since all measured values of frequency and damping were higher than the predicted values, and cross coupling was equal to the predicted values, the configuration was considered safe for maneuvers using the target-vehicle Primary Propulsion System.

TABLE 5–II.—*Comparison of Inflight Data With Ground-Test Data*

Test	Frequency, cps	Damping ratio, percent	Spring-coupling coefficient, percent
Ground	3.3	3 (Ambient temperature)	3 to 6
Inflight	4.0	4.5 to 6.5 (Temperature unknown)	3 to 6

Target-Docking Simulations and Training

The next evaluation of the target-docking systems was simulator training by the flight crews to develop proficiency for the docking and docked maneuvering phases of the actual flight. The first training phase was performed on the Translational and Docking Simulator which provided a full-scale simulation of close-in formation flying and docking maneuvers.

Differences in orbit-plane positions between the two vehicles were provided by lateral translation of the spacecraft mockup. A displacement of 22 feet either side of the center position was available. Differences in orbit altitude were represented by the vertical movement of the target-vehicle mockup with a total displacement capability of 33 feet. Closing or opening rates were simulated by moving the target vehicle toward or away from the spacecraft along a 125-foot horizontal track. Docking, latching, and rigidizing were accomplished with hardware similar to that to be used on the flight vehicle. Relative attitudes of both vehicles were provided by the ability of the spacecraft to move in all three axes: 45° to either side in yaw, 45° to either side in roll, and 40° down and 50° up in pitch.

The realism of the docking simulator was successfully demonstrated by comparing the conditions observed through the window of the trainer with those observed during the actual flights. The simulated closing and docking sequence started from a position slightly left of and below the target vehicle. The command pilot first maneuvered the spacecraft to aline the two vehicles, then translated forward with a relative velocity of approximately 1 ft/sec. The docking cone and docking bar adjusted for small alinement errors at impact and the docking cone absorbed the impact loads. After impact oscillations were damped, the spacecraft and target-vehicle mockups were rigidized and prepared for combined maneuvers.

Another part of the docking training was crew recognition of the status and safety of the systems in the target vehicle, and of the mooring system of the Target Docking Adapter. Visual observation of the target-vehicle status display (fig. 5–10), located above the docking cone, provided this information. Figure 5–10 shows a normal system condition as observed before docking. Green DOCK and PWR lights indicate that the mooring system is satisfactory for docking. The target-vehicle systems are verified by the green MAIN light, indicating that the hydraulic system pressure and the differential pressure between fuel and oxidizer are normal; by the green SEC HI and SEC LO lights, indicating that the Secondary Propulsion System is in a satisfactory condition; and by the green ATT light indicating that the target-vehicle cold-gas attitude system is activated. Upon docking, the green DOCK light is deenergized; when the vehicles are rigidized a green RIGID light is observed.

The second training phase was directed toward utilizing the target-vehicle systems, principally for attitude and translational maneuvers of the combined vehicles. This training was performed on the Gemini Mission Simulator at the Manned Spacecraft Center. The flight-crew control of the target vehicle and of the mooring system was through the encoder and docking-adapter controls, as illustrated on the spacecraft instrument display in figure 5–11. The docking-adapter controls on the center control panel

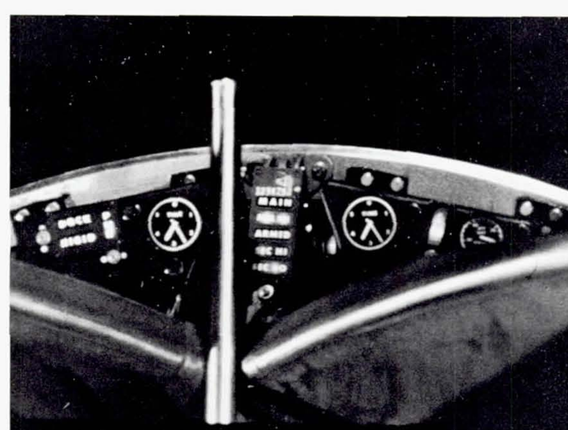

FIGURE 5–10.—Target-vehicle status display panel.

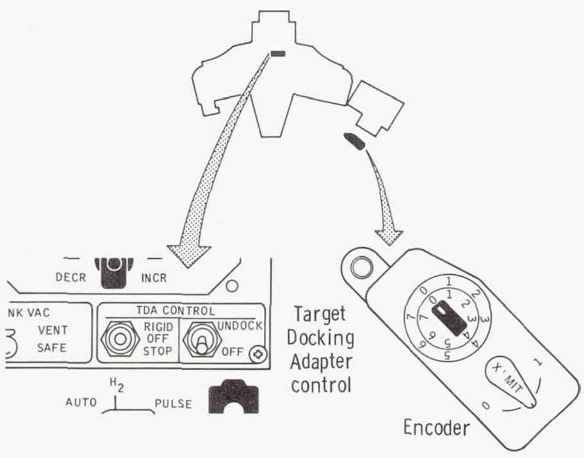

FIGURE 5-11.—Spacecraft instrument display.

were utilized for backup to the automatic rigidizing sequence and encoder-commanded unrigidizing signal. The crew used the encoder (located below the right-switch/circuit-breaker panel) to send commands to the target-vehicle propulsion, guidance, and electrical power systems. Approximately 100 commands could be sent to the target vehicle, and the sequence of the commands was significant; consequently, this phase of training was a major task.

Table 5-III shows an example of the sequence of commands required to perform a posigrade maneuver with the Primary Propulsion System. Before this sequence could be initiated, the spacecraft had to be configured for the maneuver. The spacecraft and target vehicle were then maneuvered to the proper heading; the Attitude Control System was adjusted for a Primary Propulsion System firing and for the desired velocity input; and the engine was activated. Sixteen seconds after the command to fire the Primary Propulsion System, the Secondary Propulsion System fired to establish the proper ullage configuration. The Primary Propulsion System initiate would not occur until 84 seconds after the PPS ON command, with automatic

TABLE 5-III.—*Posigrade Maneuver With the Primary Propulsion System*

Spacecraft command no.	Command title	Function
	Time = translation minus 30 min	
361	Geocentric rate normal	Establish proper heading for posigrade maneuver
310	Roll horizon sensor to yaw	
	Inertial Reference Package ON	
321	Horizon sensor to yaw	
	In phase	
460	Attitude Control System gain low	Establish necessary attitude control for Primary Propulsion Syster firing
310	Roll horizon sensor to yaw	
	Inertial Reference Package ON	
370	Attitude Control System pressure low	
450	Attitude deadband narrow	
271	Power relay reset	
	Time = translation minus 3 min	
041	Record data	Final system commands to lockout Target Docking Adapter, and prepare status display panel
471	Attitude Control System gain high, docked	
371	Attitude Control System pressure high	
271	Power relay reset	
201	Agena status display on bright	

TABLE 5–III.—*Posigrade Maneuver With the Primary Propulsion System*—Concluded

Spacecraft command no.	Command title	Function
	Time = translation time	
501	Primary Propulsion System ON	
Time = translation plus 16 sec		Secondary Propulsion System ON occurs
Time = translation plus 84 sec		Primary Propulsion System initiate occurs
When inertial velocity indicator zeros: ENGINE, STOP		Primary Propulsion System shutdown, backup to automatic shutdown
	Time = end of translation plus 2 sec	
500	Primary Propulsion System cutoff	Disable the Primary Propulsion System and reset attitude control for nonthrusting operation
460	Attitude Control System gain low	
370	Attitude Control System pressure low	
451	Attitude Control System deadband wide	
271	Power relay reset	

shutdown occurring after the desired velocity was achieved. A backup to the engine shutdown was performed by the flight crew by placing the engine switch to STOP. After shutdown the Primary Propulsion System was deactivated and the Attitude Control System was transferred to a nonthrusting configuration.

Crew training for the rendezvous and docking portions of the Gemini X, XI, and XII missions consumed an average of 89 hours per mission. This time would be approximately doubled if it included the docked maneuvering simulation training at Kennedy Space Center.

Docking and Undocking Flight Experience

Actual flight experience with docking and undocking of the spacecraft and target vehicle demonstrated that the design was sound, that testing had been adequate, and that crew training had provided a high degree of proficiency. Gemini VIII was the first mission in which a Gemini Agena Target Vehicle was placed in orbit. After a successful rendezvous and final station keeping, the following events occurred. The spacecraft was maneuvered to a position directly in line with the Target Docking Adapter at a distance of approximately 3 feet. The spacecraft attitude control system was in the rate command mode. After the command pilot had inspected the status panel, the docking cone, and the latches, he initiated the final approach by firing the aft-firing maneuver engines. Contact occurred with less than 2 inches of linear displacement, and with very little angular misalinement at a velocity of about $3/4$ ft/sec. Onboard sequence pictures of the event show a smooth operation with no evident reaction by the target vehicle. The latches appeared to engage immediately, followed by cone retraction and illumination of the rigid light. The Target Docking Adapter data indicate accelerations less than 1g

peak-to-peak in the horizontal and vertical axes, and less than ½g in the longitudinal axis. About ½ hour later, a spacecraft attitude-control problem caused an unscheduled emergency undocking. Although the combined vehicle rates at this time were 3 deg/sec in pitch, 2.5 deg/sec in yaw, and 5 deg/sec in roll, the undocking was smooth and orderly.

With one minor exception, all docking and undocking operations during the Gemini X, XI, and XII missions were equally smooth and uneventful. The exception was the second docking during Gemini XII. Flight-crew observations, onboard sequence pictures, and telemetry data indicate that the following probably occurred during this docking. Final approach of the spacecraft to the Target Docking Adapter was at a low velocity, and the point of contact was somewhat low. These factors caused the bottom docking latch to engage; however, the relative motion between the two vehicles stopped and the upper two latches did not engage. Sensing this, the command pilot immediately fired the aft-firing engines; but because the two vehicles were in contact, the thrust was insufficient to complete the dock. After about 40 seconds of unsuccessful maneuvers, a pitchup maneuver coupled with forward-firing engines caused successful separation. This condition had been encountered during tests and it was recognized that it could occur in flight; however, tests demonstrated that maneuvers, such as successfully employed in this case, would either separate the vehicles or would complete the dock, and no design changes were made.

An unexplained anomaly occurred after the second undocking maneuver during the Gemini XI mission. The undocking was accomplished by direct hardline signal from the spacecraft. Postseparation telemetry data indicated that the latches of the Target Docking Adapter had not reset; this was confirmed by crew observation. The crew recycled the unrigidized sequence using a radiofrequency command, and proper resetting followed. No further difficulties occurred but the hardline command was not used for the remaining undockings on this flight.

On all missions, while in the docked configuration, attitude control was excellent when using the various modes provided by both vehicles. Spacecraft rate command was used for random maneuvers when relatively fast operation was desired; very precise, but slow, cardinal-heading changes were made using the target-vehicle gyrocompassing maneuver. Spacecraft fixed-attitude control modes, such as platform or platform with orbital rate, provided good general control of the vehicles. However, for very precise pointing of the docked vehicles such as was required during photography, the target-vehicle Attitude Control System in the inertial mode was far superior to anything obtainable from the spacecraft systems. Because of the constant need to conserve spacecraft propellants for later phases of the missions, the target-vehicle control system was used whenever possible.

One of the most exciting aspects of the entire Gemini Program, and the primary reason for rendezvous and docking, was the capability to utilize the target-vehicle propulsion systems to greatly increase the maneuvering potential of the manned vehicle. This capability was not exercised on Gemini VIII because of the spacecraft control problem. However, Gemini X made very good use of this capability. First, as previously stated, an inflight test was performed to assure that the dynamic characteristics of the docked configuration would permit safe use of the target-vehicle Primary Propulsion System. Three Primary Propulsion System maneuvers and three Secondary Propulsion System maneuvers were performed on Gemini X. The maneuvers were all part of the highly successful and spectacular dual rendezvous of the docked vehicles with the Gemini VIII passive target vehicle which had been in orbit 4 months. Table 5–IV outlines the purposes of these maneuvers, the increased velocities realized, and the resulting orbital changes. It should be noted that the

actual velocities gained during the Gemini X firings were greater than the command values. The error was caused by a characteristic of the target-vehicle velocity meter that allowed velocity errors to build up when the meter was activated for relatively long periods (4 minutes) of time prior to a firing. On subsequent flights, the velocity meter was activated only 20 seconds prior to a firing and was set with a positive null torque instead of a negative value.

The modified lead/lag stabilizing networks of the target vehicle were first utilized in the Gemini VIII mission. Larger-than-expected initial yaw-attitude transients were noted during the undocked Primary Propulsion System firings. The transients, in conjunction with the slow response of the autopilot, were directly related to the offset angle between the vehicle center of gravity and the geometric alinement axes measured from the engine gimbal point. Relatively large vehicle displacements and rates were required to position the engine so that the thrust vector would pass through the center of gravity. The vehicle excursions represent the normal control-loop linear response in the presence of center-of-gravity offsets. A typical attitude response is presented in figure 5–12. The target vehicle for the Gemini VIII mission had particularly large yaw center-of-gravity offsets because running light batteries were added to assist in-orbit visual sighting by the flight crew. In-plane and out-of-plane velocity errors resulted from attitude transients caused by Primary Propulsion System firing and from affected orbital maneuvering accuracies.

On missions subsequent to Gemini VIII, the center-of-gravity offset problem was minimized by adding ballasts on the target vehicle to locate the center of gravity at the approximate intersection of the lateral geometric alinement axes. Offsets were reduced to within alinement and center-of-gravity location uncertainties of the system. From target-vehicle insertion firing data, the magnitude of the heading errors resulting from alinement uncertainties could be approximated to provide inflight programing correc-

TABLE 5–IV.—*Docked Maneuvers During Gemini X*

Maneuver	Engine	Initiation of maneuver ground elapsed time, hr:min:sec	Length of firing, sec	Desired velocity, ft/sec	Actual velocity, ft/sec	Resulting orbit apogee/perigee, n. mi.
Phase adjust, N_{CH1}	Primary Propulsion System	7:38:34	13	420.0	423.6	412/158.5
Height adjust, N_{CH2}	Primary Propulsion System	20:20:12	0	340.0	346.2	205.8/158.4
Circularization, N_{SR}	Primary Propulsion System	22:37:06	2	75.7	82.2	208.7/203.9
Phase adjust, N_{C1}	Secondary Propulsion System	22:45:36	10	7.7	9.7	209.9/205.0
Plane change, N_{PC}	Secondary Propulsion System	41:04:26	18	14.8	16.0	209.9/205.0
Phase adjust, N_{C1}	Secondary Propulsion System	41:35:50	4	3.5	4.4	208.5/205.5

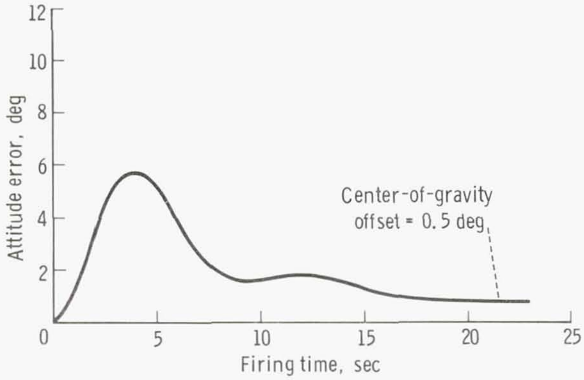

FIGURE 5-12.—Typical docked attitude response during firing.

tions for subsequent firings. Vehicle dynamic performance and the stabilizing influence which the modified lead/lag compensation network had upon the first body bending mode were as predicted in early stability studies. Except for the slow response, the maneuvers were satisfactory in all respects. The crew reported that the experience of accelerating backward produced no discomfort, and described the maneuvers as very thrilling. Table 5-V shows the three Primary Propulsion System maneuvers that were performed during Gemini XI to achieve the high-altitude apogee of 742 nautical miles. It should be noted that the modified velocity meter procedures resulted in very accurate velocities on this flight.

Onboard sequence pictures of the long firing to achieve the high altitude confirmed the crew description of visual effects of firing the Primary Propulsion System. The engine start was characterized by sparks, a yellow glow, and considerable visible flame. As full engine operation was reached, visible light was almost completely extinguished. Upon termination of the firing, the engine tailoff produced a display as spectacular as the ignition phase.

Concluding Remarks

From the experience in the Gemini Program relative to the operational characteristics of the docked configuration, several significant conclusions are apparent.

(1) The maneuvering and subsequent docking of spacecraft in orbit is practical and, when a proper design exists, is a relatively easy task.

(2) The joining of manned vehicles to unmanned craft containing large propulsion units can provide large maneuver capability where launch payload constraints prevent a combined launch.

(3) The development of docking and docked maneuvers of the Gemini spacecraft and the Gemini Agena Target Vehicle was in many respects a remarkable example of engineering success. It was a venture into an entirely new area of operation. No prior technology was applicable. It had all the impediments and interfaces of a combined effort by several large prime contractors, their subcontractors, and several Government agencies. Yet, most of the potential problems were eliminated in the drafting room, a few were discovered and corrected during test, and some were removed at the conference table. The efforts were culminated during the flight operations when all design parameters were easily met and problems were few.

TABLE 5-V.—*Docked Maneuvers Using Primary Propulsion System During Gemini XI*

Effect of maneuver	Initiation of maneuver ground elapsed time, hr:min:sec	Length of firing, sec	Desired velocity, ft/sec	Actual velocity, ft/sec	Resulting orbit apogee/perigee, n. mi.
Plane change	4:28:48	3	110.0	109.8	164.2/154.6
Raise apogee	40:30:15	25	920.0	919.6	741.5/156.3
Lower apogee	43:52:55	22.5	920.0	919.47	164.2/154.6

6. OPERATIONS WITH TETHERED SPACE VEHICLES

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Introduction

Basically, two modes of tethered space-vehicle operations were explored in the Gemini Program. One mode of operation consisted of intentionally inducing an angular velocity in the tethered system by translational thrusting with the spacecraft propulsion system. The other mode involved tethered, drifting flight during which the effect of gravity gradient on the motion of the system was of interest. These two modes of tethered-vehicle operation will be individually discussed.

Rotating Tethered Vehicles

The tether evaluation in the rotational mode was accomplished during the Gemini XI mission. This exercise was to evaluate the basic feasibility of rotating tethered-vehicle operations as the operations might apply to generating artificial gravity or to station keeping. The exercise consisted of connecting the spacecraft and target vehicle with a 100-foot Dacron tether, and then using the translational thrusting capability of the spacecraft propulsion system to induce a mutual rotation. The result of this mutual rotation was that the vehicles essentially maintained a constant separation at the ends of the tether. Figure 6–1 is an illustration of the spacecraft/target-vehicle tethered configuration.

Analytical Studies

The analytical studies made in support of the rotating tethered-vehicle exercise consisted of two distinct phases. The first phase was a general exploration of the properties of tethered-vehicle dynamics. The second phase consisted of an analysis of the specific spacecraft/target-vehicle tethered configuration of the Gemini XI and XII missions. Primarily, the analytical studies were made using a 12-degree-of-freedom digital computer program. This program numerically integrated the equations of motion of two rigid bodies, each having 6 degrees of freedom and connected by an elastic tether. The program allowed the bodies to have arbitrary mass properties, and the tether attachment points to be arbitrarily specified. The tether was mathematically described as a massless spring obeying a linear force-elongation relationship, and as exhibiting a linear dashpot-type damping property. Since a model for the dynamic behavior of the tether was not included in the analysis, tether motions were not predictable from these studies. In this particular analysis, it was assumed that the only significant external forces on the system were control forces exerted by the spacecraft control system. This assumption eliminated gravity forces which were shown

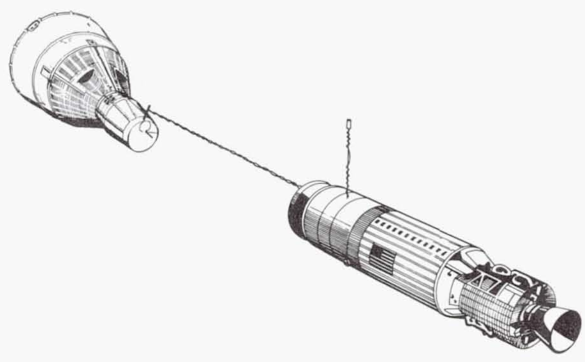

Figure 6–1.—Gemini spacecraft/target-vehicle tethered configuration.

to have negligible effect on short-term tether operations such as spinup and despin maneuvers. These studies predicted the dynamic behavior of tethered-system response to initial conditions and to simple, digitally simulated, control-system inputs; however, there was need for a study to reflect the interaction of man with the tethered system.

To supplement the digital studies, a 12-degree-of-freedom, real-time, man-in-the-loop simulation of the tether problem was implemented. This simulation was used to study the effects of pilot real-time inputs into the motion of a tethered-vehicle system by means of an attitude and translational control system. Information about the dynamic behavior of the tethered system was obtained from manual attempts to spin up the system, to control oscillations, and to despin the system.

Properties of tethered-vehicle dynamics.—The first study phase resulted in the establishment of the basic feasibility of the tethered-vehicle exercise. Two rigid bodies connected by a single elastic tether were found to have no alarming dynamic characteristics. The tethered system, however, was found to exhibit oscillational motions that were very complex and peculiar but which could be controlled to some extent with the spacecraft attitude-control system. The most interesting results of the first phase of the study were that tether damping was not very effective for reducing the attitude oscillations of a rotating tethered system, and that tether damping was quite effective in eliminating a slack/taut tether oscillational condition. These two properties of tethered-system motion are illustrated in figures 6–2 and 6–3.

Figure 6–2 illustrates two spinup starts which were identical, except that damping was present in the tether in one case, and no damping was present in the other case. The figure also presents a time history of tension in the tether, and the yaw angle of the spacecraft relative to the target vehicle. It can be seen that while the tension in the tether was strongly affected by damping, the attitude oscillation was relatively insensitive to tether damping.

Figure 6–3 illustrates the effectiveness of tether damping in eliminating a slack/taut tether mode of oscillation. This run started with an initially slack tether that quickly became taut, causing the slack/taut tether oscillation. A time history of the distance between tether attachment points is provided. Since the unstretched tether length was 100

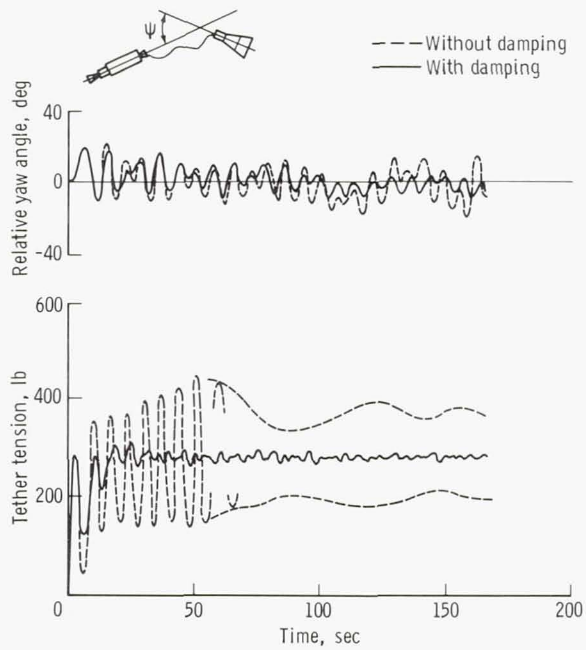

FIGURE 6–2.—Effect of tether damping on the attitude oscillations of tethered systems.

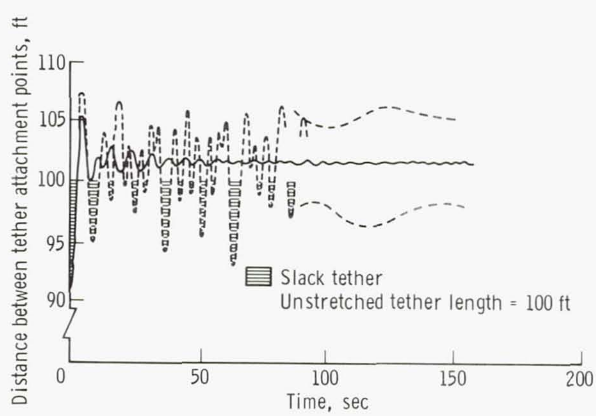

FIGURE 6–3.—Effect of tether damping on slack/taut oscillations.

feet in this run, any time the distance between the tether attachment points was less than 100 feet the tether was slack. It is apparent from figure 6–3 that with no tether damping, the slack/taut condition continued throughout the run; but with tether damping, the slack/taut condition was quickly controlled and resulted in a constantly taut tether condition.

Spacecraft/target-vehicle tethered configuration.—The second phase of the analytical study involved choosing a specific configuration for the spacecraft/target-vehicle tethered system. The selection of a specific configuration primarily involved the hardware and operational aspects. This freedom of choice was possible because the first phase study verified that a rotating tether-system operation was feasible and safe; besides, at this point in time, any possible configuration could be thoroughly studied. The tether length was specified as 100 feet as a compromise between maintaining safe separation of the spacecraft and the target vehicle and for minimizing fuel usage to obtain a given angular rate for the system. The tether size and material were dictated by an early program objective of producing significant artificial gravity effects (high tether loads). The tether spring rate of 600 pounds per foot was intentionally high so the tether could be broken by impact loading as a backup means of jettisoning the tether and the target vehicle if the primary jettisoning procedure should fail. Dacron webbing with a breaking strength of 6000 pounds was chosen as the tether material. The tether attachment points on the two vehicles were determined on the basis of minimum hardware implication on the Gemini Program. Attaching the tether to the spacecraft docking bar also provided a convenient scheme for jettisoning the tether. After it was decided that large artificial gravity effects would not be attempted in the Gemini Program, an 800-pound break link was installed in the tether to lower the requirements on the spacecraft propulsion system for impact breaking of the tether. The final tethered-vehicle configuration was then studied analytically to determine specific dynamic behavior.

Operational Aspects

The operational procedure for spinning up the tethered spacecraft/target-vehicle system consisted of backing the spacecraft away from the target vehicle until the tether was almost taut, then firing the translational thrusters to provide thrust on the spacecraft normal to the line between the vehicles. This imparting of angular momentum to the tethered system generally resulted in a net change in velocity of the center of mass of the system, and subsequently changed the orbit of the vehicles. This effect would not have been present if the system spinup had been accomplished with a pure couple; however, due to the passiveness of the target vehicle in the exercise, the spinup moment on the system had to be supplied solely by the spacecraft translation-control system.

The first complication associated with the operational implementation of the spinup tether exercise involved the fact that the spacecraft lateral translation thrusters had a significant component of thrust in the forward longitudinal direction. As a result, an attempt to spin up the system by firing only the lateral thrusters resulted in a significant closing rate between the vehicles. This closing rate produced an appreciable period of tether slackness, culminating in an extensive slack/taut tether oscillatory mode. The alternatives to this spinup procedure were to orient the spacecraft so that its lateral thrust vector was, in fact, normal to the line between the vehicles, or to simultaneously thrust aft and laterally, thus holding the tether in tension during the spinup maneuver. Both methods had merit, depending upon the degree of spin rate desired for the system. Since the lateral and aft firing technique was applicable in all cases and was operationally simple, it was chosen as the operational technique for spinup of the system. For long-duration spinups, the aft thrusting could be terminated eventually, because the

tether would remain taut during the remainder of the spinup due to the motion of the system.

During the spinup procedure, attitude control was required to maintain accurate thrusting to establish a desired spin plane. After the spinup was accomplished, neither the safety nor success of the exercise required further attitude control. Because tether damping did not prove to be an effective means of damping attitude oscillations, active attitude control was required when it became desirable to rapidly reduce spacecraft oscillations. It was found through simulation that the spacecraft control system could effectively reduce the attitude oscillations of the spacecraft; also, when the target vehicle was oscillating, those oscillations would ultimately be propagated through the tether to the spacecraft.

It was evident from the analyses that a differential rolling motion of the spacecraft relative to the target vehicle would probably be excited during the spinup maneuver. This mode of oscillation would be difficult to control with the spacecraft attitude-control system. Probably more difficult to control would be a rolling motion in which the target vehicle and the spacecraft were rolling together. Stopping this latter mode would require inducing a relative roll oscillation so that the tether could be used as a torsional spring which, although weak, would exert a roll moment on the passive target vehicle. Since mild rolling motions would not jeopardize the tether exercise, there was no reason for undue alarm.

From a safety-of-operation standpoint, establishment of a despin procedure was necessary. Such a procedure would enhance the probability of successful jettisoning of the tether at the termination of the exercise. The despin maneuver was essentially the inverse of the spinup maneuver. One procedure for despinning was to locate the spin plane of the system, either visually or with body-rate information available in the spacecraft, and then apply thrust in the spin plane and opposite the direction of spin. An alternative despin procedure involved applying thrust to reduce the line-of-sight rate to zero by visual observation of the spacecraft/target-vehicle line-of-sight motion. The despin maneuver invariably left the target vehicle with residual angular rates when the tether eventually became slack; however, this could be controlled by activating the target-vehicle control system in the despin procedure. An interesting phenomenon was discovered during the operational studies of the despin maneuver. Due to the location of the spacecraft attitude-control thrusters, and to the fact that attitude control of the spacecraft caused translation (the attitude-control moments not being couples), it was possible to automatically despin the rotating tethered system. By activating the rate-command attitude-control mode in the spacecraft and by commanding zero attitude rates, the attitude-control system would attempt to drive the spacecraft body rates to zero and produce a net translational thrust which slowly, but surely, would despin the system.

Crew Training

The crew training in preparation for the spinup tethered-vehicle exercise was primarily familiarization through simulation practice. To provide a realistic simulation of the interaction of two vehicles tethered together, a real-time simulation of the tethered-vehicle system was implemented.

The simulation facility consisted of a high-fidelity crew-station mockup, a planetarium-type projection visual display, and a hybrid-computer complex. The equations of motion describing two unconstrained rigid bodies (6 degrees of freedom per body) connected by a massless elastic cable were solved in real time on the hybrid-computer complex. This mathematical model included the off-symmetrical tether attachment points on the spacecraft and target vehicle, as well as the actual inertia properties of the vehicles. Best estimates of the tether-spring constant and damping characteristics were used for the training simulations. Included in the solution

of the governing equations of motion was a simulation of the spacecraft attitude and translational control system. This simulation allowed real-time astronaut control inputs to properly effect the motions of the tethered vehicles. All basic flight instrumentation, as well as engineering parameters, were displayed in real time in the crew station.

The visual presentation consisted of a planetarium-type gimbaled Earth-scene horizon and star-field projection. The visual presentation of the target vehicle consisted of two spots of light from dual-target projectors. The two spots represented the ends of the target vehicle. This presentation allowed a visual recognition of maneuvering relative to the target vehicle, as well as observation of the attitude oscillations of the target vehicle. In flight, the tether would supply a visual cue concerning the separation distance between the two vehicles; however, in simulation, visual representation of the tether was not possible and the cue was supplied by a display in the crew station.

The training simulations usually began with the spacecraft undocked, but close to the target vehicle. The astronaut was then required to translate away from the target vehicle to a tether-extended position where the spinup maneuver would be initiated. After the system achieved the desired spin rate, the astronaut was free to observe the subsequent motions and obtain a feel for the behavior of the tethered system. Attitude control could be attempted in a direct, pulse, or rate-command mode of attitude control. Typical training exercises consisted of intentionally inducing large attitude oscillations in the spacecraft by means of the attitude-control system, and subsequently reapplying control moments to reduce these oscillations. Following these maneuvers, the astronaut could finish the exercise by practicing the despin procedure. Practice in breaking the tether with impact loading was also possible, since tether tension levels resulting from various maneuvers were displayed to the astronaut.

In addition to the crew training usage of the tether simulation, valuable engineering knowledge was gained concerning the general behavior of the tethered systems as well as of the specific configuration selected for Gemini. It was possible to observe in real time the response of a tethered system to very complex forcing functions (that is, inputs by a pilot). Although not directly associated with the flight maneuvers, the functions nevertheless yielded insight into the system behavior. The simulation allowed the design engineer to personally intervene in the scientific solution of the tether motion by way of a control system. The simulation was used to determine system response to control thrusters stuck in the ON position. Before the Gemini XI mission, the simulation was used to determine the effects of a degraded thruster prior to and in support of the actual spinup. Fuel usage for the spinup procedures was also determined in this training simulator.

Flight Results

During the Gemini XI mission, a total lateral thrusting of approximately 13 seconds was applied to the tethered system and resulted in a system spin rate of approximately 0.9 degree per second. Slack/taut tether oscillations were induced during the spin following the termination of aft thrusting. This was due primarily to the fact that the tether tension associated with the low spin rate was smaller than the tether tension induced by thrusting aft; hence, at termination of aft thrusting, the tether simply catapulted the vehicles toward one another. After approximately 1½ orbits of the Earth, the spinup operation was terminated with a despin type of maneuver and the tether was jettisoned.

The results of the rotating tethered-vehicle maneuvers during the Gemini XI mission were essentially as anticipated. By comparing the motion pictures of the maneuver taken during the mission with the observations in the training simulation, it is evident that the simulation was quite accurate in

predicting the general behavior of the tethered system. The flight crew found that the active damping of oscillations with the spacecraft attitude-control system was easier in flight than in the training simulation. This effect was probably due to the degraded sensory information available to the astronaut in the simulation as compared with the actual flight. It was observed that cable slack/taut oscillations damped out more rapidly in flight than in the simulation. This discrepancy was traced to a conservative value for the tether damping constant which corresponded to a room-temperature tether rather than a cold tether which would have a higher damping constant. As anticipated by analysis, the differential roll motion between the vehicles did, in fact, occur and was approximately to the extent predicted.

An interesting event occurred during the deployment of the tether. Near the end of deployment, a cable-dynamics phenomenon known as the skip-rope effect became significant. This behavior, although obviously possible, had not been predicted by the tether analyses employed in the design of the tether maneuver, since the studies did not include tether degrees of freedom. After the skip-rope mode of oscillation subsided, the spinup maneuver was successfully conducted with no evidence of significant cable-dynamics effects, thus confirming the analytical assumption that cable dynamics were not significant in the rotational behavior of this particular tethered system.

Gravity Gradient

The gravity-gradient tether exercise was accomplished during the Gemini XII mission to study the feasibility of using gravity-gradient effects in the stabilization of manned spacecraft. The exercise consisted of tethering the orbiting vehicles together, then arranging the vehicles one above the other at the ends of the extended tether (that is, along a local vertical). By imparting the proper relative velocities to the vehicles in this arrangement, the vehicles would proceed into a constantly taut tether configuration and the tethered system would be captured by the gravity gradient. This captured behavior would be manifested by oscillation of the system about the local vertical.

Analytical Studies

Analytical studies of the gravity-gradient tether exercise ranged from simple feasibility studies to fairly sophisticated analyses. While the operational feasibility of gravity-stabilized satellites was well established, the stability of two rigid bodies tethered together in orbit was questionable. Therefore, analytical studies were first aimed at exploring the basic behavior of a tethered system in a gravity field, and then at establishing the operational aspects of obtaining a gravity-gradient-stabilized tethered system.

The first feasibility studies were conducted using a mathematical model that consisted of two point masses (each with 3 degrees of freedom) subject to an inverse-square central force field. The two point masses were assumed to be connected by an elastic tether which satisfied a linear force-elongation relationship. The equations describing this system were numerically integrated in a digital computer program to yield time histories of the significant parameters in the analysis. This phase of the analytical study established that at least two point masses could be tethered together and gravity gradient stabilized. This study, of course, had applicability to the actual situation since it could be argued that two rigid bodies connected with a tether of sufficient length would exhibit particle-like behavior. Since there was no effective damping mechanism in the proposed tethered system, and since the gravity-gradient exercise could continue over but a few orbits, the success of the exercise was strictly a matter of giving the tethered system the proper initial conditions. This being the case, the first phase of the study consisted of determining the response of the tethered

system to various combinations of initial conditions.

The initial conditions for a perfect start were established; these included a slightly taut tether, and a relative velocity of about 0.138 ft/sec for a 100-foot tethered spacecraft/target-vehicle combination. The perfect start, of course, also included an initial alinement along a local vertical and an approximately circular orbit for the system. Response to the perfect start consisted of continued alinement of the two point masses along the local vertical and of a constantly taut tether. Perturbations to this perfect start involved off-nominal relative velocities which were not compatible with continued motion along the local vertical, or an initially slack tether with or without range rate between the bodies. The tethered point masses were found to be reasonably tolerant of off-nominal starting conditions. For small perturbations, the solutions to the motions of the tethered point masses were in agreement with linearized dumbbell-satellite theory. This point-mass analysis was eventually modified to include an oblate earth as the attracting force on the point masses. This change was found to have negligible effect on the behavior of the tethered system. From the first phase of study, it was concluded that gravity-gradient stabilization could possibly be obtained with the spacecraft and target vehicle in the tethered configuration. Figure 6–4 illustrates typical results obtained from the point-mass analysis on the sensitivity of the system motion to initial relative velocity between the point masses.

The second phase of the analytical studies was conducted using a mathematical model consisting of two rigid bodies in planar motion subject to an inverse-square central force field, and connected by an elastic tether. The equations of motion describing this mathematical model were integrated numerically in a digital computer program to provide time histories of significant parameters. This phase of the study was implemented to answer questions concerning the rigid-body attitude response of the spacecraft and the target vehicle during the gravity-gradient exercise, and to confirm the validity of the conclusions drawn from the point mass analysis. From the results of this rigid-body study, it was found that (1) there was good agreement between the rigid body and the particle analysis concerning capture limits and tolerance to starting perturbations; and (2) there could be considerable rigid-body rotation of the target vehicle and the spacecraft during the gravity-gradient exercise. Figure 6–5 illustrates a typical time history provided by the planar rigid-body analysis. Of importance was the determination that the capture sensitivity of the system was not significantly related to the rigid-body-attitude initial conditions. This fact was certainly welcome from the operational standpoint of setting up a captured system. On the other hand, the large rigid-body excursions of the vehicles would have an operational implication on such things as observation of the total system motion during the gravity-gradient exercise. While this rigid-body study provided valuable information, there were still a few questions concerning the rigid-body response of the vehicles and the stability of the system with all degrees of freedom present.

To answer these questions, a final study phase was implemented. The final phase con-

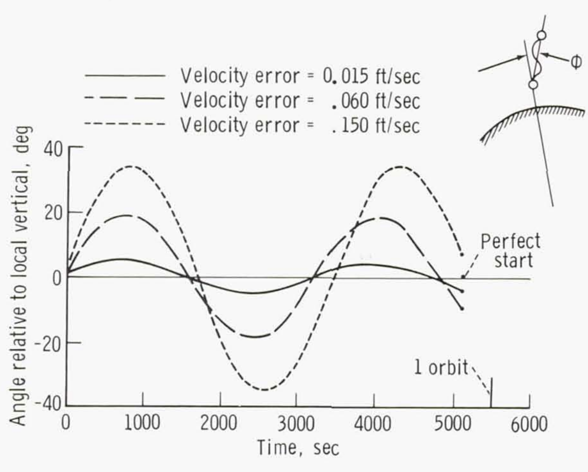

FIGURE 6–4.—Effect of off-nominal relative velocity on motion of gravity-gradient tethered system.

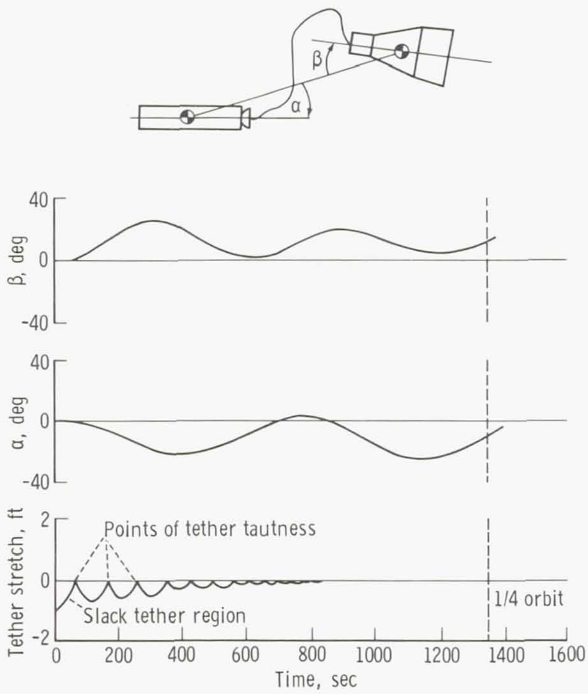

FIGURE 6-5.—Effects on rigid-body attitude response during gravity-gradient motion due to initial tether slackness of 1 foot.

sisted of solving the equations of motion describing two rigid bodies (each with 6 degrees of freedom) in an inverse-square central force field and connected by a linear elastic tether. This study confirmed the applicability of the lesser analyses that had been performed, in that good comparisons of capture limits and response to perturbations were obtained. As expected, the results of the final study indicated that a captured system would still be likely to have large rigid-body-attitude excursions; however, of even more significance, was the finding that there were no unforeseen instabilities in the behavior of the proposed gravity-gradient exercise. This final phase of study was primarily concerned with the spacecraft/target-vehicle configuration which would be used in the mission.

This concluded the analytical study phase of the tethered-vehicle gravity-gradient experiment. With the theoretical validation of the exercise completed, the problem then was to devise an operational technique to provide the proper initial conditions for the tethered system.

Operational Aspects

The objective of the gravity-gradient-stabilized tethered-vehicle exercise was to orient the vehicles one above the other (along a local vertical), and to provide proper starting conditions so that the subsequent motion would, at worst, be a limited amplitude oscillation of the system about a local vertical, and, at best, a continued perfect orientation along a local vertical. The proper starting conditions consisted of a slightly slack tether and a relative velocity of 0.138 ft/sec. Although it was relatively easy to position one vehicle directly over the other with a slightly slack tether, it was much more difficult to obtain a relative velocity of 0.138 ft/sec between the vehicles. A deviation of more than 0.23 ft/sec from the perfect relative velocity would mean that the gravity-gradient torque on the system could no longer contain the oscillations of the system around the local vertical; the system would then cartwheel, or be spun up.

The problem of obtaining the correct relative velocity between the spacecraft and the target vehicle was approached as follows. The perfect initial relative velocity corresponded to that relative velocity which would exist between the separated bodies if they were both attached to the same radius vector from the center of the Earth and rotating at orbital rate. It was decided to make use of this fact in the starting procedure. The capability existed on board the spacecraft to provide information to the flight crew from which the longitudinal axis of the vehicle could be made to coincide at all times with the local vertical direction. By positioning the spacecraft directly above the target vehicle with the longitudinal axis of the spacecraft maintained continuously along a local vertical, deviations from the perfect relative-velocity conditions would be manifested as drift of the target vehicle relative to the space-

craft. This drift could be detected quantitatively by the flight crew using the optical sight, and could be converted to an equivalent drift rate. From the drift rate, the deviation in relative velocity from the perfect start could be determined; hence, an appropriate velocity correction could be applied with the spacecraft translational thrusters. A perfect relative-velocity start would result in a zero-drift rate of the target vehicle relative to the spacecraft, as long as the longitudinal axis of the spacecraft was continuously along a local vertical. Figure 6–6 shows a flight chart from which the flight crew could take quantitative drift measurements (as angular drift in the optical sight) over a measured period of time and find the equivalent drift rate in the form of a relative-velocity correction. The flight chart indicates the expected maximum oscillation of the system from a local vertical for a given error in relative velocity. After the flight crew had ascertained that an acceptable initialization had been accomplished, the flight plan required that all thrusting be terminated and the drifting system observed to determine the success of the initialization. While a perfect starting condition dictated a very slightly taut tether, it was operationally more feasible to start the system with a definitely slack tether, and a zero-closure rate. This was due to the minimal perturbation to, and

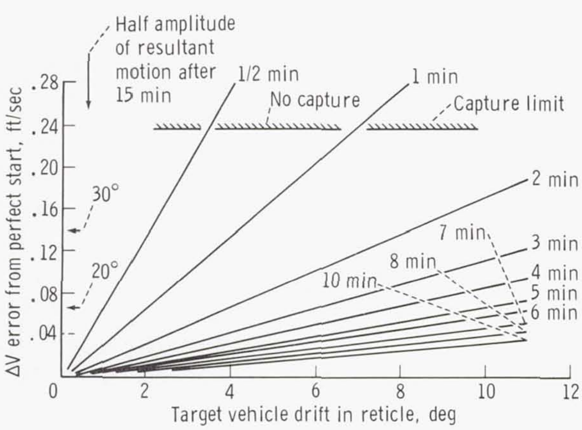

FIGURE 6–6.—Starting procedure chart for Gemini XII gravity-gradient tether exercise.

rapid recovery of the system from, an initially slack tether. The gravity-gradient effects would soon draw the tether taut (this being the stable configurations for the tethered system) for the remainder of the operation. The penalty paid for an initially slack tether was an increase in the angle of oscillation of the system relative to a local vertical.

Crew Training

Crew training for the gravity-gradient tether exercise consisted of briefings and simulator exercises. The significant flight-control task involved measuring the drift of the target vehicle in the optical sight, then applying the proper translational thrust to correct the relative velocity of the vehicles. The training was accomplished in the Gemini Mission Simulator, which had the capability to start a flight simulation run with the spacecraft docked with the target vehicle. The simulation exercise could then proceed with the undocking, followed by a maneuver to reach a position approximately 100 feet above the target vehicle. From this position, the use of the flight chart for the gravity-gradient starting procedure could be practiced. The mission simulator did not include tether dynamics or a visual simulation of the tether. This deficiency did not greatly hinder training for the gravity-gradient exercise, since the cable was not supposed to be taut during the starting procedure. The significant task to be practiced in training was to maintain a local vertical with the aid of the spacecraft instrumentation, and to detect and remove target-vehicle drift rates relative to the spacecraft.

Flight Results

There were three orbits allotted to the gravity-gradient tether exercise on the Gemini XII mission. Approximately half of this orbit time was used in establishing the starting conditions for the exercise. The remainder of the allotted time was spent observing the subsequent motion of the system.

The initialization of the system consisted of various translational and attitude thrusting maneuvers by the spacecraft, and an active stabilization of the target vehicle using the target-vehicle control system. After the flight crew had ascertained that acceptable initial conditions had been achieved, the crew deactivated the target-vehicle control system and terminated all spacecraft thrusting. The resulting motion was one of limited amplitude oscillations relative to local vertical. It was evident that the system was indeed captured by the gravity gradient. After initial perturbations, the tether became constantly taut, and the attitude oscillations of the spacecraft were of sufficiently limited amplitude that the crew were able to view the target vehicle almost continuously. Under these conditions, the target vehicle was never observed to rise toward the horizon by more than approximately 60° from local vertical.

The initialization of the gravity-gradient exercise was greatly hampered because some of the control thrusters on the spacecraft were malfunctioning. Attitude control had degraded to the extent that the preflight planned procedure for setting up the gravity-gradient exercise could not be accomplished. Despite this handicap, the crew was able to devise a backup procedure consisting of judicious use of remaining thrust capability to provide initial conditions for a successful gravity-gradient capture.

The simulation training for the gravity-gradient exercise was adjudged by the crew to present a more difficult problem than the actual flight situation. The crew concluded that, with a properly functioning control system, the gravity-gradient-capture initial conditions could have been accomplished with relative ease and certainty.

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MAN'S ACTIVITIES IN SPACE

7. LIFE SUPPORT SYSTEMS FOR EXTRAVEHICULAR ACTIVITY

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Introduction

The Gemini Program has provided the U.S. Space Program with the initial steps in the study of manned extravehicular activity. Extravehicular activity was planned for 6 of the 10 manned Gemini flights and was actually performed during 5 flights. One prerequisite for attempting extravehicular operations was a reliable life-support system to provide the extravehicular pilot with a habitable environment while outside the protective confines of the spacecraft. The life-support system consisted basically of a space suit, a portable environmental control system, and an umbilical link with the spacecraft. This paper will trace the development of the suits, the environmental control system, the umbilical, and the related components from the original concepts through the modifications imposed by specific missions.

Testing

All elements of the extravehicular life-support systems were subjected to comprehensive unmanned and manned testing. Unmanned testing was performed individually on the space suits, the portable environmental control systems, and the umbilicals, and most manned testing concentrated on end-to-end tests. These manned tests included operation with the flight spacecraft for final verification of satisfactory performance.

The unmanned tests included humidity, vibration, explosive decompression, acceleration, oxygen compatibility, exposure to simulated space environment, temperature cycling, and shock. In some instances, tests were performed on a single life-support system element to fulfill some special requirement. For example, the space suits were tested for their ability to retain integrity during seat ejection tests.

The manned test series was performed at the Manned Spacecraft Center and at the spacecraft contractor facilities. Qualification tests for demonstrating the adequacy of metabolic heat rejection under induced workloads up to 2400 Btu/hr were performed in high-altitude and space simulation chambers. Operation of the self-contained oxygen supplies of the Gemini IV and Gemini VIII through XII chest packs was verified as a suitable emergency mode should the extravehicular crewman lose the spacecraft oxygen supply. The crews practiced the various steps required to return to the spacecraft Environmental Control System in a decompressed cabin environment. This type of testing was performed in a vacuum chamber equipped with operational life-support system gear and a boilerplate Gemini spacecraft.

Space Suits

During an extravehicular mission the space suit becomes, in effect, a small, close-fitting pressure vessel which has to maintain a structurally sound pressure environment and provide the pilot with metabolic oxygen and thermal control. The space suit must also provide the body-joint mobility necessary for

the pilot to perform the assigned extravehicular tasks.

The basic Gemini space suit was a multilayer fabric system generally consisting of a comfort liner, a gas bladder, a structural restraint, and an outer protective cover. To permit easy donning and doffing of the suit and components, quick disconnects were located at the wrists for glove connections, at the neck for helmet connections, and at the waist for ventilation-gas connections. Suit entry and body waste management were provided by a structurally redundant pressure-sealing zipper. Internal to the suit, a gas distribution system directed a flow of oxygen to the helmet area for metabolic use and thermal control, and over the limbs and body for thermal control.

Accessories provided on the suit included handkerchiefs, pencils, survival knife, scissors, neck dam, wrist dams, parachute harness, and stowage pockets for the flight-data books and charts (fig. 7–1). Equipment added to the space suit for extravehicular missions included: (1) extravehicular coverlayer, (2) pressure thermal gloves, (3) visor temperature-control coating, and (4) sun visor.

Gemini IV Mission

The Gemini IV mission objectives included short-duration extravehicular activity and evaluation of the basic extravehicular equipment. The basic (G3C Series) Gemini suit was adapted for extravehicular use (fig. 7–2) by incorporating the following:

(1) The extravehicular coverlayer consisted of nylon felt material for micrometeoroid protection, seven layers of aluminized

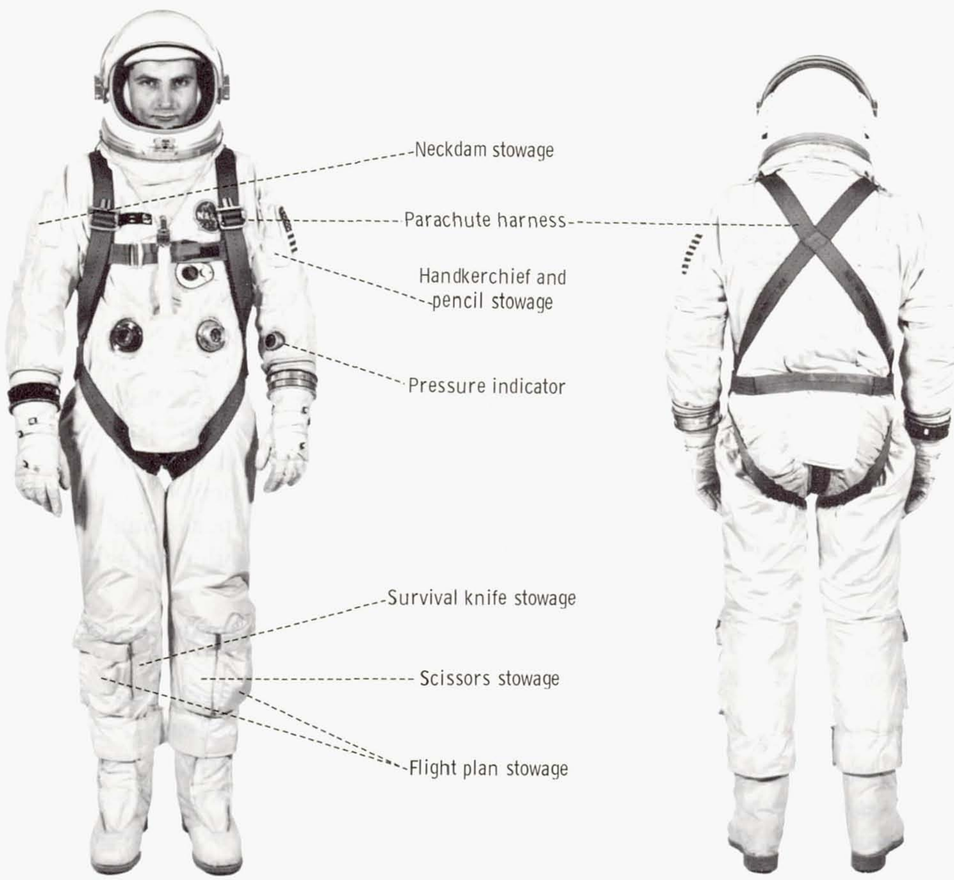

FIGURE 7–1.—Gemini G4C extravehicular space suit.

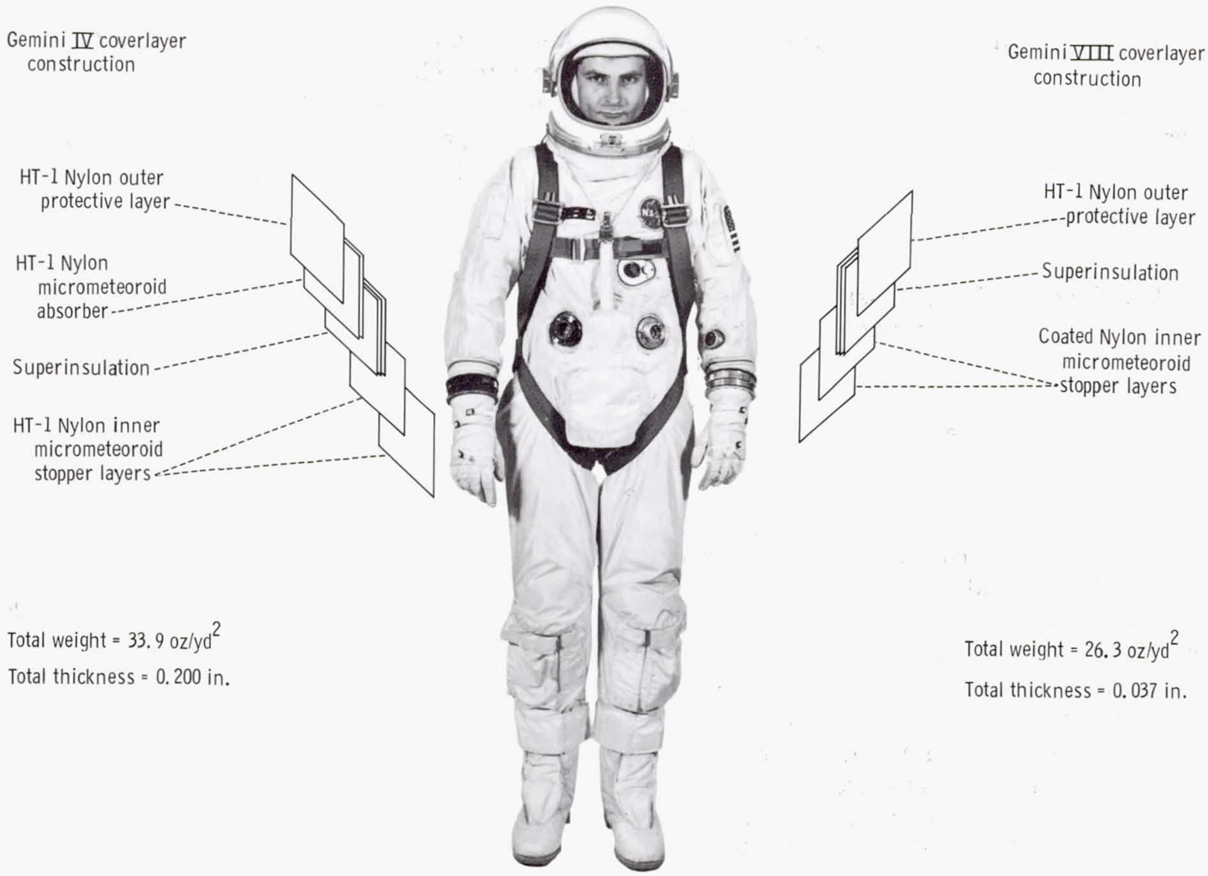

FIGURE 7–2.—Gemini IV and VIII extravehicular space suit.

Mylar superinsulation, and an outer covering of high-temperature nylon cloth.

(2) The extravehicular visor was a two-lens assembly with the outer lens providing visible and infrared energy attenuation, and the inner lens providing impact protection and thermal control.

(3) Thermal overgloves were provided for protection from conductive heat transfer.

During the Gemini IV mission, no difficulties were experienced with any of the space-suit equipment. The mission demonstrated the following:

(1) The adequacy of the micrometeoroid and thermal protection of the coverlayer

(2) The acceptability of the visible light attenuation of the sun visor

(3) The adequacy of the thermal-control coating on the impact visor to maintain the pressure-visor surface temperature at the proper level

(4) The adequacy of the pressurized suit mobility to permit the pilot to egress and ingress the spacecraft

(5) The need for reduced coverlayer bulk to improve unpressurized suit comfort

Gemini VIII Mission

The space suit (fig. 7–2) used for the Gemini VIII mission was basically the same as the suit provided for the Gemini IV mission, with the following exceptions:

(1) The micrometeoroid protective layer was improved to provide significant reductions in coverlayer bulk (fig. 7–2).

(2) The thermal protection for the gloves, previously a part of the overglove, was incorporated into the basic pressure glove to

provide integrated thermal-conduction protection.

The Gemini VIII extravehicular equipment was not evaluated in flight due to early termination of the mission.

Gemini IX–A Mission

The Gemini IX–A mission imposed some very difficult requirements upon the space-suit assembly. To use the Astronaut Maneuvering Unit in conjunction with the space suit, it was necessary to redesign the lower portion of the extravehicular coverlayer to protect the pilot from the high-temperature (1300° F) impingement by the thruster plume of the Astronaut Maneuvering Unit. The suit was modified as follows:

(1) To afford protection from the high-temperature plume, the extravehicular coverlayer in the leg areas included a stainless-steel fabric outer covering to provide thermal energy distribution and erosion protection. A high-temperature superinsulation was used below the outer cover; the superinsulation consisted of alternate layers of double aluminized film and lightweight fiber glass.

(2) To further protect the visor from impact damage, the plexiglass pressure visor was replaced with a coated polycarbonate pressure visor. This modification also permitted the use of a single-lens sun visor.

Due to fogging of the pressure visor during the latter portion of the extravehicular activity, the Astronaut Maneuvering Unit experiment was not completed; consequently, the plume protection provided for the legs could not be evaluated. However, the mission indicated the need for an inflight application of antifog solution to preclude visor fogging.

Gemini X, XI, and XII Missions

The space suits for the Gemini X, XI, and XII missions were generally of the same configuration as the suits provided for the Gemini VIII and IX–A missions. The specific experiments and operations of each flight required only minor modifications to the suits. These missions continued to expose man to the extravehicular environment, and each exposure offered areas for improvement of the space-suit equipment.

Environmental Control Systems

Two different portable environmental control systems were developed for use in Gemini extravehicular activity. These included the open-loop system used on Gemini IV and the semi-open-loop system used for Gemini VIII through XII. The basic functions of both systems were identical: (1) to provide metabolic oxygen within the suit, (2) to provide the necessary controls to maintain suit pressure at the proper level, (3) to provide ventilation gas for carbon-dioxide washout, (4) to provide a means of removing the thermal load generated by the extravehicular pilot, and (5) to provide an emergency oxygen supply to assure pilot safety in case of loss of the primary oxygen supply. The Gemini IV Ventilation Control Module System was composed of a Ventilation Control Module, two multiple gas connectors, a 25-foot umbilical, and a restraint system.

The Gemini VIII through XII Extravehicular Life-Support System consisted of a chest pack, two multiple gas connectors, two hoses connecting the multiple gas connectors to the inlet and outlet ports of the chest pack, and a restraint system. In addition, an umbilical was an integral part of the system when operating from the spacecraft supply systems. For Gemini VIII, IX–A, and XII, a 25-foot umbilical and an electrical cable were utilized. For Gemini X and XI, a 50-foot and a 30-foot umbilical, respectively, performed the combined function of the electrical cable and 25-foot umbilical.

Ventilation Control Module System

The Ventilation Control Module (fig. 7–3), flown on Gemini IV, was mounted on the pilot's chest by Velcro straps attached to the

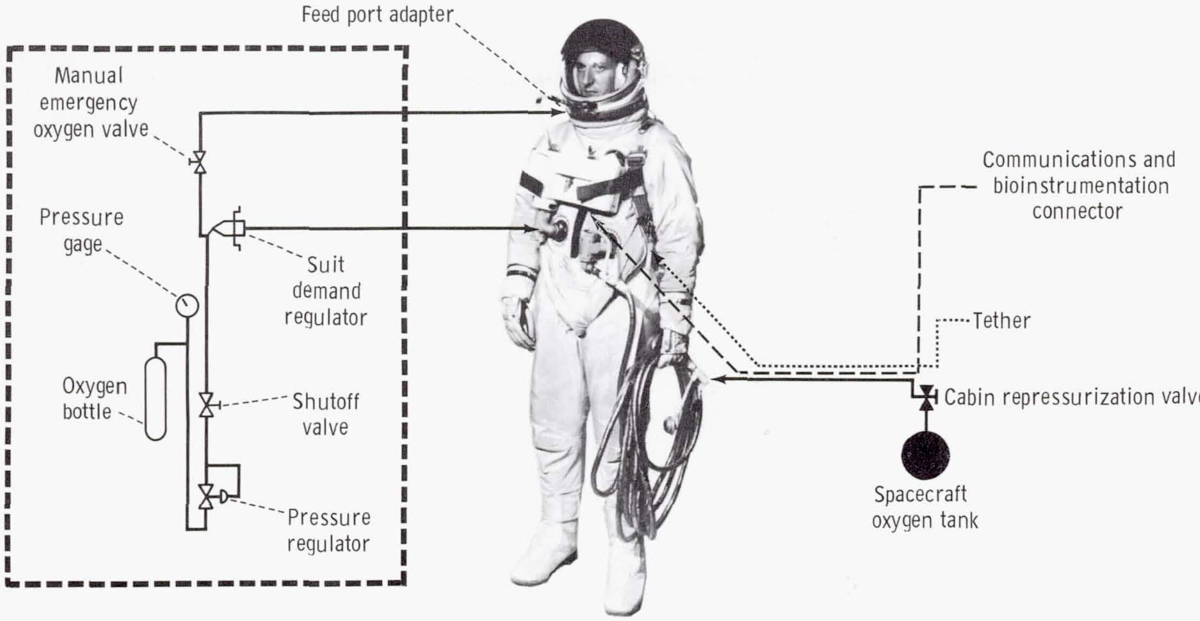

FIGURE 7–3.—Gemini IV Extravehicular Life-Support System.

parachute harness, and was connected to the suit-ventilation outlet fitting through a multiple gas connector. The Ventilation Control Module was an open-loop system; the gas was not recirculated through the system. In operation, oxygen flow of approximately 9 lb/hr was supplied to the suit to provide ventilation and for oronasal carbon-dioxide washout for metabolic rates not greater than 1000 Btu/hr. The oxygen was supplied from the primary spacecraft oxygen supply through a 25-foot umbilical and a flow restrictor. The exhaust flow from the suit was controlled by a demand regulator so that suit pressure was maintained at approximately 4 psia. The emergency oxygen supply in the Ventilation Control Module was capable of supplying oxygen for 7.5 to 9 minutes. The pilot could have activated an emergency oxygen valve to initiate oxygen flow directly into the helmet by means of an adapter installed in the helmet feed port. If a leak had developed in the suit, a makeup flow of oxygen, sufficient to maintain suit pressure, would have been initiated automatically from the emergency supply.

Extravehicular Life-Support System Chest Pack

The Extravehicular Life-Support System chest pack (fig. 7–4) was flown on the Gemini VIII through XII missions. This system was designed to provide greater heat-rejection capability than the Gemini IV system, while requiring no more oxygen makeup flow from the spacecraft. The chest pack was secured by Velcro straps attached to the parachute harness, and was connected to the suit ventilation inlet and outlet fittings through two multiple gas connectors. The chest pack was a semi-open-loop system; approximately 75 percent of the ventilation gas was recirculated through the system (fig. 7–5). The chest pack was designed to accommodate average metabolic rates of 1400 Btu/hr with peaks of 2000 Btu/hr. Tests showed that the system was capable of higher heat loads, provided the higher loads were not imposed at startup. Normally, oxygen was supplied at approximately 90 psig from the spacecraft through a quick-disconnect fitting attached to the cabin repressurization valve; however, the Extravehicular Support Package and the Astronaut Maneuvering Unit backpacks car-

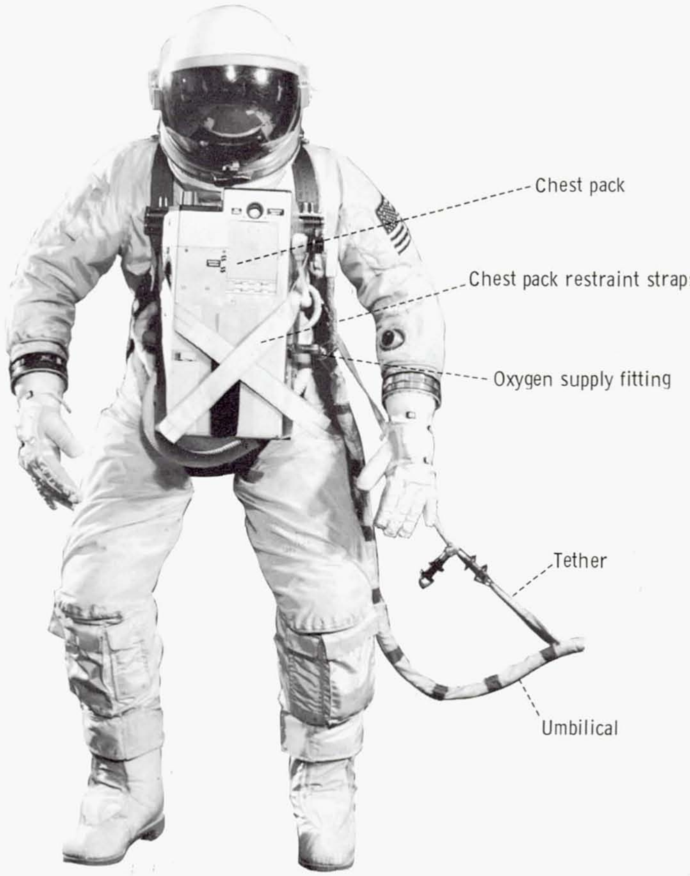

FIGURE 7-4.—Gemini VIII through XII life-support system.

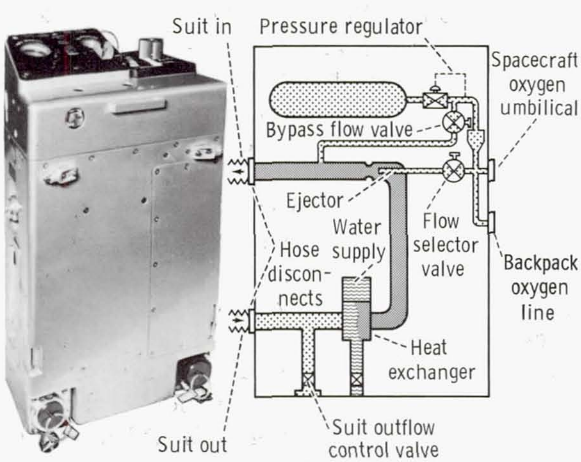

FIGURE 7-5.—Gemini VIII through XII Extravehicular Life-Support System.

ried a self-contained oxygen supply for chest-pack use, which would permit the extravehicular pilot to maneuver detached from the spacecraft oxygen system. The primary oxygen was supplied through a three-position flow-selector valve to an ejector where the 90 psig gas expanded to 4 psia. The gas expansion drove the recirculated secondary vent gas through the heat exchanger of the chest pack. The flow-selector valve permitted the pilot to select a medium or high flow (18 to 22 acfm) depending on cooling requirements. In case of blockage in the ejector, or if additional cooling or carbon-dioxide washout were required, the primary oxygen flow could be bypassed around the ejector through a valve. Suit pressure was maintained at a nominal 3.7 psig by a poppet-type outflow valve. An acceptable carbon-dioxide level was maintained by dumping overboard through the outflow valve an amount of vent gas equal to the amount of primary oxygen introduced to the system through the ejector.

If a leak in the suit loop had developed and caused the suit pressure to drop below 3.4 psig, makeup primary oxygen would have been automatically metered to the system through a demand regulator to maintain suit pressure.

The majority of the cooling for the Extravehicular Life-Support System was provided by the recirculating ventilation gas from the suit passing through an evaporative heat exchanger. In the condenser portion of the heat exchanger, the gas was cooled to approximately 45° F by the evaporation of stored water. Since the gas from the suit was about 85° F with a relative humidity of 85 percent (nominal), this cooling removed the water vapor by condensation. The condensate was then wicked to the evaporative portion of the heat exchanger to provide additional evaporative water. This type of boiling-condensation-reboiling technique is called bootstrapping.

If the normal oxygen flow to the chest pack had been interrupted, decreasing pressure in the umbilical would have automatically actuated a 30-minute emergency supply of oxygen. A visual and audio warning system on the chest pack indicated when oxygen was being used from the emergency supply. Visual and audio warning also denoted decreasing suit pressure. A special regulator acted to maintain suit pressure above 3.3 psi in the event of a suit leak, and the supply to this regulator was arranged such that makeup flow could be drawn from the spacecraft, the self-contained emergency supply, or simultaneously from both sources. Additional warning devices were available if the Astronaut Maneuvering Unit had been used.

Mission Results and Implications

The Gemini IV extravehicular activity lasted 36 minutes, and the pilot reported good thermal control except during high work periods such as ingress. Ingress into the spacecraft and closure of the hatch were difficult tasks, and caused the pilot to become overheated. The Ventilation Control Module System operated within the specified limits; however, high metabolic heat loads could not be sustained because of the inherent limited rate of heat rejection.

The semi-open-loop system was flown on Gemini VIII; however, because of the early termination of the mission, extravehicular activity was not conducted. Gemini IX–A was the first mission to evaluate the performance of the semi-open-loop Extravehicular Life-Support System. Due to the formation of fog on the visor and the resulting reduced visibility, the planned extravehicular activity was not completed. Higher-than-expected workloads were evident throughout the 2 hour 7 minute extravehicular period. The chest pack was designed for a nominal metabolic rate of 1400 Btu/hr and a maximum of 2000 Btu/hr for short periods. Medical data, crew comments, and metabolic simulations all indicated that much higher workloads were experienced. Tests after the mission showed that visor fogging occurred at metabolic rates above 2400 Btu/hr, although no fogging occurred at lower rates. The high rates, in effect, overpowered the capabilities of the evaporator-condenser. Even in medium flow the cooling capability for physiological comfort was adequate, but the evaporator-condenser could not overcome the thermal load sufficiently to prevent fogging. Visor fogging was further induced by high respiration rates (30 to 40 breaths per minute) which humidified 55 to 75 percent of the total gas flow to the helmet to near saturation. This high humidity raised the dewpoint enough so that visor fogging occurred even at normal operating temperatures. The pilot commented that the only time he became uncomfortably warm was during ingress. From this statement and from postflight examination of the evaporator-condenser, it was evident that the evaporator-condenser performance was degraded due to dryout at some period during the extravehicular activity. That period probably occurred very close to ingress.

The Gemini X extravehicular activity was terminated early because of spacecraft problems unrelated to the Extravehicular Life-Support System. Comments by the pilot and the biomedical data gathered during the 39-minute extravehicular activity indicated that the Extravehicular Life-Support System operated completely within specifications.

The Gemini XI extravehicular activity was prematurely concluded after 33 minutes. The pilot stated that the Extravehicular Life-Support System provided adequate cooling; however, the pilot stated that he was fatigued after a relatively brief period of activity outside the spacecraft. Because of a problem in securing the sun visor during the preparations for the extravehicular activity, the pilot experienced high workloads and profuse perspiration. After egress, difficulties involved in the pilot's attempts to attach the extravehicular camera and the spacecraft/target-vehicle tether resulted in high respiration rates and rapid fatigue. It is believed that the chest pack was saturated with warm, moist gas before proper evaporator-condenser operation could reduce the temperatures resulting from the problems before egress.

During the 2 hours 8 minutes of Gemini XII extravehicular activity, the Extravehicular Life-Support System operated completely within specifications. The problem of excess workload was resolved by the use of improved restraints for body positioning and frequent rest periods. This mission proved that at workloads within the design limits, the Extravehicular Life-Support System would function normally, and would provide a comfortable suit environment.

In summary, the Ventilation Control Module System operated satisfactorily within the design capabilities. Other than the possible depletion of heat-exchanger water at the end of Gemini IX–A extravehicular activity, the Extravehicular Life-Support System performed exceptionally well. It is evident, however, that future systems of this type will require increased cooling and metabolic heat-rejection capabilities. Crew comments have also indicated the desirability of eliminating bulky packages from the chest area, and of reducing the volume of self-contained life-support systems. Umbilicals from the spacecraft permit the use of smaller life-support packages, and the use of umbilical systems should be considered for future extravehicular applications.

Umbilicals

Several types of umbilicals have been used in accomplishing the Gemini extravehicular activities. These include the 25-foot umbilical used on Gemini IV, IX–A, and XII; the 50-foot umbilical used on Gemini X; and the 30-foot umbilical used on Gemini XI. Except for the Gemini IV umbilical, which interfaced directly with the space suit, all umbilicals were designed to interface with the Extravehicular Life-Support System chest pack.

The 25-foot umbilical (fig. 7–6) used for Gemini IX–A and XII supplied gaseous oxygen, either directly to the space suit or through the Extravehicular Life-Support System. The 50-foot and 30-foot umbilicals (fig. 7–7) supplied gaseous oxygen only through the Extravehicular Life-Support System and supplied gaseous nitrogen to the Hand Held Maneuvering Unit. The gaseous oxygen was supplied from the spacecraft primary supply at a nominal flow rate of 8 to 9 lb/hr at 90 psia and 65° F. The gaseous nitrogen was supplied from tanks in the spacecraft adapter section (at the inlet to the Hand Held Maneuvering Unit) at a nominal flow rate of 2 lb/min at 75 psia and 0° F.

During the standup extravehicular activity, short hose extensions connected the pilot's space suit to the spacecraft Environmental Control System. In this closed-loop operation, no interface with the Extravehicular Life-Support System was required, and the normal spacecraft ventilation flow rates were provided.

All of the umbilicals were of similar materials and of the same basic design. Each umbilical consisted of wire-reinforced, sili-

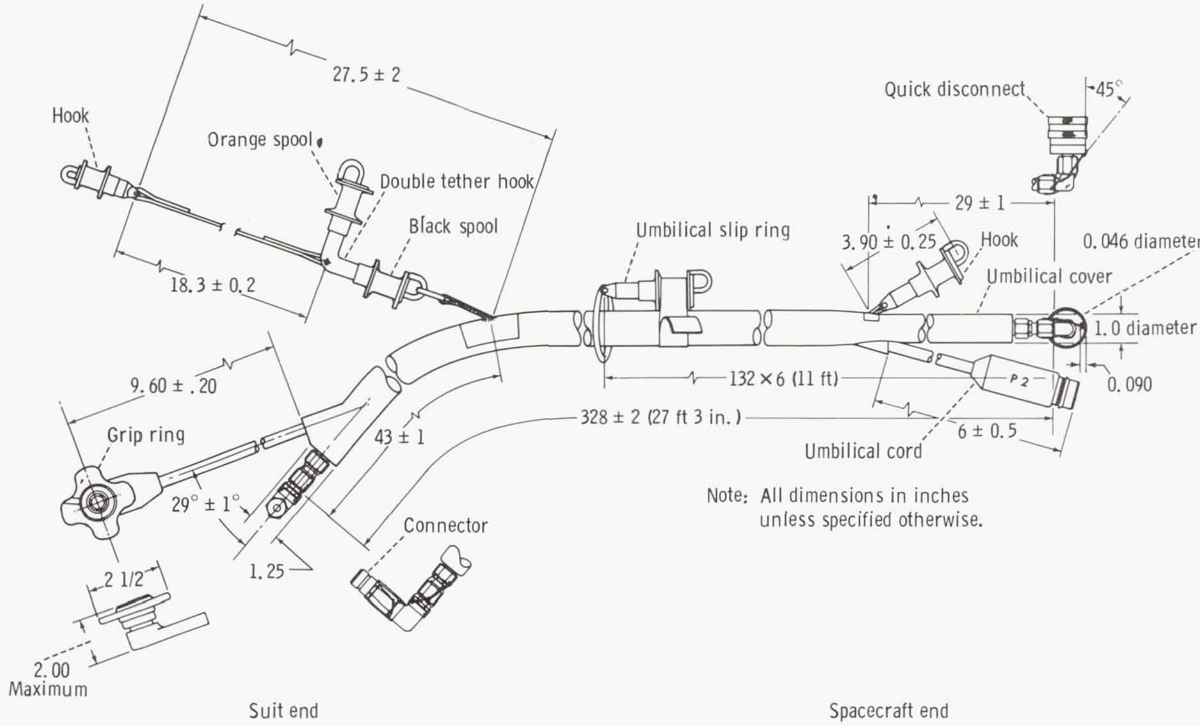

FIGURE 7–6.—Extravehicular Life-Support System, 25-foot umbilical.

cone rubber-lined hose; a 1000-pound test nylon structural tether; and wiring for voice communication, electrical power, and measurements of heart and respiration rates. For the 25-foot umbilical, the oxygen hose was 3/16-inch inside diameter. For the 50-foot and 30-foot umbilicals, the oxygen hose was ¼-inch inside diameter and the nitrogen hose ⅜ inch.

The umbilicals utilized multilayers of Mylar superinsulation for thermal protection. The temperature of gaseous oxygen supplied to the Extravehicular Life-Support System had to be maintained above —15° F to prevent freezing in the ejector. Because of the proximity of the cold nitrogen line to the oxygen line, thermal control was more critical for the 50-foot and 30-foot umbilicals than for the 25-foot umbilical.

The umbilicals were covered with nylon fabric, and chafing protection was provided where required, particularly in the area where the umbilical emerged from the cabin and contacted the hatch sill. The structural tethers were designed so that during the worst conditions of stretch under applied load, no strain was imposed on the oxygen and nitrogen hoses, or on the electrical wiring and connections. In all umbilical designs, the load was transmitted to the spacecraft through a tether attachment point located on the egress handle just inside the cabin. The loads were applied through the parachute harness of the extravehicular pilot. The 25-foot umbilical was attached by a hook to the upper part of the parachute harness; the 50-foot and 30-foot umbilicals were attached to the parachute harness at the pilot's hip.

The extensive test program for the 25-foot umbilical contributed to the development of the 50-foot and 30-foot umbilicals. The materials and the design experience gained from the development of the 25-foot umbilical were used extensively in the fabrication of the longer umbilicals. Based upon the previous experience, the test program was reduced to pressure-temperature performance, leak tests, electromagnetic interference, and

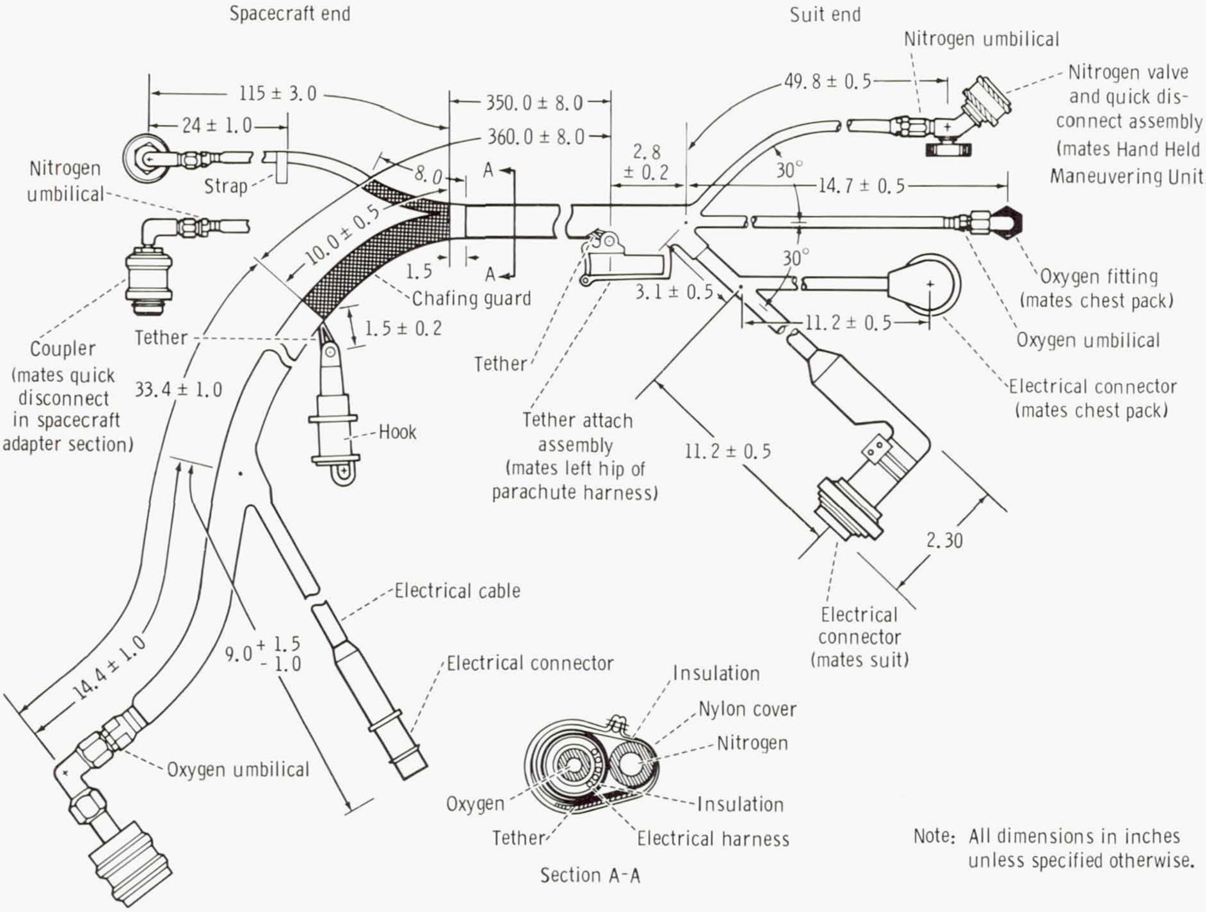

FIGURE 7-7.—Extravehicular Life-Support System, 30-foot umbilical. The 50-foot umbilical is similar.

static and dynamic structural tests. As in the case of the 25-foot umbilical, extensive unmanned altitude-chamber tests were conducted, as well as several manned chamber tests for end-to-end confirmation of the umbilical and the interface with other equipment.

The Gemini Program has shown that extravehicular activity with umbilicals is a useful, operational mode. The umbilical produced no unfavorable torques or forces on the extravehicular pilot; in fact, the pilot was hardly aware of the umbilical. Because of the length and bulk, some difficulty was experienced with the 50-foot umbilical during ingress. Therefore, any umbilical should be kept as small as practicable. Assuming that future spacecraft will be larger than the Gemini spacecraft, umbilical size may not be a problem; however, excessive length would still be undesirable. The donning of the umbilicals proved quite easy and allowed a complete system checkout prior to the extravehicular activity. Incorporation of the propulsion system supply proved satisfactory; this has many possible future uses, such as a power supply for tools.

The umbilical concept is particularly applicable to near-vehicle operations or operations in close quarters where the bulk of a self-contained life-support pack would be undesirable. Umbilical-based life-support systems would be less useful for operations that involved approaching a tumbling vehicle. However, the ease of development and the successful utilization of umbilicals during the

Gemini Program indicate a promising approach to extravehicular activity for future space programs.

Conclusion

The success of the Gemini XII extravehicular activity was largely due to the assimilation of information from preceding flights into a comprehensive program for system testing and flight-crew training. The input to this program from the NASA/Industry Life-Support System Team aided in the generation of extravehicular tasks within a planned time, mobility, and workload envelope.

8. BODY POSITIONING AND RESTRAINTS DURING EXTRAVEHICULAR ACTIVITY

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Summary

One of the foremost conclusions obtained from the experience with extravehicular activity during the Gemini Program was that man's capability to perform work was drastically reduced without the proper restraint provisions. However, with the proper restraint provisions his capability was quite comparable to his 1g capability.

Introduction

This paper describes the body positioning and restraint problems encountered during extravehicular activity in the Gemini Program, and the types of restraint equipment which were used.

The requirement for body restraints during extravehicular activity was indicated on Gemini IV. After depletion of the propellant in his maneuvering unit, the pilot evaluated the umbilical as an aid in body positioning and in moving through space. It was concluded that the umbilical was reliable only as an aid in moving to its origin, and that handholds would be required for other extravehicular maneuvers. The significance of the requirement was emphasized when body-restraint problems contributed to the premature termination of the Gemini IX–A and Gemini XI extravehicular activities. The Gemini XII mission verified that, with adequate restraint provisions, man can perform a great variety of tasks, some of considerable complexity. On Gemini XII, 44 pieces of equipment were provided for extravehicular body restraint in contrast to the 9 pieces of body-restraint equipment provided for Gemini IX–A extravehicular activity.

Control of Body Position

Foot Restraints

The first major work task attempted during Gemini extravehicular activity was the checkout and donning of the Astronaut Maneuvering Unit on Gemini IX–A. The original restraint provisions for this task were two handbars and a horizontal footbar. Velcro on the footbar was intended to mate with Velcro on the pilot's boots; however, the need for additional body restraint for this task was demonstrated in the zero-g airplane (fig. 8–1). A pair of foot restraints was added to the horizontal footbar, and on subsequent flights in the zero-g airplane, checkout of the Astronaut Maneuvering Unit was easily accomplished (fig. 8–2). The pilot would force his feet into the restraints, and the frictional force would contain his feet, allowing him to have both hands free for working.

However, during the Gemini IX–A extravehicular activity, the pilot was not able to maintain body position using only foot restraints. The attempts at two-handed tasks, primarily the tether connections, were exceedingly difficult because every few seconds the pilot had to stop working and use his hands to regain proper body position. The foot restraints were even less satisfactory when unstowing the Astronaut Maneuvering

FIGURE 8-1.—Donning of Astronaut Maneuvering Unit without foot restraints.

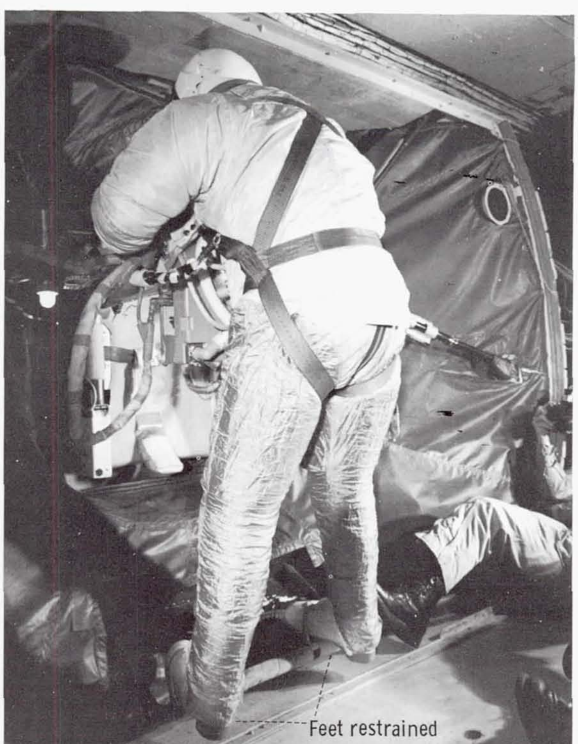

FIGURE 8-2.—Donning of Astronaut Maneuvering Unit using foot restraints.

Unit controller arms. When the pilot bent forward and applied a downward force to the controller arm, he created a moment which forced his feet out of the restraints. The inadequacy of the foot restraints caused the pilot to exert a continuous high workload to maintain control of body position, in addition to the work involved in performing the tasks. Heat and perspiration were produced at a rate exceeding the removal capability of the life-support system, and fog began accumulating on the space-suit visor. This fogging progressed until the pilot's vision was almost totally blocked, forcing him to abandon his attempts to don and use the Astronaut Maneuvering Unit.

As a result of this experience during Gemini IX–A, new requirements for foot restraints were developed and the investigation of underwater simulation of zero-g was initiated. Numerous equipment modifications were also incorporated to simplify the extravehicular activity tasks on subsequent missions.

Analysis of the Gemini IX–A body-restraint problem resulted in the following criteria for design of new foot restraints: motion must be restrained in all 6 degrees of freedom, and restraint of the feet must involve no mechanical devices. Molded fiberglass foot restraints incorporating these features were designed for the Gemini XI and XII spacecraft. The restraints were custom fitted to the pilot for each flight, and were mounted on a platform attached to the inside surface of the spacecraft adapter equipment section (fig. 8–3). During the zero-g airplane training, the Gemini XI and XII flight crews used and evaluated the foot restraints and found them completely adequate for all tasks envisioned. The Gemini XII flight crew also trained with the restraints in the underwater zero-g simulation facility with the same results.

Underwater Zero-Gravity Simulation

The initial evaluation of the underwater zero-g simulation was conducted by the

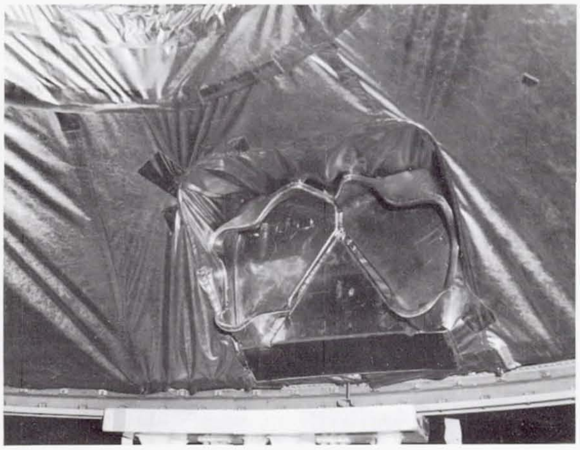

FIGURE 8-3.—Foot restraints used during Gemini XII extravehicular activity.

Gemini IX–A pilot shortly after the mission. The configuration of the mockup equipment was similar to that of the Gemini IX–A spacecraft, and the pilot repeated the Astronaut Maneuvering Unit checkout and donning procedures previously attempted in flight. The pilot concluded that the underwater zero-g simulation very nearly duplicated the actual weightless condition and the accompanying problems experienced in flight. The extravehicular tasks planned for Gemini X, XI, and XII were then performed in the underwater zero-g simulation, and recommendations were made concerning the required restraints and the feasibility of proposed tasks. Underwater simulation of zero-g has great applicability to extravehicular activities, particularly to the problems of body positioning and restraints.

Handholds and Tether Devices

Several restraint problems were encountered during Gemini X extravehicular activity, but performance of the planned tasks was not seriously affected. The pilot had difficulty controlling his body position while using the edge of the target-vehicle docking cone as a handrail to move to the area of the Experiment S010 Agena Micrometeorite Collection package. Attachment of the umbilical nitrogen fitting was also a difficult task because the handrail provided for restraint did not properly deploy. The tasks were accomplished with one hand, while the other hand was used for restraint.

For the Gemini XI mission, the tether for the spacecraft/target-vehicle tether evaluation was assembled and stowed so that the pilot could attach it to the spacecraft docking bar with one hand. With the other hand, the pilot could use one of the three handholds on the back surface of the docking cone for maintaining his position. However, the pilot had trained to have both hands free, and he had been able to wrap his legs around the spacecraft nose and wedge his legs into the docking cone. The pilot could force himself into position by arm force using the handholds provided. In the zero-g airplane, the task was so easy that the pilot was able to move from the hatch, force himself into the restrained position, and make the complete tether hookup in a single parabola (about 30 seconds). In flight, however, the restraint technique proved extremely difficult, and the pilot expended a great deal of energy during the 6 minutes that were required to move from the hatch and make the tether hookup. This was the major factor in his inability to continue the flight plan for the extravehicular activity. As in the case of the Gemini IX–A pilot, the prime expenditure of energy by the Gemini XI pilot was the continuous struggle to maintain body position in order to perform the required tasks. Apparently, the frictional forces exerted by the pilot in wedging his legs into the docking cone were not sufficient to overcome the tendency of the pressurized suit to expand and push him out of the docking cone.

As a result of this experience, it was decided that the Gemini XII flight crew would include underwater zero-g simulation in the training for extravehicular activity. As a result of the problems encountered during Gemini extravehicular activities, the extravehicular objective for Gemini XII was changed to an evaluation of body restraints instead of the evaluation of the Astronaut Maneuvering Unit. The objective of the re-

straint evaluation was to determine what type of restraints were required for representative extravehicular tasks.

Restraint Equipment

The use of restraint devices for extravehicular activity on the Gemini Program is summarized in table 8–I. Descriptions of these devices and results of their use follow.

Rectangular Handrail

Two rectangular handrails (fig. 8–4) were installed along the spacecraft adapter section to assist the extravehicular pilot in moving from the cockpit to the adapter equipment section where various tasks were to be performed; for example, donning the Astronaut Maneuvering Unit. The handrails were flush with the spacecraft surface at launch, and were 1.5 inches above the spacecraft surface when deployed. The aft handrail deployed automatically when the spacecraft separated from the launch vehicle. The forward handrail was manually deployed by the extravehicular pilot.

The Gemini IX–A and XII pilots used the handrails to travel the 8 feet from the cockpit to the aft end of the spacecraft. The limited suit mobility and interference by the life-support system chest pack required the pilots to traverse the handrail by moving the hands one after the other to the side, rather than hand over hand. The Gemini X pilot used the handrail to travel from the hatch to the end of the adapter retrograde section and return, and then as a handhold while making and breaking the nitrogen connection on the 50-foot umbilical. Comments by the pilots indicated that the configuration of this handrail was the best for travel between two points on the spacecraft surface. A rectangular, rather than a cylindrical, cross section

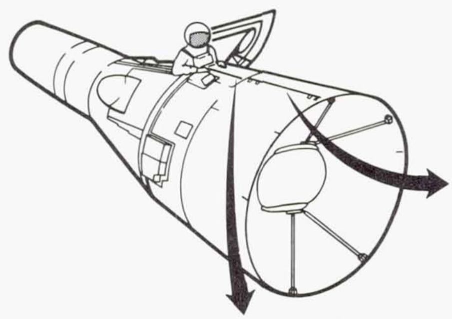

FIGURE 8–4.—Extendable handrails.

TABLE 8–I.—*Restraint Devices Used During Gemini Extravehicular Activities*

Restraint device configuration	Gemini mission			
	IX–A	X	XI	XII
Rectangular handrail	X	X	X	X
Large cylindrical handrail (1.38 in. dia)	X			X
Small cylindrical handrail (0.317 in. dia)				X
Telescoping handrail				X
Fixed handhold			X	X
Rigid Velcro-backed portable handhold				X
Flexible Velcro-backed portable handhold	X			
Waist tethers				X
Pip-pin handhold/tether-attach device				X
Pip-pin antirotation device				X
U-bolt handhold/tether-attach device				X
Foot restraints	X			X
Standup tether		X	X	X
Straps on space-suit leg			X	X

was preferred because the rectangular shape offered more resistance to rotation for a given hand force, and allowed better control of body attitude. In a pressurized Gemini suit, the width of the rectangular handrail (1.25 inches) was a good size for gripping.

Large Cylindrical Handrails

A pair of large cylindrical handrails (fig. 8–5) was furnished in the adapter equipment section to permit the pilot to move from the rectangular handrails to the work area, and to provide restraint while positioning his feet in foot restraints or while working. The two handrails were symmetrically located on each side of the work station. Although the pilots indicated a preference for rectangular cross section, they were able to use the cylindrical handrails to introduce the significant body torques required to position their feet in the foot restraints. The diameter (1.38 inches) of the cylindrical handrails was the most favorable size.

Small Cylindrical Handrails

There were two segments of small cylindrical handrails (figs. 8–6 and 8–7) rigidly mounted on the forward surface of the cylindrical portions of the Target Docking Adapter on the Gemini XII target vehicle. The handrails were small enough to be used as waist tether-attach points, as well as for handholds. Although the handrail was not evaluated extensively, the configuration was usable as a handhold, and the pilot considered the size a good feature since it permitted direct attachment of the waist tethers.

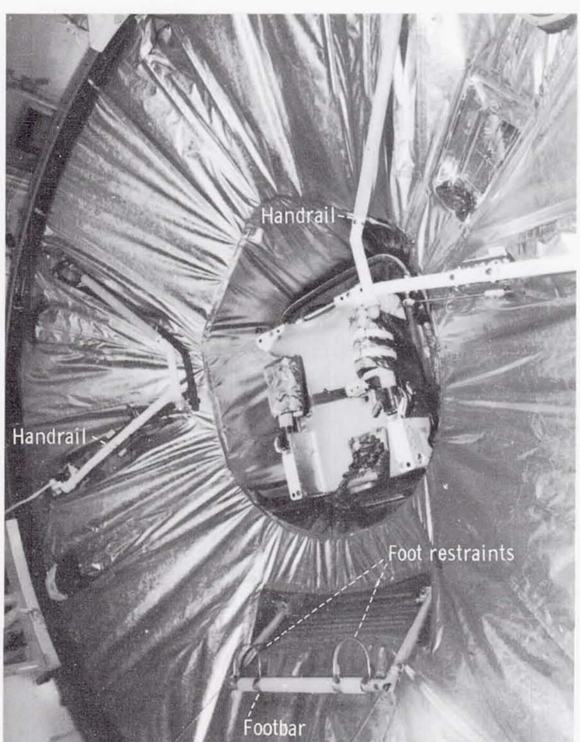

FIGURE 8–5.—Handrails and foot restraints in the Gemini IX–A spacecraft adapter equipment section.

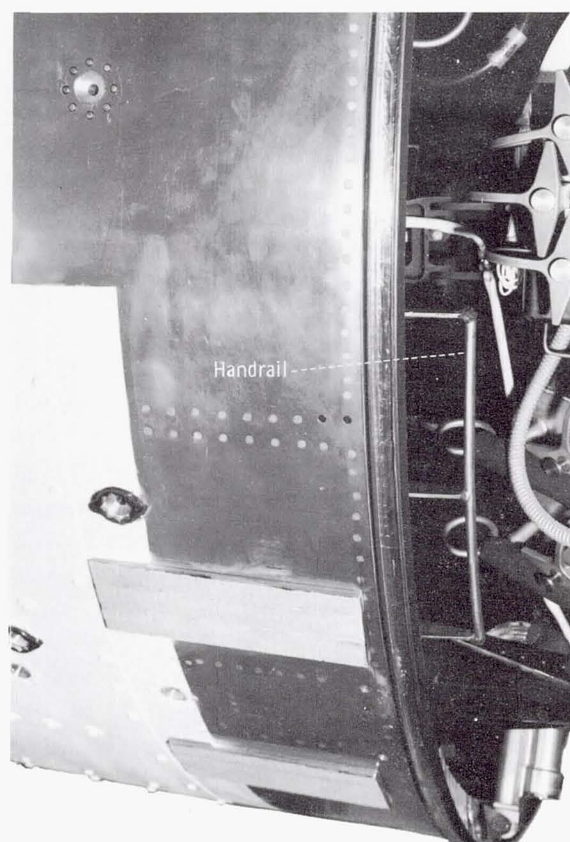

FIGURE 8–6.—Handrail on left side of target vehicle.

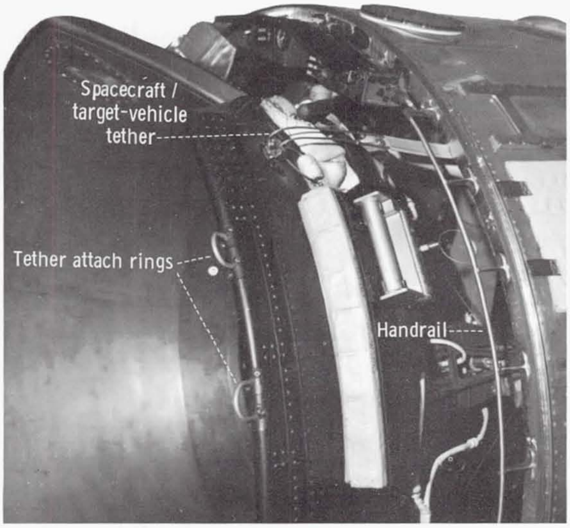

FIGURE 8-7.—Handrail on right side of target vehicle.

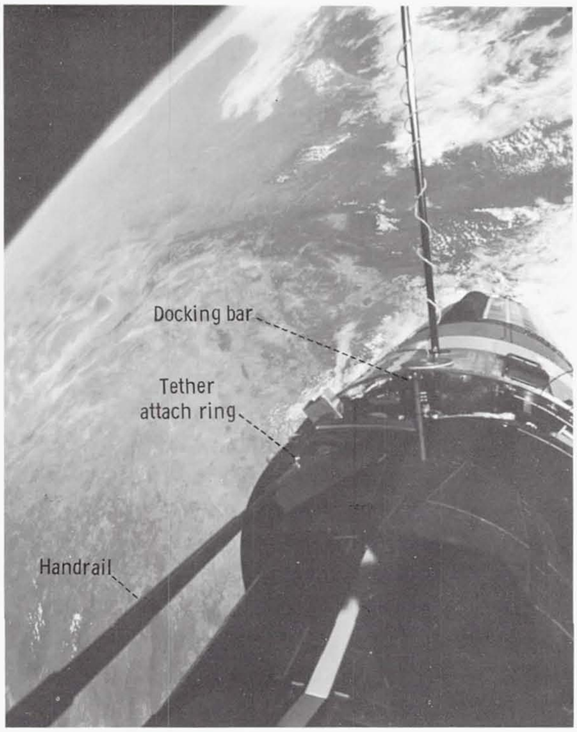

FIGURE 8-9.—Telescoping handrail attached to vehicles.

Telescoping Cylindrical Handrail

The Gemini IX–A and XI pilots used the spacecraft Reentry Control System thrusters as handholds for travel from the spacecraft hatch to the spacecraft nose; however, the thrusters were neither well located nor easy to use for that purpose. On each of these missions, the extravehicular pilot went over the top of the docking bar on his first attempt to propel himself from the thrusters to the spacecraft nose.

During Gemini XII, the telescoping handrail (figs. 8–8 and 8–9) solved the problem of travel from the spacecraft hatch to the spacecraft nose. The telescoping handrail was stowed in the compressed condition near the hinge of the right hatch, located above the pilot's right shoulder. After the cabin was depressurized and the hatch was opened for standup extravehicular activity, the pilot unstowed and manually extended the handrail. The pilot then installed the small end of the handrail in a special receptacle in the target-vehicle docking cone, and the large end on a mounting bolt in the spacecraft center beam, between the hatches. During the umbilical extravehicular activity, the pilot used this handrail for two round trips between the spacecraft hatch and the spacecraft nose, and as a handhold for several changes in body attitude. The nonrigidity of the handrail was considered undesirable by the pilot; when the handrail flexed, the pilot no longer had absolute control of body position and attitude. While attaching the spacecraft/target-vehicle tether, the pilot also used the ring on the telescoping handrail for a waist tether-attach point. At the conclusion of the umbilical extravehicular period, the pilot removed and jettisoned the handrail.

FIGURE 8-8.—Telescoping handrail compressed.

Fixed Handhold

Three fixed handholds (fig. 8–10) were provided on the back of the docking cone on the Gemini XI target vehicle to provide restraint for the spacecraft/target-vehicle tether attachment. Two identical handholds were provided on the back of the docking cone on the Gemini XII target vehicle. The handholds proved very useful in flight, and the friction coating was a good feature.

Flexible Velcro-Backed Portable Handhold

Flexible Velcro-backed portable handholds (fig. 8–11) were evaluated as restraints and as maneuvering aids during the Gemini IX–A mission. Two fabric-backed nylon Velcro pile pads were carried in the spacecraft. The pilot attached the pads to his gloves with an elastic strap wrapped around the palms of the hands. There were about 80 patches of nylon Velcro hook on the surface of the spacecraft to engage the pile handholds. Some of the significant results included the following: (1) the elastic attachment was not adequate, as one of the handholds was pulled off his glove; (2) the contact forces were not sufficient to accommodate controlled maneuvering or control of body attitude, but were sufficient for station keeping; (3) the unprotected Velcro hook on the spacecraft nose was degraded by launch heating.

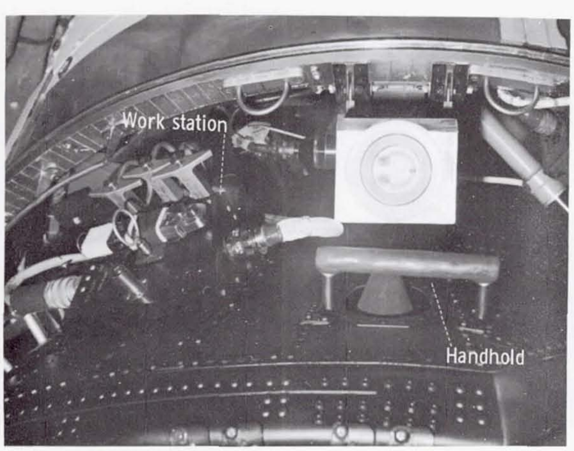

FIGURE 8–10.—Target vehicle extravehicular work station and handhold.

FIGURE 8–11.—Flexible Velcro-backed portable handhold.

Rigid Velcro-Backed Portable Handhold

For Gemini XII, four trowel-shaped, rigid, Velcro-backed, portable handholds (fig. 8–12) were installed in the extravehicular work areas. The handholds were coated with resilient material, with a tether-attach ring at one end. Two of the handholds had about 9 square inches of nylon-pile Velcro, and two had about 16 square inches of polyester-pile Velcro. The handholds were stowed for launch on a surface of hook Velcro and further restrained by a pip-pin device. Four areas of polyester hook Velcro on built-up flat surfaces were located on the target vehicle to engage the Velcro on the handholds. Polyester Velcro has greater adhesive force than nylon Velcro, and does not require protection from launch heating.

Detailed evaluations of the rigid Velcro-backed portable handholds were not included in the flight plan for Gemini XII extravehicular activity. Analyses and simulations indicated a number of limitations concerning

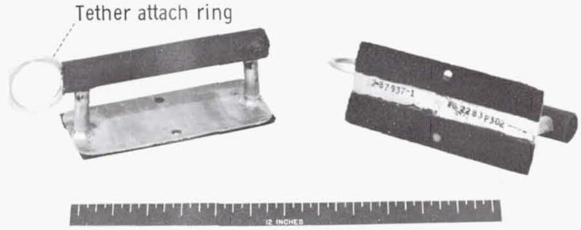

FIGURE 8–12.—Rigid Velcro-backed portable handhold.

the usefulness of the devices. For example, best utilization requires that the Velcro be placed in shear rather than tension, and this complicates the usage. Also, the restraint force should be significantly greater than the required applying force; this is not true of nylon Velcro. Polyester Velcro is better, but has not been evaluated as thoroughly as the nylon. The use of steel Velcro would make these devices feasible, but the potential hazard to the space suit is not tolerable at this time.

Waist Tethers

The Gemini XII waist tethers (fig. 8–13) were made of stiff nylon webbing with a length-adjustment buckle and a large hook for attachment to the various tether-attach rings. The waist tethers were looped around the pilot's parachute harness and were fastened with two large snaps. A large fabric tab was provided to facilitate opening the snaps of a pressurized suit. A D-shaped ring was provided for making length adjustments, and was used several times by the pilot. The adjustment buckle, a conventional single-loop buckle, allowed length adjustment between approximately 32 and 21 inches.

The tether attachment to the pilot, slightly below waist level, was considered well located by the pilot. A special device, consisting of a thin metal plate with a ring on each end for attaching the waist tether hooks, was provided to restrain the waist tethers while not in use. The device was slightly longer than the front width of the life-support system chest pack and was attached with Velcro. The pilot used a variety of devices for attaching the tethers in the spacecraft adapter section and on the target vehicle. The pilot used about six different pairs of tether-attach points which had been selected during training. At one time, because of the lack of good control of body attitude, the Gemini XII pilot experienced a slight difficulty in moving a tether to a new attach point. With one hand occupied in making a waist tether attachment, the pilot had to use the other hand to control body attitude. Therefore, a pair of handholds or other restraints near each pair of tether-attach points was desirable. Also, it was determined that the waist tether-attach points should be as far apart as possible, consistent with the pilot's reach in the pressurized suit. The attachments were easier to make when the attach points were located at the pilot's sides rather than directly in front of him; and torques were cancelled better with widespread tether-attach points. The pilot observed that few adjustments were required to the tether length; consequently, provisions for adjustments could be eliminated from future body tethers.

With only the waist tethers for restraint, the pilot was able to use a conventional torque wrench to install and tighten a bolt to about 200 inch-pounds on the spacecraft adapter section work station (fig. 8–14). Again, with only the waist tethers for restraint, the pilot was able to pull nylon Velcro pile strips 4

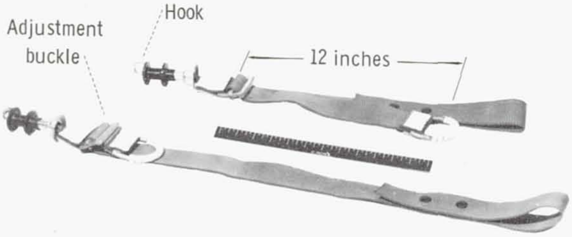

FIGURE 8–13.—Waist tethers.

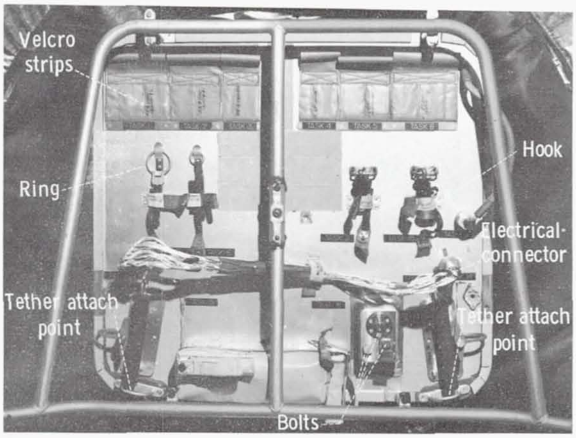

FIGURE 8–14.—Gemini XII extravehicular adapter work station.

inches long and 5 inches wide from both nylon and steel Velcro hook, and to disconnect and reconnect three electrical connectors. The pilot also made a variety of hook and ring connections, including hooks and rings of the same sizes which had proved impossible for the Gemini IX–A pilot to connect.

The waist tethers, when attached to the tether-attach points on the target vehicle (fig. 8–15), provided the required restraint for the Gemini XII pilot to attach the spacecraft/target-vehicle tether; activate the Experiment S010 Agena Micrometeorite Collection package; and disconnect and connect fluid connectors and an electrical connector. The pilot used the Apollo torque wrench to exert greater than 100 inch-pounds of torque; he concluded that man's capability is even greater, and could be determined in the underwater zero-g simulation. The pilot was able to perform these tasks with one waist tether attached and one hand on a handhold, and then to repeat the tasks without using waist tethers. He strongly recommended, however, that body tethers be included in the restraint systems for future tasks involving torque. It is probable that body tethers will provide a greater capability for applying torque; minimize the effort required in controlling body position; and, if a tool should slip, eliminate the possibility of it drifting away.

One of the best features of body tethers is the elimination of the constant anxiety of drifting into an unknown and uncontrolled body position, while performing work or while resting. The waist tethers permitted the Gemini XII pilot to relax completely during the designated rest periods and at any other desired time. During previous umbilical extravehicular activity, the pilots had been required to hang on with one or both hands and rest, as well as possible, in this condition. Of course, the work required to control body position eliminated the possibility of complete rest.

Pip-Pin Handhold/Tether-Attach Devices

Seven pip-pin handhold/tether devices (fig. 8–16) were used during Gemini XII. These devices used a conventional pip-pin mechanism with ball detents for attachment to the spacecraft. The T-shape of the pip-pins facilitated their use as handholds, and a loop was installed for tether attachment. The pilot used the devices as handholds during changes in body position and as waist tether-attach points during some of the work tasks on the target vehicle.

The T-shaped pip-pins were a convenient shape and size for hand gripping. When the rotational freedom of the devices was removed, the devices made excellent handholds, and allowed complete control of body attitude. The elimination of rotational freedom also made waist tether attachment much easier.

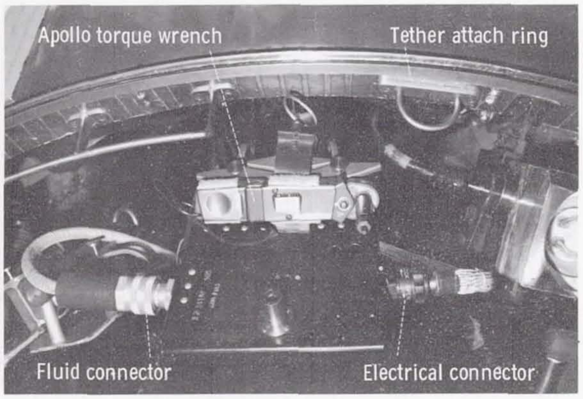

FIGURE 8–15.—Target vehicle extravehicular work station.

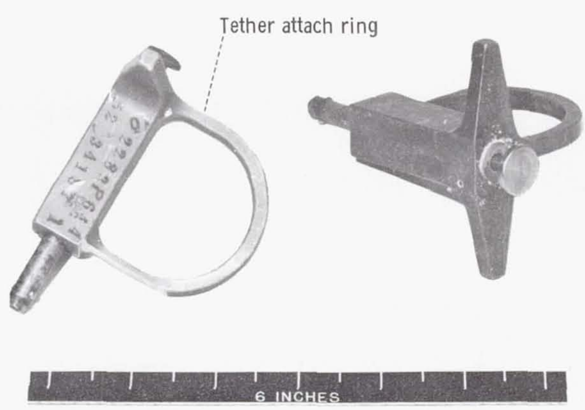

FIGURE 8–16.—Pip-pin device.

Pip-Pin Antirotation Devices

The pip-pin antirotation devices (fig. 8–17) were installed over 11 of the pip-pin attachment holes. Without the antirotation device, the pip-pins were free to rotate, and would do so when given any small torque. Experience during Gemini XII showed that the antirotation devices were valuable when the pilot applied torque to the pip-pins, such as performing most tasks while tethered. However, with the antirotation device in place, the pip-pins had to be installed in one of eight specific orientations, which complicated the installation. Therefore, if pip-pin devices of this type are to be used, antirotation devices are very desirable, but the requirement for such precise alinement is undesirable.

U-Bolt Handhold/Tether-Attach Devices

Nine U-bolt handhold/tether-attach devices (fig. 8–18) were installed in the extravehicular work areas on Gemini XII. The pilot used

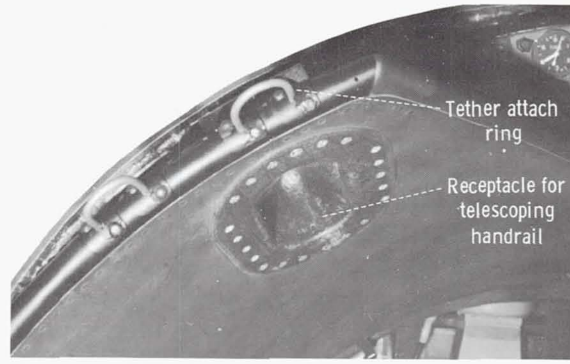

FIGURE 8–18.—Extravehicular restraint provisions on target vehicle docking cone.

two of the U-bolts installed in the spacecraft adapter as waist tether points during the work without foot restraints, but the close proximity (about 4 inches) to the bolt platform caused some inconvenience during the bolt torquing. The pilot found the U-bolts on the target vehicle useful for waist tether attachment and as handholds during work tasks and position changes.

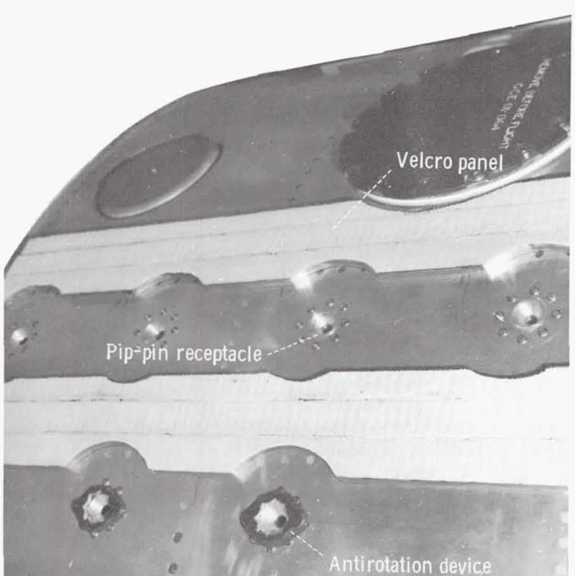

FIGURE 8–17.—Pip-pin and Velcro attachment points.

Foot Restraints

The Gemini IX–A foot restraints (fig. 8–5) were not adequate for body restraint even in the absence of external forces. The molded foot restraints on the Gemini XII spacecraft, however, were considered by the pilot to be far superior to all other restraint devices he evaluated. With his feet in these restraints (fig. 8–19), the pilot was able to nearly duplicate his 1g proficiency in performing tasks. He applied torques in excess of 200 inch-pounds, and performed alinement (fluid connector) and cutting operations. In addition to performing work tasks, the Gemini XII pilot evaluated the body-attitude constraints imposed by the foot restraints. The pilot was able to force himself backward (pitch up) about 90°; however, a significant effort was required to maintain that position. He was able to roll ±45°, and his yaw capability was almost ±90°.

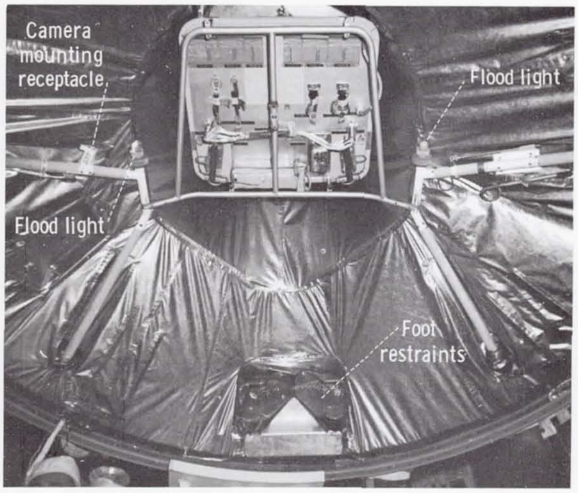

FIGURE 8–19.—Gemini XII adapter provisions for extravehicular activity.

Standup Tether

To prevent stressing the pilot's oxygen and electrical connections with the spacecraft, standup tethers (fig. 8–20) were used during the standup extravehicular activity on Gemini X, XI, and XII. The standup tethers were attached to the extravehicular pilot's parachute harness and to the left side of the pilot's seat. The tethers were constructed of thin nylon webbing and had a conventional single-loop adjustment buckle. The command pilot held the free end of the tether and usually performed the required adjustments, although on Gemini XII the extravehicular pilot was also able to make adjustments.

Space-Suit Leg Straps

For Gemini XI, a strap (fig. 8–21) about 9 inches in length was sewed on the left leg (in the calf area) of the pilot's space suit. When not in use, the strap was folded inside a Velcro pocket on the space suit. During the umbilical extravehicular activity, with the pilot standing in the seat, the command pilot opened the Velcro pocket and pulled out the strap. The strap was intended to serve the same purpose during umbilical extravehicular activity that the standup tether served during the standup extravehicular activity.

On the Gemini XII mission, identical straps were sewed on both legs of the pilot's space suit. The straps were not used, however, because the command pilot found it easier to hold the pilot's foot to secure him.

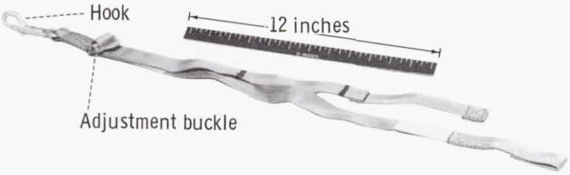

FIGURE 8–20.—Standup tether.

FIGURE 8–21.—Space-suit leg strap.

Concluding Remarks

Provision of adequate body restraints is one of several factors which can assure the success of an extravehicular activity mission.

Based on the extravehicular experience accumulated in the Gemini Program, it was concluded that thorough analysis and detailed training for extravehicular activity must be continued, and that the body-restraint requirements indicated by the analysis and the training must be met. During the extravehicular activity, restraints must be provided for rest as well as for work tasks.

The restraints that were found to be most satisfactory during the Gemini Program included:

(1) Gemini XII foot restraints, for rest and localized work

(2) Gemini XII waist tethers, for rest and localized work

(3) Rectangular handrail, for translating across a spacecraft surface

(4) Pip-pin devices, for combination tether-attach points and handholds

9. EXTRAVEHICULAR MANEUVERING ABOUT SPACE VEHICLES

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Introduction

The purpose of this report is to summarize what has been learned from the Gemini Program concerning extravehicular maneuvering in the near vicinity of the spacecraft. Maneuvering with the Hand Held Maneuvering Unit was scheduled for the Gemini IV, VIII, X and XI missions, and with the Astronaut Maneuvering Unit for the Gemini IX–A and XII missions.

The evaluations of the maneuvering equipment planned for Gemini VIII, IX–A, X, and XI were not completed because of problems with spacecraft equipment before the evaluations were scheduled. Because of increased emphasis on the evaluation of body-restraint problems, the Astronaut Maneuvering Unit was not carried on Gemini XII.

Even though only limited extravehicular maneuvering was accomplished during the Gemini Program, a number of significant maneuvering systems were readied for flight and were actually carried into space. One purpose of the first portion of this report is to describe, in general, the maneuvering equipment used for extravehicular activity during the Gemini Program. The second portion describes the ground training equipment and the methods used in preparing the flight crews for extravehicular maneuvering. The third portion recounts the brief, but interesting, flight results obtained with the Hand Held Maneuvering Unit during Gemini IV and Gemini X, and draws a comparison between flight performance and ground training indications.

Gemini Extravehicular Maneuvering Units

Prior to the development of the Hand Held Maneuvering Unit utilized on the Gemini IV mission, several experimental hand-held gas-expulsion devices were evaluated at the Air Bearing Facility, Manned Spacecraft Center. While working with the early Hand Held Maneuvering Units, some preconceived ideas were abandoned and some new ideas were generated. The following were learned from the early concepts:

(1) For translating, the tractor mode was inherently stable and easiest to control.

(2) Tractor nozzles placed far apart and parallel provided much less gas-impingement loss than nozzles placed side by side and canted outward.

(3) Due to lack of finger dexterity in pressurized gloves, the trigger operating the pusher and tractor valves had to be operated by gross movements of the hand as opposed to finger or thumb manipulation.

(4) Because of the constraints placed on arm and hand movement by the pressurized suit, together with the need to easily aline the thrust with the operator's center of gravity, the handle of the space gun had to be on top, and certain angles had to be built into the Hand Held Maneuvering Unit to insure easy aiming of thrusters when the pilot's arm and the hand were in a natural hard-suit position.

(5) Precise attitude control was enhanced by utilizing a proportional thrust system, rather than an off-on system, for controlling thrust level.

Gemini IV Hand Held Maneuvering Unit

The configuration for the Gemini IV Hand Held Maneuvering Unit (fig. 9–1) was evolved from early concepts, mission requirements, and available qualified components. The 4000-psi storage tanks were the same as the emergency bailout bottles used in the Gemini ejection seat. The pressure regulator had been used in the Mercury Environmental Control System. A summary of the operating characteristics of the Gemini IV maneuvering unit is provided in table 9–I, and a cutaway drawing is shown in figure 9–2.

Mission requirements dictated that the Hand Held Maneuvering Unit be stowed inside the spacecraft cabin. This required the selection of a propellant gas which would not contaminate the spacecraft atmosphere if leakage occurred; oxygen in the gaseous form was chosen as the propellant. Since very limited storage space was available, the Hand Held Maneuvering Unit was stowed in two sections: the handle assembly and the high-pressure section. The two sections were joined by connecting a coupling at the regulator and inserting a pin adjacent to the pusher nozzle (fig. 9–2).

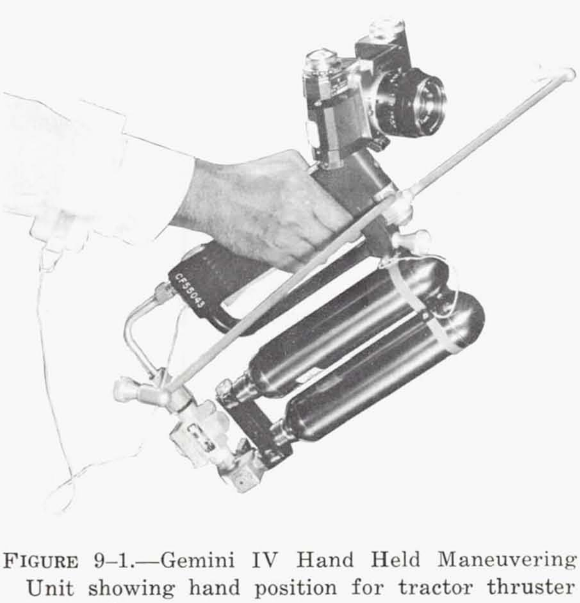


FIGURE 9–1.—Gemini IV Hand Held Maneuvering Unit showing hand position for tractor thruster application.

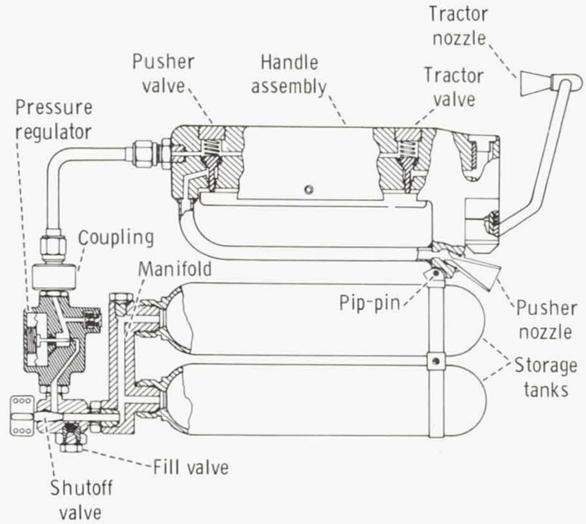


FIGURE 9–2.—Cutaway drawing of Gemini IV Hand Held Maneuvering Unit.

TABLE 9–I.—*Gemini IV Hand Held Maneuvering Unit Characteristics*

Thrust, lb	0 to 2
Total impulse, lb×sec	40
Total available ΔV, ft/sec	6
Trigger preload, lb	15
Trigger force at maximum thrust, lb	20
Storage-tank pressure, psi	4000
Regulated pressure, psi	120
Nozzle-area ratio	50:1
Empty weight, lb	6.8
Oxygen weight, lb	0.7
Gross weight, lb	7.5

After gaseous oxygen left the 4000-psi storage tanks (fig. 9–2), it passed through a manifold to a shutoff and fill valve. When this valve was opened, the oxygen entered a pressure regulator which reduced the pressure to 120 psi. The low-pressure oxygen entered the handle of the Hand Held Maneuvering Unit and passed through a filter to two valves. The valve located at the rear of the handle permitted the gas to flow through the trigger guard to the pusher nozzle. The valve located at the forward end of the unit ported gas through a swivel joint, then through two arms to the tractor nozzles. The arms of the tractor nozzles folded back for

compact storage. The pusher and tractor valves were actuated by depressing the trigger. The amount of force applied to the pusher or tractor valve determined the thrust level. A force of 15 pounds applied to the valve poppet initiated gas flow to the nozzle; as the force was increased to 20 pounds, the thrust level increased proportionately from 0 to 2 pounds.

The gas storage tanks held only 0.7 pound of oxygen. This provided a total impulse of 40 lb × sec, or 2 pounds of thrust for 20 seconds. If used continuously, this total impulse would accelerate the extravehicular pilot and the life-support system (215 pounds) to a velocity of 6 ft/sec.

Gemini VIII Hand Held Maneuvering Unit

In the Gemini VIII mission, the total impulse was increased to 600 lb × sec (15 times more than the Gemini IV unit). A summary of the Gemini VIII maneuvering system characteristics is given in table 9–II. Eighteen pounds of Freon 14 gas were stored at 5000 psi in a 439-cubic-inch tank. The tank was mounted in a backpack (fig. 9–3) which also housed an identical tank filled with 7 pounds of life-support oxygen. Freon 14 was chosen as a propellant because, even though its specific impulse (33.4 seconds) was lower than oxygen (59 seconds) or nitrogen (63 seconds), its density was almost three times as great, therefore providing more total impulse for a slight increase in total mass. This can be illustrated by the following calculations:

$$7 \text{ lb } O_2 \times 59 \text{ lb} \times \text{sec/lb} = 413 \text{ lb} \times \text{sec total impulse}$$

$$18 \text{ lb Freon } 14 \times 33.4 \text{ lb} \times \text{sec/lb} = 600 \text{ lb} \times \text{sec total impulse}$$

The calculations indicate a 45-percent increase in total impulse for Freon 14 over oxygen at the same maximum tank pressure (5000 psi). Inasmuch as the weight of the extravehicular pilot with all gear except propulsion gas was about 250 pounds, the use of Freon 14, rather than oxygen or nitrogen, was an excellent tradeoff as far as the change-in-velocity capability was concerned.

TABLE 9–II.—*Gemini VIII Hand Held Maneuvering Unit Characteristics*

Propellant, gas	Freon 14
Thrust, lb	0 to 2
Specific impulse (calculated), sec	33:4
Total impulse, lb × sec	600
Total available ΔV, ft/sec	54
Trigger preload, lb	15
Trigger force at maximum thrust, lb	20
Storage-tank pressure, psi	5000
Regulated pressure, psi	110±15
Nozzle-area ratio	50:1
Weight of propellant, lb	18
Weight of Hand Held Maneuvering Unit, lb	3

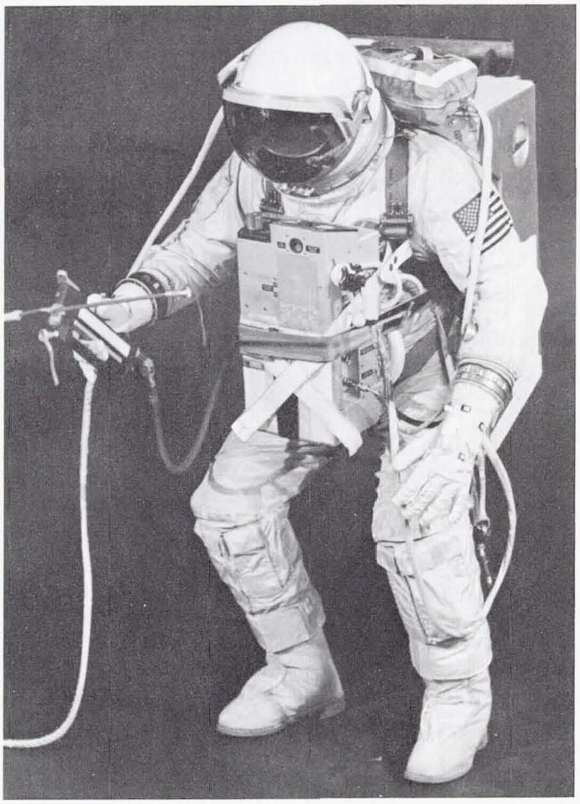


FIGURE 9–3.—Gemini VIII Hand Held Maneuvering Unit, backpack, and chest pack.

The expansion of the Freon 14 from 5000 psi to 110 psi resulted in temperatures of approximately —150° F in the Hand Held Maneuvering Unit handle assembly. The low temperatures caused the poppet valves to stick open when actuated. To make the valves operable at —150° F, Teflon cryogenic seals were used in place of the elastomer seals which had been satisfactory for the Gemini IV Hand Held Maneuvering Unit. Even though qualification testing demonstrated that the redesigned poppet valves would operate at low temperatures, two shutoff valves were incorporated in the system. One of the valves (fig. 9–4) was located immediately upstream of the coupling, and was designed to prevent the gas from escaping in case the poppet valves failed to close. The other shutoff valve was located in the backpack, upstream of the flexible feedline and was designed to shut off the gas flow in the event of an accidentally severed hose. The extra precautions were taken to reduce the possibility of uncontrolled gas escaping from the system and causing the extravehicular pilot to tumble. The handle of the Hand Held Maneuvering Unit was also modified to provide the pilot with a better grip (fig. 9–4).

Gemini X Hand Held Maneuvering Unit

For Gemini X, the handle of the Hand Held Maneuvering Unit (fig. 9–5) was further modified by sloping the handle to provide easier movement of the pilot's hand from pusher to tractor actuation. Grooves were cut in the handle to accommodate the restraint wires in the palm of the suit glove. The single rocking trigger was replaced with two shorter triggers pivoted at the end. This modification reduced the actuation forces from between 15 and 20 pounds to between 5 and 8 pounds, and also reduced the distance the hand had to be shifted to go from pusher to tractor mode or vice versa.

On the Gemini X flight, the propellant was stored in two 439-cubic-inch tanks in the spacecraft adapter section and was fed to the Hand Held Maneuvering Unit through a 50-foot dual umbilical (fig. 9–6). One hose in the umbilical provided life-support oxygen and the other hose provided nitrogen gas to the Hand Held Maneuvering Unit. Nitrogen was selected as a propellant to reduce slightly some of the low-temperature problems encountered with Freon 14. The two nitrogen tanks provided a total impulse of 677 lb ×

FIGURE 9–4.—Shutoff valve upstream of coupling of Gemini VIII Hand Held Maneuvering Unit. Arms in near folded position.

FIGURE 9–5.—Gemini X Hand Held Maneuvering Unit configuration.

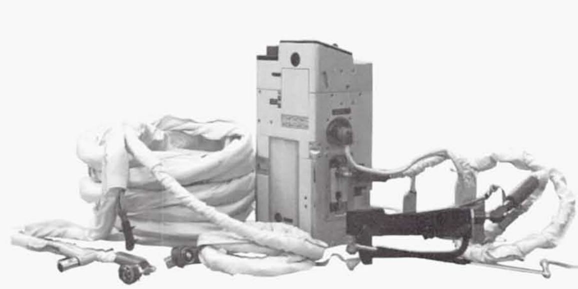


FIGURE 9–6.—Fifty-foot dual umbilical used in Gemini X shown connected to Extravehicular Life-Support System and Hand Held Maneuvering Unit.

sec, amounting to 84 ft/sec change in velocity of the extravehicular pilot. A list of other pertinent characteristics is provided in table 9–III.

TABLE 9–III.—*Gemini X and XI Hand Held Maneuvering Unit Characteristics*

Propellant	Nitrogen gas
Thrust, lb	0 to 2
Specific impulse, sec	63
Total impulse, lb×sec	677
Total available ΔV, ft/sec	84
Trigger preload, lb	5
Trigger force at maximum thrust, lb.	8
Storage-tank pressure, psi	5000
Regulated pressure, psi	125±15
Nozzle-area ratio	50:1
Weight of usable propellant, lb	10.75
Weight of Hand Held Maneuvering Unit, lb	3
Weight of extravehicular pilot, lb	260

A hardline was routed from the tank installation in the spacecraft adapter section to a recessed panel behind the hatch. The hardline was clamped to the adapter-section structure at numerous points to provide heat shorts for warming the cooled gas (due to adiabatic expansion during use).

After connecting the life-support side of the dual umbilical to the oxygen system in the pressurized spacecraft and making the proper connections to the Extravehicular Life-Support System chest pack, the pilot egressed the cabin and moved to a recessed panel behind the hatch. The pilot connected the Hand Held Maneuvering Unit propellant side of the dual umbilical to the nitrogen supply by means of a push-on connector and a shutoff valve provided on the recessed panel.

Gemini XI Hand Held Maneuvering Unit

In the Gemini XI mission, the Hand Held Maneuvering Unit was stowed in the spacecraft adapter section rather than in the cabin. The screw-on coupling was changed to a quick-disconnect coupling (fig. 9–7) to simplify connecting the Hand Held Maneuvering Unit to the umbilical. The extravehicular pilot had to perform this operation with one hand in a limited access area and in a pressurized suit. Several features were incorporated in the push-on coupling to provide immediate interchanging of the Hand Held Maneuvering Unit with a gas-powered tool for possible future maintenance and assembly operations in space.

FIGURE 9–7.—Gemini XI Hand Held Maneuvering Unit in inverted position showing quick-disconnect coupling.

The propellant gas storage-tank installation for Gemini XI was identical to the Gemini X configuration and provided the same operational characteristics (table 9–III). A 30-foot dual umbilical was employed rather than the 50-foot dual umbilical used on Gemini X.

Astronaut Maneuvering Unit

The Air Force Astronaut Maneuvering Unit (fig. 9–8) was scheduled for evaluation on the Gemini IX–A and the Gemini XII missions. Pertinent characteristics of the Astronaut Maneuvering Unit are listed in table 9–IV.

The Astronaut Maneuvering Unit backpack contained hydrogen peroxide, nitrogen, and oxygen tanks; two sets of rate gyros; twelve 2.3-pound thrust chambers with associated solenoid-operated valves; self-contained radio and telemetry equipment; and

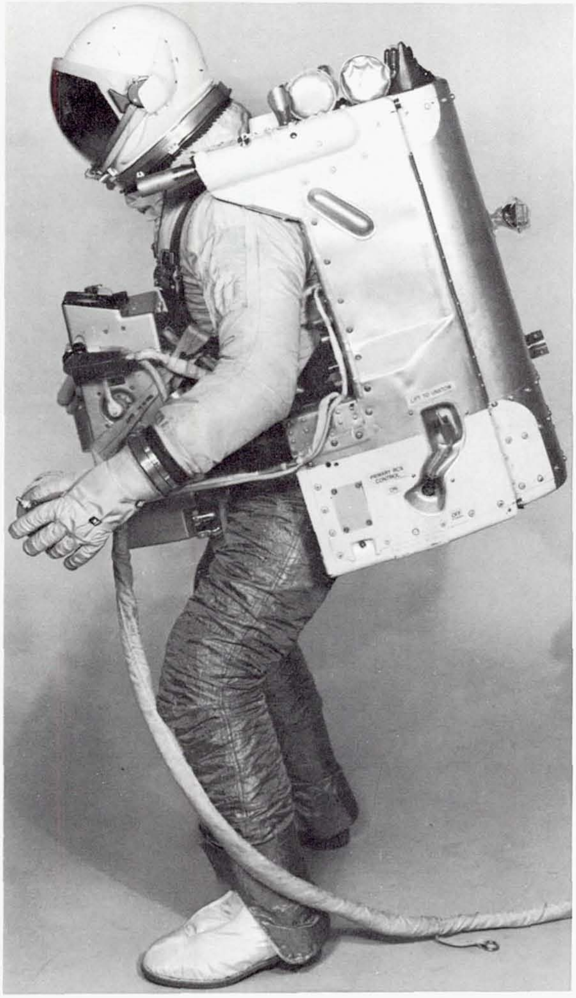


FIGURE 9-8.—The Air Force Astronaut Maneuvering Unit as configured for Gemini IX-A. Extravehicular Life-Support System (chest pack) also shown.

other miscellaneous equipment. The backpack was designed to provide attitude control and stabilization about the yaw, pitch, and roll axes, as well as translation in the fore-and-aft and up-and-down directions. Attitude control could be achieved either by using the thrusters in a direct manual on-off mode or in a rate-command mode.

The Astronaut Maneuvering Unit was capable of providing a change in velocity of about 250 feet per second for an all-inclusive extravehicular pilot weight of 407 pounds. The gross weight of the Astronaut Maneuvering Unit, 168 pounds, included a 19-pound oxygen bottle which held 7 pounds of gaseous oxygen for the Extravehicular Life-Support System. The nitrogen in the Astronaut Maneuvering Unit was used to expel the hydrogen peroxide through the catalyst beds and then through the reaction nozzles.

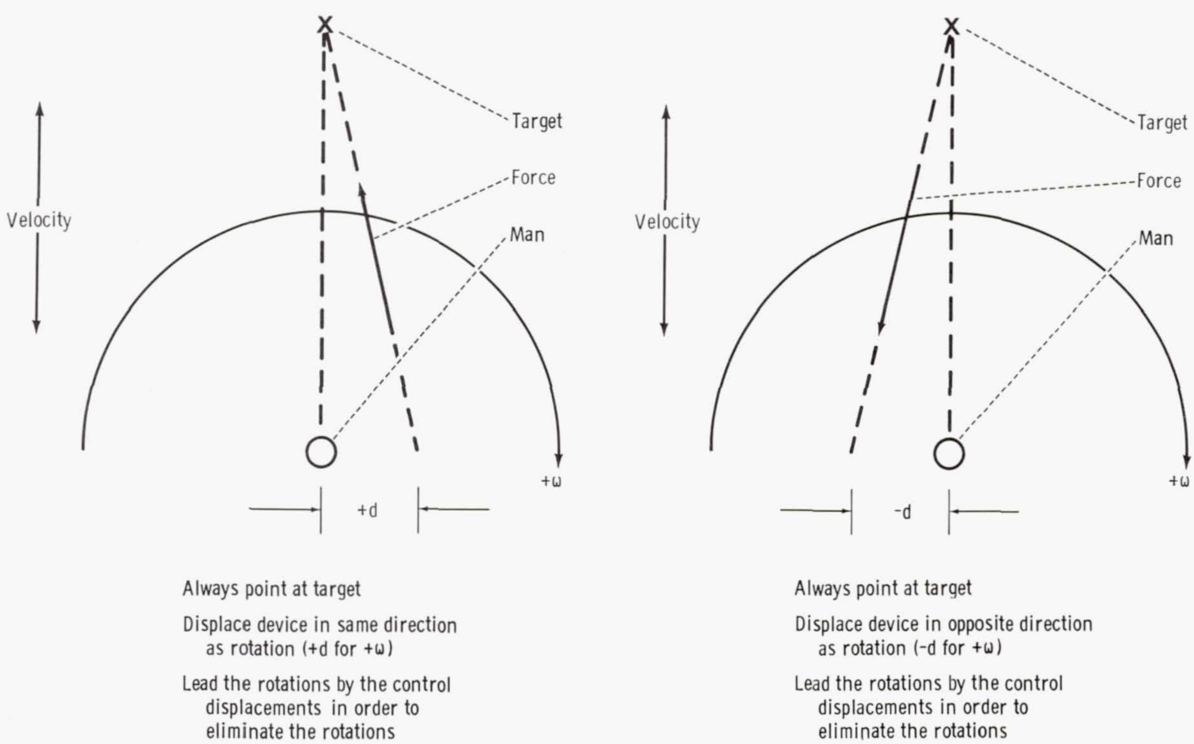
TABLE 9-IV.—*Gemini IX-A Astronaut Maneuvering Unit Characteristics*

Propellant	90 percent hydrogen peroxide
Total thrust (fore-and-aft or up-and-down), lb	4.6
Pitch moment, in.-lb	63.5
Roll moment, in.-lb	44.2
Yaw moment, in.-lb	47.7
Specific impulse, sec	169
Total impulse, lb×sec	3100
Total available ΔV, ft/sec	250
Controller characteristics:	
Breakout:	
Fore-and-aft, lb	4.5
Up-and-down, lb	4.5
Pitch, lb	4.0
Roll, lb	4.0
Yaw	Small
Maximum force:	
Fore-and-aft, lb	9.75
Up-and-down, lb	9.75
Pitch, lb	10.5
Roll, lb	10.5
Yaw, in.-lb	13.0
Maximum deflection, deg:	
Fore-and-aft	6
Up-and-down	6
Pitch	6
Roll	6
Yaw	4.5
Attitude-limit cycle periods, sec:	
Pitch	59
Roll	50
Yaw	3.2
Attitude deadband, deg	(3 axes) ±2.4
Maximum control rates, deg/sec:	
Pitch	18
Roll	27
Yaw	18
Maximum nitrogen tank pressure, psi	3500
Regulated hydrogen peroxide pressure, psi	455
Nozzle-area ratio	40:1
Weight of propellant, lb	24
Weight of Astronaut Maneuvering Unit, lb	168
Weight of extravehicular pilot, lb	407

Ground Training for Extravehicular Maneuvering

Hand Held Maneuvering Unit Control Logic

A number of different procedures could be used successfully to move from one point to another in space with a Hand Held Maneuvering Unit. Figure 9–9 illustrates the particular procedures selected for use with the Gemini systems. The figure illustrates tractor thrusting for either forward or backward translation, as well as pusher thrusting, and applies to any of the three possible rotational control axes: yaw, pitch, or roll. For example, in figure 9–9(a) assume that the illustration refers to the yaw axis so that our view of the man is from directly above; that is, the label "MAN" refers to the end of a line running from the operator's head to foot. The Hand Held Maneuvering Unit is held in front of the man's center of gravity at the position of the label "FORCE." The force in this case is pointed forward as it must be when considering the tractor mode. Assume that a disturbance occurs and causes a rotation to the right, indicated by the curved velocity arrow labeled "$+\omega$." To eliminate this disturbance, the Hand Held Maneuvering Unit must be moved laterally toward the right side; however, the thrust line of the Hand Held Maneuvering Unit must be pointed directly at the target. By pointing directly at the target at all times, the operator (1) insures that he will eventually arrive exactly at the target, (2) maximizes the desired control moment, and (3) minimizes the amount of fuel required for attitude control. The third rule on the illustration refers to phase lead and states that the control motions should lead the disturbances if the rotational motions are to be completely damped. If, instead of leading the rotational motions, the control motions remain exactly in phase with the rotational motions, the result is a con-



(a) Tractor mode.

(b) Pusher mode.

FIGURE 9–9.—Rules for attitude control during translation with Hand Held Maneuvering Unit.

stant-amplitude snaking oscillation as the operator translates toward or away from the target.

The foregoing procedures first appear complicated and overly sophisticated. In actual practice, the pilot never consciously thinks of the rules while using the Hand Held Maneuvering Unit. Application of the procedures may be compared with the actions and reactions required to ride a bicycle. The skilled operator of the Hand Held Maneuvering Unit looks directly at the target. The control loop is closed directly from the target motion to the eyes and brain of the operator, with resulting error signals feeding the operator's muscular command system. The control system of the Hand Held Maneuvering Unit is a personal adaptive control system. The accuracy of this system in space with all the 6 degrees of freedom active is not yet known, inasmuch as the planned Gemini flight evaluations did not cover this point.

On the 3-degree-of-freedom air-bearing facility, using any one of the three rotational axes and two translation axes, the accuracy of a skilled operator is within less than 1 inch of the intended target (from distances of approximately 25 feet). At longer ranges, the same degree of accuracy could be maintained because the control logic is a terminal-guidance type. Also, the operator's axis system does not have to be alined with the direction of motion while using the Hand Held Maneuvering Unit. The operator must physically see the target and point at the target while keeping the thrust force through his center of gravity. With regard to ease of use, the Hand Held Maneuvering Unit was designed so that when held in the operator's right hand with the thrust line along the operator's X-axis, the muscles in the right arm and hand are in a completely unstrained position.

Astronaut Maneuvering Unit Control Logic

The control logic preferred by the pilots of Gemini IX–A and Gemini XII follows. From an initially stabilized position, generally facing the target, thrust is applied to produce a forward velocity proportional to the range to be flown. As soon as this velocity is achieved, yaw 90° away from the original attitude and coast toward the target. The line-of-sight drifts of the target can be eliminated by using the up-and-down and fore-and-aft translational thrusters. Just prior to arriving at the target, yaw back to the original attitude facing the target and apply braking thrust.

This control procedure involves only two discrete yaw rotations and no roll or pitch rotations. The control procedure minimizes attitude-control fuel requirements because the inertia of the extravehicular pilot is at a minimum about the yaw axis. Also, the control procedure is probably the simplest for a maneuvering unit that does not have lateral-translation capability.

Air-Bearing Training Equipment

The most important requirement for an air-bearing facility, and the most difficult to achieve and maintain, is a flat, hard, smooth floor. The floor of the Air-Bearing Facility at the Manned Spacecraft Center consists of 21 cast-steel machinist's layout tables each 3 feet wide by 8 feet long. Each table weighs about 2200 pounds and is flat to within approximately 0.0002 inch. The pattern is seven tables wide and three tables long comprising a total floor area of 21 by 24 feet. After leveling, the joints between adjacent tables are accurate to about 0.0004 inch, and the overall floor is estimated to be flat within approximately 0.002 inch. The leveling procedure must be repeated about every 6 months, due to settling of the building foundation. This degree of floor accuracy allows free movement of simulators with air cushions approximately 0.001 inch thick. Such low flight altitudes are desirable because the required airflow is quite low, and the attendant possible turbine-blade (jet propulsion) effect resulting from uneven exhaust of the air from the air bearings is negligible. This turbine-blade effect is extremely undesirable

because it confuses the results produced by low-thrust jets such as those of the Hand Held Maneuvering Unit.

Figures 9–10 to 9–13 show some of the air-bearing simulators utilized for extravehicular training during the Gemini Program. Figure 9–10 shows the Gemini X pilot on a yaw training simulator in preparation for that mission. In this particular case, compressed air for the Hand Held Maneuvering Unit, for the pressurized suit, and for floating the air-bearing equipment flowed from a 130-psi service air supply through a dual umbilical identical to the one used in the Gemini X flight. A skilled technician was employed to minimize the effect of the umbilical drag during training.

Figure 9–11 shows the Gemini VIII pilot during a yaw training session prior to the mission. The Extravehicular Support Package was supported by metal legs; three supporting air pads were utilized for the necessary added stability because of the large combined mass and volume of both the Ex-

FIGURE 9–11.—Three-pad air-bearing simulator for yaw-axis training with backpack-supported maneuvering devices.

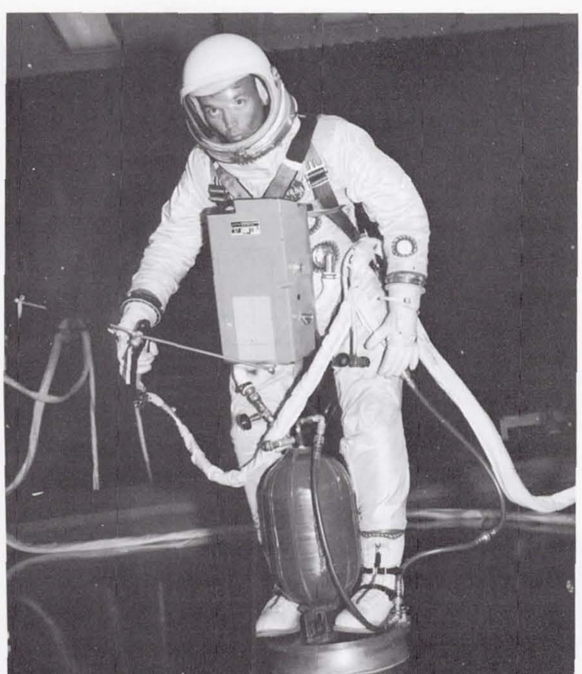


FIGURE 9–10.—Single-pad air-bearing simulator for yaw-axis training with Hand Held Maneuvering Unit.

FIGURE 9–12.—Three-pad air-bearing simulator during pitch-axis training with Hand Held Maneuvering Unit.

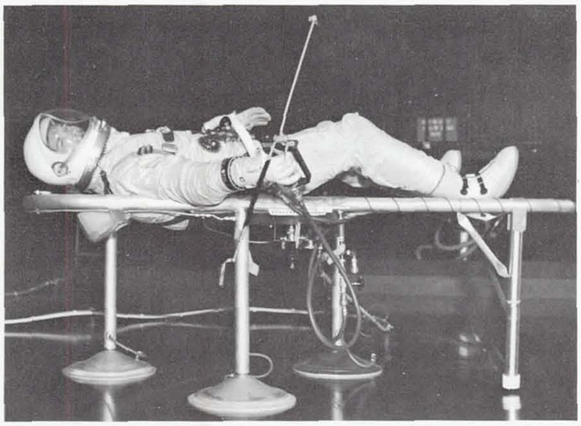


FIGURE 9–13.—Three-pad air-bearing simulator during roll-axis training with Hand Held Maneuvering Unit.

travehicular Support Package (backpack) and the Extravehicular Life-Support System (chest pack). In the simulator, compressed air for floating the platform is carried in an oxygen bottle mounted on the platform; and compressed air for the Hand Held Maneuvering Unit is carried in a high-pressure bottle located inside the Extravehicular Support Package (as on Gemini VIII). No umbilical or tether was utilized. This simulator was also used in training for the Astronaut Maneuvering Unit.

Figure 9–12 shows the Gemini X pilot in pitch-axis training on a different type of simulator. The cot is made of lightweight aluminum tubing which does not appreciably change his inertia in pitch. Three pads are used to provide satisfactory tipping stability. The compressed air needed to power the Hand Held Maneuvering Unit, to pressurize the suit, and to float the air-bearing equipment is supplied by the service air supply through the 3/8-inch-inside-diameter umbilical (fig. 9–12). This umbilical contains small air-bearing supporters which allow more accurate simulation of the in-space effect of a similar umbilical.

Figure 9–13 shows the Gemini X pilot in roll-axis training on the same simulator. Roll-axis training was practiced by looking at the target while translating to it, and by looking at the ceiling while translating to the side. The latter case is important because in normal use of the Hand Held Maneuvering Unit, rolling velocity should be kept at zero while translating and looking forward.

Types of Training Runs

The following is a representative list of the types of training runs made on the air-bearing equipment in preparation for extravehicular activity maneuvering. The runs were made in the yaw and pitch modes; most were also made in the roll mode.

(1) Familiarization with air bearing.

(2) Use of muscle power to control attitude.

(3) With Hand Held Maneuvering Unit in hand, control attitude while being towed to target.

(4) With hip-kit compressed-air bottle and no umbilical, translate from point *A* to a collision with point *B*. The points *A* and *B* are any two specific points in the training area.

(5) Repeat preceding step, but completely stop 1 foot in front of point *B*.

(6) With initial rotational velocity at point *A*, stop rotation, proceed to point *B*, and stop completely 1 foot in front of point *B*.

(7) With both initial random rotation and translation in vicinity of point *A*, stop both initial rotation and translation, proceed to point *B*, and stop completely 1 foot in front of point *B*.

(8) Starting from rest at point *A*, intercept a target moving with constant velocity at right angles to the line of sight.

(9) Make precision attitude changes of 45° and 90°, stopping any translation existing at end of run.

(10) Without the Hand Held Maneuvering Unit, practice pushing off from simulated spacecraft and stopping completely by gently snubbing the umbilical.

(11) Practice hand walking the umbilical back to the simulated spacecraft, being careful not to generate excessive translational velocity.

(12) Investigate elasticity and wrap-up tendencies of umbilical by hitting end of umbilical with various initial translational and rotational velocities.

Amount of Training

Air-bearing training received by the prime pilots of Gemini IV, VIII, IX–A, X, and XI follows:

Mission	*Training, hr*
IV	12
VIII	20.5
IX–A	3
X	13.25
XI	20

The 6-Degree-of-Freedom Simulator

In addition to the 3 hours of air-bearing training with the Astronaut Maneuvering Unit in preparation for Gemini IX–A extravehicular activity, the pilot completed approximately 11 hours of training on the Manned Aerospace Flight Simulator (fig. 9–14). This simulator consisted of a production-type Astronaut Maneuvering Unit with controls wired into a hybrid computer facility. The simulator provided the subject with small-amplitude pitch, roll, and yaw rotations and up-and-down translation acceleration cues which later were damped out. The visual display simulated clouds over an ocean, and a horizon with blue and red dots representing the front and rear ends of a target vehicle. These were all projected on the inner surface of a spherical screen mounted about 8 feet in front of the pilot. The dots varied in size to represent a target vehicle at ranges from approximately 250 feet to essentially zero range. The object of most training runs was to aline the two ends of the spacecraft (superimpose the dots), and to move in to a simulated arrival position with respect to the target.

FIGURE 9–14.—The Manned Aerospace Flight Simulator used during training with the Astronaut Maneuvering Unit.

Inertia Coupling Training-Aid Model

During the Gemini VIII extravehicular training, the question arose as to whether controlled rotations about one axis of an extravehicular pilot might lead to uncontrolled rotations about the other two axes due to inertia coupling or product-of-inertia effects. To gain a qualitative idea of the possible seriousness of these effects, a 1-to-4.5 scale model of the Gemini VIII pilot was constructed and mounted in a set of extremely light gimbals. The model (fig. 9–15) was based upon three-view scale photographs of the pilot in a pressurized suit, and carved from wood. The scale weight and center-of-gravity position of the pilot, the Extravehicular Support Package, and the Extra-

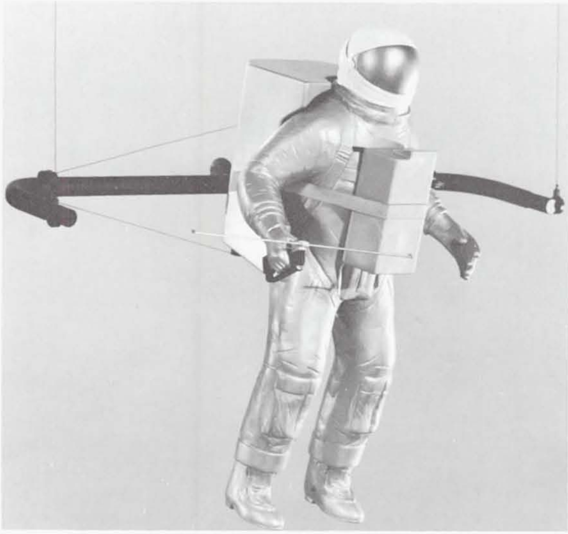


FIGURE 9-15.—Inertia coupling training-aid model.

vehicular Life-Support System were closely duplicated, although no attempt was made to measure and duplicate the moments of inertia of these items. The gimbal arrangement is shown in figure 9-16. The yaw axis is at the top; the half-pitch gimbal is next; innermost is the roll gimbal, which consisted of two ball bearings inside the body of the model. The yaw and pitch gimbals were also mounted on ball bearings. The gimbal weight was only about 0.2 that of the model.

Investigations of inertia coupling effects were conducted by rotating the model about one of the major axes while holding the other two axes fixed, then by suddenly releasing the two fixed gimbals. The following results were observed.

(1) Following a pure yaw rotational input, when the pitch and roll gimbals were released, slow up-and-down changes in pitch attitude resulted. As the motion slowed due to gimbal-bearing friction, the model rotated 90° in roll so that the original yawing motion became a pure pitching motion. This attitude then was stable because no coupling was evidenced if the model was again spun about the original axis of rotation.

(2) Following a pure pitch rotational input, the model merely slowed to zero rotational velocity (because of gimbal-bearing friction) without exhibiting inertia coupling tendencies of any kind.

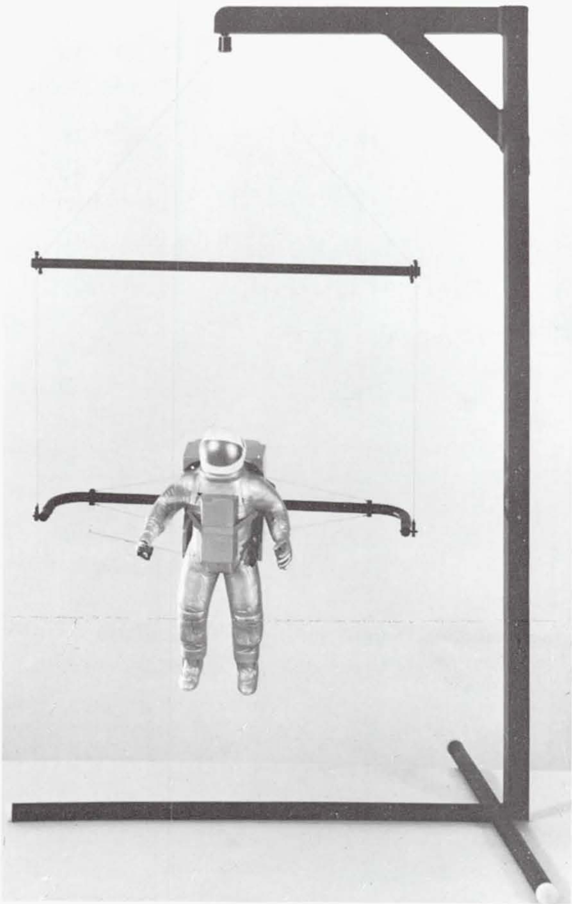


FIGURE 9-16.—Inertia coupling training-aid model showing gimbal suspension system.

(3) Following a pure roll rotational input, release of the pitch and yaw gimbals immediately resulted in a confused pitching, yawing, and rolling tumbling motion.

The behavior of the model was obviously in consonance with the observed shape of the model. For example, the mass distribution of the model, and also of an extravehicular pilot, are almost symmetrical about the *YZ* plane; therefore, practically no rolling or yawing moments are generated due to the effects of centrifugal force acting upon local mass asymmetry when the model is pitched. However, the model with backpack and chest pack

is considerably asymmetrical about the *YZ* plane; therefore, it is not surprising that large pitching and yawing moments resulted from pure roll.

The tests performed with the model resulted in adoption of the following simple maneuvering rules for the extravehicular pilot. The rules are designed to eliminate or reduce greatly the chance of encountering inertia coupling effects.

(1) Never roll. Always establish the attitude toward the target by yawing, then pitching. Never roll while translating.

(2) In case inertia coupling effects are encountered, always stop the rolling velocity first, the yawing velocity second, and the pitching velocity last.

In connection with possible inertia coupling effects, two final comments should be made. First, the extravehicular pilots were not unique in being subject to inertia coupling effects. Airplanes and spacecraft are also subject to such coupled motions. Second, it is difficult to understand how these effects could be encountered by an extravehicular pilot at the end of an umbilical or tether. In such a case, the umbilical or tether should effectively eliminate all large rotations other than those about the axis of the umbilical or tether. This observation strongly suggests that tether and umbilical reels, controlled by the extravehicular pilot, should be developed as soon as possible. Air-bearing tests indicate that body rotations which can cause umbilical wrap-up about the subject tend to be eliminated rapidly by the umbilical as long as the subject does not already possess translational velocity toward the spacecraft umbilical attach point. The reason for this action is that the rotational energy causing wrap-up has to be converted to translational kinetic energy in order for wrap-up to continue. The proportionality factor for energy transformation in this direction is qualitatively very low. Therefore, the practice of always operating at the end of a straight umbilical may help eliminate undesirable angular rotations about the two body axes not coincident with the axis of the umbilical.

Hand Held Maneuvering Unit Flight Performance and Comparison With Ground Training

Gemini IV Extravehicular Activity

The Gemini IV pilot made the first powered extravehicular maneuvering in history. Figure 9–17 is one of the many photographs taken by the command pilot and shows the extravehicular pilot in the perfect posture for maneuvering with a Hand Held Maneuvering Unit. The pilot described his experiences with the Hand Held Maneuvering Unit and with the umbilical as follows:

> I left [the spacecraft] entirely under the influence of the gun, and it carried me right straight out, a little higher than I wanted to go. I wanted to maneuver over to your [command pilot's] side, but I maneuvered out of the spacecraft and forward and perhaps a little higher than I wanted to be. When I got out to what I estimate as probably one-half or two-thirds the way out on the tether, I was out past the nose of the spacecraft. I started a yaw to the left with the gun and that's when I reported that the gun really worked quite well. I believe that I stopped that yaw, and I started translating back toward the spacecraft. It was either on this translation or the one following this that I got into a bit

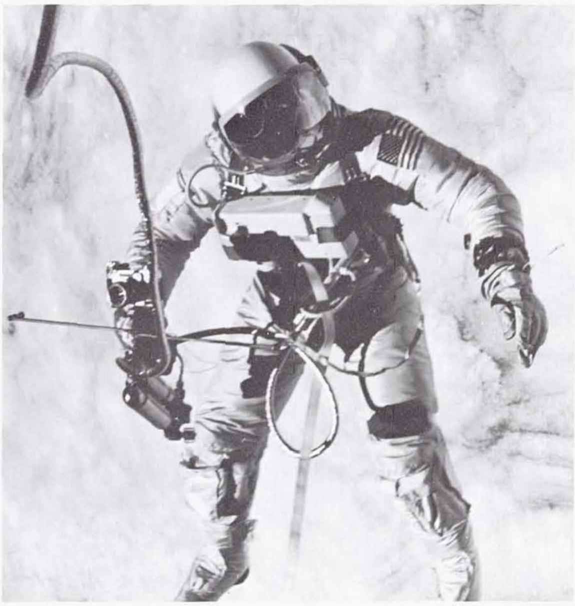


FIGURE 9–17.—Extravehicular activity during Gemini IV. Note classic posture exhibited by pilot for maneuvering with Hand Held Maneuvering Unit.

of a combination of pitch, roll, and yaw together. I felt that I could have corrected it, but I knew that it would have taken more fuel than I had wanted to expend with the gun, so I gave a little tug on the tether and came back in. This is the first experience I had with tether dynamics and it brought me right back to where I did not want to be. It brought me right back on top of the spacecraft, by the adapter section.

This is the first time it had happened. I said [to command pilot]: "All right, I'm coming back out [to front of sparecraft] again." This is one of the most impressive uses of the gun that I had. I started back out with the gun, and I decided that I would fire a pretty good burst too. I started back out with the gun, and I literally flew with the gun right down along the edge of the spacecraft, right out to the front of the nose, and out past the end of the nose. I then actually stopped myself with the gun. That was easier than I thought. I must have been fairly fortunate, because I must have fired it right through my cg. I stopped out there and, if my memory serves me right, this is where I tried a couple of yaw maneuvers. I tried a couple of yaw and a couple of pitch maneuvers, and then I started firing the gun to come back in [to the spacecraft]. I think this was the time that the gun ran out. And, I was actually able to stop myself with it out there that second time too. The longest firing time that I put on the gun was the one that I used to start over the doors up by the adapter section. I started back out then. I probably fired it for a 1-second burst or something like that. I used small bursts all the time. You could put a little burst in and the response was tremendous. You could start a slow yaw or a slow pitch. It seemed to be a rather efficient way to operate. I would have liked to have had a 3-foot bottle out there—the bigger the better. It was quite easy to control.

The technique that I used with the gun was the technique that we developed on the air-bearing platform. I kept my left hand out to the side [fig. 9–17] and the gun as close to my center of gravity as I could. I think that the training I had on the air-bearing tables was very representative especially in yaw and pitch. I felt quite confident with the gun in yaw and pitch, but I felt a little less confident in roll. I felt that I would have to use too much of my fuel. I felt that it would be a little more difficult to control and I didn't want to use my fuel to take out my roll combination with the yaw.

As soon as my gun ran out [of fuel] I wasn't able to control myself the way I could with the gun. With that gun, I could decide to go to a part of a spacecraft and very confidently go.

Now I was working on taking some pictures and working on the tether dynamics. I immediately realized what was wrong. I realized that our tether was mounted on a plane oblique to the angle in which I wanted to translate. I remember from our air-bearing work that every time you got an angle from the perpendicular where your tether was mounted, it [the tether] gave you a nice arching trajectory back in the opposite direction. You're actually like a weight on the end of a string. If you push out in one direction and you're at an angle from the perpendicular, when you reach the end of a tether, it neatly sends you in a long arc back in the opposite direction. Each time this arc carried me right back to the top of the adapter, to the top of the spacecraft, in fact, toward the adapter section.

One thing though that I'll say very emphatically—there wasn't any tendency to recontact the spacecraft in anything but very gentle contacts. I made some quite interesting contacts. I made one that I recall on the bottom side of the right door in which I had kind of rolled around. I actually contacted the bottom of the spacecraft with the back of my head. I was faced away from the spacecraft, and I just drifted right up against it and just very lightly contacted it. I rebounded off. As long as the pushoffs are slow, there just isn't any tendency to get in an uncontrollable attitude.

Gemini X Extravehicular Activity

It was intended that the Gemini X pilot perform an extensive evaluation of the Hand Held Maneuvering Unit including precise angular attitude changes and translations. However, the flight plan for the extravehicular activity required a number of other activities prior to this evaluation. One of the planned activities was to translate to the target vehicle at very short range using manual forces alone and to retrieve the Experiment S010 Agena Micrometeorite Collection package attached near the docking cone. The pilot described the use of the Hand Held Maneuvering Unit at this time as follows:

Okay, we're in this EVA. I got back and stood up in the hatch and checked out the gun and made sure it was squirting nitrogen. That's the only gun checkout I did. In the meantime, John maneuvered the spacecraft over toward the end of the TDA, just as we had planned. He got in such a position that my head was 4 to 5 feet from the docking cone. It was upward at about a 45° angle, just as we planned. I believe at one time there you said you had trouble seeing it, and I gave you [command pilot] some instructions about "forward, forward," "stop, stop." So I actually sort of talked John into position.

I translated over by pushing off from the spacecraft. I floated forward and upward fairly slowly and contacted the Agena. I grabbed hold of the docking cone as near as I can recall, at about the 2 o'clock position. If you call the location of the notch in it, the 12 o'clock, I was to the right of that—at about the 2 o'clock position and I started crawling around. No, I must have been more about the 4 o'clock position, because I started crawling around at the docking cone counterclockwise, and the docking cone itself, the leading edge of the docking cone, which is very blunt, makes a very poor handhold in those pressure gloves. I had great difficulty in holding on to the thing. And, as a matter of fact, when I got over by the S010 package and tried to stop my motion, my inertia [the inertia of] my lower body, kept me right on moving and my hand slipped and I fell off the Agena.

When I fell off, I figured I had either one of two things to do. I could either pull in on the umbilical and get back to the spacecraft, or I could use the gun. And I chose to use the gun. It was floating free at this time. It had come loose from the chestpack. So, I reached down to my left hip and found the nitrogen line and started pulling in on it and found the gun, and unfolded the arms of the gun and started looking around. I picked up the spacecraft in view. I was pointed roughly toward the spacecraft. The spacecraft was forward and below me on my left. The Agena was just about over my left shoulder and below me, or down on my left side and below me. I used the gun to translate back to the cockpit area. Now, I was trying to thrust in a straight line from where I was back to the cockpit, but in leaving the Agena I had developed some tangential velocity, which was bringing me out around the side and the rear of the Gemini. So what happened was, it was almost as if I was in an airplane on down wind for a landing, and in making a left-hand pattern I flew around and made a 180° left descending turn, and flew right into the cockpit. It was a combination of just luck, I think, being able to use the gun. At any rate, I did return to the cockpit in that manner, and John again maneuvered the spacecraft. When I got to the cockpit, I stood up in the hatch and held on to the hatch. John maneuvered the spacecraft again up next to the Agena. This time we were, I think, slightly farther away, because I felt that rather than trying to push off I would use the gun and translate over. And I did, in fact, squirt the gun up, depart the cockpit and translate over to the docking cone using the gun as a control device. The gun got me there. It wasn't extremely accurate. What happened was, as I was going over, I guess in leaving the cockpit, I somehow developed an inadvertent pitch-down moment, and when I corrected this out with the gun, I developed an upward translation as well as an upward pitching moment. So I did damp out the pitch. I converted that downward pitch moment into an upward pitching moment, and then I was able to stop my pitch entirely. But in the process of doing that, I developed an inadvertent up translation, which nearly caused me to miss the Agena. As a matter of fact, I came very close to passing over the top of the Agena; and I was just barely able to pitch down with the gun and snag a hold of the docking cone as I went by the second time.

During further technical debriefings, the Gemini X pilot made several other comments. Concerning the response characteristics of the Hand Held Maneuvering Unit, he stated that the thrust levels of 0 to 2 pounds were about right. These levels provided adequate translational response without making the rotational response seem overly sensitive. The Gemini IV pilot made the same comment.

With respect to ability to transfer the control skills acquired on the 3-degree-of-freedom air-bearing simulators to the 6 degrees of freedom existing in space, the Gemini X pilot stated that the transfer was easy and natural. He was, perhaps, a little surprised that the pitch degree of freedom gave more control trouble than the yaw degree of freedom. Due to a very low body inertia about the yaw axis, yawing motions generated with the Hand Held Maneuvering Unit are naturally much faster than either pitch or roll motions.

Finally, in answer to the question of whether he had acquired any rolling motions during brief periods of maneuvering with the Hand Held Maneuvering Unit, the Gemini X pilot stated that no rolling motions whatever had been experienced. This is significant for two reasons:

(1) Based upon indications of the inertia coupling model, and upon the Gemini IV extravehicular activity, the Gemini X pilot had trained specifically to avoid rolling motions, and to stop them immediately if they should occur.

(2) If rolling motions can be totally eliminated, then control with the Hand Held Maneuvering Unit is reduced practically to a simple 3-degree-of-freedom situation involving yawing and pitching rotations, and linear translations.

Concluding Remarks

Based upon the short periods of extravehicular maneuvering during two Gemini missions, the Hand Held Maneuvering Unit is a simple device suitable for translating easily between selected points on a spacecraft or anywhere in the general vicinity of the spacecraft. Thrust values ranging from 0 to 2 pounds are desirable for present-day Hand Held Maneuvering Units. Controlled movement about a spacecraft on a fixed-length umbilical without a maneuvering device is difficult, if not impossible. However, such maneuvering does not appear to result in uncontrollable attitudes if care is taken to avoid large translational velocity inputs when leaving the spacecraft.

As a result of work with a gimbal-mounted scale model of an extravehicular pilot, it appears that confused tumbling motions due to inertia coupling effects are likely to occur during extravehicular maneuvering if excessive simple rotational velocities (especially rolling velocities) are attained. Therefore, it is recommended that until additional extravehicular maneuvering experience has been gained, rolling velocities be maintained close to zero during extravehicular maneuvering, and the extravehicular pilot mass distribution be kept nearly symmetrical.

Three-degree-of-freedom air-bearing simulators are satisfactory devices for extravehicular maneuvering ground training. A minimum of 10 hours of such training is recommended.

10. MEDICAL ASPECTS OF GEMINI EXTRAVEHICULAR ACTIVITIES

By G. Fred Kelly, *M.D., Medical Operations Office, NASA Manned Spacecraft Center; and* D. Owen Coons, *M.D., Medical Operations Office, NASA Manned Spacecraft Center*

Introduction

The medical aspects of Gemini extravehicular activities are principally concerned with the physiological responses to high workloads, high thermal stresses, and low fatigue tolerance. Analysis of physiological instrumentation data from extravehicular flights and training operations contributed significantly to the understanding of extravehicular workloads and the means of controlling these workloads.

Background

The success of the Gemini IV extravehicular activity provided the initial confidence that man could accomplish extravehicular operations easily and with a minimum of physiological constraints. The Gemini IV mission also tended to indicate that elaborate physiological instrumentation would not be required. Accordingly, medical instrumentation requirements for future extravehicular activities were kept to a minimum. The requirements included one lead for an electrocardiogram and one lead for obtaining respiration rate. Because the pilot was able to monitor the suit pressure, this measurement was deleted for Gemini IX–A and subsequent flights. Other instrumentation which would have been desirable included carbon-dioxide concentration and body temperatures; however, feasible means of measuring these parameters were not readily available.

Medical Evaluation of Extravehicular Activities

During the extravehicular portions of Gemini IX–A and XI, excessive workload appeared to be a limiting factor. An evaluation of flight data indicated that there may have been an excessive thermal load imposed upon the extravehicular pilot during these activities. The high respiration rates encountered during Gemini XI indicated that a buildup in the carbon-dioxide level may have been a problem. Since there were no actual data on thermal conditions, oxygen, or carbon-dioxide levels, and no direct measure of metabolic load, a quantitative evaluation of the potential problem areas was not possible.

Although there was no direct measure of metabolic load, the electrocardiogram and impedance pneumogram provided some useful information, but only if certain limitations and inaccuracies were considered. These parameters have been monitored during a great many physiological and psychological tests under widely varying conditions. This information reconfirms that heart rate responds to psychological, physiological, and pathological conditions. There is considerable individual variation in these responses. However, in the absence of a more scientific approach to the problem, and because a quantitative indication of the workload actually experienced in flight appeared to be of primary importance, the feasibility of using heart rate as a quantitative indication of workload was investigated.

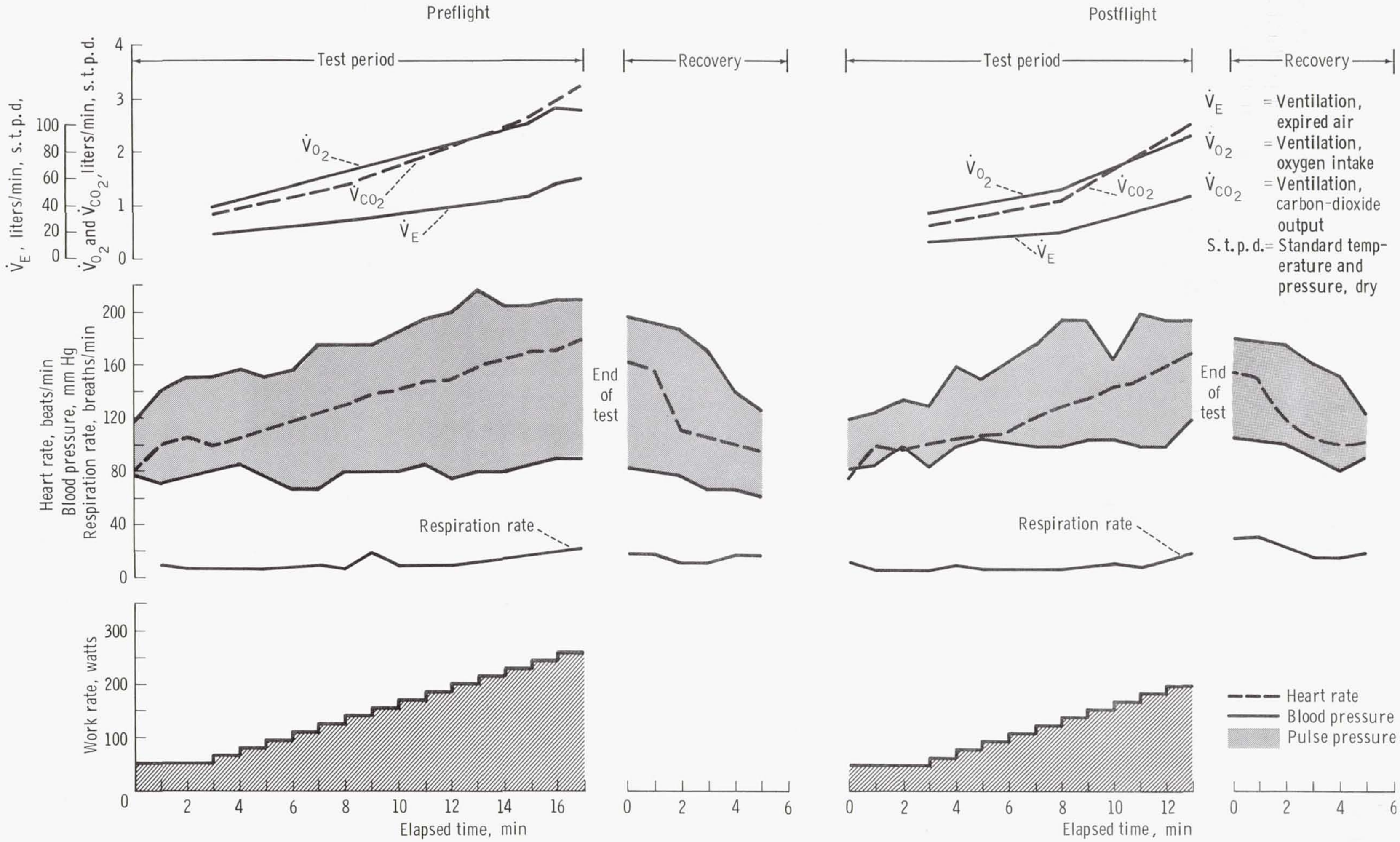
On Gemini IX–A, X, XI, and XII, preflight and postflight exercise tests using the bicycle ergometer were performed on the pilots. During the tests, the subject performed a measured amount of work in increasing increments while heart rate, blood pressure, and respiration rate were monitored; periodic samples of expired gas were collected for analysis. The data were translated into oxygen utilization curves and heat-energy plots (fig. 10–1). Using the plots and the heart-rate data obtained during each flight (figs. 10–2 and 10–3), an approximate workload curve was plotted against the time line for the extravehicular activity. The derived data were not entirely believable, since there is no method to account for the effect on heart rate resulting from thermal or other environmental variations. Also, the psychogenic effect of a new and different environment could certainly increase the heart rates without a corresponding change in metabolic rate. The plots were useful in evaluating the workloads for the Gemini XII extravehicular activity. The accuracy of the plots may be expected to increase as the oxygen consumption increases toward maximum oxygen utilization. This value varies with individuals and with the degree of physical conditioning, and is dependent upon the amount of oxygen which can be transported from the environment to the body tissues.

The area of major interest in evaluating workloads during extravehicular activities is during high workload periods. Furthermore, any error introduced by unknown factors would increase the observed heart rate for a given workload level. This tends to increase the usefulness of such a plot for preflight planning and for inflight monitoring of extravehicular activities. When data from previous flights, altitude chamber tests, 1g walkthroughs, and underwater zero-g simulations are examined in this manner, a quantitative indication may be derived of work expended on various tasks (fig. 10–4). This is important in the postflight assessment of the relative physiological cost of various tasks, and in determining acceptable tasks and realistic time lines during simulations and preflight planning. The use of heart-rate and respiration-rate data, when coupled with voice contact and an understanding of programed activities, proved an extremely important and useful method for real-time monitoring of extravehicular pilots.

The major factors which apparently produced the highest workload prior to Gemini XII were high suit forces, insufficient body-position restraints, and thermal stress. This was indicated when the Gemini XI pilot expended an exceptionally high effort in attaching the spacecraft/target-vehicle tether to the docking bar. Difficulties in maintaining body position in the weightless environment made the task much more difficult than had been expected.

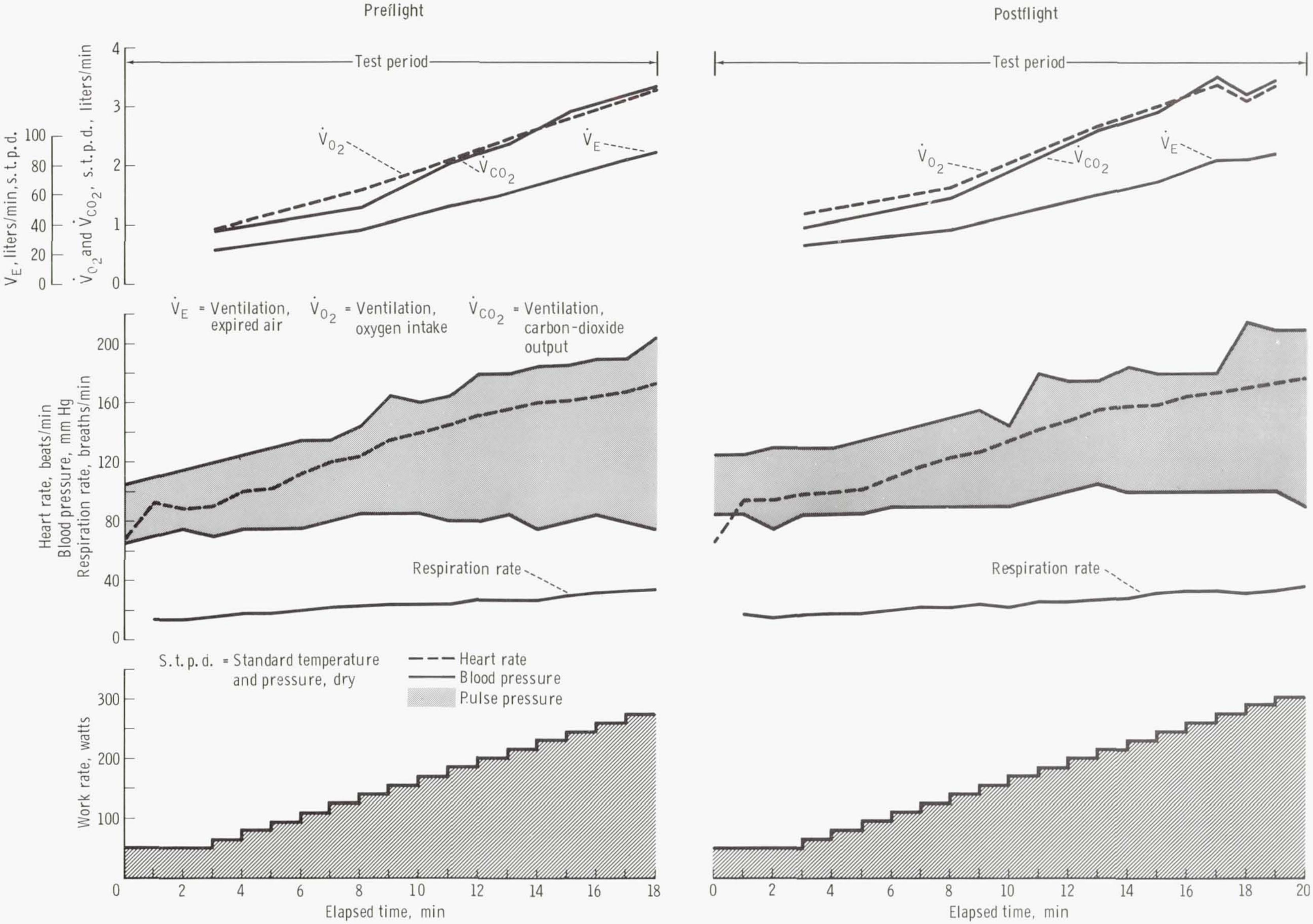
The pilot used the large torso and leg muscles in attempting to straddle the spacecraft nose and found that he had to work against the pressurized space suit in order to force his legs into an unnatural position. The high workload subjectively described by the pilot was confirmed by heart and respiration rates (fig. 10–2(*d*)). The high respiration rates also indicate the possibility of increased carbon-dioxide level. The Extravehicular Life-Support System was not designed to handle workloads of the magnitude indicated by these rates in terms of either thermal control or carbon-dioxide removal. It is probable that the thermal and carbon-dioxide buildup, along with psychogenic factors which were certainly present, contributed to the high heart rates recorded. However, this would make heart rate and respiration rate data no less useful in the real-time monitoring of a crew during flight if stress or potential danger were in fact present.

In planning for Gemini XII, it was deemed important to avoid workloads which would exceed the capacity of the Extravehicular Life-Support System. It had been determined that the Extravehicular Life-Support System was capable of handling 2000 Btu/hr while maintaining a carbon-dioxide level equal to approximately 6 mm of mercury. During the



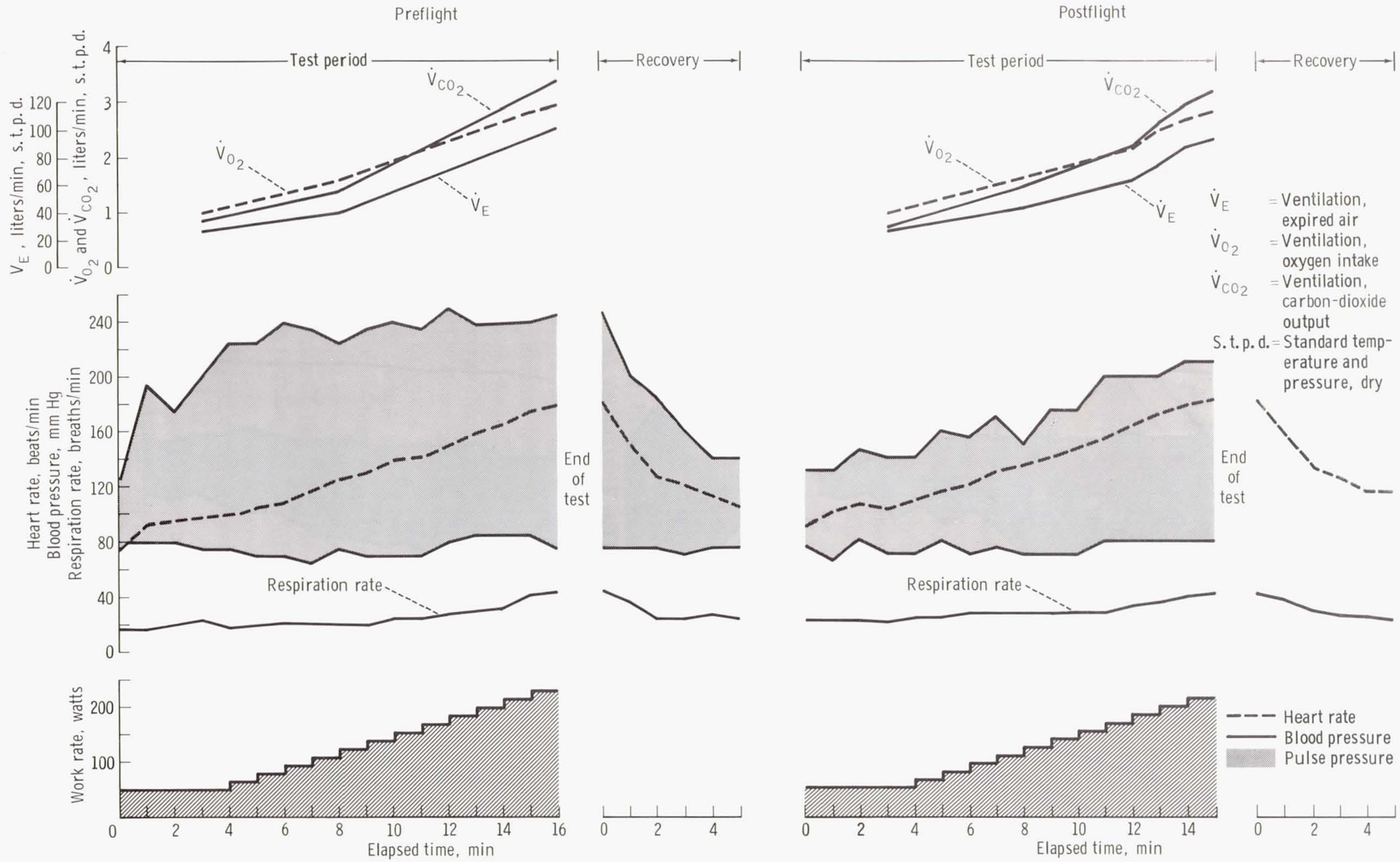
(*a*) Gemini IX–A pilot.

FIGURE 10–1.—Ergometry studies.



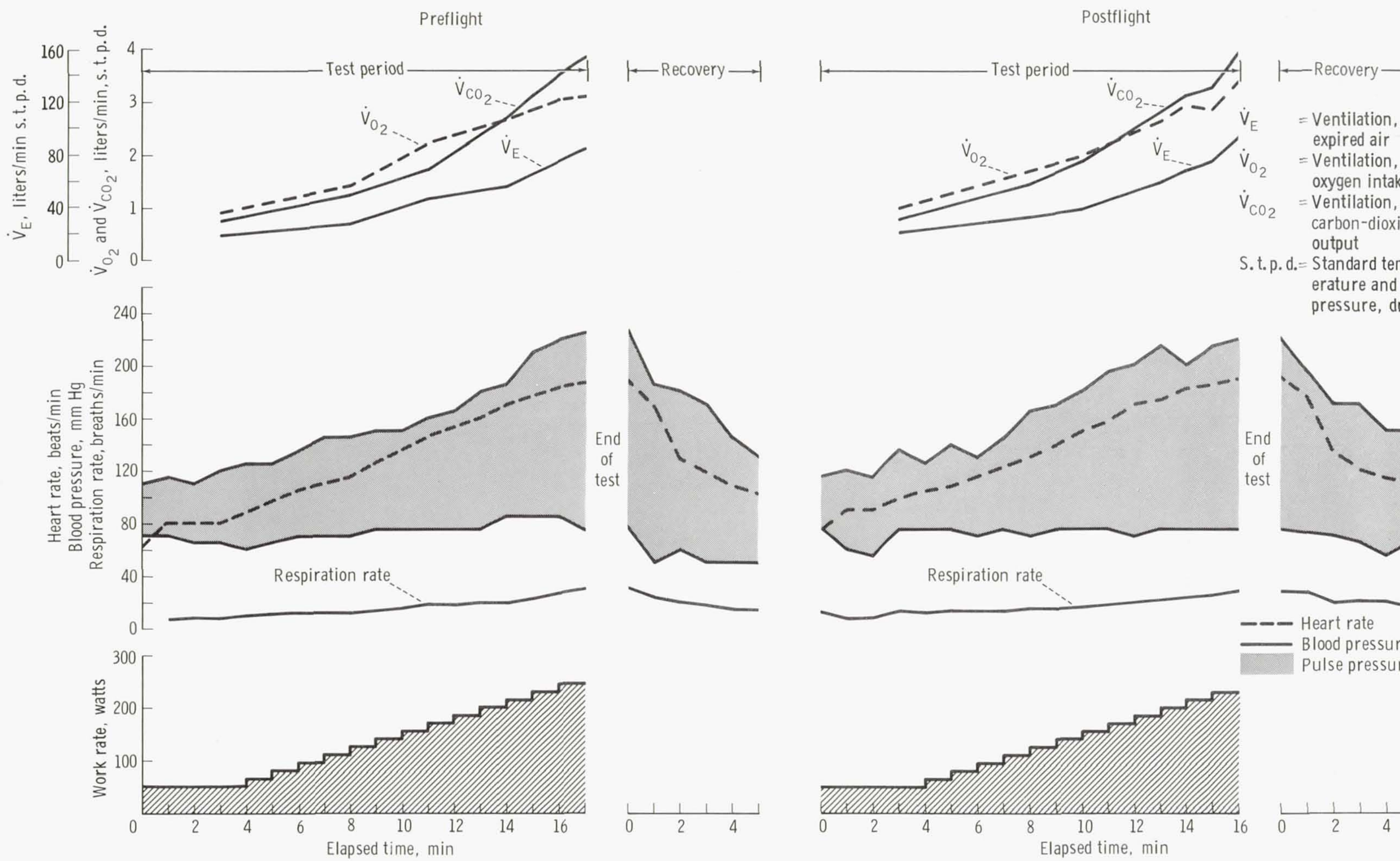
(*b*) Gemini X pilot.

FIGURE 10–1.—Continued.



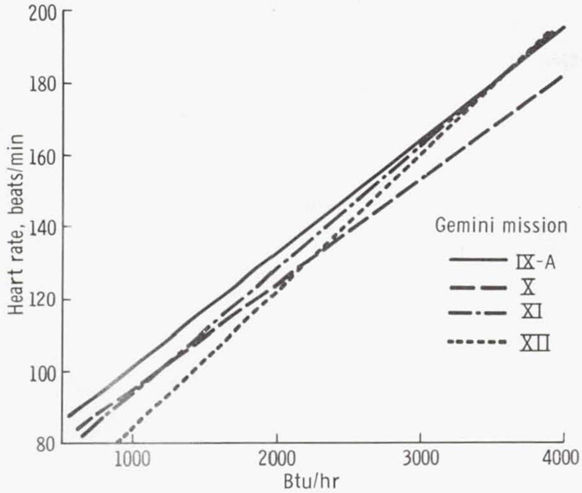
(*c*) Gemini XI pilot.

FIGURE 10–1.—Continued.



(*d*) Gemini XII pilot.

FIGURE 10-1.—Continued.



(e) Gemini IX–A through XII preflight studies.

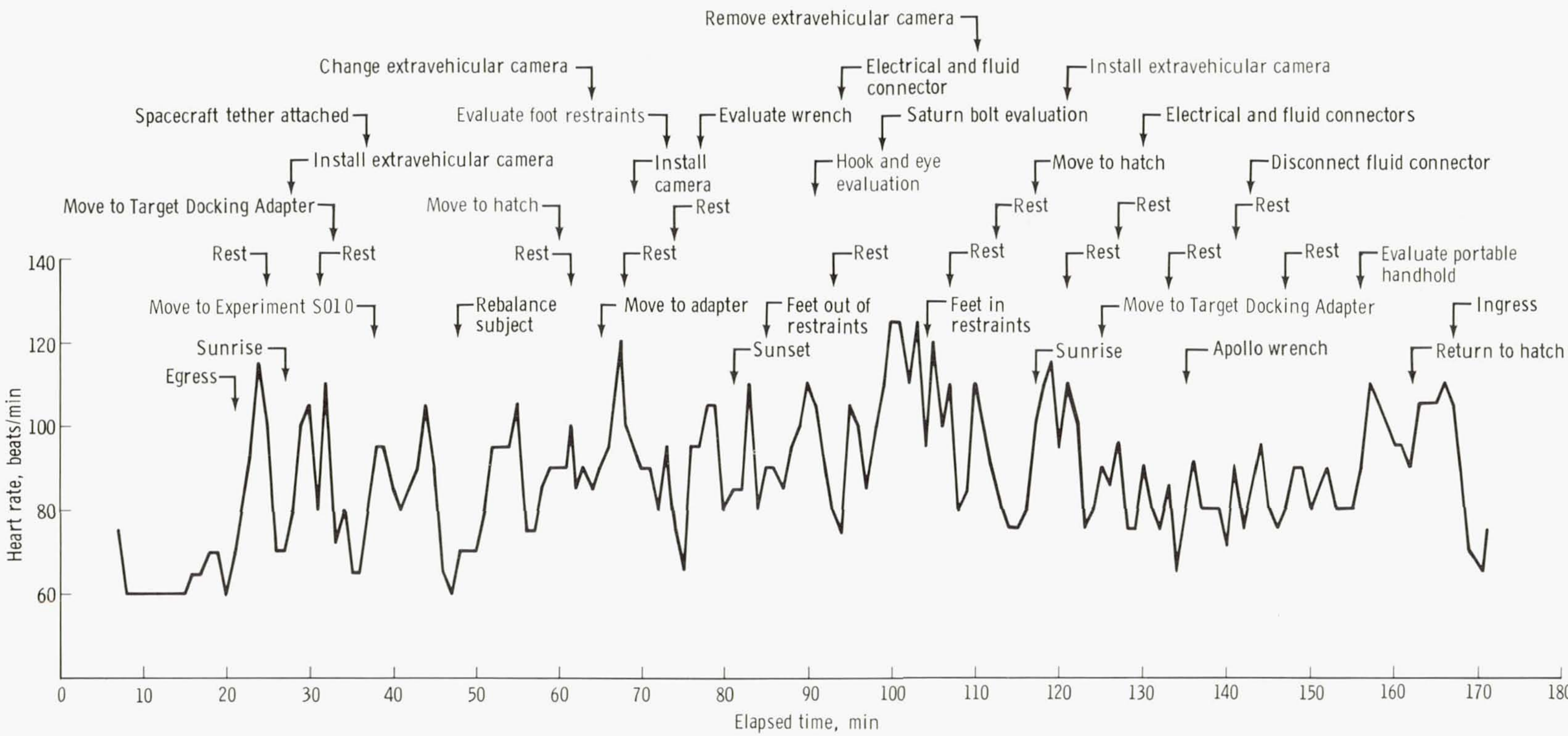
FIGURE 10–1.—Concluded

preflight ergometry studies (fig. 10–5), the pilot heart rate was 122 beats per minute when the workload was 2000 Btu/hr. It should be noted that a total heat capacity higher than 2000 Btu/hr was possible for short periods of time, and that sustained heat dissipation of a percentage of thermal load produced by higher levels of work was also within the capabilities of the Extravehicular Life-Support System. Because of these and other factors which are known to cause increases, heart rates above 122 beats per minute were expected and observed during the planned extravehicular activities on Gemini XII. Figure 10–3 (e) is a graph of heart rate related to events during the Gemini XII umbilical extravehicular activity. Only once did the pilot's heart rate exceed expected levels. This occurred during a period of unscheduled activities when psychogenic factors contributed heavily to the heart rate. When the pilot was asked to decrease the activities, heart rates returned to a resting level in less than 1 minute.

During each period of standup extravehicular activity in Gemini XII, two sessions of programed exercise were performed. The exercises consisted of moving the arms against the restrictive forces of the pressurized space suit. Both arms were brought from the neutral position to the sides of the helmet once each second for 60 seconds. An attempt was made to correlate heart rate during these inflight exercise periods with preflight exercise tests (fig. 10–5). When compared in this manner, there appeared to be no significant difference between the heart-rate data for the exercises performed before flight and those performed in flight. Only qualitative conclusions, however, can be drawn from these data. Quantitative and scientifically valid conclusions must await the results of more detailed and precisely implemented inflight medical experimentation in which controlled conditions are possible and adequate data collection is feasible.

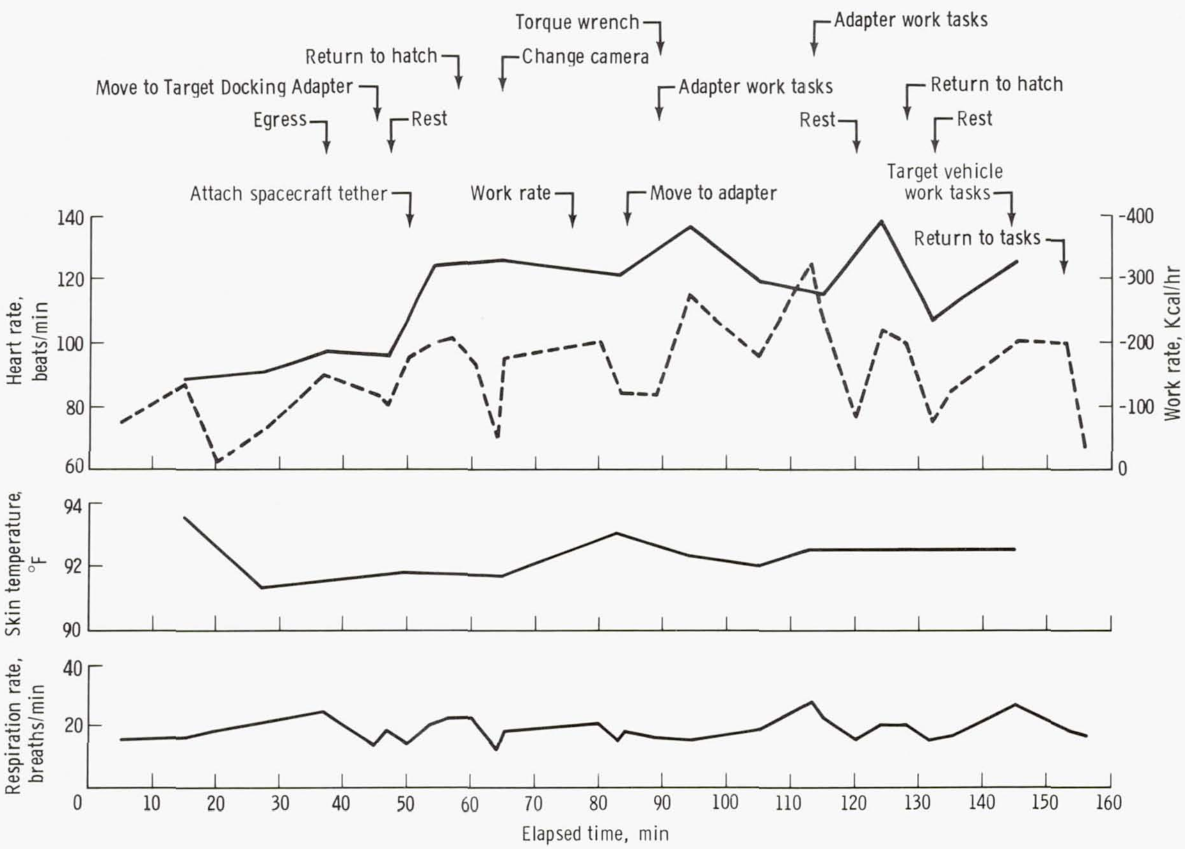
Certain other factors are considered significant in the medical aspects of the Gemini extravehicular activities. One of these factors, the art of conserving energy, has been briefly mentioned, and was demonstrated by the pilot of Gemini XII. The pilot of Gemini XII was able to condition himself to relax completely within the neutral position of the suit. He consciously tried to determine when a group of muscles was found to be tense while performing no useful work, and then tried to subjectively relax these muscles. All movements were slow and deliberate. When small movement of the fingers was sufficient to perform a task, the pilot used only the necessary muscles. If a restraint strap would substitute for muscle action, the pilot would rely on the restraint strap to maintain position, and would relax the muscles which would otherwise have been required for this task.

Chronic fatigue and degraded physical condition may have been a problem during extravehicular activity. Sleep during the first night of each flight was inadequate, and preparation activities for extravehicular maneuvers were detailed and fatiguing. Furthermore, the pace of preflight activities and the pressures of planning, training, and preparation to meet a flight schedule predisposed the crew to fatigue. During the final weeks of preparation for a flight, each crew found that time



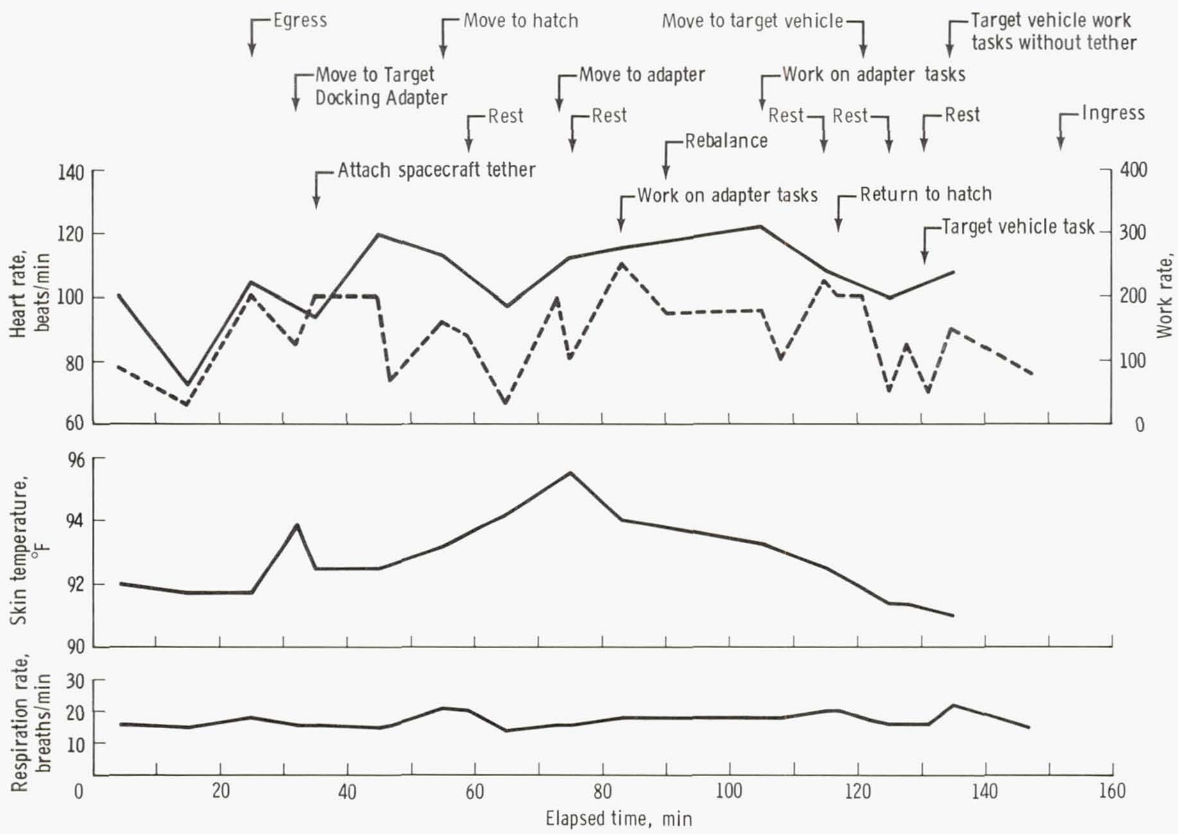
(*a*) Gemini XII pilot.

FIGURE 10-2.—Heart rates from underwater simulations.



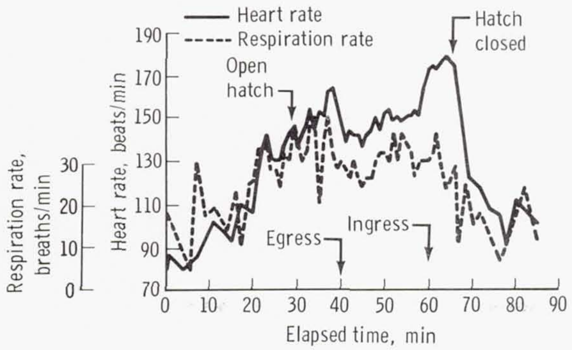
(*b*) Gemini XII pilot.

FIGURE 10–2.—Continued.



(*c*) Gemini XII pilot.

FIGURE 10-2.—Concluded.



(*a*) Gemini IV pilot.

FIGURE 10–3.—Physiological data during umbilical extravehicular activity.

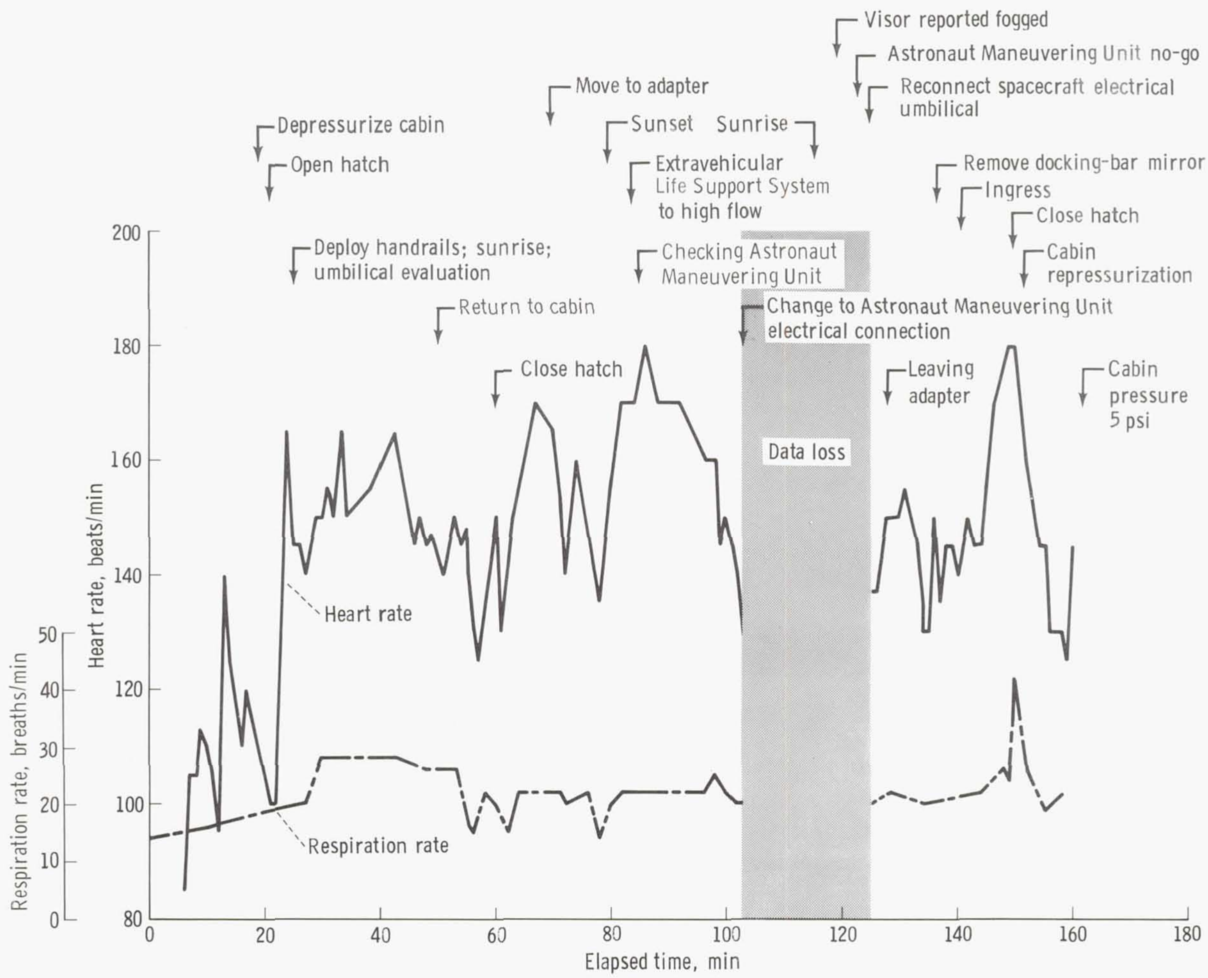
for rest, relaxation, and even physical conditioning was at a premium, and often these activities were omitted.

The possibility exists that hematological or cardiovascular changes observed in weightless flight decrease the metabolic efficiency of man during the extravehicular activities requiring a relatively high workload. Until more detailed information is available from well-founded medical experimentation during flight, the relative importance of such factors cannot be assessed.

Conclusions

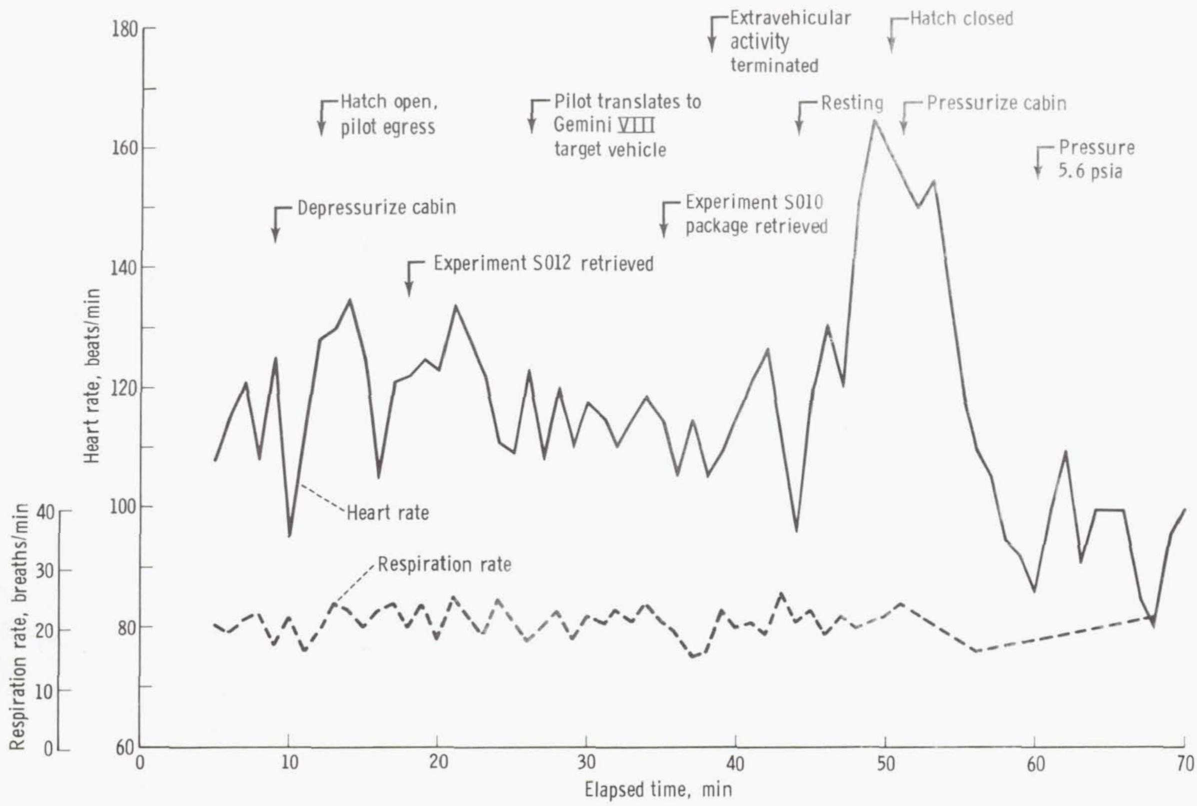
The experience gained from the Gemini extravehicular activities has provided information which will be invaluable in planning future missions. There have been no indications that the efficiency of man during extravehicular activities is significantly altered. The major factors which appear to have produced the highest workload during the extravehicular activity are high suit forces, insufficient body-position aids, and thermal stress. The success of Gemini XII conclusively demonstrated that these factors can be minimized through careful planning. Evaluation of physiological factors during the extravehicular activity has been significantly compromised by the lack of adequate instrumentation. Much can be learned about the physiological responses to extravehicular activities from simulations in the zero-g aircraft and in an underwater mockup. Without specific knowledge of the thermal and environmental conditions, however, a realistic simulation of extravehicular activities will be incomplete and possibly misleading.

The successful completion of the Gemini extravehicular activities indicates that life-support planning has been essentially sound. The success of Gemini XII indicates that within the limitations of the experience gained, time lines and work tasks can be tailored so that flight objectives can be accomplished. There are no medical contraindications to presently planned extravehicular activities.



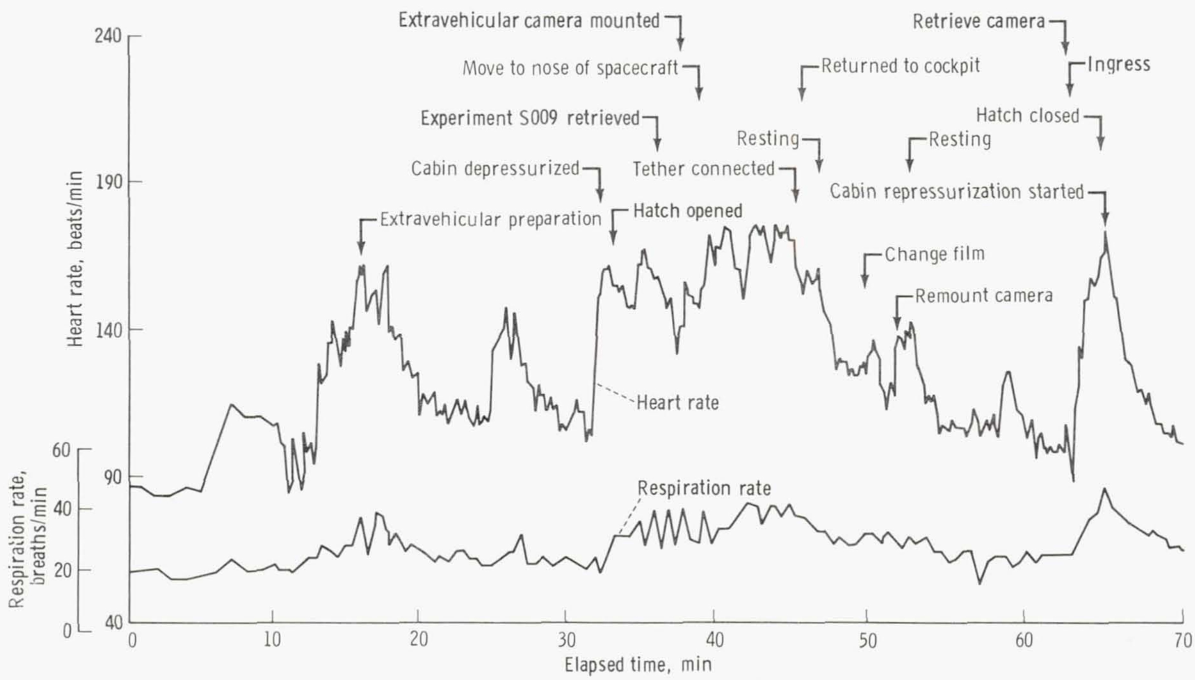
(*b*) Gemini IX–A pilot.

FIGURE 10–3.—Continued.



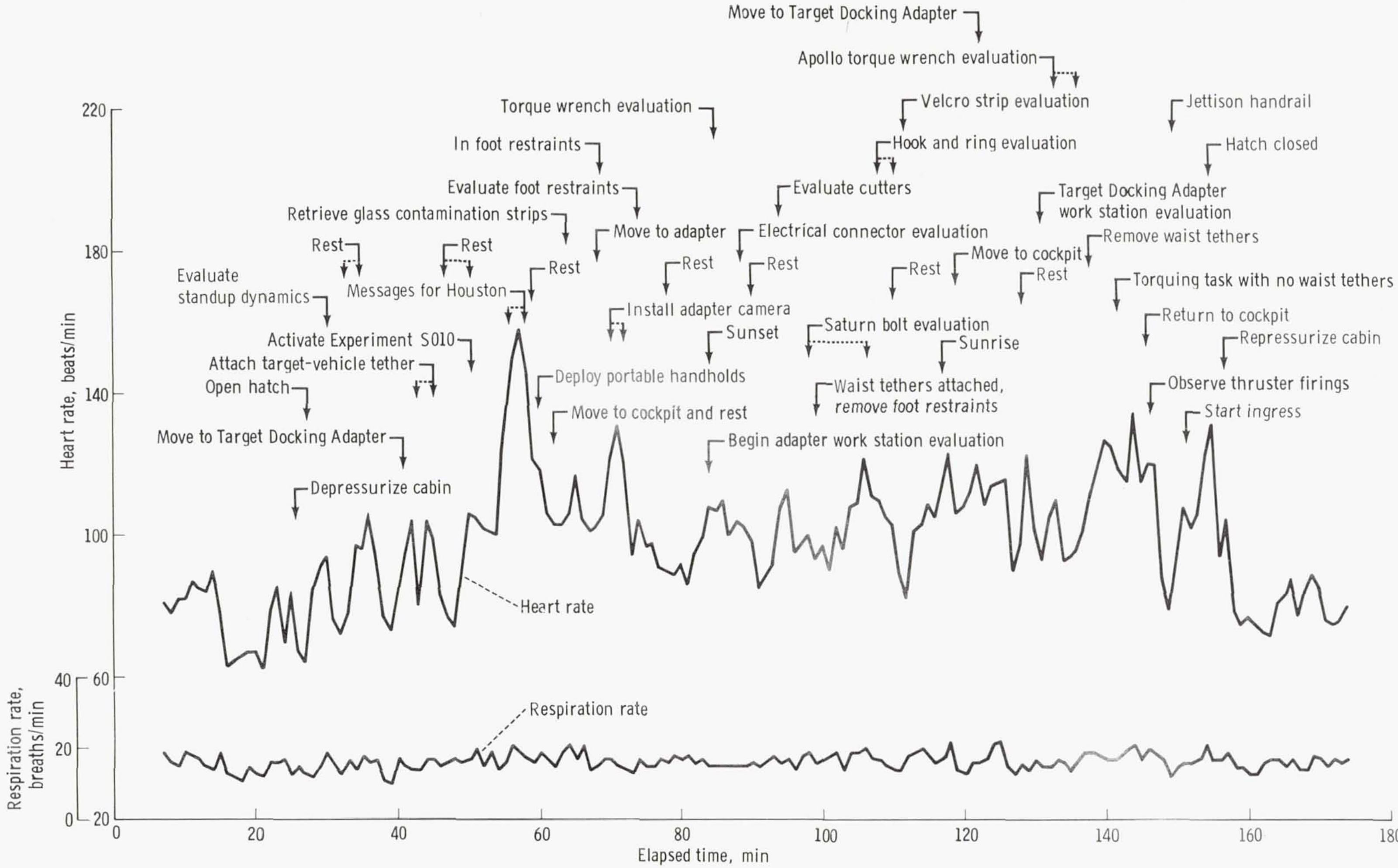
(*c*) Gemini X pilot.

FIGURE 10-3.—Continued.



(*d*) Gemini XI pilot.

FIGURE 10–3.—Continued.



(*e*) Gemini XII pilot.

FIGURE 10–3.—Concluded.

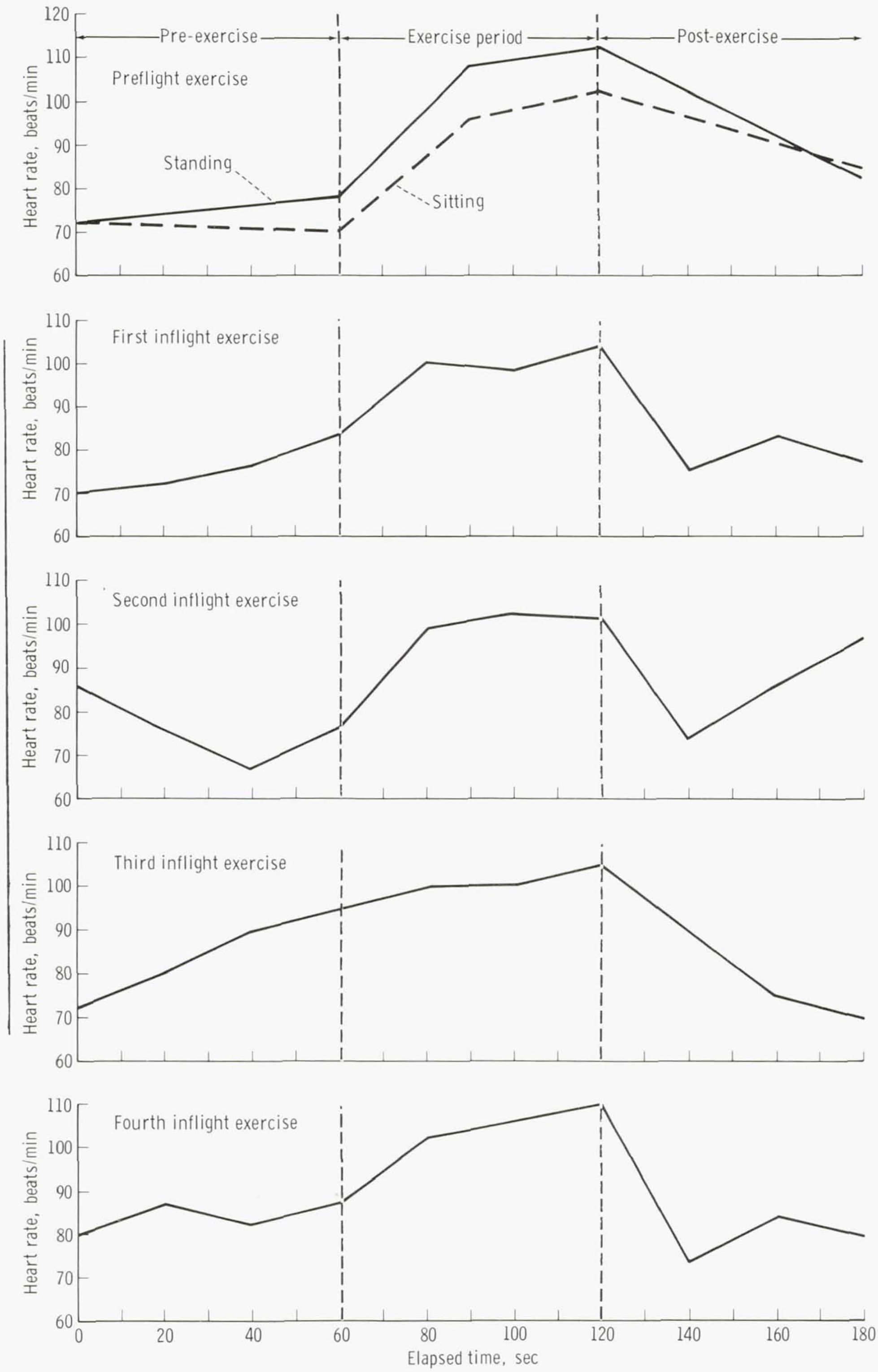
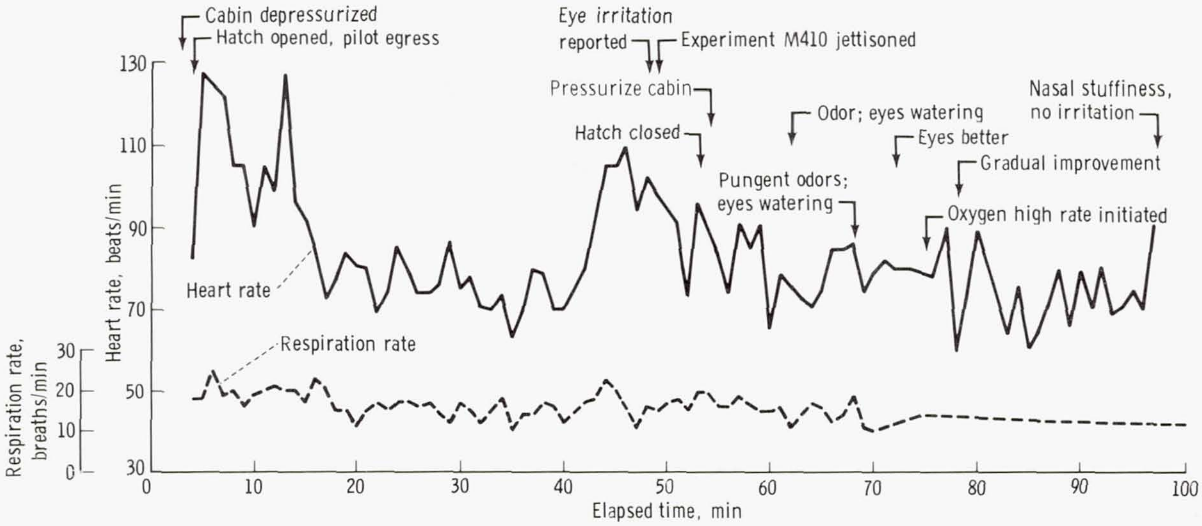
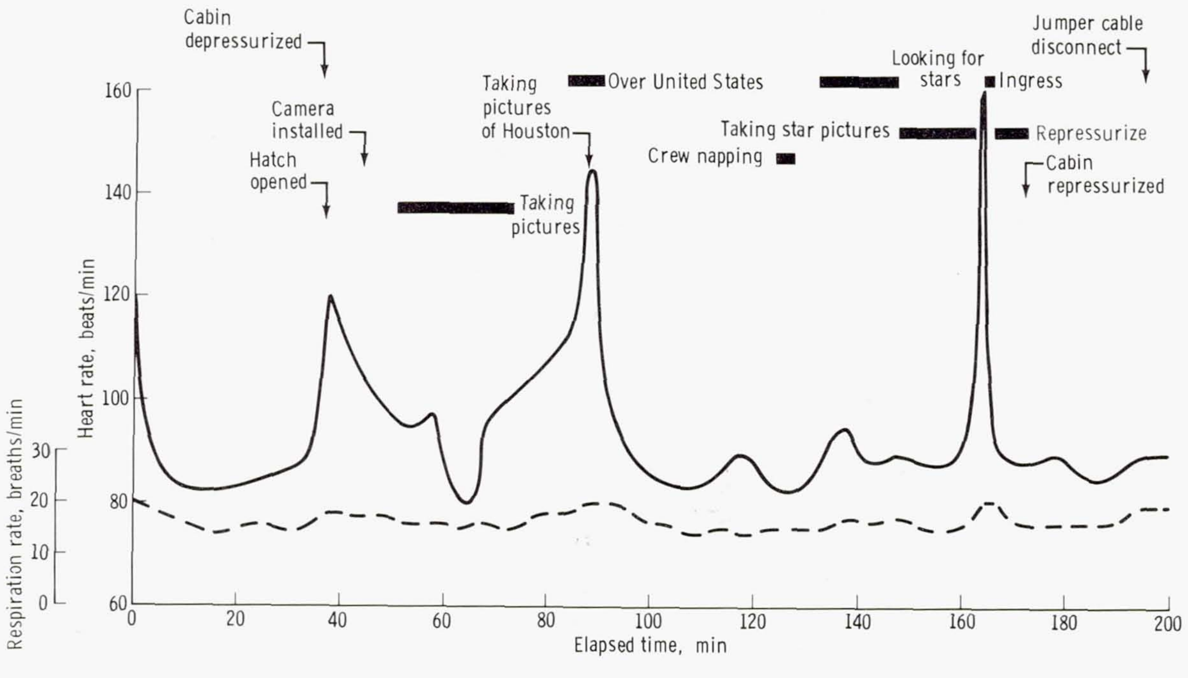


FIGURE 10-4.—Preflight and inflight exercise test, Gemini XII pilot.



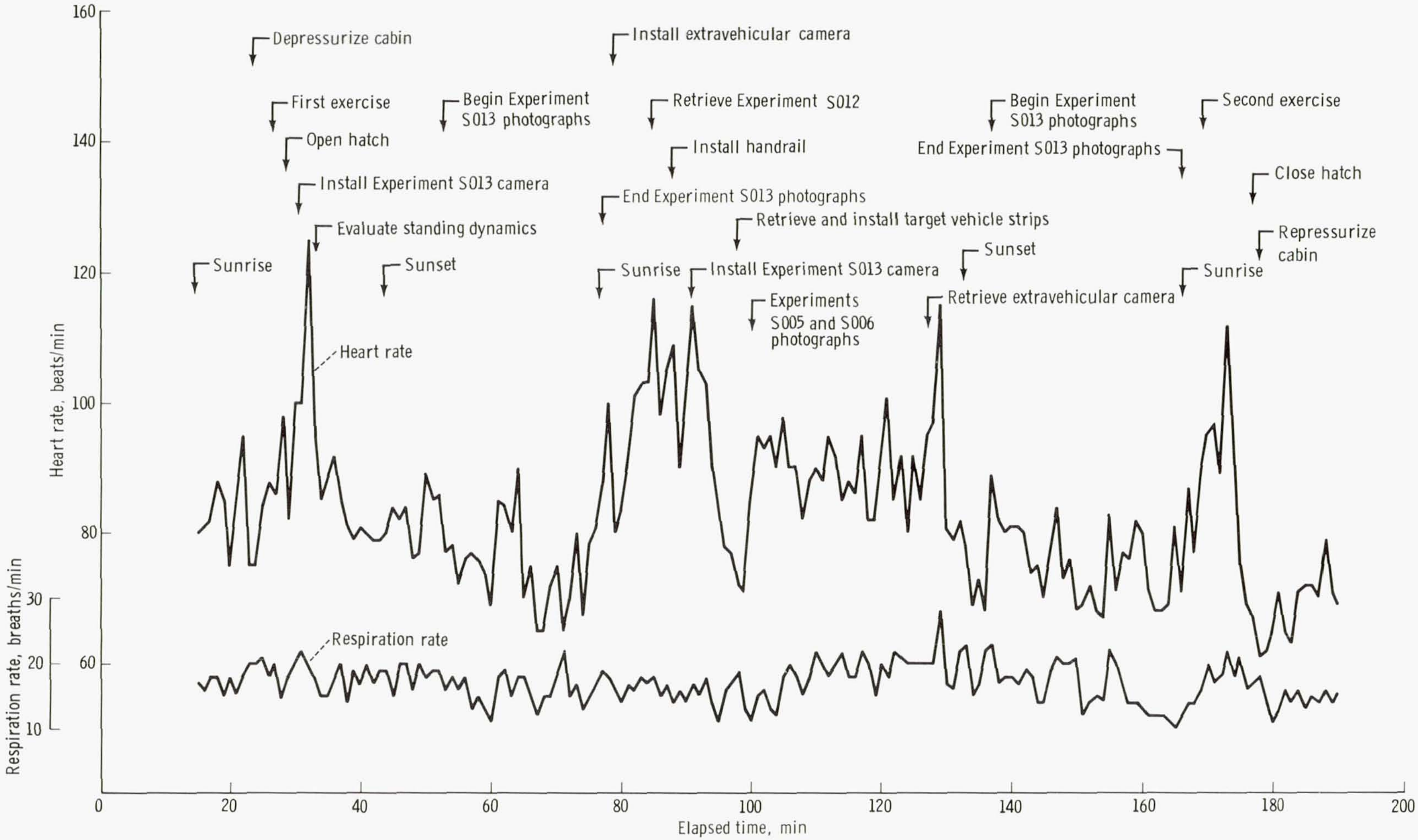
(*a*) Gemini X pilot.

FIGURE 10–5.—Physiological data during standup extravehicular activity.



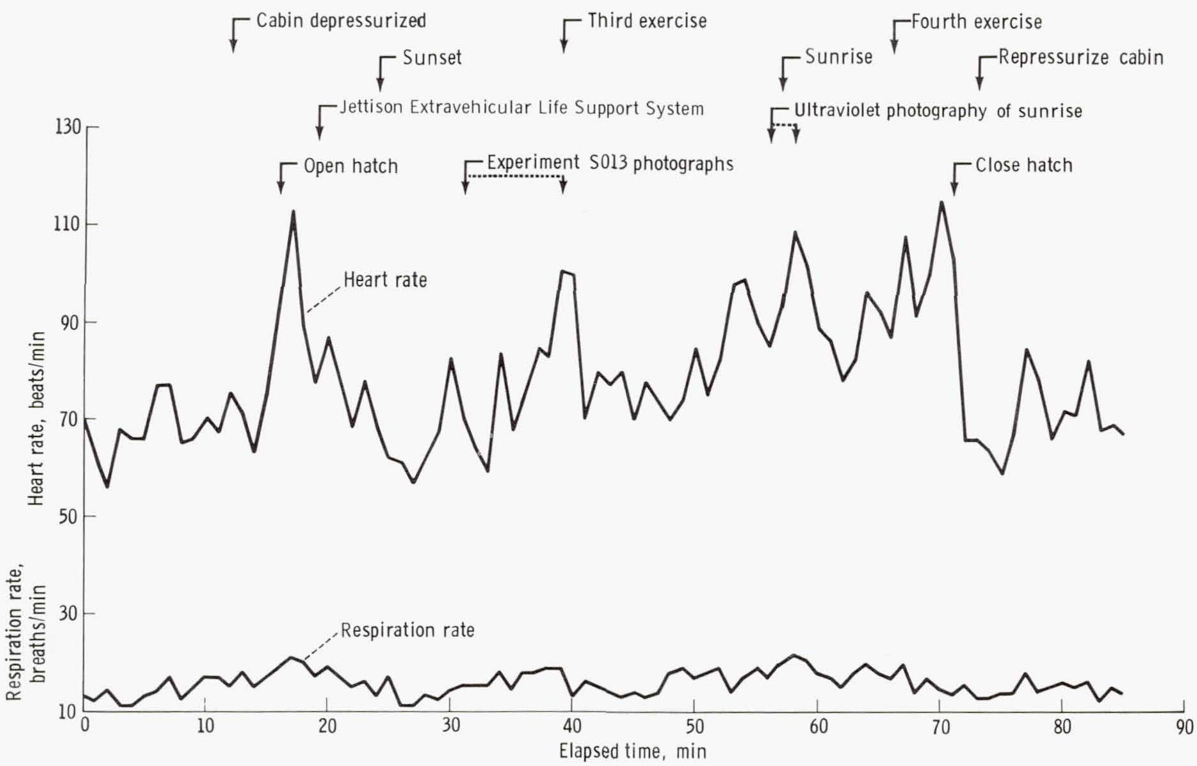
(*b*) Gemini XI pilot.

FIGURE 10–5.—Continued.



(c) First standup extravehicular activity of the Gemini XII pilot.

FIGURE 10–5.—Continued.



(*d*) Second standup extravehicular activity of the Gemini XII pilot.

FIGURE 10–5.—Concluded.

11. SUMMARY OF GEMINI EXTRAVEHICULAR ACTIVITY

By REGINALD M. MACHELL, *Office of Spacecraft Management, Gemini Program Office, NASA Manned Spacecraft Center;* LARRY E. BELL, *Crew Systems Division, NASA Manned Spacecraft Center;* NORMAN P. SHYKEN, *Senior Engineer, McDonnell Aircraft Corp.; and* JAMES W. PRIM *III, Office of Spacecraft Management, Gemini Program Office, NASA Manned Spacecraft Center*

Introduction

The Gemini Program has provided the first experience in extravehicular activity in the U.S. manned space effort. The original objectives included the following:

(1) Develop the capability for extravehicular activity in free space.

(2) Use extravehicular activity to increase the basic capability of the Gemini spacecraft.

(3) Develop operational techniques and evaluate advanced equipment in support of extravehicular activity for future programs.

In general, these principal objectives have been met. Some of the problems encountered during the equipment evaluation caused the emphasis to be shifted from maneuvering equipment to body-restraint devices.

The initial Gemini design guidelines contemplated missions with 30 to 60 minutes of extravehicular activity with very low workloads and metabolic rates (500 Btu/hr). Various ground simulations subsequently indicated the need for longer periods of extravehicular activity and greater heat-dissipation capabilities if significant useful results were to be obtained. The design criteria for the extravehicular life-support equipment were ultimately set at a mission length of 140 minutes with a normal metabolic rate of 1400 Btu/hr and a peak rate of 2000 Btu/hr. The flight results indicated that in several instances this metabolic rate was unintentionally exceeded. The final mission, Gemini XII, demonstrated the equipment and procedures by which the workload and the metabolic rates could be maintained within the desired limits.

One of the most difficult aspects of developing an extravehicular capability was simulating the extravehicular environment. The combination of weightlessness and high vacuum was unattainable on Earth. Zero-gravity aircraft simulations were valuable but occasionally misleading. Neutral buoyancy simulations underwater ultimately proved to be the most realistic duplication of the weightless environment for body positioning and restraint problems. The novel characteristics of the extravehicular environment and the lack of comparable prior experience made intuition and normal design approaches occasionally inadequate. The accumulation of flight experience gradually led to an understanding of the environment and the techniques for practical operations.

Extravehicular Mission Summary

Extravehicular activity was accomplished on 5 of the 10 manned Gemini missions. A total of 6 hours 1 minute was accumulated in five extravehicular excursions on an umbilical (table 11–I). An additional 6 hours 24 minutes of hatch-open time were accumulated in six periods of standup extravehicular activity including two periods for jettisoning equipment. The total extravehicular time for the Gemini Program was 12 hours 25 minutes.

TABLE 11-I.—*Summary of Gemini Extravehicular Activity Statistics*

Mission	Life-support system	Umbilical length, ft	Maneuvering device	Umbilical extravehicular activity time, hr:min	Standup time, hr:min [a]	Total extravehicular activity time, hr:min
IV	VCM	25	Hand Held Maneuvering Unit	0:36	None	0:36
VIII	ELSS, ESP	25	Hand Held Maneuvering Unit	None	None	None
IX-A	ELSS, AMU	25	Astronaut Maneuvering Unit	2:07	None	2:07
X	ELSS	50	Hand Held Maneuvering Unit	0:39	0:50	1:29
XI	ELSS	30	Hand Held Maneuvering Unit	0:33	2:10	2:43
XII	ELSS	25	None	2:06	3:24	5:30
Totals for Gemini Program				6:01	6:24	12:25

[a] Includes mission equipment jettison time.

Gemini IV

Two of the objectives of the Gemini IV mission were to establish the initial feasibility of extravehicular activity and to evaluate a simple maneuvering device. The life-support system was a small chest pack called the Ventilation Control Module, with oxygen supplied through a 25-foot umbilical hose assembly (fig. 11-1). The Hand Held Maneuvering Unit was a self-contained, cold-gas propulsion unit which utilized two 1-pound tractor jets and one 2-pound pusher jet. The G4C space suit was worn with an extravehicular cover layer for micrometeorite and thermal protection. While outside the spacecraft, the pilot also wore a special sun visor designed for visual protection.

The Gemini IV pilot was outside the spacecraft for 20 minutes and followed the time line shown in figure 11-2. The results proved the feasibility of simple extravehicular activity without disorientation. The utility of the Hand Held Maneuvering Unit for self-propulsion without artificial stabilization was tentatively indicated, although the 20 seconds of available thrust were not enough for a detailed stability and control evaluation. The

FIGURE 11-1.—Gemini IV extravehicular system.

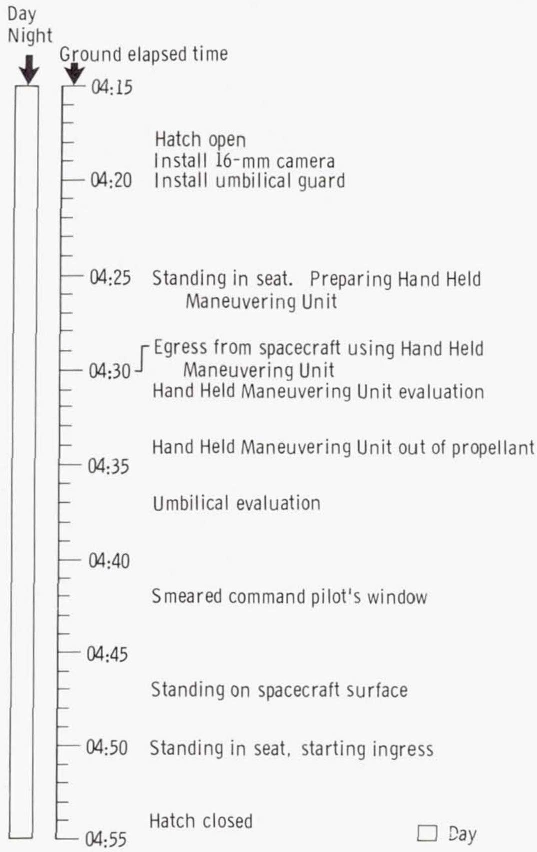


FIGURE 11-2.—Gemini IV extravehicular time line.

extravehicular pilot evaluated the dynamics of a 25-foot tether, and was able to push from the surface of the spacecraft under gross control. The umbilical tether caused the pilot to move back in the general direction of the spacecraft. The tether provided no means of body positioning control other than as a distance-limiting device. Ingress to the cockpit and hatch closure was substantially more difficult than anticipated because of the high forces required to pull the hatch fully closed. The hatch-locking mechanism also malfunctioned, complicating the task of ingress. Efforts by the extravehicular pilot in coping with the hatch-closing problems far exceeded the cooling capacity of the Ventilation Control Module. The pilot was overheated at the completion of ingress, although he had been cool while outside the spacecraft. Several hours were required for the pilot to cool off after completion of the extravehicular period; however, no continuing aftereffects were noted. Because of the previous hatch-closing problems, the hatch was not opened for jettisoning the extravehicular equipment.

The inflight experience showed that substantially more time and effort were required to prepare for the extravehicular activity than had previously been anticipated. The increased hazards of extravehicular activity dictated meticulous care in the inflight checkout before the spacecraft was depressurized. The flight crew found the use of detailed checklists a necessary part of the preparations for extravehicular activity. The Gemini IV mission proved that extravehicular activity was feasible, and indicated several areas where equipment performance needed improvement.

Gemini VIII

The next extravehicular activity was planned for the Gemini VIII mission and was intended to evaluate the Extravehicular Life-Support System. This system was a chest pack with a substantially greater thermal capacity than the Ventilation Control Module used during Gemini IV, and had an increased reserve oxygen supply. In addition, the extravehicular activity was intended to evaluate the Extravehicular Support Package, a backpack unit containing an independent oxygen supply for life support; a larger capacity propellant supply for the Hand Held Maneuvering Unit; and an ultrahigh-frequency radio package for independent voice communications. A detailed evaluation was also planned on the Hand Held Maneuvering Unit while the pilot was on a 75-foot lightweight tether. The extravehicular equipment is shown in figure 11-3. The Gemini VIII mission was terminated before the end of the first day because of a spacecraft control-system malfunction, and no extravehicular activity was accomplished.

Equipment design became very complicated during preparation for the Gemini VIII mission because of the need to provide the pilot

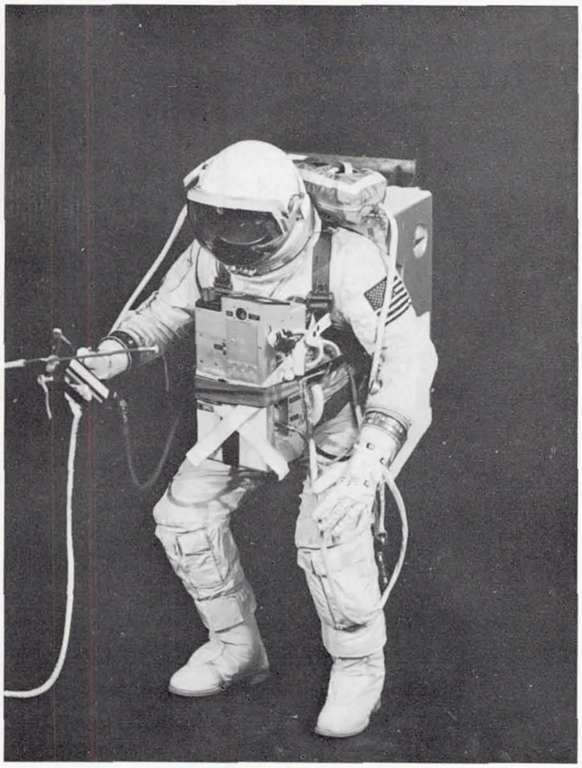


FIGURE 11-3.—Gemini VIII extravehicular system.

with connections to a chest pack, a backpack, several oxygen and communication lines, and a structural tether. Acceptable designs and procedures were established; however, the handling procedures were more difficult than was desirable. Although the Gemini VIII extravehicular equipment was not used in orbit, its use in training and in preparation for flight provided initial insight into the problems of complicated equipment connections.

Gemini IX–A

The prime objective of the Gemini IX–A extravehicular activity was to evaluate the Extravehicular Life-Support System and the Air Force Astronaut Maneuvering Unit. The Astronaut Maneuvering Unit was a backpack which included a stabilization and control system, a hydrogen-peroxide propulsion system, a life-support oxygen supply, and an ultrahigh-frequency radio package for voice communications. The mission profile planned for the extravehicular activity was very similar to the profile intended for Gemini VIII. The hatch was to be opened at sunrise of a daylight period when good communications could be established with the tracking stations in the continental United States. The first daylight period was to be devoted to familiarization with the environment and to performance of preparing simple evaluations and experiments. The succeeding night period was to be spent in the adapter equipment section of the spacecraft checking out and donning the Astronaut Maneuvering Unit. The second daylight period was to be spent evaluating the Astronaut Maneuvering Unit. At the end of this period the pilot was to return to the cockpit, discard the Astronaut Maneuvering Unit, complete a simple scientific photographic experiment, and ingress. The equipment for extravehicular activity during Gemini IX–A is shown in figures 11–4 and 11–5.

The Gemini IX–A extravehicular activity proceeded essentially as planned for the first daylight period, and is indicated in the time line of figure 11–6. The pilot experienced higher forces than expected in moving the hatch in the partially open position, but this condition did not cause any immediate difficulties. While outside the spacecraft, the pilot discovered that the familiarization tasks and evaluations required more time and effort than the ground simulations, and that minor difficulties were experienced in controlling body position. Prior to the end of the first orbital day, the pilot proceeded to the spacecraft adapter and began the preparations for donning the Astronaut Maneuvering Unit. The task of preparing the Astronaut Maneuvering Unit required much more work than had been anticipated, principally because of the difficulties in maintaining body position on the foot bar and the hand bars. At approximately 10 minutes after sunset, the visor on the extravehicular pilot's helmet began to fog. The fogging increased in coverage and severity until the crew were forced to discontinue the activities with the Astro-

FIGURE 11-4.—Gemini IX-A extravehicular system.

FIGURE 11-5.—Gemini IX-A adapter provisions for extravehicular activity.

naut Maneuvering Unit. After sunrise, the fogging decreased slightly, but increased again when the extravehicular pilot expended any appreciable effort in his tasks. Although the Astronaut Maneuvering Unit was finally donned, the extravehicular activity was terminated early because of the visor fogging, and the Astronaut Maneuvering Unit was not evaluated. The pilot experienced further difficulties in moving the hatch in the intermediate position; however, the forces required to close and lock the hatch were normal. The overall time line for the Gemini IX-A extravehicular activity is shown in figure 11-6.

Postflight evaluation indicated that the Extravehicular Life-Support System functioned normally. It was concluded that the Astronaut Maneuvering Unit preparation tasks and the lack of adequate body restraints had resulted in high workloads which exceeded the design limits of the Extravehicular Life-Support System. Visor fogging was attributed to the high respiration rate and high humidity conditions in the helmet. The pilot reported that he was not excessively hot until the time of ingress. It was concluded that the performance of the Extravehicular Life-Support System heat exchanger may have been degraded at this time because the water supply of the evaporator became depleted.

As a result of the problems encountered during the Gemini IX-A extravehicular activity, several corrective measures were initiated. To minimize the susceptibility to visor fogging, it was determined that an antifog

solution should be applied to the space-suit helmet visors immediately prior to the extravehicular activity on future missions. Each extravehicular task planned for the succeeding missions was analyzed in greater detail for the type of body restraints required and the magnitude of the forces involved. An overshoe type of positive foot restraint was installed in the spacecraft adapter and was designed to be used for the extravehicular

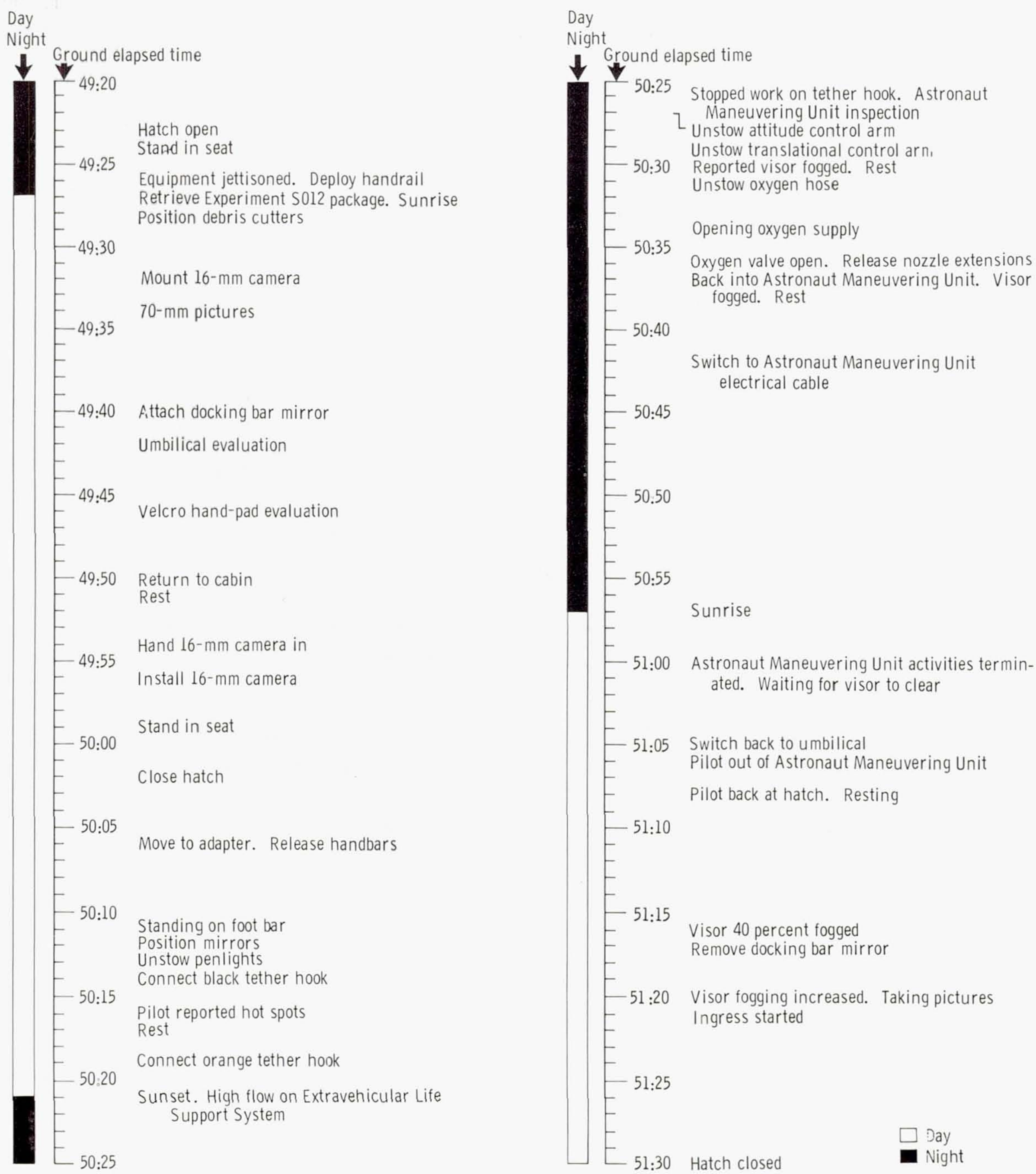


FIGURE 11-6.—Gemini IX-A extravehicular time line.

tasks planned for Gemini XI and XII. The analysis showed that all extravehicular tasks planned for the Gemini X, XI, and XII missions could be accomplished satisfactorily. As another corrective step, underwater simulation was initiated in an attempt to duplicate the weightless environment more accurately than did the zero-gravity aircraft simulations.

Gemini X

The prime objective of the Gemini X extravehicular activity was to retrieve the Experiment S010 Agena Micrometeorite Collection package from the target vehicle that had been launched for the Gemini VIII mission. The package was to be retrieved immediately after rendezvous with the Gemini VIII target vehicle, and the umbilical extravehicular activity was to last approximately one daylight period. In addition, it was planned to continue the evaluation of the Hand Held Maneuvering Unit; to retrieve the Experiment S012 Gemini Micrometeorite Collection package from the spacecraft adapter; and to conduct several photographic experiments. Photography was scheduled for 1½ orbits during a period of standup extravehicular activity.

The extravehicular equipment included the Extravehicular Life-Support System, the improved Hand Held Maneuvering Unit, and the new 50-foot dual umbilical. One hose in the umbilical carried the normal spacecraft oxygen supply to the Extravehicular Life-Support System. The other hose carried nitrogen for the Hand Held Maneuvering Unit. The umbilical was designed so that the Hand Held Maneuvering Unit and all oxygen fittings could be connected before the hatch was opened; however, the nitrogen supply for the Hand Held Maneuvering Unit had to be connected outside the spacecraft cabin. The configuration and operation of this umbilical were simpler than the complicated connections with the Gemini VIII and IX-A equipment. The 50-foot umbilical had the disadvantage of requiring a substantial increase in stowage volume over the 25-foot single umbilical assembly used on Gemini VIII and IX-A. The extravehicular equipment for Gemini X is shown in figure 11-7. For the standup extravehicular activity, short extension hoses were connected to the spacecraft Environmental Control System to permit the pilot to stand while remaining on the spacecraft closed-loop system. The pilot also used a fabric-strap standup tether to take any loads required to hold him in the cockpit.

The standup activity commenced just after sunset at an elapsed flight time of 23 hours

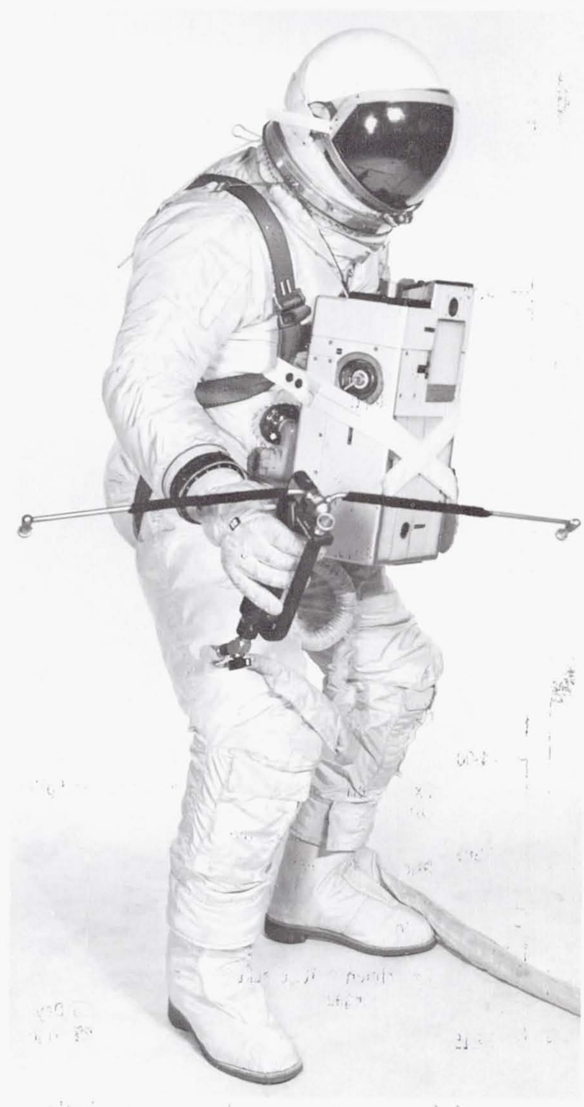


FIGURE 11-7.—Gemini X extravehicular system.

24 minutes, and proceeded normally for the first 30 minutes (fig. 11–8). The pilot was well restrained by the standup tether, and since there were no unusual problems with body positioning, ultraviolet photographs of various star fields were taken with no difficulty. Immediately after sunrise, both crewmembers experienced vision interference caused by eye irritation and tears, and the crew elected to terminate the standup activity at this time.

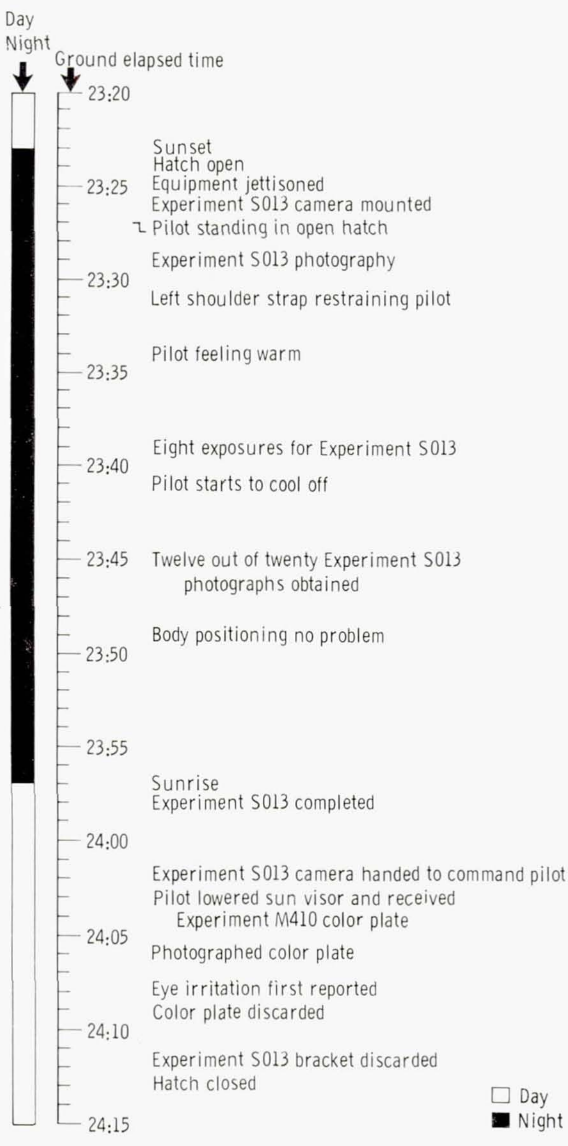


FIGURE 11–8.—Gemini X standup extravehicular time line.

The eye irritation subsided gradually after ingress and hatch closure. The cause of the eye irritation was not known, but was believed to be related to the simultaneous use of both compressors in the spacecraft oxygen-supply loop to the space suits. The crew verified that, prior to the umbilical extravehicular activity, no significant eye irritation was experienced when only one suit compressor was used while the cabin was decompressed.

The Gemini X umbilical extravehicular activity was initiated at an elapsed flight time of 48 hours 42 minutes, immediately after rendezvous with the Gemini VIII target vehicle. The sequence of events is indicated in figure 11–9. The pilot retrieved the Experiment S012 Gemini Micrometeorite Collection package from the exterior of the spacecraft adapter, then moved outside to connect the nitrogen umbilical supply line for the Hand Held Maneuvering Unit. The pilot then returned to the cockpit. Meanwhile, the command pilot was flying the spacecraft in close formation with the target vehicle (fig. 11–10). With the docking cone of the target vehicle approximately 5 feet away, the pilot pushed off from the spacecraft and grasped the outer lip of the docking cone. In moving around the target vehicle to the location of the Experiment S010 Agena Micrometeorite Collection package, the pilot lost his hold on the smooth lip of the docking cone and drifted away from the target vehicle. He used the Hand Held Maneuvering Unit to translate approximately 15 feet back to the spacecraft. The pilot then used the Hand Held Maneuvering Unit to translate to the target vehicle. On his second attempt to move around the docking cone, the pilot used the numerous wire bundles and struts behind the cone as handholds, and was able to maintain satisfactory control of his body position. Retrieval of the Experiment S010 Agena Micrometeorite Collection package was accomplished without difficulty. While carrying the package, the pilot used the umbilical to

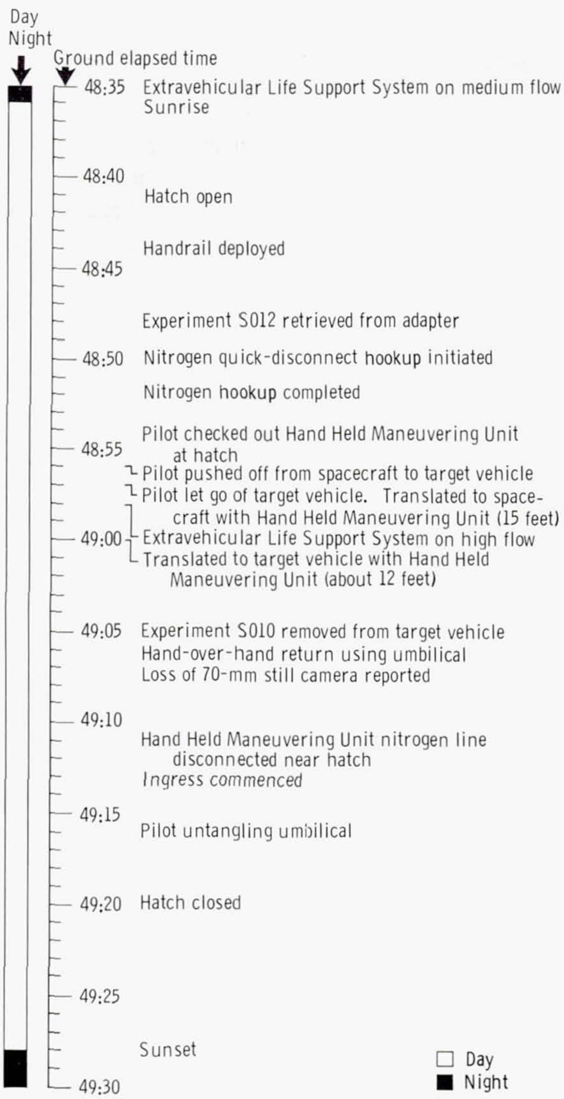


FIGURE 11-9.—Gemini X umbilical extravehicular time line.

pull himself back to the cockpit. At this time, the spacecraft propellant supply had reached the lower limit allotted for the extravehicular activity and the station-keeping operation, and the extravehicular activity was terminated.

During the first attempt to ingress, the pilot became entangled in the 50-foot umbilical. Several minutes of effort were required by both crewmembers to free the pilot from the umbilical so that he could ingress. The

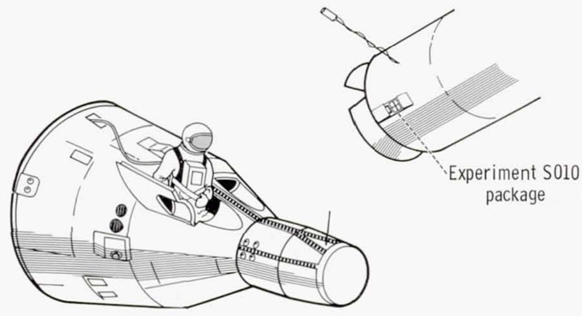


FIGURE 11-10.—Beginning of the Gemini X extravehicular transfer.

hatch was then closed normally. Fifty minutes later the crew again opened the right hatch and jettisoned the Extravehicular Life-Support System, the umbilical, and other miscellaneous equipment not required for the remainder of the mission.

During the umbilical extravehicular activity, the pilot reported the loss of the 70-mm still camera. The camera had been fastened to the Extravehicular Life-Support System with a lanyard, but the attaching screw came loose. It was also discovered that the Experiment S012 Gemini Micrometeorite Collection package had been accidentally thrown out or had drifted out of the hatch. The package had been stowed in a pouch with an elastic top, but appeared to have been knocked free while the 50-foot umbilical was being untangled.

The principal lessons learned from the extravehicular phase of this mission included the following:

(1) Preparation for extravehicular activity was an important task for which the full-time attention of both crewmembers was desirable. Combining a rendezvous with a passive target vehicle and the extravehicular activity preparation caused the crew to be rushed, and did not allow the command pilot to give the pilot as much assistance as had been planned.

(2) The tasks of crew transfer and equipment retrieval from another satellite could be accomplished in a deliberate fashion without excessive workload. Formation flying with another satellite could be accomplished

readily by coordination of thruster operation between the command pilot and the extravehicular pilot.

(3) Equipment not securely tied down was susceptible to drifting away during extravehicular activity, even when precautions were being taken.

(4) The bulk of the 50-foot umbilical was a greater inconvenience than had been anticipated. The stowage during normal flight and the handling during ingress made this length undesirable.

Gemini XI

The prime objectives of the Gemini XI extravehicular activity were to attach a 100-foot tether between the spacecraft and the target vehicle, and to provide a more extensive evaluation of the Hand Held Maneuvering Unit. In addition, several experiments, including ultraviolet photography, were scheduled for standup extravehicular activity. The umbilical extravehicular activity was scheduled for the morning of the second day so that the spacecraft/target-vehicle tether evaluation could be accomplished later in that same day.

The equipment (fig. 11–11) for the Gemini XI extravehicular activity was the same as for the Gemini X mission, except that the dual umbilical was shortened from 50 to 30 feet to reduce the stowage and handling problems. An Apollo sump-tank module was mounted in the spacecraft adapter section, and incorporated two sequence cameras designed for retrieval during extravehicular activity. The Hand Held Maneuvering Unit was also stowed in the adapter section. A molded overshoe type of foot restraint was provided for body restraint while performing tasks in the spacecraft adapter (fig. 11–12).

The Gemini XI umbilical extravehicular activity was initiated at an elapsed flight time of 24 hours 2 minutes. Almost immediately, there were indications of difficulty. The first significant task after egress was to position and secure the external sequence camera. After the camera was secured, the pilot indicated that he was fatigued and out of breath. The pilot then moved to the front of the spacecraft, and assumed a straddle position on the Rendezvous and Recovery Section in preparation for hooking up the spacecraft/target-vehicle tether. While maintaining position and attaching the tether, the pilot expended a high level of effort for several minutes. After returning to the cockpit to rest, the pilot continued to breathe very heavily and was apparently fatigued. In view of the unknown effort required for the re-

FIGURE 11–11.—Gemini XI extravehicular system.

FIGURE 11–12.—Foot restraints installed in the adapter section for Gemini XI and XII missions.

maining tasks, the crew elected to terminate the extravehicular activity prior to the end of the first daylight period. Ingress and hatch closure were readily accomplished. The time line for the umbilical extravehicular activity is shown in figure 11–13.

The Gemini XI standup extravehicular activity was initiated at an elapsed flight time of 46 hours 6 minutes, just prior to sunset. The crew began the ultraviolet stellar photography as soon as practical after sunset, and the photography of star patterns was readily accomplished. The extravehicular pilot operated at a very low work level, since he was well restrained by the standup tether. As in the Gemini X standup extravehicular activity, the crew had little difficulty with the standup tasks. After completing the planned activities (fig. 11–14), the pilot ingressed and closed the hatch without incident.

Discussions with the crew and analysis of the onboard films after the flight revealed several factors which contributed to the high rate of exertion during the umbilical activity and the subsequent exhaustion of the pilot. The factors included the following:

(1) The lack of body restraints required a high level of physical effort to maintain a straddle position on the nose of the spacecraft.

(2) The zero-gravity aircraft simulations had not sufficiently duplicated the extrave-

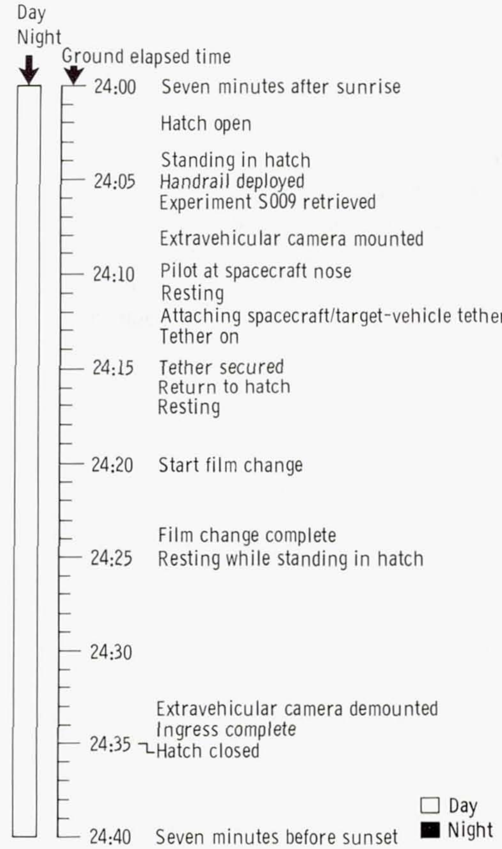


FIGURE 11–13.—Gemini XI umbilical extravehicular time line.

hicular environment to demonstrate the difficulties of the initial extravehicular tasks.

(3) The requirement to perform a mission-critical task immediately after egress did not allow the pilot an opportunity to become accustomed to the environment. This factor probably caused the pilot to work faster than was desirable.

(4) The high workloads may have resulted in a concentration of carbon dioxide in the space-suit helmet high enough to cause the increased respiration rate and the apparent exhaustion. Although there was no measurement of carbon-dioxide concentration in flight, there was an indication of an increase in concentration at high workloads during testing of the Extravehicular Life-Support System. For workloads far above design lim-

FIGURE 11-14.—Gemini XI standup extravehicular time line.

its, this concentration could reach values that would cause physiological symptoms, including high respiration rates and decreased work tolerances.

Gemini XII

The results of the Gemini XI mission raised significant questions concerning man's ability to perform extravehicular activity satisfactorily with the existing knowledge of the tasks and environment. The Gemini X umbilical activity results had established confidence in the understanding of extravehicular restraints and of workload; however, the Gemini XI results indicated the need for further investigation. The Gemini XII extravehicular activity was then redirected from an evaluation of the Astronaut Maneuvering Unit to an evaluation of body restraints and extravehicular workload. Attachment of the spacecraft/target-vehicle tether and ultraviolet stellar photography were other objectives. The extravehicular equipment for the Gemini XII mission included a new work station in the spacecraft adapter (fig. 11–15), a new work station on the Target Docking Adapter (fig. 11–16), and several added body restraints and handholds. The pilot's extravehicular equipment (fig. 11–17) was nearly identical to that of Gemini IX–A.

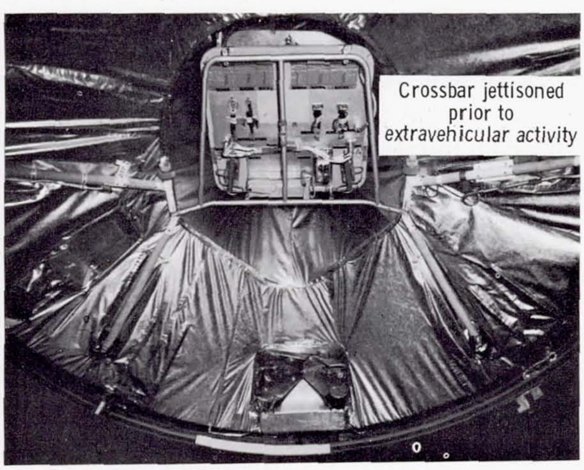


FIGURE 11–15.—Gemini XII adapter provisions for extravehicular activity.

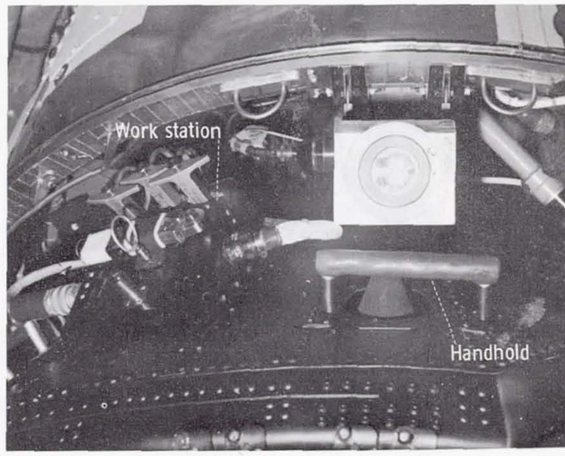


FIGURE 11–16.—Gemini XII extravehicular work station on Target Docking Adapter.

The flight-crew training for the Gemini XII extravehicular activity was expanded to include two periods of intensive underwater simulation and training (fig. 11–18). During these simulations, the pilot followed the intended flight procedures, and duplicated the planned umbilical extravehicular activity on an end-to-end basis. The procedures and times for each event were established, and were used to schedule the final inflight task sequence. The underwater training supplemented extensive ground training and zero-gravity aircraft simulations.

To increase the margin for success and to provide a suitable period of acclimatization to the environment before the performance of any critical tasks, the standup extravehicular activity was scheduled prior to the umbilical activity. The planned extravehicular activity time line was intentionally interspersed with 2-minute rest periods. Procedures were also established for monitoring the heart rate and respiration rate of the extravehicular pilot; the crew were to be advised of any indications of a high rate of exertion before the condition became serious. Finally, the pilot was trained to operate at a moderate work rate, and flight and ground personnel were instructed in the importance of workload control.

The first standup extravehicular activity

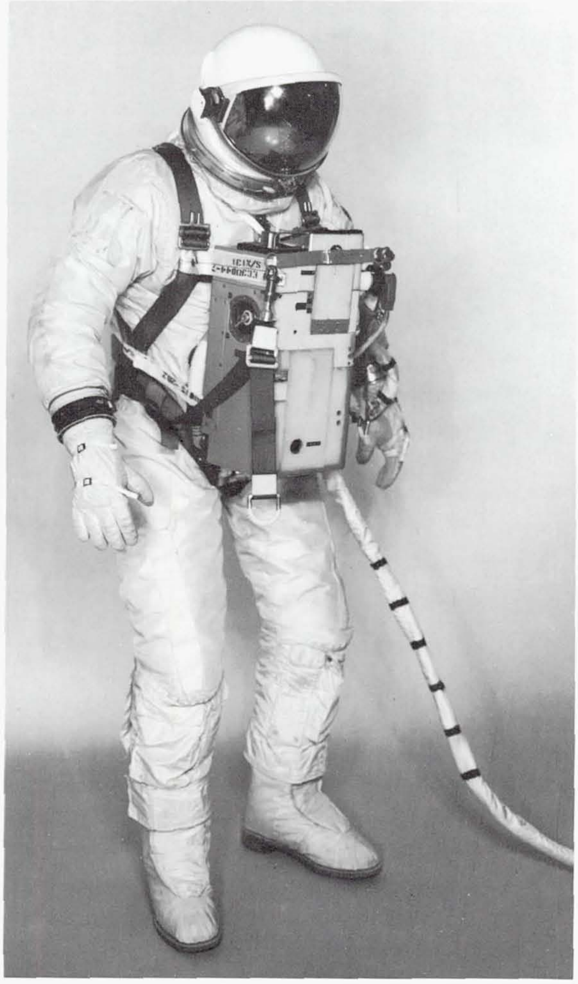


FIGURE 11-17.—Gemini XII extravehicular system.

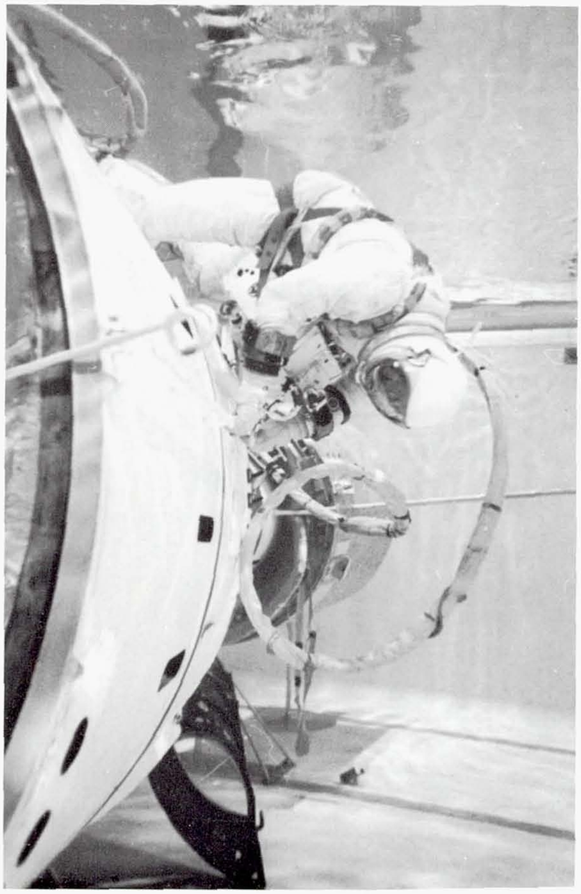


FIGURE 11-18.—Underwater simulation of Gemini XII extravehicular activity.

was very similar to that of the two previous missions. As indicated by the time line in figure 11-19, the ultraviolet stellar and the synoptic terrain photography experiments were accomplished on a routine basis. During the standup activity, the pilot performed several tasks designed for familiarization with the environment and for comparison of the standup and umbilical extravehicular activities. These tasks included mounting the extravehicular sequence camera and installing an extravehicular handrail from the cabin to the docking adapter on the target vehicle. The standup activity was completed without incident.

The umbilical extravehicular activity preparations proceeded smoothly, and the hatch was opened within 2 minutes of the planned time (fig. 11-20). The use of waist tethers during the initial tasks on the Target Docking Adapter enabled the pilot to rest easily, to work without great effort, and to connect the spacecraft/target-vehicle tether in an expeditious manner. In addition, the pilot activated the Experiment S010 Agena Micrometeorite Collection package on the target vehicle for possible future retrieval. Prior to the end of the first daylight period, the pilot moved to the spacecraft adapter where he evaluated the work tasks of torquing bolts, making and breaking electrical and fluid connectors, cutting cables and fluid lines, hooking rings and hooks, and stripping patches of

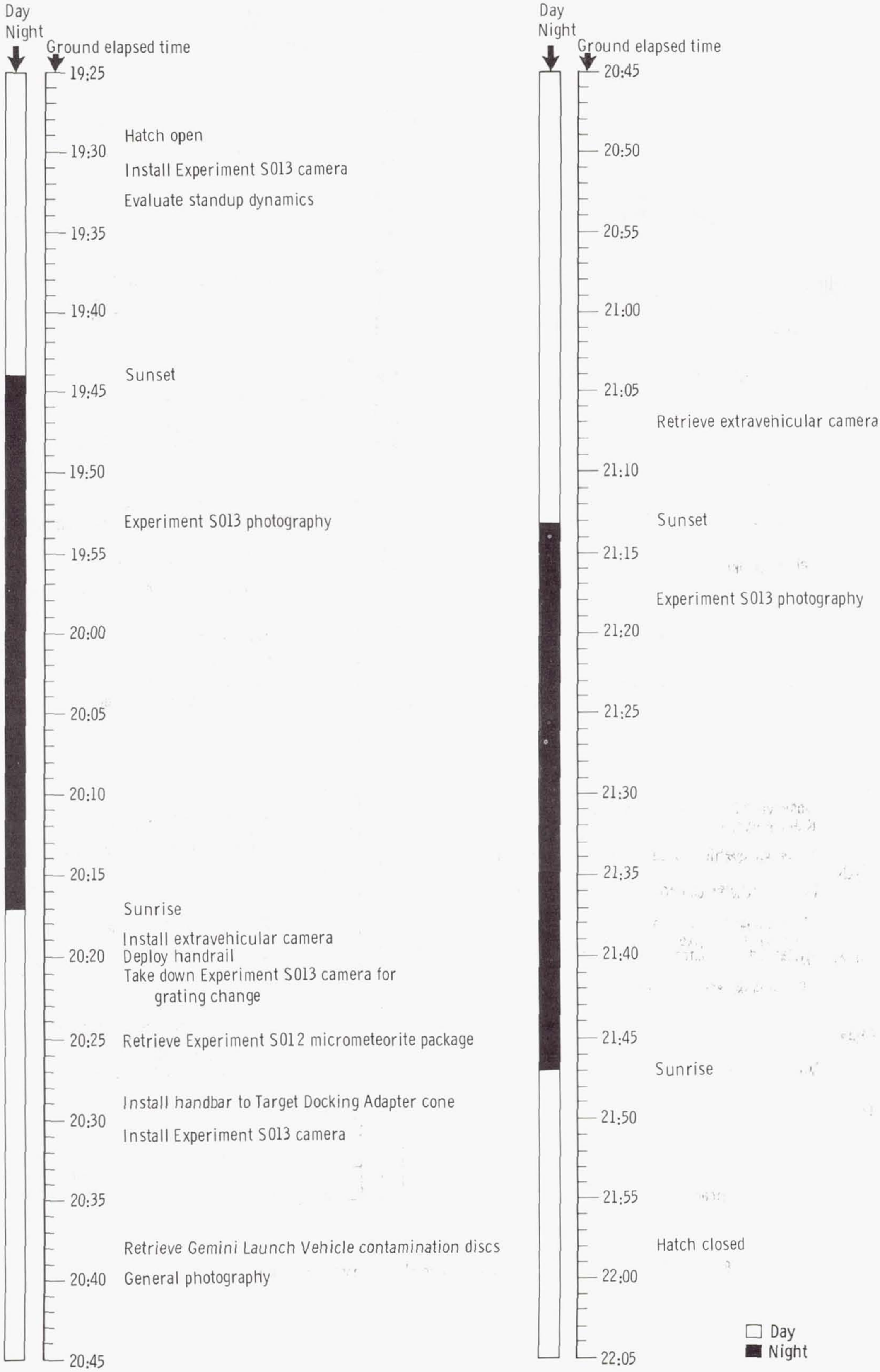


FIGURE 11-19.—Gemini XII first standup extravehicular time line.

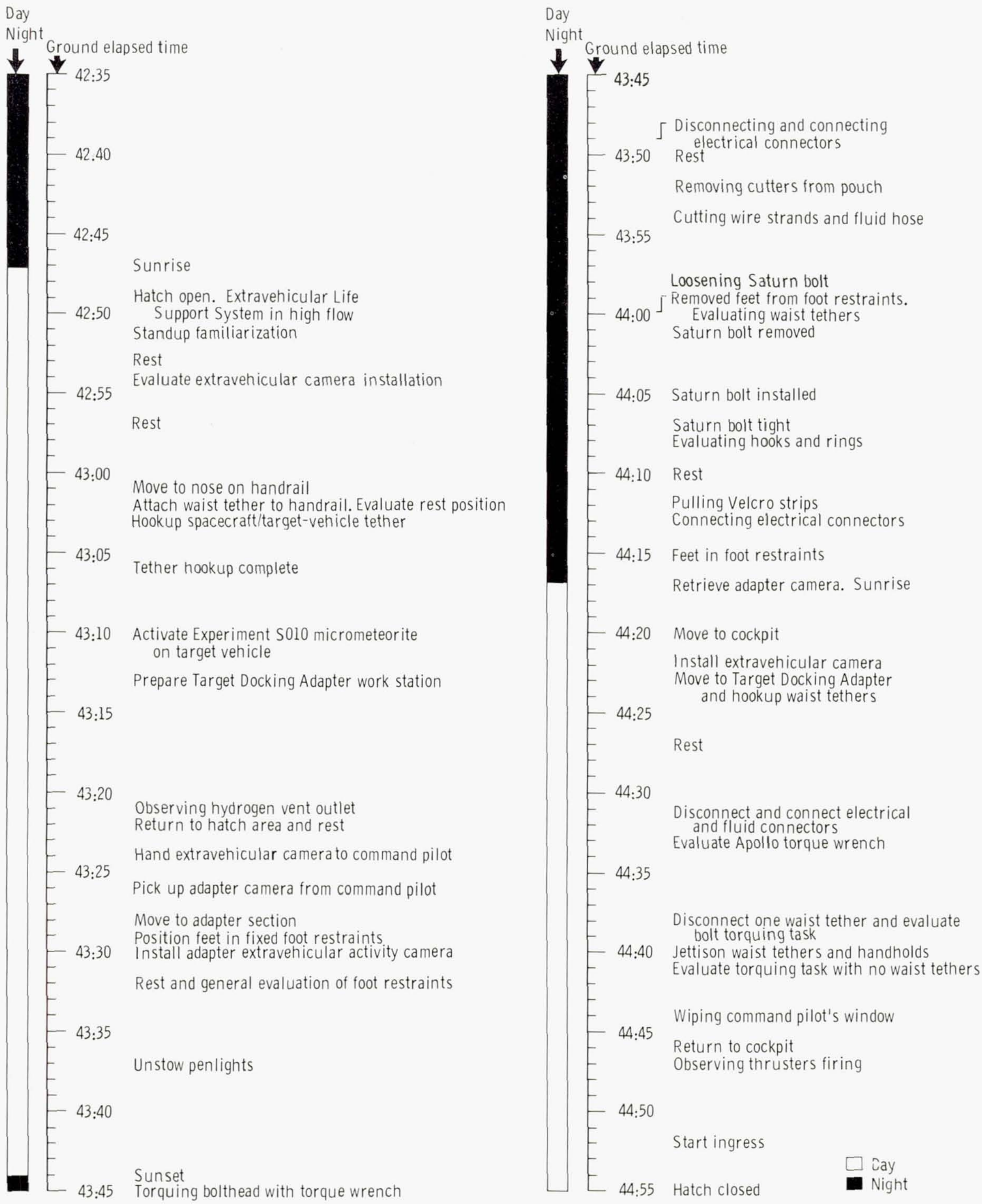


FIGURE 11–20.—Gemini XII umbilical extravehicular time line.

Velcro. The tasks were accomplished using either the two foot restraints or the waist tethers, and both systems of restraint proved satisfactory.

During the second daylight period of the umbilical activity, the pilot returned to the target vehicle and performed tasks at a small work station on the outside of the docking cone. The tasks were similar to those in the spacecraft adapter and, in addition, included an Apollo torque wrench. The pilot further evaluated the use of two waist tethers, one waist tether, and no waist tether. At the end of the scheduled extravehicular activity, the pilot returned to the cabin and ingressed without difficulty.

A second standup extravehicular activity was conducted (fig. 11–21). Again, this activity was routine and without problems. The objectives were accomplished, and all the attempted tasks were satisfactorily completed.

The results of the Gemini XII extravehicular activity showed that all the tasks attempted were feasible when body restraints were used to maintain position. The results also showed that the extravehicular workload could be controlled within desired limits by the application of proper procedures and indoctrination. The final, and perhaps the most significant, result was the confirmation that the underwater simulation duplicated the actual extravehicular environment with a high degree of fidelity. It was concluded that any task which could be accomplished readily in a valid underwater simulation would have a high probability of success during actual extravehicular activity.

Extravehicular Capabilities Demonstrated

In the course of the Gemini missions, a number of capabilities were demonstrated which met or exceeded the original objectives of extravehicular activity. The basic feasibility of extravehicular activity was well established by the 11 hatch openings and the more than 12 hours of operations in the environment outside the spacecraft. The Gemini missions demonstrated the ability to control the extravehicular workload and to maintain the workload within the limits of the life-support system and the capabilities of the pilot. Standup and umbilical extravehicular operations were accomplished during eight

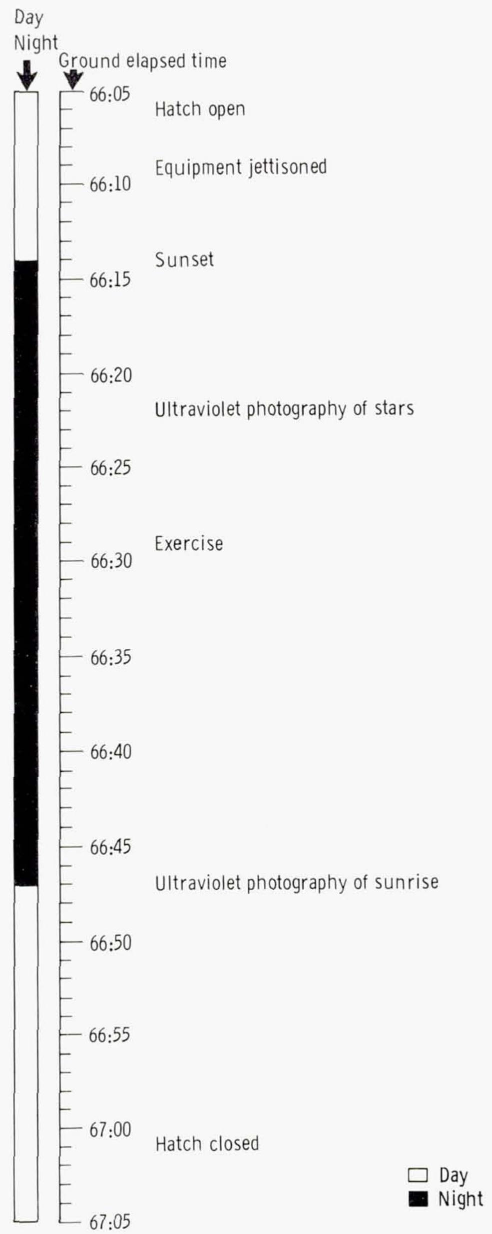


FIGURE 11–21.—Gemini XII second standup extravehicular time line.

separate nighttime periods to confirm the feasibility of extravehicular operations at night.

The need for handholds for transit over the exterior surface of the spacecraft was shown, and the use of several types of fixed and portable handholds and handrails was satisfactorily demonstrated.

The capability to perform tasks of varying complexity was demonstrated. The character of practical tasks was shown, and some of the factors that limit task complexity and difficulty were identified.

Several methods were demonstrated for crew transfer between two space vehicles and include: (1) surface transit while docked, (2) free-floating transit between two undocked vehicles in close proximity, (3) self-propulsion between two undocked vehicles, and (4) tether or umbilical pull-in from one undocked vehicle to another. All of these methods were accomplished within a maximum separation distance of 15 feet.

The Hand Held Maneuvering Unit was evaluated briefly, but successfully, on two different missions. When the maneuvering unit was used, the extravehicular pilots accomplished the maneuvers without feeling disoriented and without loss of control.

Retrieval of equipment from outside the spacecraft was demonstrated on four missions. One equipment retrieval was accomplished from an unstabilized passive target vehicle, which had been in orbit for more than 4 months.

Gemini X demonstrated the capability for the command pilot to maneuver in close proximity to the target vehicle while the pilot was outside the spacecraft. The close-formation flying was successfully accomplished by coordinating the thruster firings of the command pilot with the extravehicular maneuvers of the pilot. No damage nor indication of imminent hazard occurred during the operation.

Photography from outside the spacecraft was accomplished on each extravehicular mission. The most successful examples were the ultraviolet stellar spectral photographs taken during standup extravehicular activities on three missions and the extravehicular sequence photographs taken with the camera mounted outside the spacecraft cabin.

The dynamics of motion on a short tether were evaluated on two missions. The only tether capability that was demonstrated was for use as a distance-limiting device.

The requirements for body restraints were established, and the capabilities of foot restraints and waist tethers were demonstrated in considerable detail. The validity of underwater simulation in solving body restraint problems and in assessing workloads was demonstrated in flight and further confirmed by postflight evaluation.

In summary, the Gemini missions demonstrated the basic techniques required for the productive use of extravehicular activity. Problem areas were defined sufficiently to indicate the preferred equipment and procedures for extravehicular activity in future space programs.

Extravehicular Limitations and Solutions

While most of the Gemini extravehicular activities were successful, several areas of significant limitations were encountered. Space-suit mobility restrictions constituted one basic limitation which affected all the mission results. The excellent physical capabilities and conditions of the flight crews tended to obscure the fact that moving around in the Gemini space suit was a significant work task. Since the suit design had already been established for the flight phase of the Gemini Program, the principal solution was to optimize the tasks and body restraints to be compatible with the space suits. For the 2-hour extravehicular missions, glove mobility and hand fatigue were limiting factors, both in training and in flight.

The size and location of the Extravehicular Life-Support System chest pack was a constant encumbrance to the crews. This design was selected because of space limitations within the spacecraft, and the crews were continually hampered by the bulk of the chest-mounted system.

The use of gaseous oxygen as the coolant medium in the space suit and Extravehicular Life-Support System was a limiting factor in the rejection of metabolic heat and in pilot comfort. The use of a gaseous system required the evaporation of perspiration as a cooling mechanism. At high workloads, heavy perspiration and high humidity within the suit were certain to occur. These factors were evident on the missions where the workloads exceeded the planned values. As in the case of suit mobility, the cooling system design was fixed for the Gemini Program; hence, any corrective action had to be in the area of controlling the workload.

Work levels and metabolic rates could not be measured in flight; however, the flight results indicated that the design limits were probably exceeded several times. Inflight work levels were controlled by providing additional body restraints, allowing a generous amount of time for each task, and establishing programed rest periods between tasks. These steps, coupled with the underwater simulations techniques, enabled the Gemini XII pilot to control the workload well within the design limits of the Extravehicular Life-Support System.

The Gemini XI results emphasized the limitations of the zero-gravity aircraft simulations and of ground training without weightless simulation. These media were useful but incomplete in simulating all extravehicular tasks. The use of underwater simulation for development of procedures and for crew training proved effective for Gemini XII.

The sequence in which extravehicular events were scheduled seemed to correlate with the ease of accomplishment. There appeared to be a period of acclimatization to the extravehicular environment. The pilots who first completed a standup extravehicular activity seemed more at ease during the umbilical activity; therefore, it appears that critical extravehicular tasks should not be scheduled until the pilot has had an opportunity to familiarize himself with the environment.

Equipment retention during extravehicular activity was a problem for all items which were not tied down or securely fastened. By extensive use of equipment lanyards, the loss of equipment was avoided during the last two missions.

Concluding Remarks

The results of the Gemini extravehicular activity led to the following conclusions:

(1) Extravehicular operation in free space is feasible and useful for productive tasks if adequate attention is given to body restraints, task sequence, workload control, realistic simulations, and proper training. Extravehicular activity should be considered for use in future missions where a specific need exists, and where the activity will provide a significant contribution to science or manned space flight.

(2) Space-suit mobility restrictions were significant limiting factors in the tasks which could be accomplished in Gemini extravehicular activity. For future applications, priority efforts should be given to improving the mobility of space suits, especially arm and glove mobility.

(3) The Extravehicular Life-Support System performed satisfactorily on all Gemini missions. The necessity for a chest-mounted location caused some encumbrance to the extravehicular pilots. The use of gaseous cooling is undesirable for the increased workloads which may be encountered in future extravehicular activity.

(4) Underwater simulation provides a high-fidelity duplication of the extravehicular environment, and is effective for procedures development and crew training. There is strong evidence indicating that tasks which can be readily accomplished in a valid underwater simulation can also be accomplished in orbit. Underwater simulation should be used for procedures development and crew training for future extravehicular missions.

(5) Loose equipment must be tied down at all times during extravehicular activity to avoid loss.

(6) The Hand Held Maneuvering Unit is promising as a personal transportation device in free space; however, the evaluations to date have been too brief to define the full capabilities or limitations of this equipment. Further evaluations in orbital flight should be conducted.

(7) The Gemini Program has provided a foundation of technical and operational knowledge on which to base future extravehicular activity in subsequent programs.

OPERATIONAL EXPERIENCE

12. RADIATION ENVIRONMENT AT HIGH ORBITAL ALTITUDES

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Introduction

The Gemini X and XI space flights were highlighted by high-altitude apogees achieved by firing the Primary Propulsion System of the Gemini Agena Target Vehicle. In both flights, the docked spacecraft/target-vehicle combinations were carried much higher into the Van Allen trapped radiation belt than ever before in manned space flight.

This paper deals with the radiation environment at these altitudes and the effect of the environment on the two missions. An attempt will be made to describe the premission radiation planning for the flights, the inflight radiation measurements, the results of the postflight data analysis, and the preliminary conclusions.

Mission Planning Radiation Analysis

Environment Model

The radiation environment at the altitudes under consideration was previously mapped by unmanned satellites. The environment is composed of electrons and protons trapped in the Earth's magnetic field. Figure 12–1 shows the electron distribution. A large portion of the electrons were injected into space by a high-altitude nuclear test conducted by the United States in July 1962. These electrons augmented the natural electrons by several orders of magnitude and produced a dangerous radiation environment in near-Earth space. It has been observed that, fortunately, the intensity of these artificially injected electrons has been decaying. The decay follows the relationship

$$e^{-\Delta t/\tau} \qquad (1)$$

where Δt is the elapsed time in days from the test, and τ is the decay parameter. The energy of these trapped electrons ranges from several thousand to several million electron volts, but with a fast dropoff in intensity with energy. The electrons are especially hazardous to lightly shielded spacecraft.

Figure 12–2 shows the spacial distribution of protons. These protons result from natural causes and seem to remain relatively constant in intensity with time. The energy of the protons ranges from a few thousand electron volts to hundreds of million electron volts.

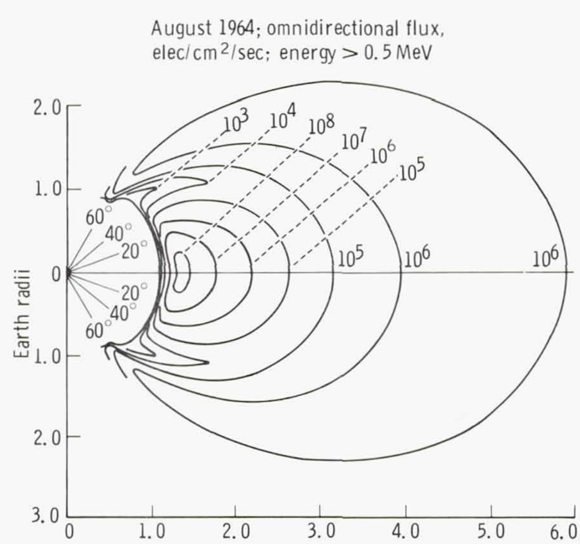

FIGURE 12–1.—Electron distribution in the Earth's field.

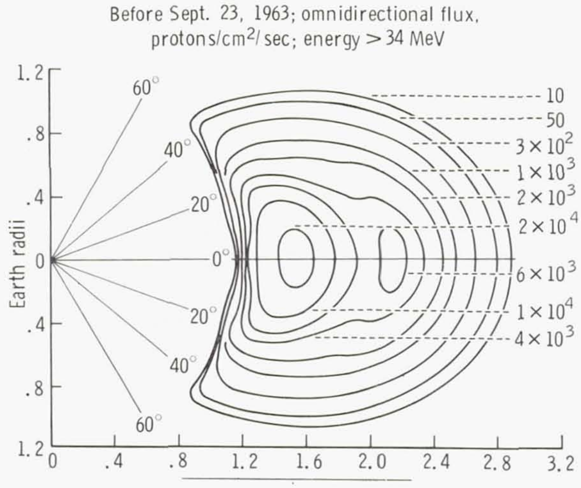

FIGURE 12–2.—Proton distribution in the Earth's field.

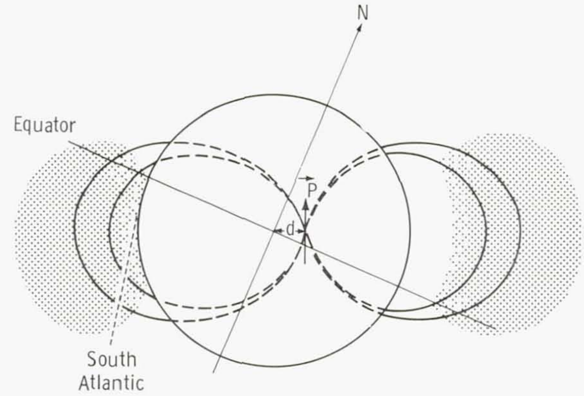

FIGURE 12–3.—South Atlantic anomaly diagram.

The higher energy protons are quite penetrating and would contribute a radiation within almost any spacecraft.

Electron and proton intensities and spectra for near-Earth space have been carefully analyzed and all of the recent satellite data have been assembled into an environmental model (refs. 1 and 2). Since the electrons are time dependent, the environment was presented as that which would have existed in August 1964. With the use of equation (1), this environment can be modified to apply to other times.

South Atlantic Anomaly

Although the spacial distribution of the trapped radiation is generally symmetrical in azimuth, the exception to this is quite important at lower altitudes. It should be recalled that the magnetic field of the Earth is approximately that which may be described by a dipole magnet at the center of the Earth (fig. 12–3). Actually, this idealized dipole magnet is both displaced from and tilted with respect to the rotational axis of the Earth. Because of the displacement of the imaginary dipole location, a region of trapped radiation (indicated by dots in fig. 12–3) is closer to the Earth's surface on one side. In addition, the tilt of the dipole rotates the region of close approach southward from the equator to the general vicinity of the South Atlantic. Since the Earth's magnetic field rotates with the Earth, the region remains in this location, and has been named the "South Atlantic anomaly." In this location, the radiation belt extends to the top of the atmosphere. Figure 12–4 shows the South Atlantic anomaly as viewed on a constant altitude contour of 160 nautical miles.

The radiation fluxes and associated spectra of the trapped electrons and protons in the South Atlantic anomaly have been measured by the following experiments flown aboard several Gemini flights:

Experiment no.	Subject	Mission
M404	Proton-electron spectrometer	IV, VII
M405	Tri-axis magnetometer	IV, VII, X, XII
M408	Beta spectrometer	X, XII
M409	Bremsstrahlung spectrometer	X, XII

These experiments measured the exterior spacecraft radiation environment during all four flights and the interior cabin radiation environment during Gemini X and XII. The preliminary results of these experiments produced a valuable description of the radiation levels in the South Atlantic anomaly at Gemini altitudes. At these altitudes the previous

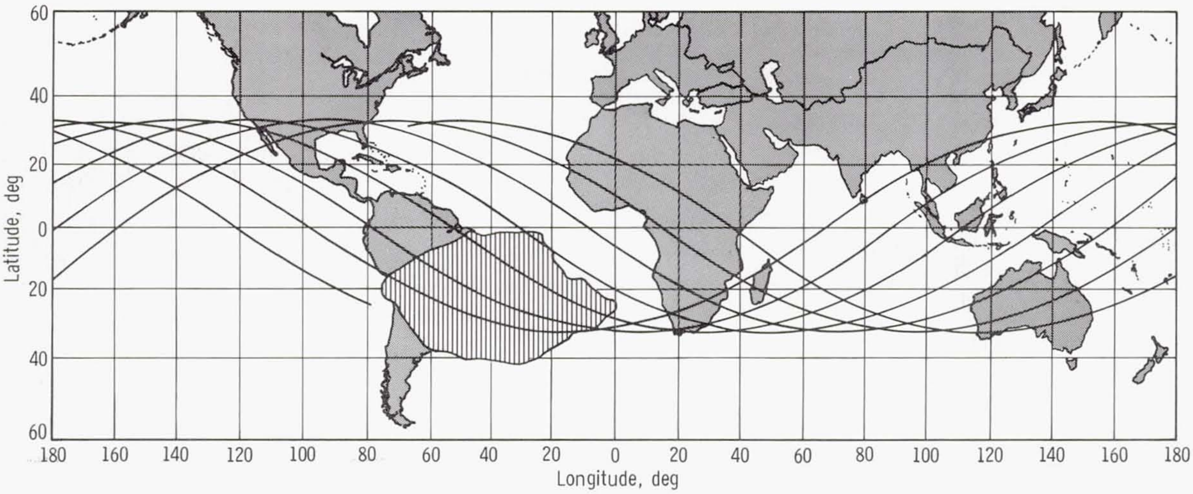

FIGURE 12-4.—Location of radiation fluxes in the South Atlantic anomaly for 160-nautical-mile altitude, 28.5° orbital ground track.

satellite model environments relied on very limited data and were consequently inaccurate.

The experiment results obtained during Gemini IV and VII were used in the premission planning of the Gemini X and XI flights to define a realistic time rate of artificial electron belt decay.

Radiation-Dose Calculations

Radiation-dose calculations are made by determining the radiation environment within the spacecraft and its resultant effect on the crew. The exterior environment, the attenuation by the spacecraft, and the response of the body to the radiation must all be considered in the calculations. In practice, the calculation of radiation dose is performed at intervals along the spacecraft trajectory and then summed to express a total dose.

A precise calculation of radiation dose received by a crewman is prohibited by the uncertain factors in the calculations. The definition of the radiation environment used is estimated to represent the actual environment only to within a factor of 2 or 3 when the variations of particle flux, energy, and direction of motion are considered. In addition, the description of the shielding about a point on the body of a crewman introduces another error factor into the calculations. In the case in point, the shielding attenuation produced by the Gemini spacecraft, the shielding geometry is quite complex. The shielding description resulting from an examination of the Gemini spacecraft mechanical drawings is estimated to be accurate only to within a factor of 2 in the subsequent calculation of radiation dose within. Finally, after assumption of an environment and the attenuation of the environment by the spacecraft shielding, a probable error results in the calculation of a tissue dose to a crewmember. The error arises from the uncertainty that as an individual proton or electron progresses into the human body, it will deposit its energy in a certain volume of the tissue, and from the uncertainty that the tissue will respond in a precise biological way to the dose. The conversion from flux at the dose point to dose in the Gemini calculations is also estimated to be accurate to within a factor of 2 or 3.

The uncertainties just described rarely add at the same point in the calculation. Instead, each uncertainty may be treated as a mathematical distribution with the factor mentioned as a deviation from the mean. In any one calculation for an individual particle, the

resultant error approximates a random sampling from each of the three distributions. In the end, all the uncertainties mentioned combine to produce an uncertainty factor of about 3 in the published dose.

In figure 12–5, the preflight estimate of the radiation dose per revolution is a function of orbital position for a 160-nautical-mile circular orbit. The dashed curve represents the dose using the August 1964 model without consideration of decay; the solid line shows the dose decayed to time of flight. The orbits are identified by a symbol which is used again to denote the dose per revolution for each revolution. The effect of the South Atlantic anomaly is clearly indicated. At this altitude, virtually all of the radiation dose is received during the six orbits passing through the anomaly.

The preflight estimate of the radiation dose per revolution is shown in figure 12–6 for the Gemini X high-altitude orbits. The dose as of August 1964 and the dose decayed to the time of flight are plotted. Figure 12–6 illustrates the dramatic increase in dose due to achieving high altitudes in the anomaly. In this case, the decayed dose increased by a factor of up to 50 in comparable revolutions; however, the Gemini X projected dose was within the allowable radiation limits for space flight.

The predicted dose for the two-revolution high-altitude portion of the Gemini XI mission was less than 1 millirad, and indicated that the Gemini XI high-altitude passes would subject the flight crew to an insignificant amount of radiation. This seemed reasonable since the Gemini XI flight would achieve apogee away from the anomaly, but not high enough to penetrate the intense regions of trapped radiation.

Protection of S009 Experiment Package

The high-altitude excursion of Gemini XI was not expected to pose a crew safety problem since the radiation doses were anticipated to be very low; however, the exterior flux of protons at these high altitudes presented a threat to an important onboard experiment package. The package was the Goddard Space Flight Center/Naval Research Laboratories cosmic-ray detector designated as scientific Experiment S009, Nuclear Emulsions. If the experiment were successful, an unshielded, time-differentiated, nuclear emulsion would be exposed at several magnetic latitudes out-

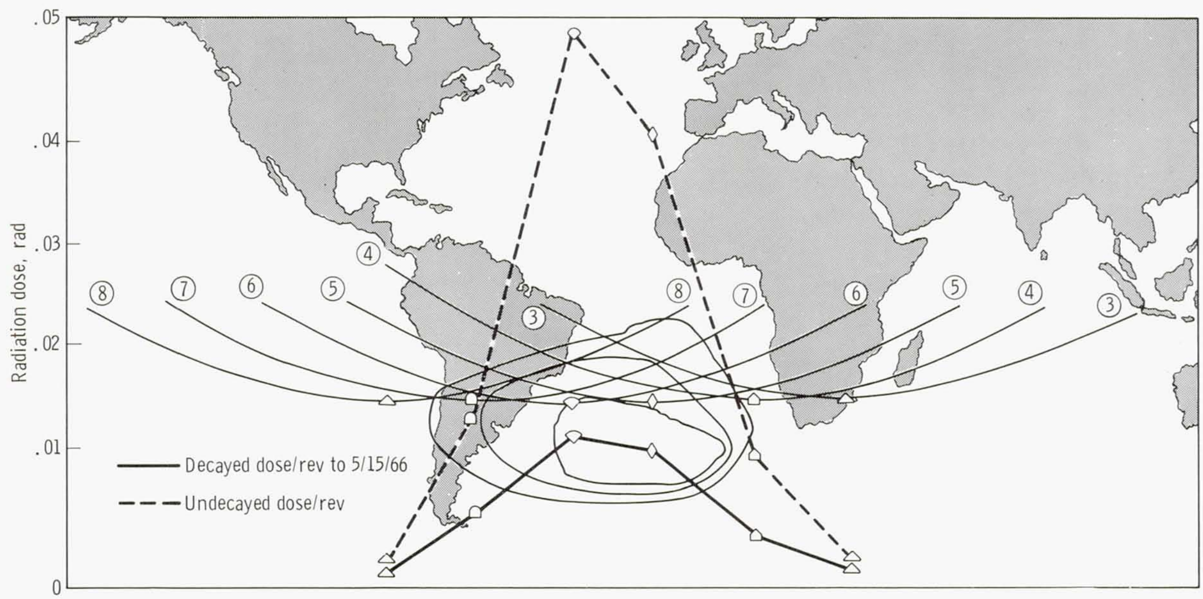

FIGURE 12–5.—Variation in radiation dose in South Atlantic anomaly. Circular orbit, 160 nautical miles.

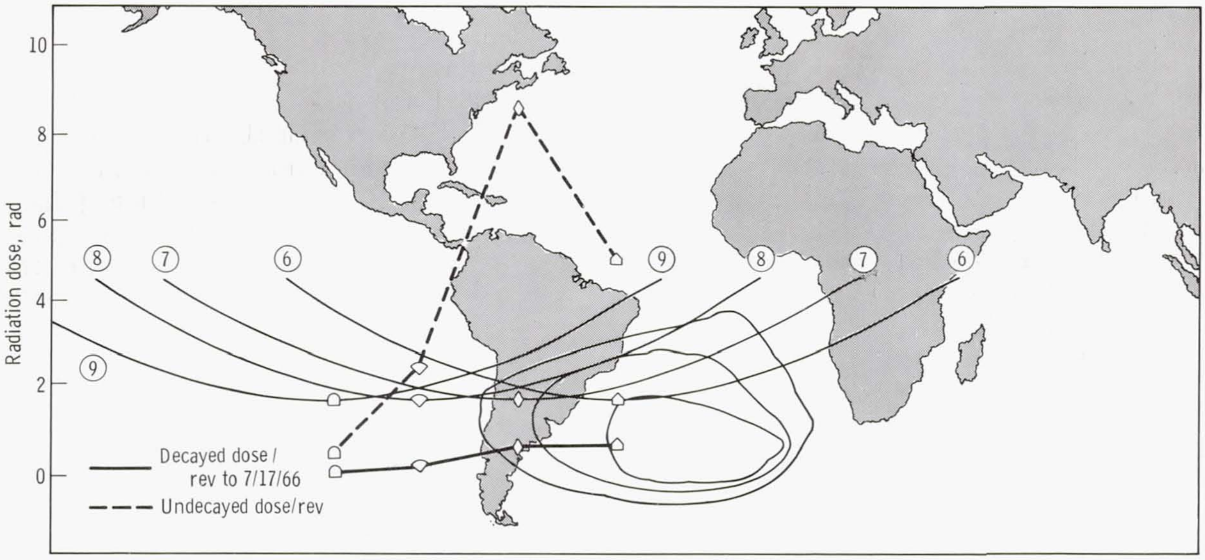

FIGURE 12–6.—Variation in radiation dose in the South Atlantic anomaly for Gemini X. Orbit, 160 by 400 nautical miles.

side the Earth's atmosphere for the first time. Subsequent identification of the cosmic rays recorded in the emulsions was considered of prime scientific importance in determining the composition of cosmic rays. Therefore, it was considered imperative that the high-altitude excursion of Gemini XI not jeopardize the success of this experiment by exposure to the higher fluxes of Van Allen belt protons (fig. 12–2) present at the higher altitudes. These protons could have rapidly ruined the emulsion in the experiment by producing an intense background from which the characteristic cosmic-ray tracks could not have been distinguished.

In establishing the flight plan for Gemini XI, many possible locations for firing the target-vehicle Primary Propulsion System to achieve the high-altitude orbits were examined for potential proton exposure. The high-altitude damage threshold of the Experiment S009 package was established as 2×10^5 proton/cm^2 within the emulsion. Upon examination, most of the possible locations for initiating the firing had to be discarded. The result of this analysis showed that initiating the high-altitude maneuver over the Canary Islands (so that the apogee would be achieved in the Southern Hemisphere over Australia) satisfied the minimum proton flux condition and the flight-plan constraints. The numerical results of this analysis are indicated in figure 12–7. A third revolution was considered as a safety factor, in the event that descent to a lower altitude had to be postponed for one revolution.

The electrons were not expected to produce a background in the emulsion because the experiment package, located on the exterior surface of the spacecraft adapter, was to be retrieved by the extravehicular pilot and placed in the crew station footwell before the high-apogee orbits. The relatively heavy shielding provided by the footwell would screen the lightly penetrating electrons, but would not completely attenuate the protons.

Inflight Measurements

During the Gemini X and XI missions, an active radiation dosimeter was utilized to enhance flight safety by providing a real-time measurement of the radiation-dose and dose rate, and to take advantage of the high-altitude portion of the flight to obtain valuable radiation data. This instrument (fig.

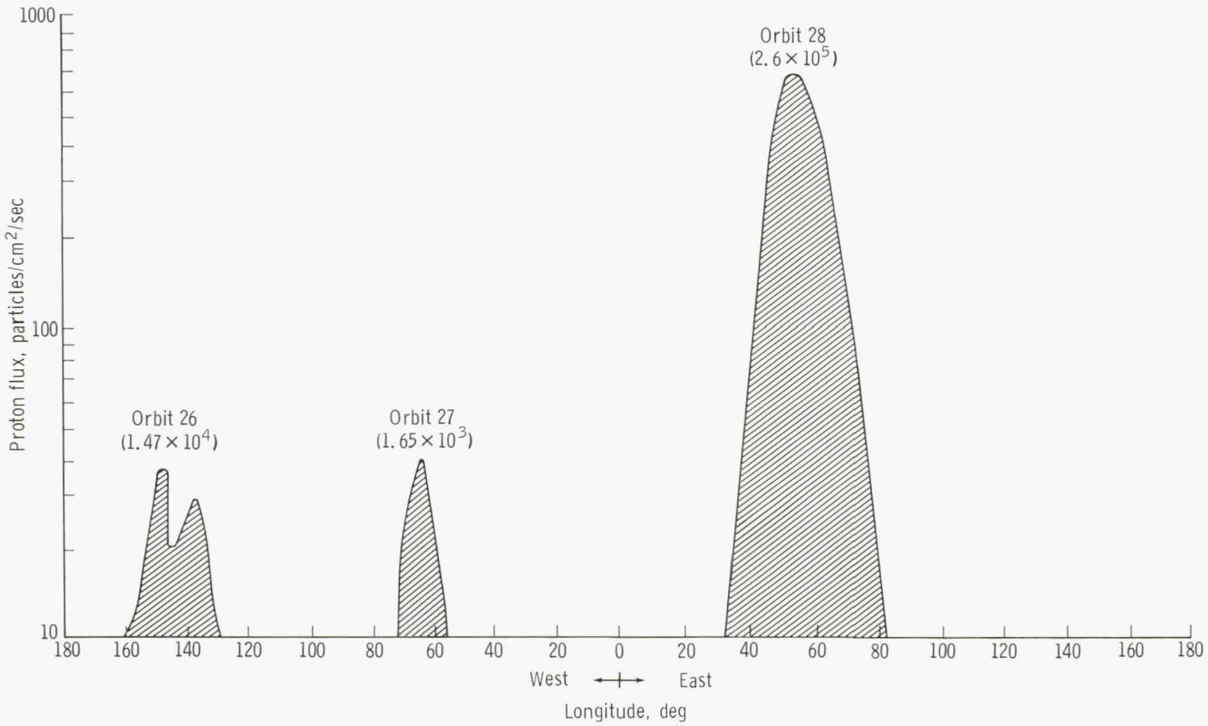

FIGURE 12-7.—Proton flux for Gemini XI

12-8), which was designated the Gemini Radiation Monitoring System, was designed, developed, and fabricated at the Manned Spacecraft Center especially for these flights. The Gemini Radiation Monitoring System consisted of two separate dosimeters sharing the same package. Each dosimeter had an ion chamber, electronics, and batteries. One dosimeter sensed the dose rate between 0.1 and 100 rads/hr and the reading was indicated on the large meter face. The other dosimeter was an integrating sensor that accumulated the dose in rads with time. This reading was indicated on the small register and ranged from 0.01 to 99.99 rads. The switch in the center was used to snub the dose-rate meter needle to prevent launch vibration damage to the delicate meter movement. The readings from the Gemini Radiation Monitoring System approximated the skin dose at the location of the instrument. No direct measurement of the depth dose was made in real time.

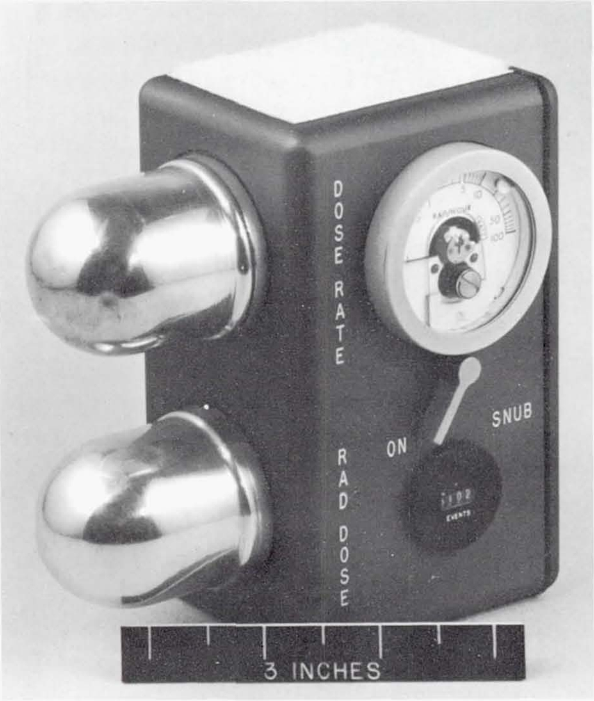

FIGURE 12-8.—Gemini Radiation Monitoring System.

During the two high-altitude flights, the Gemini Radiation Monitoring System was stowed aboard the spacecraft until shortly before the maneuver for attaining the high-apogee orbits. After the Gemini Radiation Monitoring System was unstowed, it was placed at head height between the crewmen on the Gemini X mission, and was affixed to the inside of the left hatch on the Gemini XI mission. In either case, the instrument was read before the high-altitude excursion in order to establish a baseline reading. Subsequent readings were made near the high apogees, and the dose values were reported to the ground flight controllers. Table 12–I presents the inflight crew radiation reports of the readings from the Gemini Radiation Monitoring System. In neither mission did the readings have any influence on the flight, since the reported values were well below the preplanned mission allowable dose limits.

Passive dosimeters have been worn by crewmembers on all manned Gemini flights. The passive dosimeters were packaged in plastic (fig. 12–9) and contained: thermal luminescent powder which, when heated, radiates visible light proportionate to the radiation absorbed; and various nuclear emulsions which, under microscopic analysis, determine the extent of radiation exposure. The measured doses approximated a normal skin dose at the location of the dosimeter. A summary of the measurements for all manned Gemini flights is provided in table 12–II.

TABLE 12–I.—*Summary of Gemini Radiation Monitoring System Readings*

Mission	Greenwich mean time, hr:min	Ground elapsed time, hr:min	Reading network station	Dose, rad
X	3:34	6:54	*Rose Knot Victor*	0.00
	4:49	8:09	*Rose Knot Victor*	.04
	4:59	8:20	*Rose Knot Victor*	.18
	5:17	8:37	Tananarive	.23
	14:53	18:14		.78
	Postflight			.91
XI	19:49	29:09	*Rose Knot Victor*	.00
	7:52	41:14	Carnarvon	.02
	10:02	43:23	Carnarvon	.02
	Postflight			.03 (After background removed)

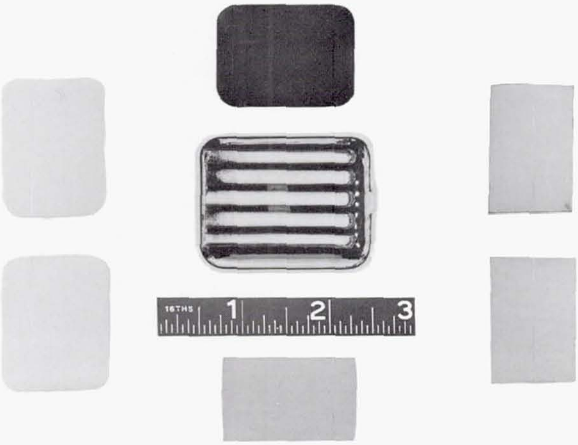

FIGURE 12–9.—Gemini passive dosimeter.

Postflight Analysis of Radiation Data

The Gemini IX–A readings (table 12–III) are representative of Gemini missions not attaining the high altitude. The table contrasts the increase in dose due to the Gemini X high-altitude passes through the South Atlantic anomaly with the negligible doses received on Gemini XI after a much higher

TABLE 12–II.—*Passive Dosimeter Results for Gemini Manned Flights*

Mission	Duration of mission	Dose to left chest of command pilot, rad
III	3 revolutions	0.020
IV	4 days	.040
V	8 days	.190
VI–A	1 day	.025
VII	14 days	.192
VIII	11 hours	All dosimeters read less than 0.010
IX–A	3 days	.018
X	3 days	.770
XI	3 days	.025
XII	4 days	.015

altitude flight opposite the anomaly in the Southern Hemisphere.

Figure 12–10 is a comparison of Gemini X inflight readings from the Gemini Radiation Monitoring System with the decayed and undecayed calculational model. The dose readings were made by the crew during the first and seventh high-altitude revolutions. The readings in the first revolution established that the environment at that altitude would not endanger the mission, and the crew was advised to begin a sleep period. After awakening, the crew reported the reading for the seventh revolution. Because of the lack of data, it is difficult to reach any definite conclusion based upon the relationships shown in figure 12–10.

The proton environment calculated for the high-altitude orbits of Gemini XI could not be confirmed by inflight measurements. The proton spectrometer data required for this comparison were not obtained on the Gemini XI flight. However, the Experiment S009 package indicated that the background of protons in the emulsion was within tolerance limits.

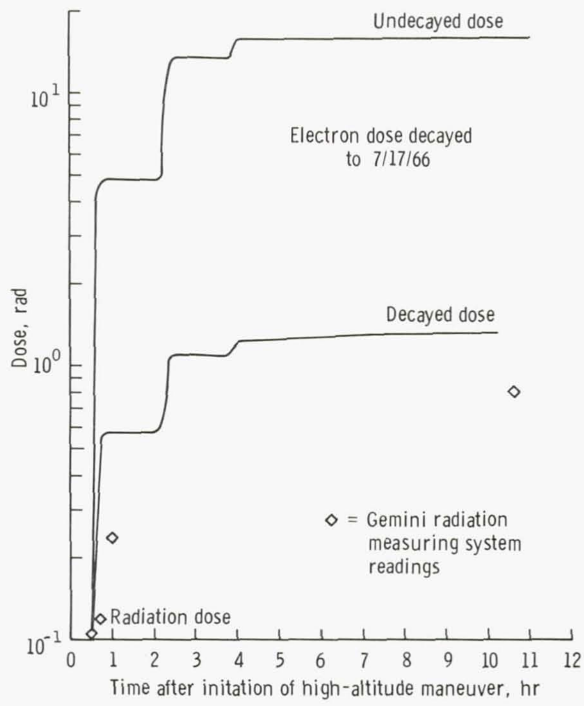

FIGURE 12–10.—Comparison of the Gemini X Radiation Monitoring System readings and the calculation model.

TABLE 12–III.—*Accumulated Radiation-Dose Comparisons*

Mission	Calculated		Measured	
	Aug. 1964 estimate, rad	Decayed estimate, rad	Passive dosimeter, rad	Gemini Radiation Monitoring System, rad
IX–A [a]	0.30	0.090	0.018	Not applicable
X [b]	17.3	1.4	.770	0.910
XI [c]	.303	.091	.025	.030

[a] Readings based upon 161-n.-mi. circular orbit for 3 days.
[b] Readings based upon 161- by 400-n.-mi. orbit for 12 hours, and 161-n.-mi. circular orbit for 2½ days.
[c] Readings based upon 161- by 750-n.-mi. orbit for 3⅓ hours, and 161-n.-mi. circular orbit for 2½ days.

Conclusions

One of the most important results of the high-altitude flights of Gemini X and XI is that manned space flight at higher altitudes is possible with a minimum of radiation dose. This is due to the confirmed continuing decay of the artificially injected electrons and to careful planning of the trajectory. Extravehicular activity, for example, would be possible during many high-altitude orbits if not performed while the spacecraft is passing through the South Atlantic anomaly.

Gemini X demonstrated the effect of the South Atlantic anomaly on the rapidly increasing dose rate at the higher altitudes of approximately 400 nautical miles. On the other hand, Gemini XI attained the highest apogee, 742 nautical miles, over Australia and was still free from significant radiation doses.

Another important result is the reasonable amount of agreement between the preflight calculations and the measured values of radiation dose. The differences are explained when the uncertainties of making these calculations are considered. It is anticipated that the shielding breakdown description for the Apollo missions will be more accurate than the description used for Gemini. An operational environment sensor is to be included on the Apollo missions; consequently, the radiation calculation should agree more closely with the measured values. As a result, greater confidence is provided for further exploration of the relatively unknown radiation environment in space.

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13. CONTROLLED REENTRY

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Summary

One of the primary objectives of the Gemini Program has been successfully achieved, that of controlling the landing point by modulating the direction of the inherent lift vector of the spacecraft during reentry. The program has utilized two reentry guidance techniques which provided steering commands based upon a logical assessment of current and predicted energy conditions. This paper presents a brief description of these two sets of reentry guidance logic, and a detailed description of the results obtained from each Gemini spacecraft reentry. During the Gemini Program, successful landing-point control has been accomplished from Earth orbits varying from an apogee/perigee of 110 by 45 nautical miles to an apogee/perigee of 215 by 161 nautical miles. The Gemini spacecraft has been flown with an average lift-to-drag ratio of approximately 0.19. This has resulted in an average reentry maneuver capability of 300 nautical miles downrange and ±27 nautical miles crossrange. The average footprint shift due to the retrofire maneuver has been 25 nautical miles, and the average navigation accuracy has been 2.2 nautical miles.

Introduction

One of the major objectives of the Gemini Program was to demonstrate accurate touchdown-point control through the use of trajectory-shaping techniques during reentry. This trajectory control was used to compensate for dispersions caused by unpredicted retrofire maneuvers, by atmospheric variations, and by uncertainties in the aerodynamic characteristics of the spacecraft. Further, trajectory control greatly minimized the recovery task for emergency reentries such as occurred on Gemini VIII.

This paper describes the results of the reentry phase of each Gemini mission. However, a brief review of the aerodynamic characteristics of the spacecraft and the guidance logic used during Gemini will be helpful in understanding the reentry results of each flight.

Aerodynamic Characteristics

Aerodynamic lift is established on a symmetrical body, such as the Gemini vehicle, by placing the center of gravity so that the resultant trim angle of attack provides the desired lift characteristics. To maintain the least amount of aerodynamic heating on the spacecraft hatches and windows during reentry, the spacecraft was flown inverted with the center-of-gravity offset toward the pilots' feet (fig. 13–1). In this inverted position, the spacecraft was rolled to the bank angle required to utilize the lift vector for downrange and lateral range-control capability. The range control, or touchdown footprint, provided with the Gemini reentry center of gravity was approximately 300 nautical miles down range and 50 nautical miles lateral range. When the maximum range was desired, the spacecraft maintained a heads-down or zero-degree bank angle (fig. 13–1).

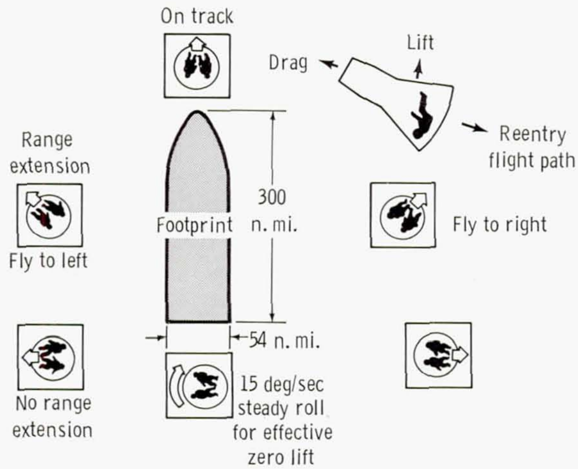


FIGURE 13–1.—Reentry control concepts.

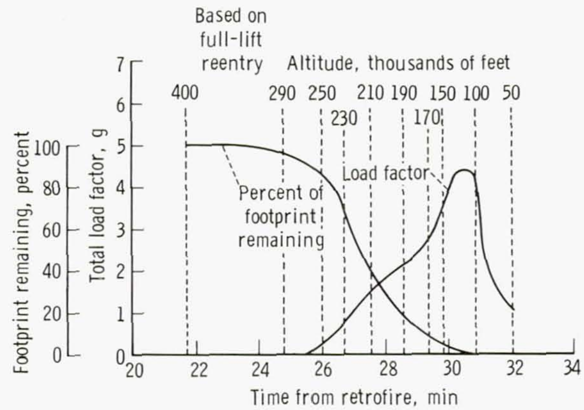


FIGURE 13–2.—Reentry maneuver capability as a function of elapsed time from retrofire.

Minimum range was obtained with either a 90° bank angle or a rolling reentry to null the effects of the lifting force.

The responsiveness of the spacecraft to the required maneuvers for accurate touchdown on the target point was dependent upon the static and dynamic stability of the spacecraft in the reentry region where the range-control capability was most significant. When a stable vehicle was not provided, the correct bank angle could not adequately be maintained for the correct response, and thereby created touchdown errors. The most significant amount of range-control capability existed while the spacecraft was in the upper reaches of the atmosphere (fig. 13–2); 80 percent of the range-control capability existed between an altitude of approximately 250 000 and 170 000 feet. The total reentry time from start of retrograde to deployment of drogue parachute varied from 29.0 minutes for Gemini VI–A to 32.5 minutes for Gemini XII, and depended on the particular retrograde orbit of each flight. Only 2.5 minutes were available for utilizing the lift capability to accurately adjust the reentry trajectory. The necessity for accurate commands and spacecraft responses during that time was clearly indicated.

It was essential that the spacecraft exhibit good stability characteristics during the effective lift portion of the trajectory in order to achieve accurate touchdown control. A qualitative summary of the stability characteristics of the spacecraft indicated that good static and dynamic stability were present in the region of most significance. At lower Mach numbers, the stability characteristics were from marginal to unstable, but the range errors were minimum. The drogue parachute was deployed at 50 000 feet to avoid the unstable dynamic stability characteristic. Results of the first few Gemini reentries raised questions concerning the accuracy of the aerodynamics; however, the analysis of the last seven flights indicated reasonably consistent aerodynamic characteristics for the Gemini reentry configuration.

Guidance Logic

Two different reentry steering techniques were developed and used during the Gemini Program, a rolling reentry technique and a constant bank-angle technique. Both utilized a predicted range computed from the range-to-go of a reference trajectory, and from the range contribution that was realized from the deviation of navigated flight conditions from corresponding reference quantities. The reference ranges and the range-to-flight condition sensitivity coefficients were stored in the onboard computer memory as a function of a parameter relating navigated

velocity and measured acceleration. Figure 13–3 illustrates the rolling reentry technique employed during the Gemini Program; this technique was based on a zero-lift reference trajectory. The control logic commanded the direction of the spacecraft lift vector necessary to steer to a zero-lift trajectory which would terminate at the target. A lifting profile was flown until a zero-lift trajectory coincided with the target point. At this point a constant roll rate was commanded to neutralize the effect of the inherent lifting capability of the spacecraft.

Figure 13–4 illustrates the guidance logic for the rolling reentry technique where *RN* is the downrange component of the total range between the spacecraft position and the target; *RC* is the crossrange component; and *RP* is the predicted zero-lift range. A bank angle *BC* is commanded based upon the ratio of *RC*/*RN*—*RP*. The control technique simultaneously nulls the downrange and crossrange trajectory errors by continuously updating *BC* based upon the ratio of range errors, until the predicted zero-lift range *RP* is equal to the downrange distance to the target *RN*. At this point, if the crossrange error is greater than a 1-nautical-mile deadband, a 90° bank angle is commanded, the direction depending on the sign (plus or minus) of the crossrange error. When the crossrange error is within the deadband, a zero-lift trajectory is initiated by commanding a constant roll rate. The rolling portion of the trajectory is interrupted occasionally in order to command any additional lift necessary to steer back to the zero-lift trajectory. The predicted zero-lift trajectory is purposely biased early in the reentry to always place the spacecraft in an undershoot condition, thereby eliminating the need for negative lift in order to reach the target. This guidance logic was used on Gemini III, IV, VIII, IX–A, X, XI, and XII.

Figure 13–5 illustrates the constant bank-angle reentry technique. This technique is

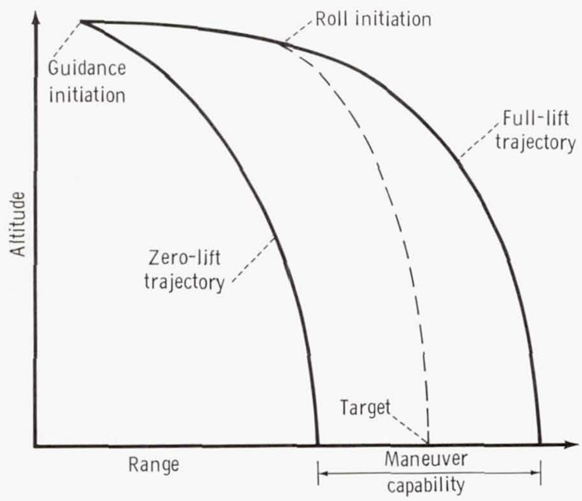


FIGURE 13–3.—Gemini rolling reentry technique.

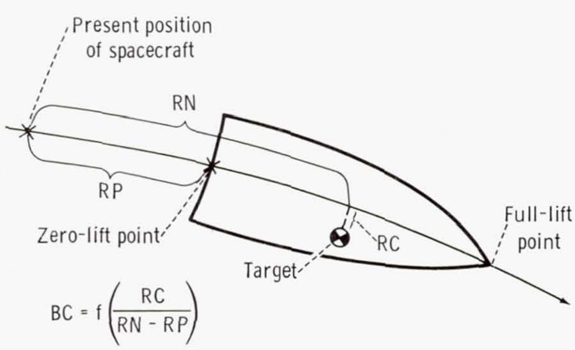


FIGURE 13–4.—Rolling reentry guidance logic.

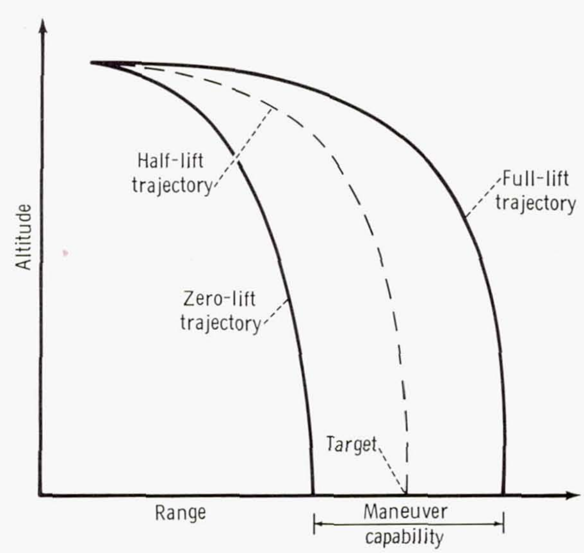


FIGURE 13–5.—Gemini constant bank angle reentry technique.

based upon a half-lift reference trajectory. The control logic commands a constant bank angle which results in a lift profile that will provide the proper longitudinal range for landing at the target point. This is accomplished by determining the difference between the range to the target and the half-lift reference-trajectory range, and by comparing the difference with a set of stored reentry-maneuver-capability data in the spacecraft computer.

Figure 13–6 shows the guidance logic used by the constant bank-angle reentry technique. In this technique, *RN* is defined as the downrange component of the total range between the spacecraft position and the target; *RC* is again the crossrange component; but *RP* is now the predicted half-lift range. A bank command is generated depending upon the value of *RN—RP*. If *RN* is equal to *RP*, a constant 60° bank angle is commanded; if *RN* is greater than *RP*, a more shallow bank angle is commanded; and if *RN* is less than *RP*, a steeper bank angle is commanded. The magnitude of this bank angle is determined by the stored downrange-extension capability of the spacecraft, ΔR. The crossrange error is controlled by reversing the direction of the bank angle when the crossrange error *RC* is equal to the crossrange capability of the spacecraft. The crossrange capability is again based upon the stored maneuver-capability data. This guidance system was flown on Gemini V, VI–A, and VII.

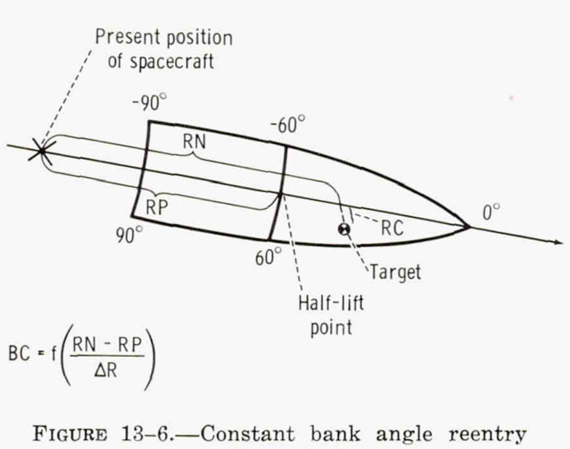


FIGURE 13–6.—Constant bank angle reentry guidance logic.

Retrofire Performance

In order for the guidance system to steer the spacecraft to a desired landing point, an accurate deorbit maneuver had to be performed. The spacecraft retrofire system consisted of four solid-propellant retrorockets which produced a velocity increment for deorbit of approximately 320 ft/sec. The spacecraft attitude was manually held at a predetermined constant inertial-pitch attitude throughout the maneuver, while the rates about the pitch, roll, and yaw axes were damped by the automatic control system. Excellent retrorocket performance was achieved on each of the missions, and the crew was able to hold the pitch attitude within approximately 2°.

Reentry Summary

The Gemini Program accomplished 11 successful reentries and showed that controlled reentry was an operational capability (fig. 13–7 and table 13–I). No reentry was attempted during the Gemini I unmanned orbital flight. Gemini II was an unmanned suborbital flight designed as a spacecraft heating test and as a check of the guidance and navigation system. The rolling reentry guidance logic was programed into the computer; however, this logic was bypassed and the reentry was flown open loop by continu-

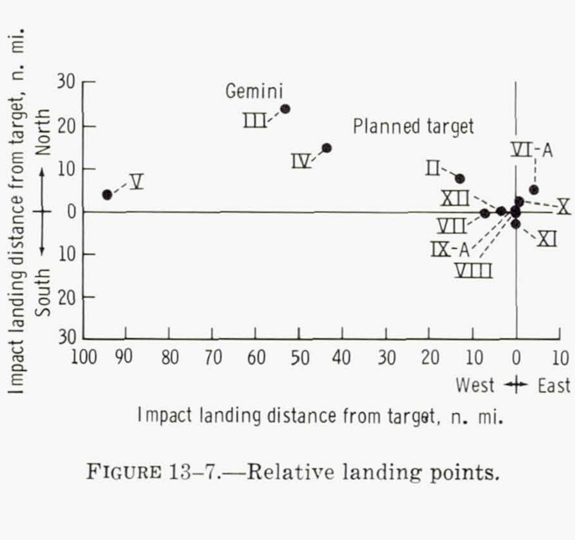


FIGURE 13–7.—Relative landing points.

TABLE 13–I.—*Gemini Reentry Summary*

Mission	Miss distance, n. mi.	Navigation error, n. mi.	Significant comments
II	14	1.2	Footprint shift
III	60	.8	Lift-drag reduction
IV	44		Footprint shift, inoperative computer
V	91	474	Invalid position update
VI–A	7	2.5	No radar below 180 000 ft
VII	6.4	2.3	Lift-drag reduction
VIII	1.4		Emergency reentry
IX–A	.38	2.2	
X	3.4	4.2	
XI	2.65	4.0	Automatic reentry
XII	2.6	2.4	Automatic reentry

ously rolling the spacecraft from the point of 0.05 g until an altitude of 80 000 feet was attained. The zero-lift point shifted 14 nautical miles due to the retrofire maneuver, and the spacecraft landed 14 nautical miles from the planned touchdown point. The footprint shift was caused by a combination of a pitch-attitude error of 3.2° during retrofire and a retrograde-velocity increment that was 1.1 percent low. Postflight analysis showed that the navigation accuracy at guidance termination was 1.2 nautical miles.

The first manned mission of the Gemini Program was Gemini III, a three-orbit mission. To assure spacecraft reentry in case of retrorocket failure, a preretrofire orbit maneuver was performed with the spacecraft propulsion system. This maneuver was completed 12 minutes before retrofire and resulted in a vacuum perigee of 45 nautical miles. The combined retrofire and preretrofire maneuver resulted in a footprint shift of 48 nautical miles. The retrofire maneuver accounted for 24.9 nautical miles of this shift. Before the deorbit maneuver, the target point was situated on the 60° contour line of the footprint, and was offset from the centerline approximately 10 nautical miles toward the south. The planned guidance technique was to fly the backup bank angle, which would simultaneously null the crossrange and downrange errors. When either the downrange or crossrange error was nulled, the crew would fly the commands generated by the spacecraft computer. The Gemini III spacecraft experienced a decrease of approximately 35 percent in the lift-to-drag ratio, resulting in a loss of approximately 160 nautical miles in the downrange maneuver capability. The loss in capability, combined with the shift of the footprint due to the deorbit maneuver, caused the target to be on the edge of the maneuver envelope of the spacecraft. Following the planned procedure, the spacecraft landed 60 nautical miles from the target. Postflight analysis indicated that if the crew had followed the commands generated by the spacecraft computer during the entire reentry, a miss distance of approximately 3 nautical miles would have occurred. Navigation accuracy on this mission was 0.8 nautical mile.

Gemini IV was a 4-day mission. A planned preretrofire maneuver was to be followed 12 minutes later by a normal retrofire. Based upon the results of Gemini III, it was planned for the crew to use the rolling reentry guidance logic and to manually follow the commands from the spacecraft computer during the entire reentry. However, because of an inoperative computer, it was necessary to fly open loop by manually rolling the spacecraft throughout reentry. The preretrofire orbit maneuver and the retrofire produced

a footprint shift of 50 nautical miles, 10 nautical miles resulting from the retrofire maneuver. The spacecraft was to be rolled at a rate of 15 deg/sec; however, because the roll-rate gyro had been turned off, the yaw thruster produced an acceleration in the roll direction which was not damped. This caused the roll rate to build to a maximum of 60 deg/sec; the spacecraft was still rolling more than 50 deg/sec at drogue parachute deployment. With the open-loop reentry, there was no way to compensate for the pre-retrofire and retrofire errors; thus, the spacecraft landed 44 nautical miles from the intended landing point.

Gemini V was an 8-day mission and was the first mission scheduled to use the constant bank-angle reentry guidance logic. As stated previously, the constant bank-angle logic commands were based upon a comparison of the range differences (actual range minus predicted half-lift range) with a set of stored maneuver-capability data. Because of the large reduction in the lift-to-drag ratio experienced by the Gemini spacecraft, the set of stored data was no longer valid; therefore, erroneous commands were generated by the spacecraft computer. Because of the short time between missions, it was impossible to update the constants in the program for Gemini V and VI–A. However, the computer calculations of the range errors (*RC* and *RN—RP*) were displayed to the crew and, as a result of preflight training, the crew could interpret these calculations to obtain the correct bank angle needed to attain a small miss distance. Therefore, it was planned for the crew to modulate the spacecraft lift vector based upon the display of these range errors.

The Gemini spacecraft normally required a navigation update before retrofire. This consisted of an Earth-centered inertial position and velocity vector, and a range angle through which the Earth had rotated from the initial alinement of the Earth-centered inertial system (midnight before lift-off) to the time that the vector was valid. When the update was sent to Gemini V, the range angle was in error by 7.9°. This caused a navigation error in the Gemini V computer of approximately 474 nautical miles. Therefore, throughout the reentry the computer displayed erroneous range data, and by the time the crew determined that the computer was in error, the spacecraft did not have the maneuver capability to steer to the target. The spacecraft landed approximately 91 nautical miles from the target. Postflight analysis indicated that after compensating for this initial-condition error, the navigation accuracy was 2.5 nautical miles. The footprint shift due to retrofire was only 5 nautical miles. The velocity increment produced by the retrorockets was 0.2 percent lower than predicted.

Gemini VI–A was a 1-day rendezvous mission; the constant bank-angle guidance logic was used in the same manner as on Gemini V. Retrofire occurred in approximately a 161-nautical-mile circular orbit with a resultant footprint shift of 22 nautical miles. The shift was due to a 0.6-percent high increment in the retrorocket velocity. The spacecraft landed 7 nautical miles from the target, and postflight evaluation indicated the navigation accuracy was approximately 2.5 nautical miles.

Gemini VII was a 14-day mission that employed the constant bank-angle logic. Modifications made to several of the guidance constants improved the usefulness of the bank command generated by the spacecraft computer; however, the primary crew display was still the range-error display. Retrofire occurred in approximately a 161-nautical-mile circular orbit with a resultant footprint shift of 41 nautical miles. The spacecraft touched down approximately 6.4 nautical miles from the target, and the navigation accuracy was 2.3 nautical miles. A 40-nautical-mile loss-of-maneuver capability was due to an overprediction of the movement of the center of gravity during the 14 days of the mission.

Gemini VIII, a scheduled 3-day rendezvous mission, was terminated by an emergency reentry into a secondary landing area. The reentry was ordered after the flight crew were forced to use the propulsion capability of the Reentry Control System to stop a high roll rate caused by a yaw-thruster anomaly in the primary spacecraft propulsion system. Because of the requirement for the propulsion capability of the Reentry Control System to control the spacecraft attitude during reentry, one of the mission rules required that activation of the Reentry Control System would require spacecraft reentry in the next planned landing area. The Gemini VIII spacecraft landed in the Western Pacific zone (area 7–3) in the seventh revolution.

The rolling-reentry logic was used for Gemini VIII and all subsequent Gemini flights, and enabled the crew to manually fly the bank-angle commands generated by the spacecraft computer. Retrofire occurred from approximately a 161-nautical-mile circular orbit and caused a 12-nautical-mile footprint shift. The spacecraft computer calculated that the spacecraft was 1.4 nautical miles from the planned target at drogue parachute deployment, and the spacecraft was sighted on the main parachute by the recovery aircraft. Because of the area in which the spacecraft was forced to land, no reentry tracking was possible; therefore, no navigation accuracy was determined for this flight.

Gemini IX–A, a 3-day rendezvous mission, used the rolling-reentry logic. The retrofire maneuver produced a footprint shift of approximately 55 nautical miles. The rather large footprint shift was caused by a retrorocket velocity that was 1.06 percent high and by a spacecraft pitch-attitude error of 2.3°. The crew manually flew the bank-angle commands generated by the spacecraft computer and landed 0.38 nautical mile from the target. Postflight evaluation showed a navigation accuracy of 2.2 nautical miles.

Gemini X was a 3-day rendezvous mission. Retrofire occurred from an orbit of 161 by 215 nautical miles. The footprint shift was approximately 43 nautical miles, and the spacecraft landed 3.4 nautical miles from the target with a navigation accuracy of 4.2 nautical miles. The rather large navigation error was caused by a yaw misalinement in the inertial platform.

Gemini XI, a 3-day rendezous mission, was the first to use the automatic mode of the attitude-control system coupled with the guidance commands to steer the spacecraft to the target. Using the rolling-reentry logic, the spacecraft landed 2.65 nautical miles from the planned target with a navigation accuracy of 4 nautical miles. A comparison of the bank-angle profile flown by the automatic system on Gemini XI with the profile manually flown on Gemini VIII and X showed only minor differences. The automatic system responded immediately to any change in the direction of the bank angle commanded by the spacecraft computer, whereas a time lapse occurred between command and response when the flight crew manually flew the bank commands. This time lapse, however, had no noticeable effect on the final landing point of the spacecraft.

The last flight in the Gemini Program, Gemini XII, was a 4-day rendezvous mission. Gemini XII used the rolling-reentry logic and was the second mission that employed automatic reentry. The spacecraft landed approximately 2.6 nautical miles from the planned target, with a navigation accuracy of 2.4 nautical miles. For the fifth time during the Gemini Program, the spacecraft descending on the main parachute was sighted by the recovery forces.

Concluding Remarks

The reentries performed during the Gemini Program have shown the following:

(1) The guidance technique had to be designed to be insensitive to large changes in spacecraft lift capability. The use of the constant bank-angle guidance technique was dependent on an accurate estimate of maneuver capability. It was, therefore, ineffective

for a mission of long duration where a large center-of-gravity variation was present or where spacecraft aerodynamic characteristics were uncertain, as on Gemini VII. The rolling-reentry guidance technique did not require a knowledge of the spacecraft lift capability, and would steer to a particular target as long as that target was within the footprint.

(2) Displays had to be available so the crew could evaluate the performance of the guidance and navigation system, and backup procedures had to be developed to assure safe reentry and accurate landing in the event of a guidance-system failure. These displays had to provide enough information to the crew to permit an intelligent evaluation of the primary guidance system. If the evaluation indicated a failure of the primary system, then backup procedures had to be available to meet the following criteria: (*a*) assure safe capture, (*b*) avoid violating heating and/or load-factor limits, and (*c*) function with a degree of accuracy such that the recovery of the spacecraft could be accomplished in a reasonable amount of time.

(3) Consistently accurate navigation could be accomplished during reentry because of a navigation-system design which performed adequately in the presence of expected inertial-measurement-system uncertainties. Even when a large inertial-platform error did occur, as on Gemini X, the effect of the error on touchdown miss distance was small, because navigation errors built up slowly before the region of maximum load factor, then increased sharply; at the same time, the maneuver capability decreased to a small fraction of the total near-maximum load factor. Although the control commands were incorrect late in reentry, because of large navigation errors, the commands could not disperse the trajectory to a great extent because of the small maneuver capability. In addition, the computer navigation equations and integration techniques had been judiciously selected to be compatible with digital computer operation.

(4) Reentry of the Gemini spacecraft was successfully controlled both manually and automatically. The ability of the pilot to adequately control the spacecraft under high load-factor conditions after long periods of weightlessness was demonstrated. The desirability of manual versus automatic control was dependent upon the severity of the control-accuracy requirements, the frequency of the control commands, and the complexity of the control limits imposed for crew safety. Reentry from Earth orbit required some degree of control accuracy but did not require an immediate response to displayed commands.

14. LAUNCH AND TARGET VEHICLE SUPPORT BY THE DEPARTMENT OF DEFENSE

By ALFRED J. GARDNER, *Program Director, Gemini Target Vehicle, Headquarters Space Systems Division, Air Force Space Systems Command*

Introduction

Cooperation between the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD), and more specifically the Department of the Air Force (USAF), is based on long historical precedent and achievement. Many years of exchange of concepts, equipment, and experimental activities between the National Advisory Committee for Aeronautics and the Air Force and its organizational predecessors laid firm ground for later years. The National Aeronautics and Space Act of 1958, providing the responsibility for the direction of the aeronautical and space activities of the United States, further stipulated one of the duties of the President, ". . . provide for effective cooperation between the National Aeronautics and Space Administration and the Department of Defense. . . ." From the earliest days, the new NASA and the USAF cooperated in numerous formal and informal ways. Air Force support of Project Mercury established many of the mechanisms, techniques, and fundamental requirements for Department of Defense support of the Gemini Program. The lessons learned by both agencies in exchange of funds, selection of personnel, procurement of vehicles, pilot safety, assurance of mission success, and launch support provided a tested foundation for effective Air Force support of Gemini.

In late 1961, when the decision was made to proceed with what ultimately became the Gemini Program, an ad hoc group comprised of NASA and Air Force representatives was appointed to recommend a detailed management and operational plan "clearly indicating the division of efforts between NASA and the DOD (Air Force). . . ." The NASA–DOD Operational and Management Plan for the Gemini Program (December 1961), with subsequent revisions, became the basis for the Air Force support of the program. The Space Systems Division of the Air Force Systems Command was designated to establish the necessary relationships with the appropriate NASA organizations to provide for development, procurement, and launch of the required launch and target vehicles.

Program offices were established in Los Angeles at the Space Systems Division of the Air Force Systems Command to manage the Gemini Launch Vehicle, a modified Titan II Intercontinental Ballistic Missile; and the Gemini Agena Target Vehicle, a modified Agena upper-stage booster. The launch vehicle for the target vehicle, a modified Atlas standard launch vehicle (SLV–3), was provided by an existing program office of this vehicle.

The management of the integration of the three vehicles into the overall Gemini Program was a function of the Gemini Program Office, NASA Manned Spacecraft Center. Within the Gemini Program Office, the principal point of contact with the Air Force Space Systems Division program offices was the Office of Vehicles and Missions. A coordinating committee system was established to maintain liaison, organization, and direction between various Government organizations and contractors.

Highlights of Air Force Technical Support

One of the most difficult aspects of system program management is the need to freeze designs in order to produce hardware on schedule versus the ever-present need to introduce changes. Reliability, time, and economy depend upon strict control of configuration and maximum standardization of production items. However, program evolution invariably leads to changing or expanded mission requirements. In anything but a pure production contract, unexpected and difficult design problems and technical difficulties are encountered. In addition, attractive and desirable improvement areas are developed as the base of program knowledge broadens and progresses. All of these sources of change are exceedingly difficult or impossible to predict or schedule, and often require significant expenditures of resources. Program histories, however, support the premise that one of the keys to program success is the manner of administrative and technical response to such changes. The organization must incorporate a flexibility to change emphasis and absorb tasks. Technical talents must be available. Financial support must be timely and of sufficient magnitude. Skillful schedule planning must introduce the changes to provide maximum realization of improvements with minimum impacts on reliability, manufacture, test, and training. Finally, the motivation of all concerned must be adequately planned in order to define and maintain desired goals and purposes. During the development of the Gemini hardware, all of the typical change influences were encountered and dealt with within the framework of the basic Gemini objectives. Some influences never progressed beyond the analysis and study stage, while others were translated into actual hardware configuration changes, and still others were expanded into major programs having critical effects on the overall program.

Throughout the development of the Gemini Launch Vehicle, every potential change, every known vehicle characteristic, and every operational plan was primarily viewed against the framework of a formal pilot-safety program plan prior to any other consideration of the change. This primary consideration resulted in other studies and changes.

Gemini Launch Vehicle

Within the Air Force Space Systems Division, the Gemini Launch Vehicle Program Office was assigned the responsibility for developing and procuring the Titan II as a launch vehicle and for the technical supervision (under a NASA Launch Director) of the launches of these vehicles. In this function, the Air Force Space Systems Division acted as a NASA contractor, and established the necessary agreements and contracts to provide all of the necessary services, equipment, and vehicles.

The objectives of the Air Force program office, based upon the requirements outlined by the NASA statement of work, were expanded and established as the basis for all resulting agreements and contracts. The fundamental objective was to exercise maximum management and technical control to strictly minimize changes to the basic Titan II vehicle. Changes were to be limited to those in the interest of pilot safety, to those necessary to accommodate the Gemini spacecraft as a payload, and to those necessary to increase the probability of mission success. Implicit in the basic objective were economy, high reliability, maintenance of schedule, and maximum cooperation with the NASA Gemini Program Office.

During the early months of the program, extensive and intensive studies, analyses, and tests were conducted to firmly identify all required changes to the basic Titan II; to identify all tests, procedures, and experimental programs; and to provide the basis for a set of detailed, comprehensive specifications for the vehicle.

In February 1962, a Technical Operating Plan was coordinated between the Space Sys-

tems Division and the Aerospace Corp. The plan outlined areas of effort and responsibilities of the Aerospace Corp. support of the Space Systems Division by providing general systems engineering and technical direction of the Gemini Launch Vehicle Program.

As part of the established mission, function, and organization, the 6555th Aerospace Test Wing is an extension of the Space Systems Division at Cape Kennedy and the Eastern Test Range. The Wing represented the Air Force in the launch-site acceptance, testing, data evaluation, and launch of various vehicles. In addition, the Wing provided management control of the various vehicle contractors, and integrated contractor and Government efforts, and assured Range support and data during the checkout and launch sequences. In support of the Gemini Launch Vehicle, various reliability, crew-safety, operational, and other committees and working groups were organized or supported. One of the outstanding achievements of the Gemini Program was the scheduling and accomplishment of the Gemini Launch Vehicle turnaround required for the Gemini VII and VI–A missions leading to the historical first rendezvous of two manned space vehicles (December 1965). Reference 1 contains a brief review of the development of the Gemini Launch Vehicle and of the flight results of the first seven Gemini missions.

Typical Gemini Launch-Vehicle Test Chronology

After final assembly of the Gemini Launch Vehicle at the Baltimore plant of the Martin-Marietta Corp., the propulsion and hydraulic systems were checked for leaks, and the electrical system was checked for continuity. The vehicle was then tested in the Baltimore Vertical Test Facility; this included a series of countdowns and simulated launches. All operations were either performed or accurately simulated and recorded.

The two stages of the vehicle were transported by air to Cape Kennedy, erected, and assembled on Launch Complex 19. A detailed checkout and verification test series was completed, culminating in a combined systems test of the vehicle. After the spacecraft was mated with the launch vehicle, a series of joint tests was completed, including joint guidance and flight controls, simulated partial countdown and launch ascent, tanking exercise, and, for missions involving the target vehicle, simultaneous launch demonstration.

Gemini Launch-Vehicle Payload Margins

Development of payload capability and trajectory prediction techniques.—At the beginning of the Gemini Program, all trajectory and payload performance predictions were based upon nominal values for all parameters. Therefore, all launch vehicles had the same payload capability except for variations due to mission differences. As vehicle parameters became available they were incorporated, and frequently created substantial changes in predicted payload capability. Each parameter update was incorporated as soon as available in order to maintain the most up-to-date prediction possible. This was desired to keep NASA continually informed of the payload capability margin for each of the vehicles, so that mission changes could be made to improve capability or to take advantage of excess capability. It was also desired to show the necessity of making performance improvement changes to the Gemini Launch Vehicle. A number of performance improvements were considered for the Gemini Launch Vehicle during the early and mid-phases of the program.

Figure 14–1 illustrates the changes in predicted Gemini Launch Vehicle minimum payload capabilities compared with time, and the changes in spacecraft weights, without experiments, compared with time. Since experiment weight averaged about 160 pounds, the actual margins between predicted capabilities and spacecraft weights were less than those shown. Near the end of the Gemini Program, it was common for the predicted payload capability margin to be negative. The worst case was —282 pounds for Gemini IX–A.

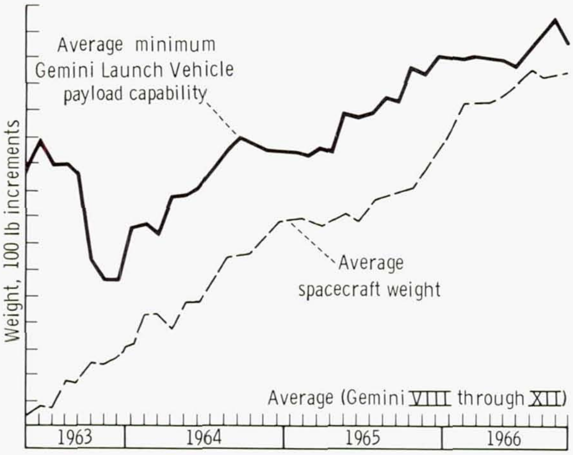


FIGURE 14-1.—History of spacecraft weight and predicted Gemini Launch Vehicle minimum payload capability.

As with any launch vehicle, the Gemini Launch Vehicle was constrained to remain within specified limits throughout the flight envelope. In particular, the vehicle was constrained by aerodynamic heating, aerodynamic loads, axial acceleration, guidance-radar look angles, guidance-radar elevation angle, dynamic pressure and angle of attack at staging, Stage I hydraulic-actuator hinge moment, and spacecraft abort criteria. Studies early in the Gemini Program quantitatively established limits in the constraint areas. Maximum or limiting values of some parameters were selected for nominal trajectories such that, if the nominal trajectory remained within these bounds, dispersed trajectories would remain within the true launch-vehicle and guidance-system capabilities.

Although the nominal payload capability for each Gemini Launch Vehicle was of considerable importance, the predicted minimum payload capability was of even greater importance. The minimum payload capability was the weight of the spacecraft that could be put into the desired orbit even under the most disadvantageous launch-vehicle performance. Most disadvantageous was defined for the Gemini Launch Vehicle as the minus 3-sigma payload capability, or that payload capability which would be equaled or exceeded 99.87 percent of the time. This percentage was shifted to 99.4 percent in the latter part of the Gemini Program.

Gemini Launch Vehicle dispersion analyses were initially performed by determining the payload capability effects of dispersions in a large number of key vehicle parameters. The parameter dispersions that were used were the 3-sigma dispersions based upon test data and theoretical analyses. Throughout the Gemini Program, attention was directed to refining estimates of 3-sigma parameter dispersions. Particular attention was given to the parameters with the most significant effects upon trajectory and payload capability performance. From the beginning of the Gemini Program, it was obvious that a very good estimate of the overall 3-sigma dispersion could be determined by considering the variations of a limited number of key parameters. These parameters were those which most affected the shape of the vehicle trajectory in the pitch plane. The following parameters were selected early and used throughout the program for simplicity and continuity:

Stage I	Stage II
Thrust	Thrust
Specific impulse	Specific impulse
Outage	Outage
Dry weight	Dry weight
Usable propellant weight	Usable propellant weight
Pitch programer error	
Pitch gyro drift	
Winds	
Atmospheric density	
Engine-thrust misalinement in pitch.	

Performance improvement program. — Since the inception of the Gemini Program, a vigorous performance improvement program was pursued to meet the ever-increasing requirements of payload capability. Initially, the total weight of the spacecraft, including experiments, was estimated at about 7000 pounds for the long-duration mis-

sions and 7250 pounds for the rendezvous missions. It quickly became apparent that these weights would be exceeded. The early spacecraft-weight growth rate was approximately 35 to 40 pounds per month, and not until deletion of the paraglider configuration was some relief obtained. Increase in the size of the spacecraft propellant tanks provided another impetus in the search for higher launch-vehicle payload capability. Ultimately, the spacecraft weights increased to the point where predicted launch-vehicle performance margins relative to the minimum (99.4 percent probability) payload capability were consistently negative. Comparison between actual spacecraft weights and achieved payload capabilities is shown in figure 14–2.

In addition to spacecraft-weight increases, changes in mission requirements had a significant effect on launch-vehicle payload capability. On early flights a 5-hour launch-window requirement was imposed, necessitating large ullage volumes in the propellant tanks to allow for propellant temperature increases. This meant fewer propellants loaded and a reduced payload capability. Optimizing the mixture ratio for the worst case in the window under dispersed propellant temperature conditions also resulted in performance decreases. For certain missions the requirements for high initial apogees and for launch azimuths considerably less or greater than 90° degraded the payload capability. Finally, the requirement to have the launch vehicle steer out as much as 0.55° of wedge angle to increase the availability of spacecraft propellant reduced the probability of achieving the desired insertion conditions. Propellant temperature-conditioning equipment was included in the areospace ground equipment so that launch-vehicle propellants could be chilled to 20° F for oxidizer and 26° F for fuel before loading. This chilling would allow greater propellant masses to be loaded in the fixed tank volumes, thus increasing payload capability. Attention was also given to the performance gain available by reducing the minimum ullages in the propellant tanks from the values used on the Titan II weapon system. Structural studies and engine start tests at reduced ullages were incorporated in the Gemini Propulsion System Test Program.

Early in 1963, the Martin Co. proposed a study of the feasibility of removing the low-

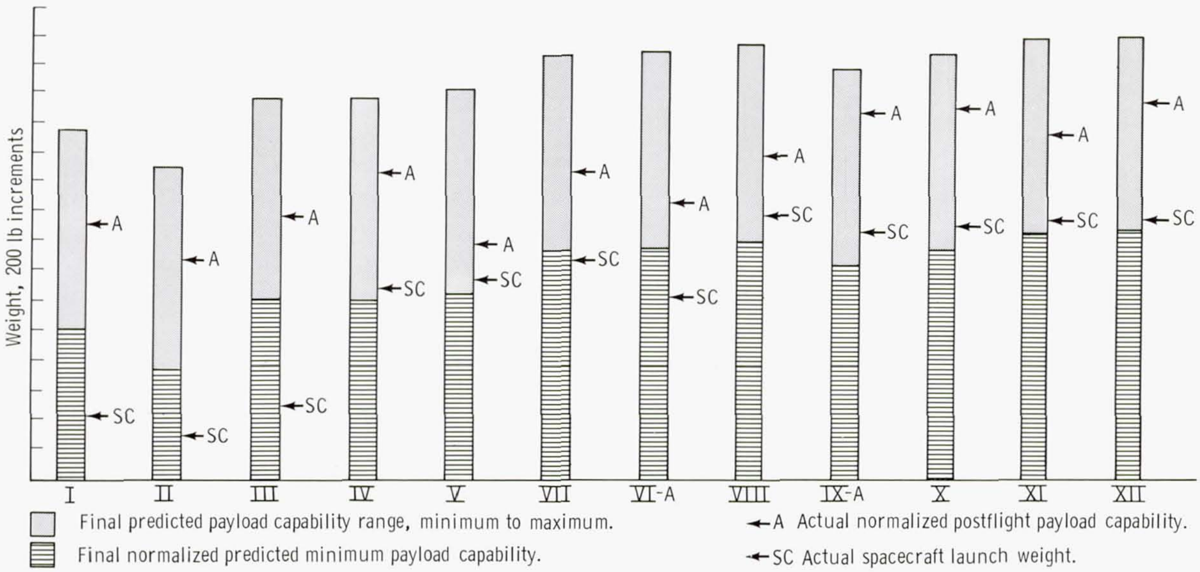


FIGURE 14–2.—Comparison of normalized predicted and achieved payload capabilities.

level propellant shutdown sensors from the shutdown circuits on both launch-vehicle stages. Removing these sensors would eliminate the large possibility of premature shutdowns due to faulty level sensor operation and would also increase payload capability by reducing the amount of trapped propellants. Data from exhaustion shutdowns on the test stand and on the Titan II flights indicated that such shutdowns did not noticeably jeopardize mission success. The shutdown function of the sensors was eliminated, although they were retained for instrumentation purposes and for closed-loop operation if later found desirable.

Changing the Titan II engine target mixture ratios on acceptance tests from 1.93 for Stage I and 1.80 for Stage II to approximately 1.95 and 1.84 would have allowed complete filling of both oxidizer and fuel tanks to ullage limits when the engines were operated in the anticipated flight environment. However, as the mixture ratio increased, the specific impulse decreased for both stages. Some of the other areas investigated were: (1) engine effects, such as heat transfer and combustion stability; (2) possible mission changes; and (3) impact of other potential performance improvement items, such as further reduced minimum ullages and constant temperature propellants. As a result of these studies, the Stage II engine mixture ratio change was eliminated because there was no payload advantage. The Stage I engine target mixture ratio was changed to 1.945, effective for the Gemini IV launch vehicle.

Titan II and launch-vehicle engine performance data were monitored throughout the Gemini Program. By May 1965, sufficient data had been accumulated to indicate that significant changes in the form of biases were likely to occur between acceptance test and flight. This analysis included the results of 10 Stage I flights and 16 Stage II flights. For Gemini IV through X, the biases indicated by the analysis were included in preflight trajectory and performance predictions. When the Stage I thrust bias and specific impulse biases were incorporated into the Gemini IV launch-vehicle preflight predictions, the added efficiency of Stage I resulted in overlofting of the Stage I trajectory. This was disadvantageous for two reasons: first, high-dispersed trajectories could result in pitch look angles which exceeded the existing allowable limits; and second, overlofting caused excessive gravity losses and Stage II pitch maneuvering. Because of these considerations, a new pitch program, developed for Gemini IV, eliminated the over-lofting and resulted in an improvement in the payload capability.

Mission-dependent performance changes.—Correct predictions of trajectory and payload capability also had to be based on differences and changes in the Gemini missions. For example, if the apogee were changed for a specific Gemini mission, it was necessary to adjust the predicted launch-vehicle payload capability accordingly. Similarly, if the launch azimuth and/or yaw steering were changed, the payload capability effects were computed and incorporated in the predicted launch-vehicle capability. For each of the rendezvous missions, it was also necessary to determine payload capabilities for the alternate missions which would be attempted if the primary mission could not be completed.

Flight-test performance.—Obtaining accurate preflight predictions and postflight analyses of vehicle propulsion performance was of great importance throughout the Gemini Program. The launch-vehicle payload capability and trajectory performance were highly dependent on the propulsion parameters of mixture ratio (the major contributor to propellant outage), specific impulse, and thrust for both stages of the vehicle. Propellant outages for Stage I and Stage II were the two largest factors in payload capability dispersion allowances. Postflight analysis of each Gemini Launch Vehicle trajectory was conducted to define the reasons for deviations from nominal and to determine changes to be made in predictions for subsequent ve-

hicles. Table 14–I compares predicted with achieved payload margins for all missions.

Gemini Launch Vehicle Stage I Tank Staging Anomaly

High-speed long-range camera coverage of the Gemini X launch vehicle showed a large orange-red cloud appearing from Stage I shortly after staging and indicating a possible breakup of the stage. A detailed review of the films revealed that the oxidizer tank vented approximately 1.2 seconds after Stage II ignition. A study of Stage II telemetry data revealed no indication of this event. Stage I telemetry was inoperative at this time, having been disabled 0.7 second earlier. A thorough study of the tank rupture isolated the following as the most probable causes: (1) Stage I turning after separation, resulting in the Stage II engine subassembly exhaust impingement and burnthrough of oxidizer tank barrel; (2) breaking of the ablative coating on the oxidizer tank dome, due to dome flexing caused by dome overheating and subsequent structural failure, resulting from high local pressures at Stage II engine start; and (3) dome or tank barrel penetration by transportation section debris. A review of the staging films revealed similar occurrences on seven Titan II flights. The same anomaly occurred during the Gemini XII mission; however, this occurrence was followed by the apparent rupture of the Stage I fuel tank and the breakup of Stage I just forward of the Martin/Aerojet interface. The results of the study and a review of all available Titan II and Gemini flight data showed no detrimental effect on mission success or crew safety due to this event.

Gemini Launch Vehicle Switchover/Switchback Studies

With the incorporation of a redundant flight control system, a detailed system evaluation was conducted to reassess the vehicle airframe, the switchover logic, and the sensor limits. The evaluation indicated that the initial selection of sensor limits, structural safety factor, and switchover logic did not result in optimum switchover capability. It became apparent that a switchover during Stage I flight from a loss of hydraulic pressure would result in the secondary flight control system being used throughout Stage II flight. This could have resulted in discarding a good, reliable, primary flight control system

TABLE 14–I.—*Predicted and Achieved Gemini Launch Vehicle Payload Capability Margins*

Mission	Payload capability margin			Difference, lb
	Predicted, lb		Achieved, lb	
	Minimum	Nominal		
I	508	1017	1171	154
II	336	1025	1066	41
III	577	1199	1396	197
IV	−62	593	767	174
V	−135	526	374	−152
VII	69	709	786	77
VI–A	265	891	778	−113
VIII	−162	492	471	−22
IX–A	−282	372	638	266
X	−217	416	571	155
XI	−175	497	528	31
XII	−51	619	869	250

during Stage II flight. To alleviate this situation, the capability of switching back to the primary system was incorporated. It was planned that switchback would only be actuated in the event the switchover was initiated by loss of hydraulic pressure and would be activated between staging and guidance enable.

The switchover flight loads during the high maximum dynamic pressure region were found to be in excess of the structural design criteria. Consequently, the concept was optimized by selecting the sensor limits that maximized crew safety. A corresponding hardware change was made to reduce the angular rate switch settings. The structural load-carrying capability was reevaluated in the light of probability considerations, which resulted in a reduced factor of safety for switchover from 1.25 to 1.10. A deliberate flight-test switchover was discussed; however, because of difficulty in initiating the switchover, and the significance of the limited results, it was decided not to perform the test.

Gemini Launch Vehicle Stage II Engine Stability Improvement Program

One of the major concerns in man rating the Titan II vehicle was the possibility of combustion instability during the Stage II start transient. The ground-test history of the original Stage II engine utilizing the production quadlet injector gave rise to certain dynamic combustion stability questions for man-rating requirements. The quadlet injector had a demonstrated instability incident rate of about 2 percent during ground tests. Even though this rate was extremely low, the effect of an instability during manned flight caused concern and resulted in the AF/NASA decision to develop a more dynamically stable Stage II injector, one that would be capable of accepting limited pulsing without instability. The development of the new injector required evaluation of several injector types. These injectors were screened by thrust-chamber assembly tests consisting primarily of newly developed bomb/pulsing techniques derived to establish instability triggering thresholds. The selected prototype injectors were then tested at the engine level for system compatability. A final candidate injector then underwent a modified qualification test program which was integrated into an engine improvement program verification test series. To provide further assurance of the adequacy of this injector for manned flight, it was flight tested by a Titan IIIC vehicle, and subsequently incorporated into the Gemini VIII launch vehicle.

Gemini Agena Target Vehicle

As with the Gemini Launch Vehicle, the Air Force Space Systems Division was the NASA contractor for the development and procurement of the Gemini Atlas-Agena Target Vehicle system. However, an attempt was made to add the effort to an existing AF/NASA organizational arrangement already established for the procurement and launch of the Atlas-Agena combination for other programs. Accordingly, NASA continued to use the Marshall Space Flight Center in the ". . . role of procurement contractor and technical advisor to the Project Office in the development, procurement and launch of Atlas/Agena Target Vehicles for the Project Gemini Rendezvous Missions. . . ." The Air Force added the development, procurement, and systems integration of the target-vehicle system to an existing program office charged with procurement and payload integration of Agena vehicles for other NASA programs. In March 1962, the target-vehicle program was initiated by NASA-Defense Purchase Request H–30247 with the details of the objectives and statement of work to be evolved in working sessions.

In January 1963, the Manned Spacecraft Center assumed direct control of the Space Systems Division effort with the withdrawal of Marshall Space Flight Center from the program. At the same time, organizational realinements began at the Space Systems

Division to provide a program office solely concerned with the target-vehicle effort. This objective was not finally achieved on a basis comparable to the Gemini Launch Vehicle office until July 1965. However, certain aspects of the initial organizational arrangements for both procurement and technical development, once established, could never be completely changed.

The objectives of the Air Force program office were evolved as a result of joint working sessions based upon Gemini mission ground rules, objectives, and requirements. The fundamental objective was to modify the basic Agena vehicle to provide the required accuracies, command and control, pilot safety, reliability, and docking capability consistent with the mission to be accomplished.

To simplify the overall Agena vehicle procurement and launch services, the unmodified basic Agena S–01B vehicles and the necessary launch-site level of effort were procured through the existing Space Systems Division Agena Program Office. The modification of the basic Agena to a target vehicle was managed by a separate program office group at the Air Force Space Systems Division.

In March 1962, a contract was issued to the Lockheed Missiles & Space Co. to provide a vehicle to be used as an in-orbit target for rendezvous with a manned spacecraft. The orbiting vehicle could be controlled by commands from the ground or from the manned spacecraft. The vehicle also had to be capable of maneuvering as part of the spacecraft after docking.

In late 1964, a Technical Operating Plan for the Target Vehicle Program had been established, and the responsibility for providing technical surveillance of the Lockheed contract was assigned to the Aerospace Corp. In keeping with the normal relationships and operations of the Space Systems Division and the 6555th Aerospace Test Wing at Cape Kennedy, the target-vehicle launch responsibilities were assigned to the SLV–3 Directorate of the Wing.

Typical Target-Vehicle Chronology

The target vehicle was initially manufactured, assembled, and tested on the standard Agena production line, and certain items unique to the target vehicle necessarily had to be incorporated as part of the initial assembly prior to final modification and systems test. These unique items included the Model 8247 engine manufactured by Bell Aircraft Corp., a 17-inch auxiliary forward equipment rack, additional helium gas capacity, and similar items.

After delivery of the basic vehicle to the Air Force, certain installations required additional modifications by Lockheed because of the peculiar requirements of the target vehicle. The changes were mainly confined to electrical and electronic packages and harnesses. After final assembly, the target vehicle was moved to the final systems test area and completely tested using a simulator for the Target Docking Adapter, when necessary, and for shroud electrical connections.

After airlift to Cape Kennedy the vehicle was inspected, checked, and alined. High-pressure checks, which for safety reasons could not be accomplished at the factory, were completed. The Secondary Propulsion System modules and heat shields were installed and alined. A complete series of interface tests was accomplished, followed by loading of ancillary fluids and gases. (All pyrotechnics, propellants, and batteries were installed at the launch stand.) The vehicle was then erected with the Atlas Target Launch Vehicle. The major remaining tests were the Joint Flight Acceptance Composite Test and the Simultaneous Launch Demonstration. The vehicle was then ready for F—1 day, precount, and final count tests.

For the actual launch of the Gemini Agena Target Vehicle, the role of each contractor included the following:

(1) Lockheed Missiles & Space Co. furnished the Gemini Agena Target Vehicle, and associated reference trajectory, range-safety package, and flight-termination sys-

tem report, and was the integrating contractor for the ascent guidance effort.

(2) General Dynamics/Convair furnished the Atlas Launch Vehicle (SLV–3) and the associated flight-termination system report and flight-test results, and conducted a comprehensive preflight data exchange with the integrating contractor.

(3) TRW Systems furnished ascent guidance equations and associated documentation for the Gemini Atlas-Agena Target Vehicle, and provided Burroughs Corp. with tray-wiring data.

(4) General Electric Co. furnished guidance canisters for the Gemini Atlas-Agena Target Vehicle, and operated the General Electric Model III System at Cape Kennedy during launches and all associated testing.

(5) Burroughs Corp. furnished wired ascent guidance trays for the Gemini Atlas-Agena Target Vehicle, and operated the computers in Guided Missile Computer Facility no. 1 at Cape Kennedy during launches and all associated testing.

Gemini Target Vehicle Project Sure Fire

On October 25, 1965, Gemini Agena Target Vehicle 5002 was launched from the Eastern Test Range as part of the scheduled Gemini VI mission. After separation from the launch vehicle, the engine malfunctioned destructively during the starting sequence, and the target-vehicle pressurization system destroyed the vehicle.

Corrective action requirements were generated based upon the results of the postflight analysis, the propulsion system and vehicle aft rack design review, and the symposium on ignition of hypergolic propellants. The engine design change recommendations were to convert the Gemini-peculiar engine (XLR 81–BA–13) to a thrust-chamber oxidizer-lead start sequence similar to the basic Agena engine (YLR 81–BA–11); to incorporate shock mounting for certain engine electrical control components; and to disable the electronic-gate shutdown capability during ascent maneuver operation. Test requirements were established to verify adequacy of the design changes and to demonstrate flightworthiness of the modified engine configuration. Results of the symposium on hypergolic ignition indicated that one significant test requirement had not been included in the original XLR 81–BA–13 engine development and the associated PERT program. The requirement was engine testing at an altitude which properly simulated the hard-vacuum space environment. An engine modification and a test program were planned, which required reliable ignition demonstration during hard-vacuum simulation tests above 250 000 feet before the Gemini VIII launch date. An Air Force, Aerospace Corp., NASA, and industry team effort spearheaded by a high-level Super-Tiger Team, as well as maximum priorities, were necessary to accomplish and manage the engine modification and test program on an accelerated, maximum-success schedule. The activity was designated Project Sure Fire and was initiated in November 1965.

Testing was initiated immediately on the turbine pump assembly. These tests provided the preliminary engine-transient performance values, defined the initial detailed design-change requirements, verified satisfactory operating characteristics of the proposed modified configurations prior to initiating engine-level testing, and verified expected operating characteristics with various imposed malfunction conditions. A total of 75 turbine pump assembly tests was accomplished between November 1965 and March 1966.

A total of 37 gas-generator/start-system tests was conducted from November 1965 through March 1966. During these tests, which were conducted at sea level and at a 240 000-foot simulated altitude, reliable gas-generator ignition was achieved throughout the range of predicted flight operating conditions, as well as for conditions normally considered conducive to producing adverse ignition characteristics. In addition, reliable ignitions were demonstrated after a gas-generator/start-system had simulated a 28-day

pad hold period and a subsequent 5-day altitude coast storage period.

A pressure switch relay box was designed for the initially proposed configuration, and the development and flightworthiness demonstration tests were conducted on this component in December 1965 and January 1966. Vibration, shock, humidity, acceleration, altitude, and electrical tests were conducted. A relay failure occurred during development vibration tests; and after a subsequent reliability analysis, the relay was removed and the relay box was converted to a junction box.

The proposed engine modification involved the addition of two pressure switches in the engine control circuit to provide the required thrust chamber oxidizer-lead start sequence. Turbine pump assembly test results indicated a high-frequency actuation-deactuation cycling characteristic of the backup oxidizer feed pressure switch during a normal engine-start sequence. Pressure-switch durability and vacuum tests were conducted, with no observed degradation of the microswitch contacts, successfully demonstrating switch operational capability at the Gemini mission altitude for a minimum 5-day period.

Vibration, shock, and hot-fire tests were conducted as part of the engine sea-level flightworthiness demonstration program. Satisfactory structural design of the new and modified component installations was verified. The 42 hot-fire tests demonstrated satisfactory operation and sequencing of the modified engine configuration, and verified successful implementation and checkout of the modified engine test and servicing procedures.

A total of 43 engine flightworthiness tests at simulated altitudes ranging from 257 000 to 453 000 feet, and two checkout firings at 85 000 feet, were conducted. The ignition-confidence, simulated-mission, low-temperature, and malfunction tests at an average simulated altitude of 356 000 feet successfully demonstrated the high-altitude flightworthiness of the modified XLR 81–BA–13 engine. Sufficient confidence in the reliability of the engine ignition had been gained from the 27 Phase I and Phase II altitude tests completed by March 4, 1966, to assure flightworthiness of the Gemini VIII target vehicle and to allow commitment of the modified engine design to flight. Significantly, the postulated target-vehicle flight failure mode was confirmed during the altitude malfunction tests; and showed that a fuel lead on the XLR 81–BA–13 engine would produce hard starts when tested at the proper altitude and that a reasonably high probability of hardware damage existed. Reevaluation of the Gemini VI data indicated that the engine damage incurred during the flight was similar to that observed during the last fuel-lead test. In addition to the successful flightworthiness demonstration of the modified engine, the altitude tests provided data on altitude ignition characteristics over a temperature range from 100° F to below zero.

An unexpected destructive hard start occurred during a checkout firing early in the altitude test program. Post-test data analysis and testing showed that excessive water and alcohol contamination (approximately 85 percent) was introduced into the engine fuel system during the prefire propellant loading operation. The fuel system became contaminated with water during test-cell downtime for instrumentation and hardware repair. An abbreviated isopropyl-alcohol flush procedure was conducted to remove water from the engine; however, the water and alcohol were not completely removed from the facility fuel system, resulting in entry of the contaminated fuel load into the engine. Full-scale and subscale thrust-chamber ignition tests were instituted to evaluate the effects of fuel contamination. Results showed that significant increases in ignition delay and peak pressures occur as the quantities of alcohol and water in the fuel are increased. Further analysis and tests clearly supported the conclusion that the checkout test failure was caused by contaminated fuel.

Further ignition tests investigated thrust-chamber ignition characteristics with fuel, oxidizer, and simultaneous propellant leads

over a range of operating temperatures and altitudes (ambient pressures). Considerable data were relatable to the XLR 81–BA–13 engine thrust chamber, and usable as an aid in explaining the differences in ignition characteristics in the main thrust chamber with fuel and oxidizer leads. When subjected to the same test conditions, the XLR 81–BA–13 engine thrust chamber produced significantly different ignition characteristics for a fuel-lead start sequence compared to an oxidizer lead. Therefore, a comparative evaluation of the differences in ignition characteristics was made, based on test data for the full-scale (engine) thrust chamber, the subscale thruster, and the engine gas generator assembly. The hardware design factors which can affect ignition were reviewed; and the dependent conditions existing in the chamber at ignition (such as mixture ratio, density, ignition delay, and ignition chemistry) were recorded or derived as the test variables of altitude, temperature, and propellant lead were changed. The proper pressure and temperature must be generated in the fuel-oxidizer mixture during the induction period just prior to ignition, and a sufficient amount of oxidizer must be present during induction to prevent long ignition delays or quenching of the reaction.

Based on analysis of the design factors and conditions in the full-scale and subscale thrust chambers at ignition, it appeared that the chemistry of the ignition was involved in producing the hard start experienced in the main thrust chamber with the fuel-lead start sequence. When oxidizer was not present in sufficient quantities during the induction period, a suitable oxidation reaction did not occur to overcome the effects that the hard vacuum produces during the propellant pre-flow and/or mixing period. Thus, proper pressures and temperatures were not developed and a long ignition delay resulted, during which secondary reactions probably occurred, producing high energy intermediate compounds. A highly reactable mixture is formed, including the unsymmetrical dimethyl hydrazine (UDMH) fuel which possesses monopropellant characteristics. The resultant mixture becomes the source of the additional energy which produces the hard start when ignition occurs. In the XLR 81–BA–13 thrust chamber, additional damage was incurred because the residence time was such that a reactable mixture accumulated downstream of the throat during the long ignition delay, causing the nozzle overpressure when ignition occurred.

Although the gas generator operates reliably with a fuel lead, this reliability is attributable to: (1) the relatively very large volume of the gas generator/turbine manifold assembly, which readily accommodates the energy stored at ignition; and (2) a preignition pressure rise, which indicates that a preigniter probably exists, similar to the main thrust chamber oxidizer-lead start sequence.

The following significant conclusions were derived from Project Sure Fire:

(1) Flightworthiness of the modified XLR 81–BA–13 engine configuration was successfully demonstrated.

(2) An oxidizer-lead start sequence is optimum for the XLR 81–BA–13 engine thrust chamber, and provides low and acceptable ignition shock levels over the range of required operating conditions.

(3) Significant differences exist between oxidizer-lead and fuel-lead ignition characteristics in the XLR 81–BA–13 thrust chamber.

(4) The conclusion indicated by the flight-failure analysis of the Gemini VI target vehicle, that an engine hard start occurred, was proven correct; and the postulation that the engine hard start was due to a fuel-lead start sequence was also correct.

(5) Fuel-lead hard starts yield high probability of damage to the thrust chamber assembly. Reevaluation of Gemini VI data indicates that an oxidizer line break occurred in the same area as that observed during the last fuel-lead test at Arnold Engineering Development Center. No reactions or adverse pressures were detected in any of

the thrust chamber manifold cavities during the fuel-lead starts at Arnold Engineering Development Center. The hard-start reactions occurred in the combustion chamber and divergent nozzle.

(6) The fuel-lead hard-start mechanism appears to involve the chemistry of the reaction during the induction period. Lack of an excess of oxidizer apparently prevents a satisfactory oxidation reaction from occurring relative to that for an oxidizer-lead start sequence. A very long ignition delay occurs, allowing an accumulation of a reactable oxidizer-fuel mixture which probably contains high-energy intermediate compounds formed during this delay.

(7) The XLR 81–BA–13 engine gas generator assembly provides reliable ignition with a fuel-lead start sequence within the range of operating requirements. Low peak pressure and very slow pressure rise rates are always obtained. These characteristics appear to be due to the large volume of the gas generator assembly, to the low potential energy in the chamber at ignition, and, perhaps most important, to a preignition pressure buildup probably attributable to a preigniter oxidizer flow.

(8) Testing at the proper simulated altitude to determine engine ignition reliability is a necessary and extremely important phase of space-flight engine development.

(9) Propellant triple-point (phase) data provide a reliable guideline for defining the minimum altitude test requirements. Further studies on the relation of phase data, propellant injection, and expansion dynamics at hard vacuum, and presence of excess fuel or oxidizer, are recommended in order to advance the state of the art.

(10) Existing ground-test technology is more than sufficient to properly simulate required altitude conditions for medium-size rocket engines.

(11) Sea-level and altitude subscale ignition tests, and full-scale sea-level ignition tests can be a valuable adjunct to full-scale altitude testing. However, full-scale altitude tests must be conducted as final proof that complete simulation of all factors affecting the ignition process for a specific configuration have been demonstrated.

Results of Project Sure Fire were positive and on March 17, 1966, the engine was committed to launch. The engine performed as desired through all phases of the mission, including demonstrations of multiple starts and maneuver capability.

Gemini Target Vehicle Stability During Docked Engine Firing

The target-vehicle control system was originally designed to provide stable flight for an Agena vehicle with a conventional payload. For Gemini, the control system was required to provide stability during Primary Propulsion System firings while in the docked configuration. The original system was designed to filter all Agena body-bending modes greater than 8 cycles per second. The system could be modified by a gain change to handle frequencies as low as 5 cycles per second. However, the docked spacecraft/target vehicle had a fundamental body-bending mode with a frequency between 2 and 4 cycles per second. A lead-lag circuit was designed by Lockheed to cope with this mode, and stability studies were performed to check out the modified system.

The fundamental mode in question involved rigid-body motion of the spacecraft/target vehicle with a flexible spring, the Target Docking Adapter, connecting them. Preliminary stiffness data showed both inplane and out-of-plane response when incorporated in the model, and indicated the inability of the modified system to provide stability. A dynamic response test was performed to provide better data for the analysis and resulted in considerably more out-of-plane coupling in the fundamental mode than had been expected. The frequency of this mode was between 2.5 and 3.0 cycles per second, depending on the weight condition. Structural damping varied between 2.0 and

5.0 percent. In the course of evaluating the test data, errors in handling the out-of-plane response were discovered in the model. With the model corrected and with the use of lower bound damping values, the lead-lag modification proposed by Lockheed was shown to provide adequate stability. The modification was flown on the Gemini VIII and subsequent Gemini Agena Target Vehicles.

As soon as the modal response of the docked spacecraft/target vehicle had been established by studies at the Massachusetts Institute of Technology and the results accepted by the contractors affected, the flight control electronics compensation was established. Previous studies by Lockheed had shown that a modification to the lead-lag shaping network already in existence could handle both the ascent dynamics and the docked dynamics with a minor change in loop gain between two flight modes. The simulation of the vehicle was increased to include the flight control system, and the potential of the revised lead-lag was confirmed.

Lockheed proceeded to mechanize and optimize the lead-lag design with the use of a single-axis digital computer simulation. Hardware components and tolerances were evaluated. The most difficult development item in the change was the perfection of the temperature-stabilized operational amplifier. Actual breadboard parts were tied into the single-axis simulator for temperature tests as well as system performance evaluations. This phase was also used to perfect test procedures and tolerances that would insure proper system performance.

Gemini Target Vehicle Center-of-Gravity Offset Problem

A major problem occurred on the Gemini VIII target vehicle during undocked, in-orbit, Primary Propulsion System powered flight. A significant vehicle yaw-heading error existed; the resulting velocity vector error affected the orbital guidance computations and resulted in adverse orbital ephemeris accuracies when making out-of-plane orbit changes. This yaw-heading error was due to a combination of yaw center-of-gravity offset, slow control-system response time, and vehicle dynamics. The yaw center-of-gravity offset was approximately twice that of the standard Agena due to the added weight resulting from the addition of two running light batteries. The slow control-system response time was caused by the redesign of the flight-control electronics package. The redesign had been required to provide stable control-system operation during the docked mode.

Orbital altitude errors ranged to approximately 120 miles during Primary Propulsion System operation. The errors were much more pronounced when the vehicle was in a $\pm 90^\circ$ configuration and a plane change was attempted. This was due to the offset being in the yaw direction and the velocity component error combining directly with the orbital velocity. These errors greatly exceeded 3-sigma values derived in prior error analyses and on-orbit guidance computations. Various solutions to the center-of-gravity problem were investigated. These consisted of removing batteries, realining the engine, adding ballast, off-loading the Secondary Propulsion System propellants, and preparing correction tables for use in trimming out potential dispersions. A parametric study was performed which related pitch-and-yaw-attitude errors to center-of-gravity offsets for the target vehicle during Primary Propulsion System operation. Attitude errors were determined as a function of firing time, vehicle center-of-gravity offsets, and vehicle weight. Results were plotted as a family of curves to provide programed attitude correction data for desired orbit changes. Average attitude error and actuator position for various times of Primary Propulsion System firings, along with transient attitude and actuator position response curves, were presented.

Atlas SLV–3 Target Launch Vehicle

The basic planning of the Gemini Program directed the use of the Air Force Atlas SLV–3 as the launch vehicle for the Gemini Agena Target Vehicle. The overall development of the Gemini Atlas-Agena Target Vehicle system was assigned to the Air Force Space Systems Division. The target-vehicle program office used the existing internal Space Systems Division management structure for the procurement of the SLV–3 vehicles. The SLV–3 contracts covered necessary services and equipment from General Dynamics/Convair, Rocketdyne, Acoustica, General Electric, Burroughs, and the Aerospace Corp. Seven Atlas SLV–3 vehicles were procured and launched during the Gemini Program.

After final assembly at the factory, the tanks were mated to the engine section; various subassembly kits were installed and tested prior to a final composite test of the complete vehicle. The vehicle was then shipped to Cape Kennedy where the SLV–3 underwent inspection and final installations in the hangar prior to erection. After the vehicle was erected on Launch Complex 14, the principal tests were the SLV–3 Flight Acceptance Composite Tests and the overall Atlas-Agena Target Vehicle system test (Joint Flight Acceptance Composite Test). Finally, an SLV–3 tanking test was accomplished to establish flight readiness of the launch vehicle.

Augmented Target Docking Adapter Program

Program Development

In December 1965, the Manned Spacecraft Center delineated the Air Force Space Systems Division and contractor support requirements for the Augmented Target Docking Adapter mission. The Air Force Space Systems Division was to supply the following hardware: an SLV–3 vehicle, a Gemini target-vehicle shroud, and a Gemini target-vehicle booster adapter. Space Systems Division was also required to perform the software work necessary to place the Augmented Target Docking Adapter into orbit, using only SLV–3 boost capability.

Program Requirements

The Augmented Target Docking Adapter was originally designed as a backup vehicle for the Gemini VII/VI–A rendezvous mission and for the Gemini VIII mission. At first, it was not known if the hard start experienced by the Gemini VI target vehicle could be corrected before the Gemini VIII mission. The Manned Spacecraft Center requested a vehicle that would permit docking even though it would have no maneuver capability. The Augmented Target Docking Adapter consisted of a target-vehicle shroud, a Target Docking Adapter, an equipment section, a Gemini spacecraft Reentry Control System module, and a battery section.

The insertion conditions required a near-circular orbit of 161 nautical miles with dispersions no greater than ±20 nautical miles and an inclination angle of 28.87°. The steering mode was to be the crossing of the ascending mode. A 2500-pound payload was used for planning.

Gemini Atlas–Agena Target Vehicle Launch History

Gemini VI Mission

Since the Gemini VI mission was to be the first Gemini rendezvous mission, the primary objective was the rendezvous and docking of the Gemini spacecraft with the Gemini Agena Target Vehicle. Another objective involved checkout of the target vehicle while docked, and included commands from the spacecraft to the target vehicle, determination of target-vehicle safety status, and test of target-vehicle attitude maneuver capability. A small Secondary Propulsion System firing in the docked configuration was also planned, although no docked Pri-

mary Propulsion System firing was planned. This mission was also the first simultaneous countdown for the launch of two vehicles (the Gemini Atlas-Agena Target Vehicle and, 101 minutes later, the Gemini Launch Vehicle and spacecraft).

The Gemini Atlas-Agena Target Vehicle for the Gemini VI mission was launched at 10 a.m., eastern standard time, October 25, 1965. The ascent portion of the flight was normal until time for the target-vehicle Primary Propulsion System to fire for the insertion maneuver; the engine suffered a hard start and subsequent explosion, and the vehicle failed to achieve orbit.

Gemini VIII Mission

The Gemini Atlas-Agena Target Vehicle for the Gemini VIII mission was launched at 10:03:03 a.m., eastern standard time, March 16, 1966. The ascent phase was very close to nominal with insertion into an orbit 161.4 by 161.7 nautical miles. The insertion parameters were as follows:

Semimajor axis, n. mi.	3603.05
Inclination angle, deg	28.86
Eccentricity	0.0006
Period, min	90.47

Following undocking and reentry of the spacecraft, eight orbital firings were performed by the target-vehicle Primary Propulsion System during Gemini VIII. The duration ranged from the 0.85-second minimum-impulse firing to a 19.6-second plane change, with the majority between 1 and 3 seconds. Of the eight firings, five utilized the short 22-second A-ullage sequence, and the other three used the 7-second C-ullage sequence. Based upon the available data, the Primary Propulsion System performed normally during all eight firings. During the 19.6-second out-of-plane maneuver, a major system anomaly became apparent. The vehicle attitude in yaw was considerably off the intended heading, resulting in a large in-plane velocity component. This same heading offset was also noted on the second out-of-plane maneuver, or inclination-adjust maneuver, and again resulted in a large in-plane velocity component. It was later determined that these errors were caused by a large center-of-gravity offset from the centerline, and by the dynamic response of the guidance and control system being too slow to correct for center-of-gravity errors. It was decided that additional out-of-plane maneuvers would not be made.

An in-plane retrograde maneuver resulted in lowering the apogee to 200 nautical miles, and the results were nearly perfect. The yaw offset was again noted, but the firing was short; slight yaw-heading errors have much less effect on the resulting orbit when the maneuver is performed in-plane. Based upon this success, two more in-plane maneuvers, dwell initiate and dwell terminate, were performed to deplete some of the propellants and to achieve a circular orbit of 220 nautical miles. These maneuvers were very successful and accurate, although the yaw offset was noted during each firing. The center-of-gravity offset problem was the only major system problem during the mission.

Operation of the Secondary Propulsion System was desired until the propellant was depleted; however, because of the excessive control-gas usage during the spacecraft malfunction, only 15 pounds of Attitude Control System gas remained when the first Secondary Propulsion System firing was to be initiated. The operation was planned for 20 seconds to provide the first actual in-orbit operation of the Secondary Propulsion System and to verify control-gas usage rates. The first Secondary Propulsion System Unit II operation occurred over Grand Canary Island in revolution 41. The firing was performed using flight control mode FC–7 to reduce velocity-vector errors caused by center-of-gravity offset. Over the Eastern Test Range during revolution 42, the second operation of the Secondary Propulsion System was performed at the existing heading of $+90^\circ$. This maneuver was also performed with docked gains to reduce thrust-vector

errors caused by center-of-gravity offset. The maneuver appeared nominal, except that 5 pounds of control gas were expended. The target-vehicle orbit after the final Secondary Propulsion System firing was 220 by 222 nautical miles with a 28.867° inclination angle.

During the Gemini VIII mission, 5439 commands to the target vehicle were sent, accepted, and executed. The Gemini Atlas-Agena Target Vehicle was launched within 1 second of the scheduled lift-off time.

Gemini IX Mission

The Gemini Atlas-Agena Target Launch Vehicle for the Gemini IX mission was launched May 17, 1966. A normal countdown and lift-off occurred. After 120.6 seconds of flight, the vehicle experienced a loss-of-pitch control in one booster engine. Tracking film showed that after the loss-of-pitch stability, the vehicle pitched downward in excess of 180°, and changed in azimuth toward the left (northward). Flight control data also indicated that the vehicle pitched downward; extrapolated and integrated data revealed that the vehicle pitched down 216° from the 67° reference at 120.6 seconds. Radar data from the Grand Bahama Island station at 436 seconds, approximately 136 seconds after vernier engine cutoff, placed the vehicle about 103.4 nautical miles from the launch site, headed in a northerly direction at 97 000 feet in altitude, and descending. These data correlated well with a set of radar impact coordinates which placed vehicle impact 107 miles from the launch site in a northeasterly direction. The exact reason for the loss of the engine pitch control is unknown, but the data indicate that a short-to-ground occurred in the circuit for the servoamplifier output-command signal. This short-to-ground may have been caused by cryogenic leakage in the thrust section.

Gemini IX-A Mission

The Gemini IX–A Target Launch Vehicle with the Augmented Target Docking Adapter was launched from Cape Kennedy at 10:00:02 a.m., eastern standard time, June 1, 1966. The Target Launch Vehicle was steered into a predetermined coast ellipse and nodal crossing. The insertion orbital elements were as follows:

Apogee altitude, n. mi.	167.1
Perigee altitude, n. mi.	161.0
Period, min	90.50
Inclination, deg	28.87

Gemini X Mission

The Gemini Atlas-Agena Target Vehicle for the Gemini X mission was launched at 3:49:46 p.m., eastern standard time, July 18, 1966. The insertion parameters were as follows:

Semimajor axis, n. mi.	3603
Inclination angle, deg	28.85
Eccentricity	0.0008
Period, min	90.46

The ascent phase was nominal with insertion into an orbit of 163.4 by 159.0 nautical miles. The largest dispersion noted in the ascent guidance equations was 1.5 sigma. The target vehicle was commanded into docking configuration from the ground. Prior to docking, the Gemini spacecraft had a higher-than-predicted usage of propellants. This altered the flight plan and resulted in more docked time, more reliance on the target vehicle, and more maneuvers using target-vehicle capability.

Gemini XI Mission

The Gemini XI Atlas-Agena Target Vehicle was launched at 8:05:01 a.m., eastern standard time, September 12, 1966. The ascent phase was nominal with insertion into an orbit of 165.7 by 156.3 nautical miles. The insertion parameters were as follows:

Semimajor axis, n. mi.	3602.5
Inclination angle, deg	28.84
Eccentricity	0.0013
Period, min	90.56

The launch was originally scheduled for September 9, 1966; however, it was delayed

1 day due to an oxidizer leak in the Gemini Launch Vehicle. The second scheduled launch on September 10, 1966, was scrubbed at T—140 minutes due to a suspected autopilot malfunction in the Target Launch Vehicle. During the ascent Primary Propulsion System firing, it was determined that the magnitude of the center-of-gravity offset problem encountered during Gemini VIII had been successfully eliminated. The target-vehicle command system responded properly to all ground and spacecraft commands during the mission.

Gemini XII Mission

The Gemini Atlas-Agena Target Vehicle for the Gemini XII mission was launched at 2:07:59 p.m., eastern standard time, November 11, 1966. The ascent phase was nominal with insertion into an orbit of 163.6 by 159.0 nautical miles. This was the most accurate insertion for the target vehicle in the Gemini Program. The insertion parameters were:

Semimajor axis, n. mi.	3603.0
Inclination angle, deg	28.86
Eccentricity	0.0009
Period, min	90.56

The launch was originally scheduled for November 9, 1966; however, the launch was delayed 2 days due to a malfunction in the secondary autopilot of the Gemini Launch Vehicle. During the target-vehicle ascent maneuver, an apparent anomaly occurred 140 seconds after Primary Propulsion System initiation. At this time a 30-psi drop occurred in thrust-chamber pressure for approximately 1 second, then returned to normal for the remaining 42 seconds of the firing. This did not affect the Gemini Atlas-Agena Vehicle insertion conditions. The docked posigrade Primary Propulsion System maneuver originally planned was canceled due to uncertainties about the significance of the chamber-pressure-drop anomaly.

Reference

1. ANON.: Gemini Midprogram Conference, Including Experiment Results. NASA SP-121, 1966.

15. MISSION SUPPORT BY THE DEPARTMENT OF DEFENSE

By Royce G. Olson, *Director, Department of Defense Manned Space Flight Support Office, Patrick Air Force Base, Florida*

Introduction

The Secretary of Defense designated the Commander of the National Range Division, Air Force Systems Command, Lt. General Leighton I. Davis, as the Department of Defense Manager for Manned Space Flight Support Operations. This designation, organizationally under the Joint Chiefs of Staff, emphasized DOD support of the Gemini Program. General Davis was given the responsibility and authority to insure complete and responsive support to NASA's needs. Through the National Range Division, he directed the long-range planning for the design and acquisition of supporting resources such as range ships and aircraft, high-quality communications, and range instrumentation.

The DOD Manager established a small supporting joint staff which was the single point of contact for the final coordination and marshaling of all supporting resources prior to each mission. These officers served as the operational control staff during mission periods when the DOD Manager assumed operational control of all committed DOD resources. The areas of support responsibility included launch, network, recovery, communications, ground medical, meteorological, public affairs, and miscellaneous logistics.

Launch and Network Support

Manned Space Flight Network

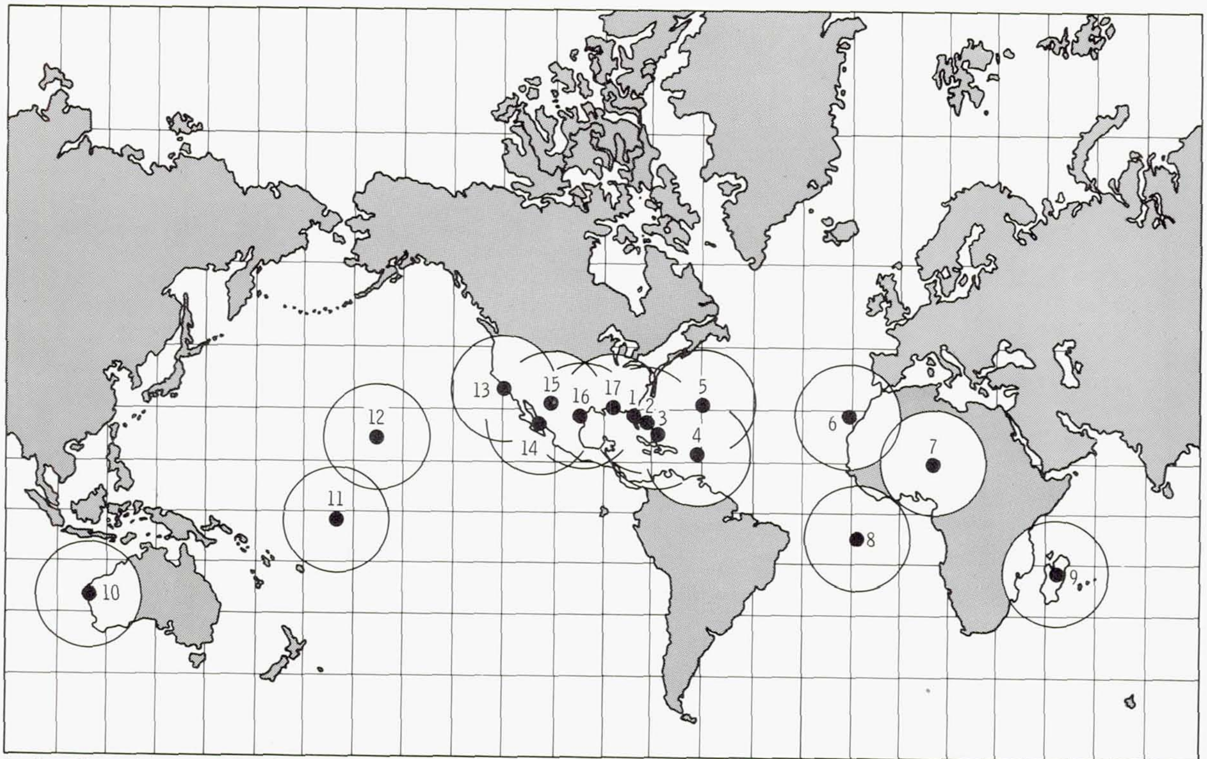
The responsibility of the Manned Space Flight Network during the Gemini Program was to control, to communicate with, and to observe by electronic methods the performance of the spacecraft (systems and occupants) and, on most missions, the Gemini Agena Target Vehicle. The global tracking and reentry network established for Project Mercury and modified for the Gemini Program was a joint NASA/DOD venture. The network was developed by integrating existing DOD range resources with stations established and operated by NASA at strategic sites around the world. In addition, the Australian Weapons Research Establishment operated two stations for NASA. Figure 15–1 shows the location of the tracking sites in the standard configuration for the Gemini rendezvous missions. The locations of the tracking ships varied somewhat as specified by individual mission needs.

DOD Support

DOD support to the Manned Space Flight Network was provided by several agencies.

Eastern Test Range.—The Eastern Test Range (U.S. Air Force) facilities were used in the launch and the orbital phases of the missions. Standard launch-site and instrumentation support were provided as necessary for the launching and performance evaluation of the Gemini Launch Vehicle. The services included propellants, pad safety, range safety, metric and optical tracking, telemetry, and communications, as well as command and control support.

Certain selected facilities at Cape Kennedy and at Eastern Test Range downrange stations also comprised a part of the network for tracking the target vehicle and the spacecraft during orbit and reentry. The facilities included: C-band radars for tracking the spacecraft and target vehicle and S-band radars for tracking the target vehicle; tele-



1. Cape Kennedy (DOD)
2. Grand Bahama Island (DOD)
3. Grand Turk Island (DOD)
4. Antigua (DOD)
5. Bermuda (NASA)
6. Canary Island (NASA)
7. Kano, Nigeria (NASA)
8. Ascension Island (DOD)
9. Tananarive, Malagasy (NASA)
10. Carnarvon, Australia (WRE)
11. Canton Island (NASA)
12. Kauai, Hawaii (NASA)
13. Pt. Arguello, Calif. (DOD)
14. Guaymas, Mexico (NASA)
15. White Sands, N. M. (DOD)
16. Corpus Christi, Tex. (NASA)
17. Eglin AFB, Fla. (DOD)

DOD ships Rose Knot Victor, Coastal Sentry Quebec, Range Tracker to be positioned as necessary.
Radar and telemetry aircraft to be positioned as needed.

FIGURE 15–1.—Gemini network stations.

metry recording and display equipment; command and control equipment; ground communications, both voice and teletype; and spacecraft voice communications. The stations designated for orbital support were Cape Kennedy and Grand Bahama, Grand Turk, Antigua, and Ascension Islands.

In addition to the land-based stations, two Eastern Test Range ships, the *Coastal Sentry Quebec* and the *Rose Knot Victor*, were an integral part of the network. These ships provided telemetry, command and control, and communications coverage. The Eastern Test Range also positioned JC–130 aircraft in the primary Atlantic Ocean recovery area to record terminal spacecraft telemetry, and to relay flight-crew voice communications from the landing area to the Mission Control Center—Houston. The resources of the Eastern Test Range were augmented, on a mission-by-mission basis, by such facilities as the C-band radar at Pretoria, South Africa, and instrumented ships.

Pacific Missile Range.—The Pacific Missile Range (U.S. Navy) facilities provided tracking ship support and voice-relay telemetry aircraft for the Eastern Pacific landing area. Early in the Gemini Program, the Pacific Missile Range operated the Hawaii, Canton Island, and California tracking sites. Later the National Range Division and the Western Test Range were established, and the

national range resources were realined. As a result, the operations of the Hawaii and the Canton Island sites were transferred to NASA; and the operation of the California site, to the Western Test Range.

Western Test Range.—The Western Test Range (U.S. Air Force) facilities operated the California tracking site. Although not considered a Gemini network station, the U.S. Navy ship *Range Tracker* participated in the Gemini III through Gemini X missions with radar, telemetry, and communications.

White Sands Missile Range.—The White Sands Missile Range (U.S. Army) facilities provided C-band radar support throughout the Gemini Program.

Air Proving Ground Center.—The Air Proving Ground Center (U.S. Air Force) facilities provided C-band radar support throughout the Gemini Program.

North American Air Defense Command.—The North American Air Defense Command support to manned space flight began with Project Mercury. The ability to skin track and catalog orbiting objects, and to compute impact data and separation distances, was beneficial to the Gemini Program. The North American Air Defense Command assisted NASA Goddard Space Flight Center in computing launch-vehicle impact points; provided ephemeris information on the Gemini Agena Target Vehicles left in orbit; and provided the capability to skin track the spacecraft.

Organization

During the coordinating (premission) phase, management of the DOD portion of the Gemini network was the responsibility of the individual range or organizational commander. In planning DOD network support, the DOD Manager and his staff coordinated with the Manned Space Flight Coordinator who was responsible for planning, arranging, and coordinating the resources of his individual range. The Assistant for Network to the DOD Manager coordinated network plans and operating procedures with the Manned Space Flight Coordinator and with NASA to assure proper integration of the DOD stations with the Manned Space Flight Network.

Twenty-four hours prior to launch, the DOD Manager assumed operational control of all DOD forces supporting the mission. The Assistant for Network was part of the operational staff and provided the DOD Manager with network-readiness reports, and assured that the DOD stations operated in accordance with the plans and procedures specified for that mission.

The entire integrated network during the mission was controlled by the network controllers on the staff of the NASA Flight Director at the Mission Control Center—Houston. They conducted the network countdown, conducted premission simulations and tests, and issued last-minute instructions. They also directed network activities during the flight, as necessary, to assure that the required network support for the mission was provided to the flight controllers. The network controllers were assisted by a joint Goddard Space Flight Center/DOD Network Support Team. This team of specialists in each major category of network instrumentation served as technical advisors to the network controllers.

During Project Mercury, and for the first portion of the Gemini Program, the network-control function was performed solely by DOD. After relocation of the Mission Control Center function from Cape Kennedy to Houston, the network-control staff was augmented by NASA personnel from the Manned Spacecraft Center and from the Goddard Space Flight Center. The network-control function was then brought under the direct control of the Manned Spacecraft Center.

Mission Highlights

Gemini I.—For Gemini I, an unmanned orbital mission, the network was in a proper configuration for the Gemini Program. The ships, *Rose Knot Victor* and *Coastal Sentry*

Quebec, were not required to support this mission.

Gemini II.—Gemini II was unmanned and ballistic, requiring only Eastern Test Range tracking facilities. The *Rose Knot Victor* was located up range under the ground track; the *Coastal Sentry Quebec* was located near the landing point. The Antigua radar tracked the spacecraft through the communications blackout period.

Gemini III.—Gemini III was manned and orbital and was the first exercise of the entire network. The U.S. Navy ship *Range Tracker* was added to the network. The communications from the *Coastal Sentry Quebec* were augmented by the U.S. Navy ship *Kingsport* and the SYNCOM II satellite. This was the first time NASA and DOD recovery communications augmented one another. All radars that had been committed to the spacecraft reentry phase obtained track.

Gemini IV.—Gemini IV was a 4-day, manned, orbital mission and used the same network configuration as Gemini III. An Eastern Test Range subcable break was successfully bypassed by using alternate routes. Telemetry monitoring of launch-vehicle reentry and breakup was available through radar tracking from Patrick Air Force Base and Kennedy Space Center.

Gemini V.—Gemini V was an 8-day, manned, orbital mission and full network support was provided. The North American Air Defense Command successfully tracked and provided impact prediction on the second stage of the launch vehicle.

Gemini VI–A and Gemini VII.—Gemini VI–A and Gemini VII used combined flight plans. Gemini VII was a 14-day manned mission; Gemini VI–A was a 2-day, manned, rendezvous mission. Full network support was provided. The ship *Wheeling* was substituted for the ship *Range Tracker.* No significant network failures occurred during the 14-day mission. The performance of the remote-site data processor was superior to that obtained during previous missions.

Gemini VIII.—Gemini VIII was planned as a 3-day rendezvous mission; however, the mission was terminated during the seventh orbit because of a spacecraft control-system malfunction after docking. The U.S. Navy ship *Kingsport* was added for this mission. Excellent network support was available throughout the spacecraft emergency and the reentry.

Gemini IX–A through Gemini XII.—Gemini IX–A was a 3-day rendezvous mission with the Augmented Target Docking Adapter. Both Gemini X and XI were 3-day rendezvous missions with the Gemini Agena Target Vehicle. Gemini XII was a 4-day rendezvous mission with the Gemini Agena Target Vehicle.

The Gemini IX–A through Gemini XII missions required identical network support. Network tracking was excellent; failures were at a minimum and had no effect on the missions. On Gemini IX–A and X, the Computer Acquisition System allowed the Eastern Test Range radars to acquire and to track the spacecraft on reentry. On Gemini XI, a computer was made available at the Western Test Range, and a vector was sent from the Real Time Computer System at the Eastern Test Range to the California site for acquisition. Tracking data were returned to the Real Time Computer System for computing acquisition information for the Eastern Test Range radars.

Summary of Network Support

Significant progress was realized during the Gemini Program not only in improving basic tracking and data transmission, but also in streamlining operation and test procedures to assure more efficient use of the available equipment. Network problems, such as communications failures, inadequate radar tracking, and difficult troubleshooting that occurred during Project Mercury, were reduced so that a fully operative network became a routine occurrence at launch time and throughout the mission.

Modifications and improvements to the C-band radars provided more accurate tracking, easier acquisition, and more rapid proc-

essing of the radar data. Using pulse code modulation, the Telemetry System allowed a much greater volume of spacecraft data to be transmitted and displayed at one time. The Digital Command System allowed more complex and a greater number of commands to be sent to the spacecraft; by computer processing, a fail-safe system was provided to assure that the proper command was, in fact, transmitted. The more extensive use of computers, both on site and at the Mission Control Centers, provided for near real-time transmission, reduction, and display of the volumes of data made available by the network. The Gemini Program provided the first real operational testing of many of these new systems and the improvements of older systems. The Digital Command System and Telemetry System, for instance, are gradually replacing older systems on the national ranges.

The Computer Acquisition System was one result of the Gemini network support developed on the DOD ranges. The reentry profile and the primary landing area of the Gemini spacecraft were such that, to provide adequate radar tracking during reentry for landing-point computation, the radars had to acquire during the blackout period. Without highly accurate acquisition information, this was almost an impossible task; however, the means were devised to solve the problem. Prior to blackout, radar-track data were provided to a central computer that had been programed for reentry. These data could be translated into an accurate driving signal to be fed to the radar which would acquire the spacecraft during blackout. The accuracy of the data enabled the radar to follow the actual spacecraft track and to find the weak beacon signal through the ion shield. By use of computers associated with each radar, data could be fed in both directions, and the radars could operate independently. A lack of equipment at the DOD ranges precluded early implementation of the system. Using the Real Time Computer System at Cape Kennedy, a successful test of the theory was accomplished on the Gemini V mission; further tests were run on subsequent missions. Refinements were made and by the time of the Gemini IX–A mission, data from the White Sands radar, processed by the Real Time Computer System, allowed the Eastern Test Range radars to acquire and track the spacecraft during reentry, proving the advantage of the system. Additional computers will be made available at the DOD ranges to add to the system so that the final configuration can be realized.

The Impact Predictor System was an outgrowth and refinement of a capability that had existed at the Eastern Test Range since the Real Time Computer System became operational. This system used radar data from other DOD ranges and the downrange Eastern Test Range sites. The data were processed by the Real Time Computer System and provided a near real-time plot of the spacecraft ground track during reentry. The spacecraft drag factor and the maneuvering information were not entered in the computer program, but the quantity of available downrange data offset this deficiency in the terminal phase of reentry.

Recovery Support

The primary mission of DOD recovery forces during the Gemini Program was to locate and to retrieve the flight crew and spacecraft, and to deliver them to NASA program managers. This responsibility began with the launch of the spacecraft and ended with the delivery of the recovered spacecraft to NASA.

Planning for the spacecraft-location function assumed that information would be available from several sources. One source in computing a probable landing point was the information obtained from the ground tracking stations. In addition, the spacecraft was equipped with a high-frequency radio beacon which enabled the worldwide DOD high-frequency direction-finding network to provide fixing information. The spacecraft was also equipped with an ultrahigh-frequency radio beacon which could be received by air-

borne forces. The airborne forces used electronic homing for all Gemini missions. An additional electronic source of information not originally anticipated was shipboard radar. Radar information from ships stationed in the Primary Landing Area was particularly valuable; and a contact in excess of 300 miles was reported by the primary recovery ship during recovery of the Gemini VII spacecraft.

Location planning also provided for visual search if electronic means failed. The spacecraft was provided with a sea dye marker to aid in daytime visual location and with a high-intensity blinking light for nighttime search. During the later missions, the location task was simplified when the spacecraft, descending on the main parachute, was visually sighted.

Retrieval of the flight crew was accomplished by helicopter on all but two missions. The Gemini VI–A and Gemini IX–A flight crews elected to remain in the spacecraft for pickup by the recovery ship. Spacecraft retrieval was accomplished by the primary recovery ship on all missions except Gemini VIII, which landed in the West Pacific Secondary Landing Area. In this case, the swimmers were deployed from an aircraft on the scene at spacecraft landing. The team attached the flotation collar to the spacecraft, and the recovery was made by the destroyer supporting the area.

During Gemini II and Gemini III, control of DOD recovery forces by the DOD Manager was accomplished from the Mission Control Center—Cape Kennedy. For all subsequent missions, the DOD Manager and his staff operated from the Recovery Control Center, Houston.

An early problem in the command and control area was the lack of real-time voice information from the recovery scene. For Gemini IV, procedures were developed whereby the flight-crew air-to-ground voice circuit could be used for on-scene recovery operations and could be relayed to the Recovery Control Center; this procedure was followed for all subsequent missions.

The use of functionally descriptive call signs for the recovery forces was instituted during Gemini VI–A and VII. This procedure aided the clarity of recovery force communications and was used in all subsequent missions.

Recovery Areas

Since recovery planning was concerned with all conceivable landing situations, the most effective approach was to orient the planning about certain geographical areas. These were the Launch Site, Launch Abort, Contingency, Secondary, and Primary Areas. All except the Contingency Area were considered planned landing areas.

Launch Site Area.—The Launch Site Area (fig. 15–2) was that area where a landing would occur following an abort in the late stages of the countdown or during early flight. For planning purposes, the area was centered on Launch Complex 19 at Cape Kennedy and extended 3 miles toward the Banana River and 41 miles seaward, with the major axis along the launch azimuth. The actual positioning of launch-site forces was oriented about a much smaller area, with the size and location determined by the launch azimuth and local winds.

The typical launch-site recovery force included four CH–3C amphibious helicopters,

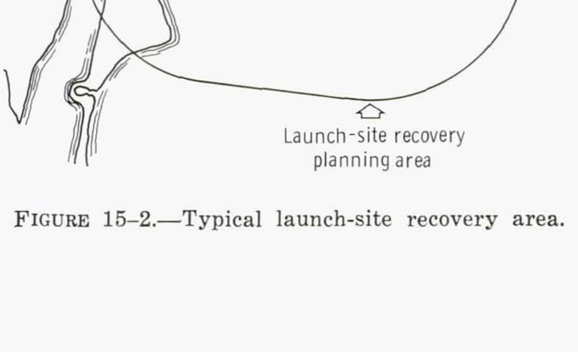


FIGURE 15–2.—Typical launch-site recovery area.

four lighter amphibious resupply cargo (LARC) vehicles, two M–113 personnel carriers, two landing vehicle tracked recovery (LVTR), two rescue boats, and one salvage vessel for in-port standby. The launch-site recovery forces were not required to effect an actual recovery during Gemini.

Launch Abort Area.—The Launch Abort Area was along the launch ground track between Cape Kennedy and the west coast of Africa. An abort might have occurred in this area during the launch phase of flight prior to Earth-orbital insertion. The recovery force posture in the Launch Abort Area underwent considerable change during the Gemini Program as confidence in the launch vehicle and spacecraft systems increased. For example, the on-station launch-abort recovery force for Gemini III consisted of eight destroyers, one fleet oiler, one fleet tug, and nine fixed-wing aircraft. The on-station launch-abort force for Gemini XII was reduced to three destroyers, one aircraft carrier, one fleet oiler, and four fixed-wing aircraft. The launch-abort recovery forces were not required to make an actual recovery during Gemini.

Contingency Recovery Area.—The Contingency Recovery Area comprised the area along the spacecraft ground tracks outside the planned landing areas. Forces supporting this area consisted of Air Force Aerospace Rescue and Recovery Service aircraft deployed to various worldwide staging bases. These forces were capable of reaching any point along the spacecraft ground track within 18 hours. There were no actual contingency-area recoveries during Gemini.

Secondary Landing Areas.—The Secondary Landing Areas which were established for the long-duration missions consisted of four circular zones. Each zone had a radius of 240 nautical miles. The zones were located in the West Atlantic, East Atlantic, West Pacific, and Mid-Pacific. Each zone was supported by a destroyer or a fleet oiler and, in some cases, by a destroyer and an oiler in company. In addition, Air Force Aerospace Rescue and Recovery Service aircraft were positioned adjacent to these zones. Target points were selected in each zone for each time the ground track passed through the zone. These target points were then covered by the supporting ship. The aircraft were on 30-minute strip alert and ready for an immediate takeoff.

The Atlantic zones were covered by the ships and aircraft which had also provided Launch Abort Area coverage during the launch phase of the mission. The East Atlantic Secondary Landing Area was normally supported by a destroyer and a fleet oiler. For Gemini XII, the ship access-time requirement for this area was increased, and sufficient coverage was provided by a fleet oiler equipped with communications and recovery equipment as well as medical personnel.

The value of Secondary Landing Areas and assigned forces was significantly demonstrated on the Gemini V and VIII missions. During the early part of Gemini V mission, the spacecraft developed electrical power-source difficulties. For several revolutions after the problem developed, the spacecraft did not pass through the Primary Landing Area. However, the spacecraft did pass through the Mid-Pacific Secondary Landing Area where air and surface forces were ready to provide support if necessary. The problem was eventually corrected, and the mission was completed as planned.

The value of the Secondary Landing Areas was even more evident during the Gemini VIII flight. Following a successful rendezvous-and-docking maneuver, the docked vehicles developed severe gyrations. The crew was forced to take emergency action which resulted in a low-fuel state in the Reentry Control System. In accordance with preplanned mission rules, the decision was made in this case to land the spacecraft in the West Pacific Secondary Landing Area. The support ship and seven aircraft were alerted, and the first aircraft on the scene sighted the spacecraft descending on the main parachute. The aircraft deployed the swimmers to attach the flotation collar to the spacecraft and to report the condition of the flight crew.

The destroyer arrived on the scene and retrieved the spacecraft and flight crew. Recovery was completed 3 hours 10 minutes after landing.

Primary Landing Area.—The Primary Landing Area was located in the West Atlantic, and the primary recovery ship was assigned to this area. An Amphibious Assault Ship was the primary recovery ship for Gemini X and Gemini XI. A support aircraft carrier was used for this function in all other missions.

The addition of the Amphibious Assault Ship has provided DOD planners more flexibility in scheduling support for manned space-flight missions. This type of ship operates more economically and does not require a rescue destroyer in company. The aircraft carrier has proved to be an effective primary recovery ship, since it serves as a launch and recovery platform for helicopters and provides excellent facilities for postmission evaluation of the flight crew. Helicopters are used in the Primary Recovery Area for the electronic location of the spacecraft and for the transport of the swim teams to and from the spacecraft. During most of the missions, separate helicopters were used for each of these functions. In Gemini XII, the functions were combined by placing the swim teams aboard the search helicopters. This satisfactory arrangement proved economical and operational.

Fixed-wing aircraft were utilized for airborne control of aircraft in the recovery area and for providing a commentary of recovery operations between the recovery forces and shore installations. This information was relayed to the Mission Control Center—Houston in real time through relay aircraft. The relay aircraft provided network support prior to landing and provided recovery support after landing until the flight crew were retrieved.

Beginning with Gemini VI–A and VII, live television broadcasts and recovery operations in the Primary Landing Area were provided. Recovery of the flight crew and spacecraft was televised for all subsequent missions except Gemini VIII. The Gemini VI–A and VII missions established the DOD capability to provide recovery support for a dual mission.

Planned Versus Actual Statistics

Table 15–I presents a compilation of the total DOD resources dedicated to each Gemini mission. The general trend toward reduction of forces as the program progressed is shown.

The second column of table 15–II indicates the distance between the planned target point and the actual landing point of the spacecraft for each Gemini mission. This table also shows the time interval between the spacecraft landing and the arrival of the flight crew aboard ship. Column 4 shows the access time established by NASA for the applicable recovery area; the access time is the principal criterion established for recovery-force operations. This is the elapsed time from spacecraft landing until first-level medical care can be provided the flight crew. Thus, a comparison of the times in columns 3 and 4 provides an indication of recovery-force performance.

Communications

Communications support by DOD forces evolved from a simple network for supporting a ballistic missile launch to complex communications networks of ships, aircraft, ground stations, and worldwide recovery bases and forces for supporting orbital space flights.

In 1960, the Air Force Eastern Test Range was committed to support the first flight of the manned spacecraft program, Mercury-Redstone 1 mission. Cape Kennedy (Cape Canaveral) and Grand Bahama Island, Eastern Test Range stations, were the primary ground stations providing tracking and telemetry support. Other stations

were being established to form a worldwide tracking network. The network included airborne platforms for automatic voice relay from a manned spacecraft to the Mission Control Center by means of high-frequency/single-sideband radio and selected ground stations. The DOD communications responsibilities increased as missions progressed from suborbital to orbital. The responsibilities involved the Eastern Test Range, the

TABLE 15–I.—*DOD Support of Gemini Missions*

Mission	Launch date	Duration, hr:min	Personnel	Aircraft	Recovery ship	Ship making spacecraft recovery	Ocean
I (unmanned)	Apr. 8, 1964	[a]5:00	6 176	None	None		
II (unmanned)	Jan 19, 1965	0:18	6 562	67	16	USS *Lake Champlain*[b]	Atlantic
III	Mar. 23, 1965	4:53	10 185	82	27	USS *Intrepid*[b]	Atlantic
IV	June 3, 1965	97:56	10 349	134	26	USS *Wasp*[b]	Atlantic
V	Aug. 21, 1965	190:55	10 265	114	19	USS *Lake Champlain*[b]	Atlantic
VI	Oct. 25, 1965	[c]0:00	10 125	125	16		
VII	Dec. 4, 1965	330:35	10 125	125	16	USS *Wasp*[b]	Atlantic
VI–A	Dec. 15, 1965	25:51	10 125	125	16	USS *Wasp*[b]	Atlantic
VIII	Mar. 16, 1966	10:41	9 665	96	18	USS *Mason*[d]	Pacific
IX–A[e]	June 3, 1966	72:21	11 301	92	15	USS *Wasp*[b]	Atlantic
X	July 18, 1966	70:47	9 072	78	13	USS *Guadalcanal*[f]	Atlantic
XI	Sept. 12, 1966	71:17	8 963	73	13	USS *Guam*[f]	Atlantic
XII	Nov. 11, 1966	94:35	9 775	65	12	USS *Wasp*[b]	Atlantic

[a] Tracking time, no recovery intended.
[b] Aircraft carrier.
[c] Mission aborted.
[d] Destroyer. Mission terminated in Secondary Landing Area. USS *Boxer* was planned recovery carrier.
[e] Gemini IX aborted May 17 due to failure of target vehicle.
[f] Amphibious Assault Ship (helicopter carrier).

TABLE 15–II.—*Gemini Recovery Operations*

Mission	Landing distance from target point, n. mi.	Time from landing to flight crew aboard recovery ship, min	Maximum ship access time, hr	Remarks
I		Unmanned		No recovery intended
II	14	Unmanned		
III	60	70	4	
IV	44	57	4	
V	91	89	4	
VI–A	7	66	4	Crew remained in spacecraft
VII	6.4	33	4	
VIII	1.1	190	6	Landing in West Pacific Zone
IX–A	0.38	52	4	Crew remained in spacecraft
X	3.4	28	4	
XI	2.65	24	4	
XII	2.6	30	4	

Eglin Gulf Test Range, the White Sands Missile Range, and the Pacific Missile Range, as well as associated ships and aircraft integrated into one network under a DOD-designated network controller. The Air Force Western Test Range, organized in 1965, includes Vandenberg Air Force Base, Calif.; Hawaii; Eniwetok; and ships and aircraft supporting the Pacific area.

During the Mercury and Gemini manned space flights, many new theories, different support and response, and mechanics of accomplishing the missions were developed by DOD. The transmission of high-speed radar data for manned missions; the use of airborne platforms for tracking, telemetry, and automatic voice relay; and the procedures for integrating the DOD Service and National Ranges with the NASA stations were improved.

While much consideration was accorded a buildup of networks to support the orbital portion of a flight, action was also taken to provide the worldwide deployed recovery forces with communications systems that were adequate, responsive, and reliable. The complete resources of DOD were made available through the facilities of the Defense Communications Agency, Unified and Specified Commands, as well as through the resources of the separate commands. Progression was evident in the method of providing teletype communications (written copy) service. Early in Project Mercury, the facilities of the Army, Navy, and Air Force were used to provide teletype information to the forces and bases under the command of each of the services. To gain operational control, to improve response time, and to insure real-time reaction, the Army (Fort Detrick, Md.) was given the responsibility for the automatic relay-switching center, interconnecting the recovery staff of the DOD Manager with the deployed recovery forces. Voice communications links were also made available from the Defense Communications Agency, commercial carriers, ranges, and military commands. Recovery communications support increased; and a vast network of dedicated, common-user circuits connecting the worldwide deployed forces on a near real-time basis was available for Gemini XII. This system was capable of supporting as many as 131 aircraft, 28 surface vessels, 30 land-based sites, and 5 major recovery control centers. Each recovery force was given a complete test prior to each mission to assure readiness to support nominal as well as nonnominal missions.

Under the direction of the DOD Manager's Assistant for Communications, the DOD communications assets were activated and tested approximately 7 days prior to flight. The assets were tested for station-to-station alinement procedures, alternate and diverse routing, and equipment and manpower readiness. For orbital support, the NASA and DOD tracking/telemetry stations integrated the communication functions systems for network simulations about 15 days prior to flight.

In addition to insuring that necessary circuitry was available and ready to support the mission, key individuals were deployed by the Assistant for Communications to key communications locations. These individuals were to provide quick response to unforeseen situations, to assist field commanders with any communications problem that could not be resolved locally, and to insure that DOD forces conformed to documented and last-minute communication needs as a single and integrated system. Possible improvements to communications equipment, terminal locations, and procedures were constantly studied to assure that the best possible support was available to manned spacecraft missions.

Meteorology

The short duration of the Project Mercury missions allowed confirmation of acceptable weather conditions in the recovery areas. In the planning stage of the Gemini Program, however, it became apparent that weather conditions in the planned recovery areas

would have to be monitored continuously in order to determine the suitability of recovery areas. As a result, the National Range Division staff meteorologist was designated the Assistant for Meteorology to the DOD Manager.

Special weather observations were made from DOD ships in the recovery areas and from weather reconnaissance aircraft. Both Air Force and Navy aircraft were used for Gemini weather reconnaissance and were specially equipped for hurricane and typhoon reconnaissance. Each of the four recovery zones for the Gemini missions was supported by one reconnaissance flight each day as needed.

Special weather support, using balloon and meteorological rocket-equipped instrumentation, was provided at selected locations with high-level atmospheric data for postflight analysis.

Bioastronautics

The Bioastronautics Operational Support Unit at Cape Kennedy was completed in time to support the launch of Gemini III on March 23, 1965.

Bioastronautics at the Air Force Eastern Test Range is one of the many complex assignments of a DOD organization. The Director of Bioastronautics is responsible for providing assistance to NASA as required in prelaunch evaluation of the flight crew, biomedical monitoring during orbital flight, medical support for recovery operations, and postflight evaluation.

Medical support for the early Jupiter flights that carried animal life was provided by a joint-services team of three officers designated as the Aero-Medical Consultant Staff. In November 1959, NASA requested DOD to provide the medical support team for Project Mercury. The DOD representative for Project Mercury support appointed his Staff Surgeon to the newly established position of Assistant for Bioastronautics to manage these support activities. The function of this new office was to organize a worldwide DOD medical support capability and to deploy people and materiel as requested by NASA. This first Assistant for Bioastronautics was responsible to the 6550th U.S. Air Force Hospital at Patrick Air Force Base and to the Air Force Missile Test Center commander. In January 1962, the Assistant for Bioastronautics was designated an additional duty position for the redesignated Deputy for Bioastronautics, Air Force Eastern Test Range. In March 1963, the Office of the Deputy for Bioastronautics was selected by the Surgeon General of the U.S. Air Force to provide primary training that would satisfy the requirements for the third year of residency training in aerospace medicine.

Public Affairs

The Director of Information of the Air Force Eastern Test Range was designated as the Assistant for Public Affairs to the DOD Manager under the DOD/NASA agreement. The areas of responsibility of the Assistant for Public Affairs began at Cape Kennedy and extended to Hawaii and to Europe.

The operation of the press sites, including fiscal management and technical organization, was also the responsibility of the Assistant for Public Affairs. The news pools at Cape Kennedy during a launch and those at sea were operated under established rules.

DOD information desks were established in the two major NASA news centers approximately 5 days before the mission and were manned until the day after spacecraft recovery. Beginning 2 hours before mission lift-off and continuing through recovery, DOD public affairs consoles in the recovery control centers were operated 24 hours a day. Manpower assistance was provided by other military commands and departments under the supervision of the Assistant for Public Affairs. Of the 10 100 newsmen accredited during the Gemini Program, nearly 7000 operated in the Cape Kennedy area, and the remainder, in Houston.

16. PRE-GEMINI MEDICAL PREDICTIONS VERSUS GEMINI FLIGHT RESULTS

By CHARLES A. BERRY, *M.D., Director of Medical Research and Operations, NASA Manned Spacecraft Center; and* ALLEN D. CATTERSON, *M.D., Office of Medical Research Operations, NASA Manned Spacecraft Center*

Summary

The Mercury and Gemini space flights provided approximately 2000 man-hours of weightless exposure for evaluating predicted effects of space flights versus actual findings. In general, the environmental hazards and the effects on man appear to be of less magnitude than originally anticipated. The principal physiologic changes noted were orthostatism for some 50 hours postflight as measured with a tilt table, reduced red-cell mass (5 to 20 percent), and reduced X-ray density (calcium) in the os calcis and the small finger. No abnormal psychological reactions have been observed, and no vestibular disturbances have occurred that were related to flight. Drugs have been prescribed for inflight use. The role of the physician in supporting normal space flight is complex, requiring the practice of clinical medicine, research, and diplomacy. Although much remains to be learned, it appears that if man is properly supported, his limitations will not be a barrier to the exploration of the universe.

Introduction

Prior to the first exposure of man to orbital space flight, the biomedical community expressed considerable concern over man's capability not only to perform in such an environment but even to survive in it. Since weightlessness was the one unknown factor which could not be exactly duplicated in a laboratory on the ground, numerous investigators and various committees predicted some effect on almost every body system. It is understandable that detrimental effects were the ones listed, as these could have been limiting factors in manned space flight. In some respects, the medical community becomes its own worst enemy in the attempt to protect man against the hazards of new and unknown environments. Frequently, the physician dwells upon the possible individual system decrements, and forgets the tremendous capability of the body to maintain a state of homeostasis in many environments. Following the first manned space flights, some of these anxieties were reduced, although most observers believed the evidence was insufficient to reject any of the dire predictions.

Predicted and Observed Environment and Human Responses

The successful and safely conducted Mercury and Gemini Programs have provided the first significant knowledge concerning man's capability to cope with the environment of space. In these programs, 19 men have flown 26 man-flights for a total weightless experience of approximately 2000 man-hours. Three individuals have flown as the single crewman in Mercury and as one of the two crewmen in the Gemini spacecraft; four individuals have flown twice in the Gemini spacecraft. The flight programs are summarized in tables 16–I and 16–II. This flight experience only scratches the surface of detailed space exploration, but should provide a sound basis for comparing the predic-

tions concerning man's support and response to this environment with the reality of the findings from the actual experience.

The space-flight environment predictions are compared with the actual observations in table 16–III.

The human responses to space flight which were predicted are compared with the observations in table 16–IV. There were more predicted system effects than were observed, though there were also several effects noted which were not predicted.

General Aspects of the Flight Program

In evaluating the results of flight programs, it is important to realize that man is being exposed to multiple stresses and that it is impossible at the present time to evaluate the stresses singly, either inflight or post-

TABLE 16–I.—*Project Mercury Manned Flights*

Flight	Crew	Launch date	Description	Duration, hr:min
MR–3	Shepard	May 5, 1961	Suborbital	0:15
MR–4	Grissom	July 21, 1961	Suborbital	0:15
MA–6	Glenn	Feb. 20, 1962	Orbital	4:56
MA–7	Carpenter	May 24, 1962	Orbital	4:56
MA–8	Schirra	Oct. 3, 1963	Orbital	9:14
MA–9	Cooper	May 15, 1963	Orbital	34:20

TABLE 16–II—*Gemini Manned Space Flights*

Gemini mission	Crew	Launch date	Description	Duration, day:hr:min
III	Grissom Young	Mar. 23, 1965	Three revolution manned test	0:04:52
IV	McDivitt White	June 3, 1965	First extended duration and extravehicular activity	4:00:56
V	Cooper Conrad	Aug. 21, 1965	First medium-duration flight	7:22:56
VII	Borman Lovell	Dec. 4, 1965	First long-duration flight	13:18:35
VI–A	Schirra Stafford	Dec. 15, 1965	First rendezvous flight	1:01:53
VIII	Armstrong Scott	Mar. 16, 1966	First rendezvous and docking flight	0:10:41
IX–A	Stafford Cernan	June 3, 1966	Second rendezvous and docking; first extended extravehicular activity	3:01:04
X	Young Collins	July 18, 1966	Third rendezvous and docking; 2 extravehicular activity periods; first docked target-vehicle-propelled high-apogee maneuver	2:22:46
XI	Conrad Gordon	Sept. 12, 1966	First rendezvous and docking initial orbit; 2 extravehicular activity periods; second docked target-vehicle-propelled high-apogee maneuver; tether exercise	2:23:17
XII	Lovell Aldrin	Nov. 11, 1966	Rendezvous and docking; umbilical and 2 standup extravehicular activity periods; tether exercise	3:22:37

TABLE 16–III.—*Space-Flight Environment*

Predicted	Observed
Micrometeorite density	Low micrometeorite density
Loss of cabin pressure-vacuum	5 psi except during extravehicular activity
Loss of suit pressure-vacuum	Space suit, wear unpressurized (pressurized on extravehicular flights)
Toxic atmosphere	100-percent oxygen
Cabin and suit temperature	Minimal variation about comfort zone
Radiation levels	Insignificant
Isolation	None
Physical confinement	Physical restraint
Weightlessness	Weightlessness
Gravity loads	Gravity loads, no problem with performance
Vibration	Minimal vibration
Severe glare	Varying illumination
(a)	Workload higher than expected

[a] Not predicted.

TABLE 16–IV.—*Human Response to Space Flight*

Predicted	Observed
Dysbarism	None
Disruption of circadian rhythms	None
Decreased g-tolerance	None
Skin infections and breakdown	Dryness, including dandruff
Sleepiness and sleeplessness	Interference (minor)
Reduced visual acuity	None
(a)	Eye irritation
(a)	Nasal stuffiness and hoarseness
Disorientation and motion sickness	None
Pulmonary atelectasis	None
High heart rates	Launch, reentry, extravehicular activity
Cardiac arrhythmias	None
High blood pressure	None
Low blood pressure	None
Fainting postflight	None

[a] Not predicted.

TABLE 16–IV.—*Human Response to Space Flight*—Concluded

Predicted	Observed
Electromechanical delay in cardiac cycle	None
Reduced cardiovascular response to exercise	None
(a)	Absolute neutrophilia
Reduced blood volume	Moderate
Reduced plasma volume	Minimal
(a)	Decreased red-cell mass
Dehydration	Minimal
Weight loss	Variable
Bone demineralization	Minimal calcium loss
Loss of appetite	Varying caloric intake
Nausea	None
Renal stones	None
Urinary retention	None
Diuresis	None
Muscular incoordination	None
Muscular atrophy	None
(a)	Reduced exercise capacity
Hallucinations	None
Euphoria	None
Impaired psychomotor performance	None
Sedative need	None
Stimulant need	Occasionally before reentry
Infectious disease	None
Fatigue	Minimal

[a] Not predicted.

flight. Man 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. Some of the stresses can be simulated in ground-based studies but the actual flight situation has never been duplicated, and more data from additional flight programs are necessary before flight

observations can be applied to the ground situation.

It is necessary to provide the capability to monitor the physiologic state of man during flight activities. A great deal of consideration has been given to the definition of a set of physiologic indices which might be easily obtained in the flight situation and which could be meaningfully monitored. Routine parameters have included measurements of voice, two leads for electrocardiogram, respiration, body temperature, and blood pressure (fig. 16–1). Other functions were added for the experiments program, but were not monitored in real time. The monitoring of man's physiologic state in flight is necessary to provide information for real-time decision making concerning the accomplishment of additional flight objectives; to assure the safety of the flight crew; and to obtain experimental data for postflight analysis for

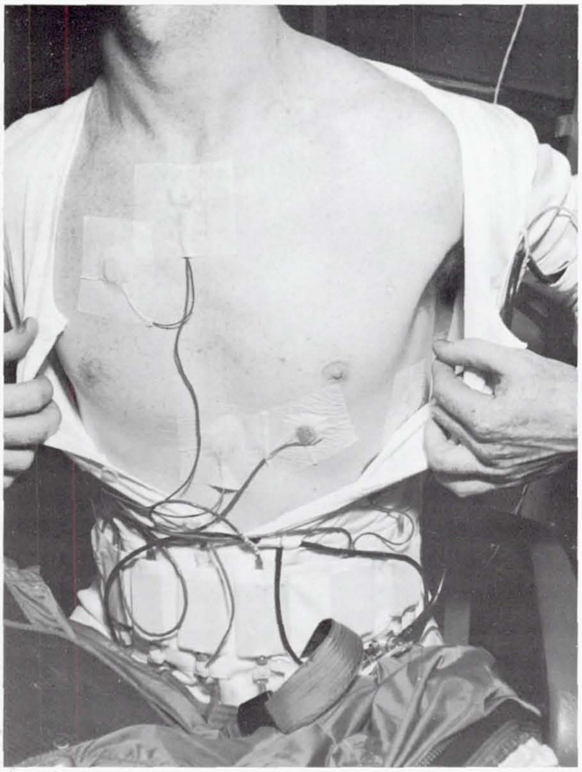


FIGURE 16–1.—Gemini biosensor harness.

predictions concerning the effects of long-duration flight upon man. The sensors and equipment should not interfere with the comfort and the function of the crew. Whenever possible, the procurement of data should be virtually automatic, requiring little or no action on the part of the crewmen. A great deal has been learned concerning the use of minimal amounts of data obtained at intermittent intervals while a spacecraft is over a tracking station. The extravehicular crewmen have been monitored by means of one lead each of electrocardiogram and of respiration-rate measurement obtained through the space-suit umbilical. Additional physiologic information, such as suit or body temperature and carbon-dioxide levels, could not be obtained due to the limited number of monitoring leads available in the umbilical.

The medical objectives in the manned space-flight program are to provide medical support for man, enabling him to fly safely in order to answer the following questions:

(1) How long can man be exposed to the space-flight environment without producing significant physiologic or performance decrement?

(2) What are the causes of the observed changes?

(3) Are preventive measures or treatment needed, and if so, what are best?

Attainment of these objectives will involve tasks with different orientation. The most urgent task is obviously to provide medical support to assure flight safety through the development of adequate preflight preparation and examination, as well as inflight monitoring. The second is to obtain information on which to base the operational decisions for extending the flight duration in a safe manner. The third task differs from the operational orientation of the first two in that it implies an experimental approach to determine the etiology of the findings observed. Frequently, many things that would contribute to the accomplishment of the last task must be sacrificed in order to attain the overall mission objective. This requires con-

stant interplay between the experimental and the operational medical approaches to the missions.

The medical profession requires a team effort by personnel with varied training and backgrounds in order to reach a common objective, the preservation or the restoration of health for mankind. This is no less true in a space-flight environment where a strong team effort is necessary, and a strong engineering interface is imperative. If man is to be properly supported, medical requirements concerning the spacecraft environment and the equipment performance must be supplied very early in the hardware development cycle. A very long leadtime is necessary to meet realistic flight schedules, and ample time must always be left for proper testing of the hardware. Flight-configured hardware should be utilized to collect the baseline physiologic data which will be compared with the inflight data.

Anticipated Problems Compared with Flight Results

The review of a number of aerospace or space medicine texts published since 1951 reveals a large number of anticipated problems involving man and the hardware or vehicle in the space environment. It appears logical to compare the predictions with the actual flight results.

Maintenance of Cabin Pressure

In regard to the vacuum of space, extrapolating from aircraft experience led to a prediction of difficulty with the maintenance of cabin pressure. To date, the spacecraft have maintained a cabin pressure of approximately 5 psia throughout the manned flights. The pressurization feature of the space suits was a backup to the cabin pressure, but was not required except during the planned excursions outside the spacecraft when the cabin was intentionally depressurized. The normal suit pressures have been approximately 3.7 psia.

Cabin Atmosphere

Reduction in cabin pressure to 5 psia, equivalent to a pressure altitude of 27 000 feet, and the further reduction to 3.7 psia in the space suit created some concern about the possible development of dysbarism. Before each mission, the crew was denitrogenated by breathing 100-percent oxygen for 2 hours; this, coupled with the further denitrogenation accomplished in the spacecraft, has proved to be ample protection. There have been no evidences of dysbarism on any of the missions.

Cabin and Suit Temperature

The maintenance of an adequate temperature in the cabin and in the extravehicular pilot's suit was also a matter of concern. The temperatures were generally within the comfort range around 70° F. During one mission, the crew reported being cold when the spacecraft was powered down and rotating. The extravehicular pilots generally have been warm while inside the spacecraft because the extravehicular suit contains additional layers of material.

Micrometeorites

Micrometeorites are a subject heading in every book relating to space flight. They are mentioned as a possible hazard to cabin integrity, to spacecraft window surfaces, and to extravehicular crewmen. No significant micrometeorite or meteorite density has been observed in the flights to date. There has been no evidence of micrometeorite hits on the extravehicular suits; however, a micrometeroite protective layer is provided.

Radiation

The radiation environment of space has been sampled by numerous probes and has been calculated at length. With one exception, the flights have not reached an altitude involving the inner Van Allen belt, but the flights have routinely passed through the

South Atlantic anomaly. The onboard radiation measuring system and the personal dosimeters attached to the crewmen confirmed that the radiation intensity was at the lower end of the calculated range. In a 160-nautical-mile orbit, the crew received approximately 15 millirads of radiation in each 24 hours of exposure. Table 16–V indicates the total doses received on the flights to date.

Light and Darkness

Many predictions were made concerning the effect of the changing light and darkness producing a day and a night every 90 minutes. It was generally predicted that this would totally disrupt the circadian rhythms, producing grave consequences. Certainly no overt effects of the 45 minutes of day and 45 minutes of night were observed on the short missions. As knowledge of sleep in the spaceflight environment increased, it was determined best to arrange the work-rest cycles so that sleep occurred at the normal Cape Kennedy sleep time. The spacecraft was artifically darkened by covering the windows, and as far as the crew were concerned, it was night. The physiological response in heart rate to the regime used on the 14-day flight is shown in figure 16–2.

TABLE 16–V.—*Radiation Doses on Gemini Missions*[a]

Mission	Duration, day:hr:min	Mean cumulative dose, mrad	
		Command pilot	Pilot
III	0:04:52	<20	42±15
IV	4:00:56	42±4.5	50±4.5
V	7:22:56	182±18.5	170±17
VI–A	1:01:53	25±2	23±2
VIII	13:18:35	155±9	170±10
VIII	0:10:41	<10	10
IX–A	3:01:04	17±1	22±1
X	2:22:46	670±6	765±10
XI	2:23:17	29±1	26±1
XII	3:22:37	<20	<20

[a] Dosimeters located in helmet, right and left chest, and thigh.

Gravity Load

During space flight, the increase of gravity load during launch and reentry, and the nullification of gravity load and production of a state of weightlessness during actual flight, were expected to produce detrimental effects. Actually, gravity loads during the missions were well within man's tolerances, with two 7g peaks occurring at launch, and with g-forces varying from 4 to 8.2g at reentry. Much concern was expressed about a decreased tolerance to gravity following weightless flight. No evidence of this has been observed; following 4 days of weightless flight, the Gemini IV crew sustained a peak of 8.2g without adverse effects.

Weightlessness has been the subject of innumerable studies and papers. It has been produced for brief periods in parabolic flight in aircraft, and simulated by water immersion and bedrest. The Gemini Program has produced a fair amount of evidence concerning the effect of the weightless spaceflight environment on various body systems.

Skin

In spite of the moisture attendant to spacesuit operations, the skin has remained in remarkably good condition through flights up to 14 days in duration. Following the 8-day flight, there was some drying of the skin

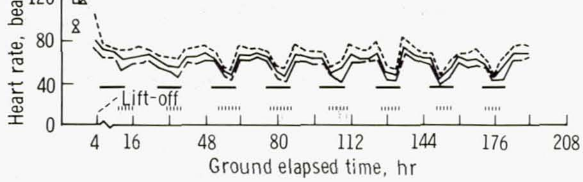


FIGURE 16–2.—Gemini VII pilot heart rate.

noted during the immediate postflight period, but this was easily treated with lotion. There have been no infections, and there has been minimal reaction around the sensor sites. Dandruff has been an occasional problem, but has been easily controlled with preflight and postflight medication.

Central Nervous System

The best indication of central nervous system function has been the excellent performance of the crew on each of the missions. This was graphically illustrated by the demanding performances required during the aborted launch of Gemini VI–A; the rendezvous and the thruster problem on Gemini VIII; the extravehicular activity on Gemini IV, IX–A, X, XI, and XII; and the many accurate spacecraft landings and recoveries. Psychological tests have not been conducted as distinct entities unrelated to the inflight tasks. Instead, the evaluation of total human performance has provided an indication of adequate central nervous system function. There has been no evidence, either during flight or postflight, of any psychological abnormalities.

The electroencephalogram (fig. 16–3) was utilized to evaluate sleep during the 14-day mission. A total of 54 hours 43 minutes of interpretable data was obtained. Variations in the depth of sleep from Stage 1 to the deep sleep of Stage 4 were noted in flight as in the ground-based data.

Numerous visual observations have been reported by the crews involving inflight sightings and descriptions of ground views. The actual determination of visual acuity has been made in flight, as well as in preflight and

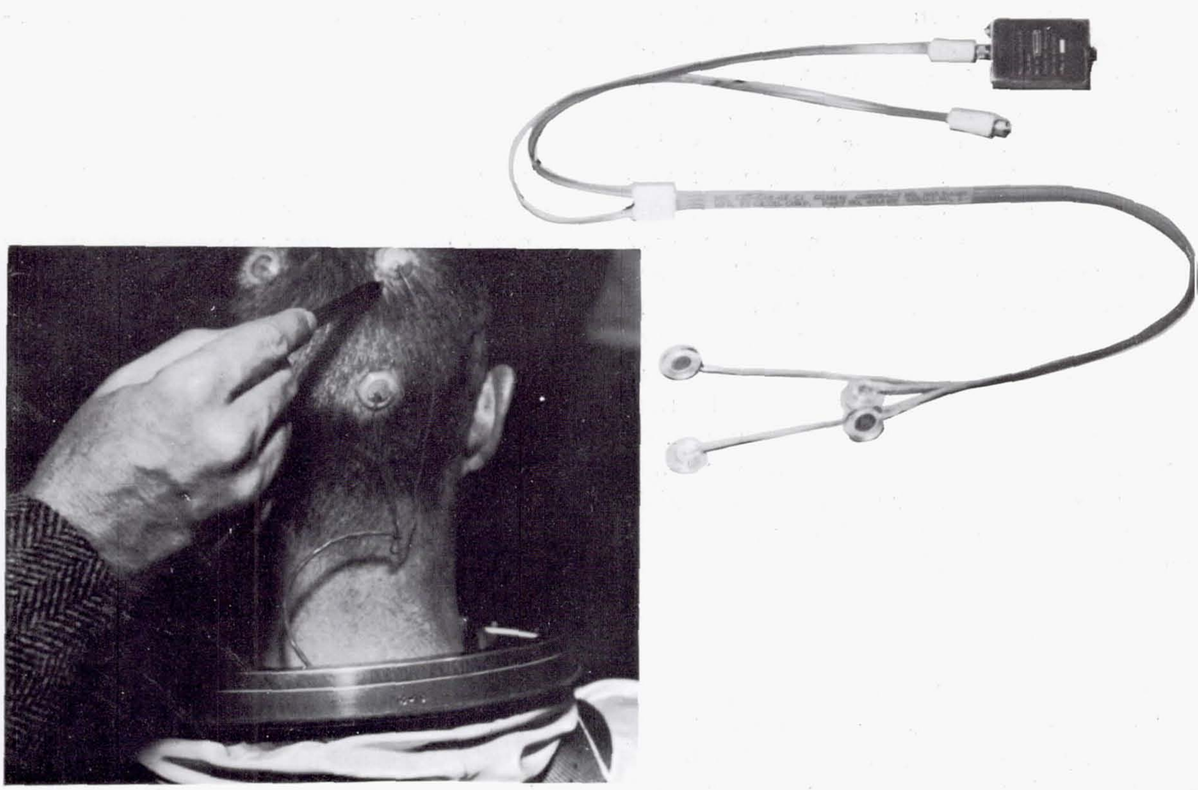


FIGURE 16–3.—Electroencephalogram equipment.

postflight examinations. All of these tests support the statement that vision is not altered during weightless flight.

As previously noted, there has been much conjecture concerning vestibular changes in a weightless environment. There has been no evidence of altered vestibular function during any of the Gemini flights. Preflight and postflight caloric vestibular function studies have shown no change, and special studies of the otolith response have revealed no significant changes. There have been ample motions of the head in flight and during roll rates with the spacecraft. There has been no vertigo nor disorientation noted, even during the extravehicular activity with occasional loss of all visual references. Several crewmen have reported a feeling of fullness in the head similar in character to the fullness experienced when one is turned upside down, allowing the blood to go to the head. However, there has been no sensation of being turned upside down, and the impression is that this sensation results from altered distribution of blood in the weightless state. To clear the record, two of the Mercury pilots developed difficulties involving the labyrinth; the difficulties were in no way related to the space flights. One developed prolonged vertigo as the result of a severe blow over the left ear in a fall, but he has completely recovered with no residual effect. The other crewman developed an inflammation of the labyrinth some 3 years after his 15-minute space flight, and, while he continues to have some hearing loss, there have been no further vestibular symptoms. It is interesting to note this absolute lack of any inflight vestibular symptoms, in spite of the fact that a number of the pilots have developed motion sickness while in the spacecraft on the water.

Eye, Ear, Nose, and Throat

There have been two inflight incidents of rather severe eye irritation. One was the result of exposure to lithium hydroxide in the suit circuit; the cause of the other remains a mystery. In a few instances, some postflight conjunctival infection has been noted, but has lasted only a few hours and is believed to have been the result of the oxygen environment. During the early portions of the flights, normally the first 2 or 3 days, some nasal stuffiness has been noted. This also is undoubtedly related to the 100-percent oxygen environment and is usually self-limited. On occasion, the condition has been treated locally or by oral medication.

Respiratory System

Preflight and postflight X-rays have failed to reveal any atelectasis. Pulmonary function studies before and after the 14-day mission revealed no alteration. There have been no specific difficulties or symptomatology involving the respiratory system; however, some rather high respiratory rates have been noted during heavy workloads in the extravehicular activity. Even when these rates have exceeded 40 breaths per minute, they have not been accompanied by symptomatology.

Cardiovascular System

The cardiovascular system was the first of the major body systems to show physiologic change following flight; as a result, it has been extensively investigated by various means (fig. 16–4). As previously reported, the peak heart rates have been observed at launch and at reentry (table 16–VI); the rates normally reached higher levels during the reentry period. The midportions of all the missions have been characterized by more stable heart rates at lower levels with adequate response to physical demands.

The electrocardiogram has been studied in detail thoughout the Gemini missions. The only abnormalities of note have been very rare, premature, auricular and ventricular contractions. No significant changes have been detected in the duration of specific segments of the electrocardiogram.

Blood-pressure measurements obtained during the Gemini VII mission revealed that

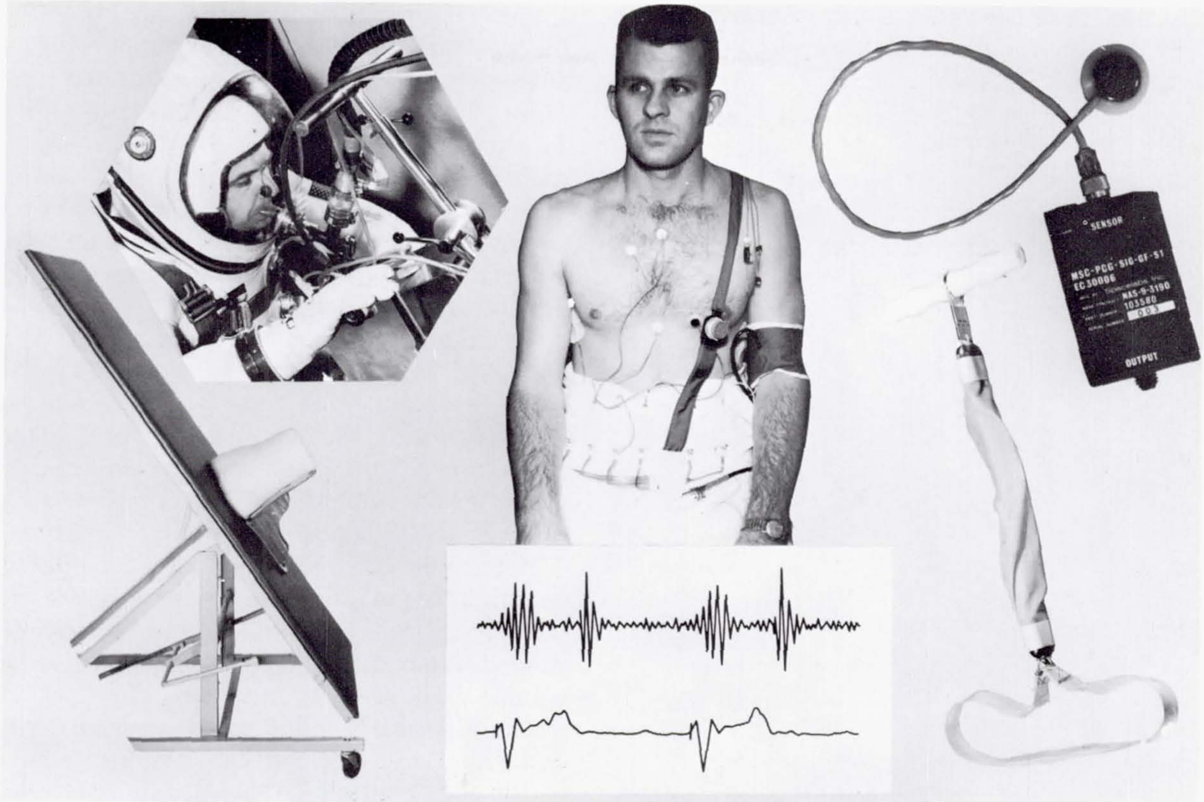


FIGURE 16-4.—Gemini cardiovascular evaluation techniques.

systolic and diastolic values remained within the envelope of normality and showed no significant changes throughout 14 days of flight. As previously reported, this included the pressures taken at the time of reentry.

Some insight into the electrical and mechanical phases of the cardiac cycle was gained during the Gemini flights. The data were derived through synchronous phonocardiographic and electrocardiographic monitoring. In general, wide fluctuations in the duration of the cardiac cycle, but within physiological limits, were observed throughout the missions. Fluctuations in the duration of electromechanical systole correlated closely with changes in heart rate. Stable values were observed for electromechanical delay (onset of ventricular activity, QRS complexes, to onset of first heart sound) throughout the missions, with shorter values observed during the intervals of peak heart rates recorded during lift-off, reentry, and extravehicular activity. The higher values observed for the duration of systole and for electromechanical delay in certain crewmembers suggest a preponderance of cholinergic influences (vagal tone). An increase in adrenergic reaction (sympathetic tone) was generally observed during lift-off, reentry, and in the few hours preceding reentry.

As a further measure of cardiovascular status, Experiment M003, Inflight Exerciser, determined the heart-rate response to an exercise load consisting of one pull per second for 30 seconds on a bungee device (force at full extension of 12 inches equaled 70 pounds). The responses for one crewman on the Gemini V mission are shown in figure 16-5. The results of the 4-day Gemini IV and the 14-day Gemini VII mission did not differ. This variant of the step test revealed no physical or cardiovascular decrement after

TABLE 16–VI.—*Peak Heart Rates During Launch and Reentry*

Gemini mission	Crewman[a]	Peak rates during launch, beats/min	Peak rates during reentry, beats/min
III	CP	152	165
	P	120	130
IV	CP	148	140
	P	128	125
V	CP	148	170
	P	155	178
VI–A	CP	125	125
	P	150	140
VII	CP	152	180
	P	125	134
VIII	CP	138	130
	P	120	90
IX–A	CP	142	160
	P	120	126
X	CP	120	110
	P	125	90
XI	CP	166	120
	P	154	117
XII	CP	136	142
	P	110	137

[a] CP indicates command pilot; P indicates pilot.

as much as 14 days in a space-flight environment.

In contrast to the Project Mercury results, orthostatism resulting from any Gemini mission has not been detectable except by means of passive tilt-table provocation. Typically, the heart-rate and blood-pressure response to a 15-minute, 70° tilt performed postflight are compared with identical preflight testing on the same crewmen. Consistently, such testing has demonstrated a greater increase in heart rate, a greater reduction in pulse pressure, and a greater increase in leg volume, as interpreted from lower limb circumference gages during the preflight tilt (fig. 16–6). The changes observed in these variables may be most significantly illustrated by examining the heart-rate changes observed during preflight and postflight tilt-table studies. When the postflight increases in heart rate during tilt are expressed as percent of the preflight tilt heart rate for each of the Gemini crews, the postflight increases are from 17 to 105 percent greater than those exhibited preflight. The increasing trend in these values was evident through the 8-day mission. A multiplicity of altered factors, such as better diet, more exercise, desuited periods, and no extravehicular activity, make the improved postflight response to the 14-day mission very difficult to interpret (fig. 16–7).

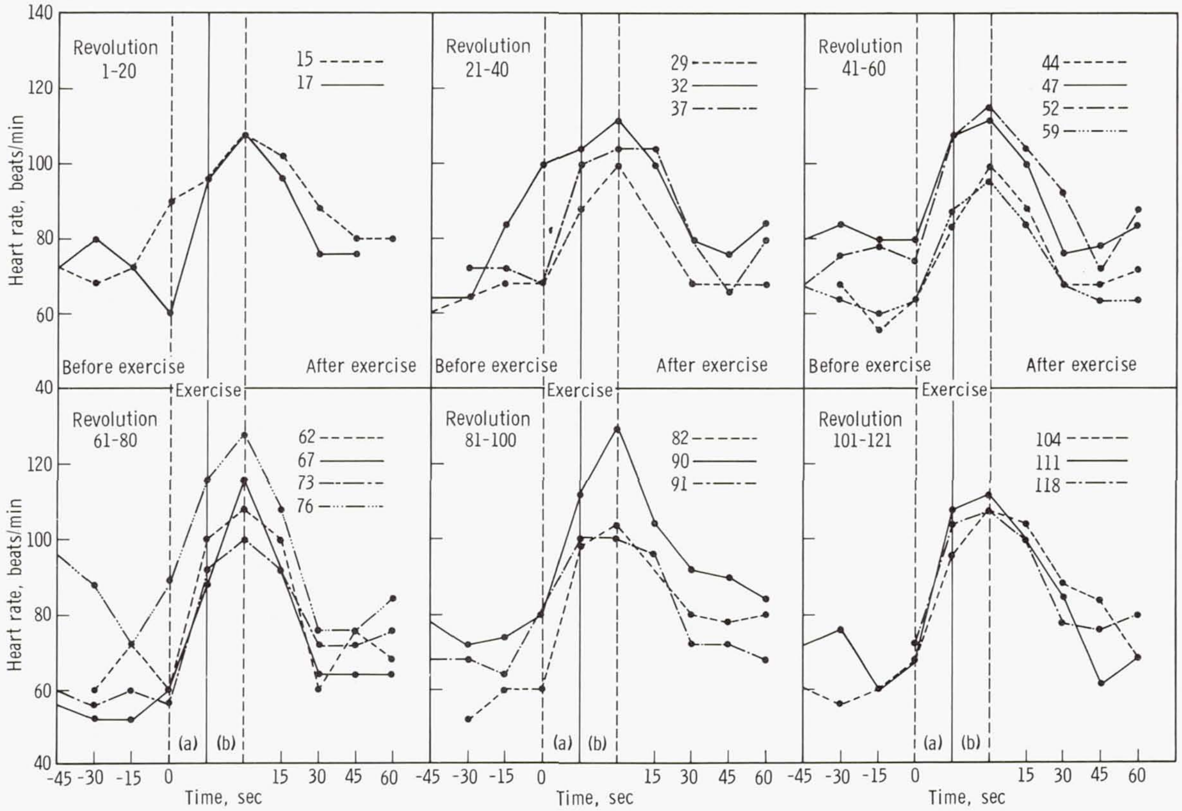
For purposes of comparison, flight data and data from bedrest studies were viewed in a like manner and show a very similar trend; however, the magnitude of the changes shows marked differences, again illustrating, perhaps, the influence of factors other than those simulated by bedrest.

When the tilt-table tests are considered, postflight leg volume was universally greater than preflight. Postmission observations ranged from 12 to 82 percent increase in volume over premission values.

The Gemini V pilot wore intermittently occlusive lower limb cuffs for the first 4 days of the 8-day mission. The Gemini VII pilot wore the cuffs for the entire 14-day mission; however, his heart-rate increases and pulse-pressure narrowing were greater than for the command pilot; the cuffs seemingly did not alter the variables.

Average resting heart rates have ranged from 18 to 62 percent higher after missions. In spite of higher resting pulse rates, the changes resulting from tilt were still greater. The exception presented by the Gemini VII crew is more apparent. The bedrest data are not remarkable.

To date, the observations of the effect of space flight on body systems have shown significant changes involving only the cardiovascular, hematopoietic, and musculoskeletal systems. Even these changes appear adaptive in nature and are measured principally during the readaptive phase to the 1g environment. It appears that adequate information has been obtained to permit anticipation of a nominal lunar mission without being surprised by unforeseen physiologic changes. Medical results from the U.S. space flights



[a] First 15 sec of exercise period.
[b] Second 15 sec of exercise period.

FIGURE 16–5.—Heart-rate response to bungee exercise, Gemini V pilot.

appear to differ from the results reported by the U.S.S.R., where there seems to be a unique problem in the area of vestibular response. In the cardiovascular area, the United States has not confirmed the U.S.S.R. reports of electromechanical delay in cardiac response, and the U.S.S.R. has not confirmed the U.S. findings of decreased red-cell mass.

The Gemini flights have also provided some excellent examples of human variability and have emphasized the necessity for care in making deductions. In making projections based on very limited results in a few people, the current trend is to bank heavily upon comparisons in a given individual; that is, differences between baseline data and responses observed during and after a flight. The crewmen who have flown twice have shown variability between flights in the same manner as have different men on the same flight. Figure 16–8 shows the heart rates for one crewman during the launch phase of both his Mercury mission and his Gemini mission. The two curves show little correlation and could as easily have come from different individuals. Obviously, confidence in the results and the definition of variability will be improved as more information is gained on future flights. Also, these are gross system findings, and much must still be accomplished in the laboratory and in flight if the mechanisms of the findings are to be understood.

Although physiological adaptation is difficult to define, it might be stated as any alteration or response which favors the survival of an organism in a changed environment. This

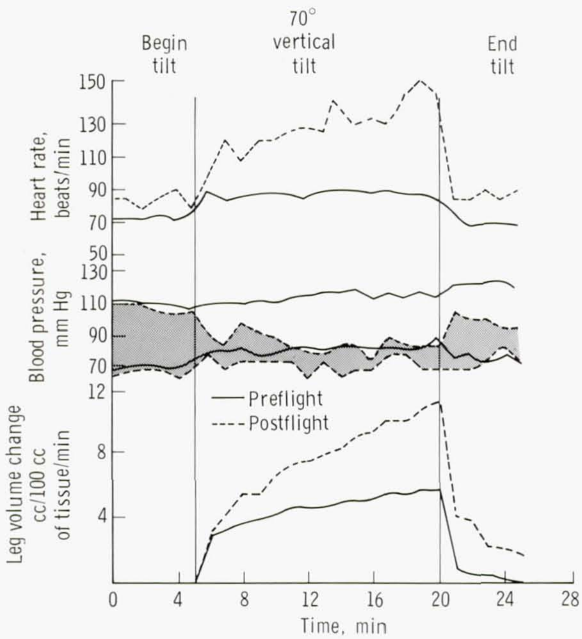


FIGURE 16-6.—Typical tilt-table response.

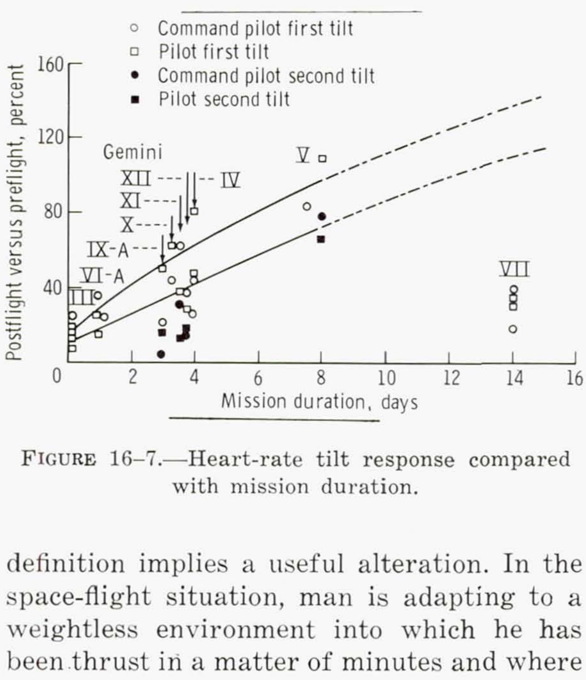


FIGURE 16-7.—Heart-rate tilt response compared with mission duration.

definition implies a useful alteration. In the space-flight situation, man is adapting to a weightless environment into which he has been thrust in a matter of minutes and where he stays a variable time; a second adaptation, required after return to the 1g environment of Earth, can be measured by direct observation. Some of the physiological changes return to normal over an extended time; for instance, the tilt responses have all

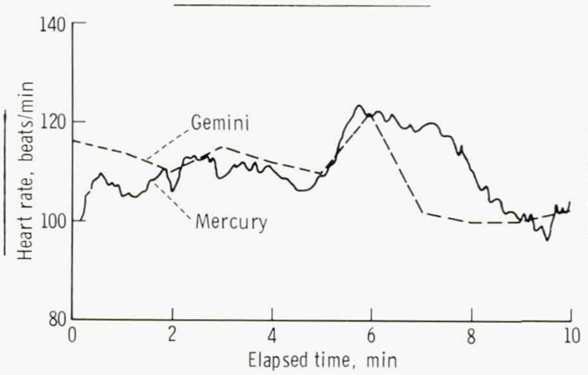


FIGURE 16-8.—Command pilot heart-rate comparisons.

returned to normal within a 50-hour period, regardless of the duration of exposure to the space-flight environment.

Blood

Significant increases have been observed in white-blood-cell counts manifested as an absolute neutrophilia following most flights. This condition has always returned to normal within 24 hours. Hematologic data derived from Gemini missions of 4, 8, and 14 days demonstrated a hemolytic process originating during flight. Specific data points include red-cell mass deficits of 12, 20, and 19 percent (command pilot) following the Gemini IV, V, and VII missions, respectively (fig. 16-9). The 12-percent Gemini IV data point is probably inaccurate. This 4-day point was calculated from RISA-125 plasma volume and peripheral hematocrit data, a method predicted on a constant relationship between peripheral and total-body hematocrit. Subsequent direct measurements showed that alteration of the peripheral/total-body hematocrit ratios do occur, thereby introducing an obvious error into the calculations. Based upon the direct measurements, the Gemini IV calculated red-cell mass deficits were reexamined and found to more closely approximate 5 percent. Other hematologic tests corroborated this disparity; however, to date, no satisfactory explanation of the phenomenon exists. Complete interpretation of

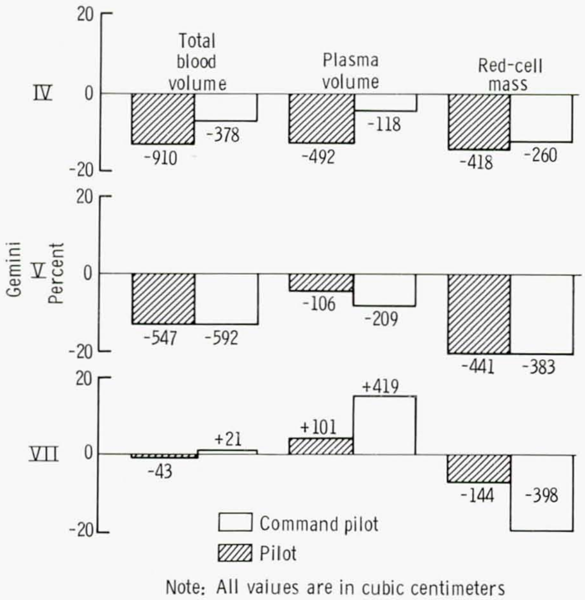


FIGURE 16–9.—Blood–volume studies for Gemini IV, V, and VII.

the red-cell mass deficit noted in the command pilot of the Gemini VII also required special consideration. It appears that no significant progression of the hemolysis occurs after the eighth day in orbit; however, this may be more apparent than real. Analysis of the related mean corpuscular volume values shows a significant increase in this parameter during the 14-day space-flight interval. If each individual erythrocyte increased in volume, a measurement of the total red-cell volume (red-cell mass) would not accurately reflect the actual loss of erythrocytes. Correcting for the postflight corpuscular volume shift, a 29-percent circulating red-cell deficit is derived. The latter figure more accurately describes the hemolytic event; therefore, it is possible that the true extent of the hemolytic process has not yet been determined.

Possible causative factors of the red-cell loss are hyperoxia (166-mm oxygen at the alveolar membrane), lack of inert diluent gas (nitrogen), relative immobility of the crew, dietary factors, and weightlessness. Only increased oxygen tension, immobility, and dietary factors are well known to influence the red cell. Dietary considerations may be of considerable importance; however, at this point no definite incriminations can be levied against the flight diet. A program to define certain diet levels of lipid soluble vitamins has recently been initiated. Specifically, alpha-tocopherol is an important antilipid oxidant and is essential in protecting the lipid at the red-cell plasma membrane. Immobility is effective in reducing red-cell mass by curtailing erythrocyte production; however, all flight observations support hemolysis as the significant event. Although not demonstrated by any previous studies, it is possible that weightlessness is a contributing factor in the hemolysis observed. Altered hemodynamics, resulting in hemostasis, could result in the premature demise of the cell. The role of a diluent gas (nitrogen) is not well understood; however, some investigators have shown significant reduction in hematologic and neurologic toxicity in animals exposed to high oxygen pressure when an inert gas is present. Therefore, the absence of an inert atmospheric diluent could be significant at the hyperoxic levels encountered within the Gemini spacecraft.

Of all the mechanisms previously stated, oxygen has the greatest proven potential as a hemolytic agent. Basically, two modes of oxygen toxicity are described. It has been demonstrated that red-cell plasma membrane lipids undergo peroxidation when exposed to conditions of hyperoxia. It has also been demonstrated that the lipid peroxides thus formed are detrimental to the cell. Specifically, lipid peroxides are known to affect enzyme systems essential for normal red-cell function. It is also possible that peroxidation of the erythrocyte plasma membrane lipids changes this tissue to curtail erythrocyte survival. The second mode of oxygen toxicity expression may be more direct, for inferential evidence is available showing a direct inhibitory effect on some glycolytic enzymes. Oxygen has several documented deleterious effects on red-cell plasma membranes and metabolic functions; any combination of these effects could be operative within a Gemini spacecraft.

Biochemical

The analysis of urine and plasma has been used as an indication of crew physiological status preflight, in flight, and postflight. Analyses of the results obtained on all three phases were performed on the 14-day Gemini VII flight, and essentially complete analyses were performed on the preflight and postflight phases of the 3-day Gemini IX-A mission.

The first attempt at accumulation of inflight data was essentially a shakedown and provided an n of 2, which for biological data is insignificant. Some of the data are presented, but interpretation is dependent upon more refined techniques and upon accumulation of a sufficient number of observations to establish variabilities and trends. The high degree of individual variation should be noted. The Gemini VII pilot and command pilot did not always respond qualitatively or quantitatively in the same way.

The biochemical determinations are grouped into several profiles, each of which provides information concerning the effect of space flight on one or more of the physiological systems. The first profile, water and electrolyte balance, is related to an examination of the weight loss which occurs during flight and the mechanisms involved in this loss. To this end, the levels of sodium, potassium, and chloride in the plasma were measured preflight and postflight, and the rates of excretion of these electrolytes in the urine were observed in all three phases of the study. Total plasma protein concentration measured both preflight and postflight was used as an indication of possible dehydration. Water intake and urine output were measured to determine whether the primary loss of weight was due to sweat and insensible losses or to changes in renal function. The vasopressin (antidiuretic hormone) and aldosterone hormones were measures in the urine in an attempt to establish the functional contribution of baroreceptors in a zero-gravity condition.

As may be expected, since one of the prime functions of the homeostatic mechanisms of the body is to maintain the composition of blood and extracellular fluid as nearly constant as possible, significant changes in plasma were not observed. As seen in figure 16–10, 48-hour pooled samples of flight urine indicate a slight reduction in the output of sodium during flight. As indicated by the hashed bars, this is associated with some increase in aldosterone excretion. Postflight, there is a marked retention of sodium. As expected, chloride excretion parallels the sodium excretion. Potassium excretion during flight (fig. 16–11) appears depressed, and in all but the command pilot of Gemini VII, it was depressed immediately postflight. This depression could be observed in total 24-hour output and in minute output. This antidiuretic hormone appeared elevated in only the first postflight sample of the Gemini VII pilot. The crudities of this biological assay may account for the inability to observe any gross changes. The retention of electrolytes is very closely associated with the retention of water postflight.

The second profile involves the estimation of the physiological cost of maintaining a given level of performance during space flight. This could be considered a measure of the effects of stress during space flight. Two groups of hormones were assayed: the first, 17-hydroxycorticosteroids, provides a measure of long-term stress responses; the second, catecholamines, provides a measure of short-term or emergency responses. The results obtained with the catecholamine determina-

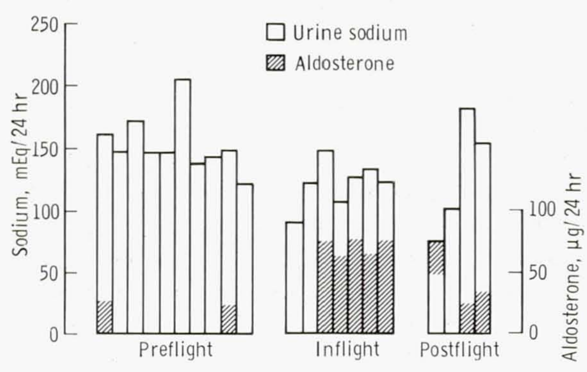


FIGURE 16–10.—Urine sodium and aldosterone, Gemini VII command pilot.

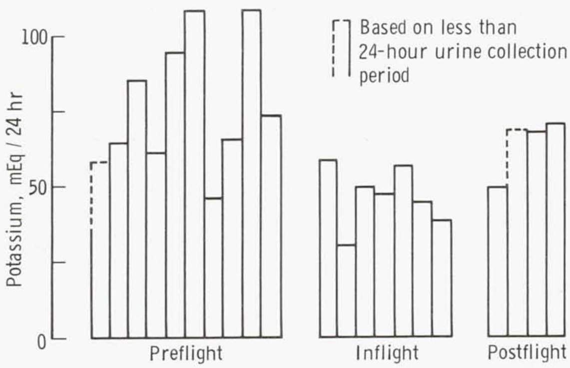


FIGURE 16-11.—Urine potassium, Gemini VII pilot.

tions are anomalous and changes observed could be considered well within the error of the methodology. As seen in figure 16-12, the 17-hydroxycorticosteroid levels are depressed during the flight. An elevation immediately postflight may be related to the stress of reentry and recovery. Although there may be considerable speculation regarding the low inflight steroids, it must be reemphasized that these results are from a single flight, and much more data will be essential before a valid evaluation is possible.

The third profile constitutes a continuing evaluation of the effects of space flight on bone demineralization. Calcium, magnesium, phosphate, and hydroxyproline are measured in plasma and in urine obtained preflight, in flight, and postflight. This is an attempt to determine whether the status, or the changes in the status, of bone mineral are accompanied by alterations in plasma calcium and hydroxyproline, and by alterations in urinary excretion of calcium, phosphate, magnesium, and hydroxyproline. The amino acid, hydroxyproline, is unique to collagen, and it was presumed that an increased excretion of hydroxyproline might accompany demineralization along with dissolution of a bone matrix (fig. 16-13). The first postflight plasma samples following the 14-day flight show a marked increase in the bound hydroxyproline, while larger quantities of calcium were excreted later in the flight than during the early phases of the flight. This is consistent with a change in bone structure.

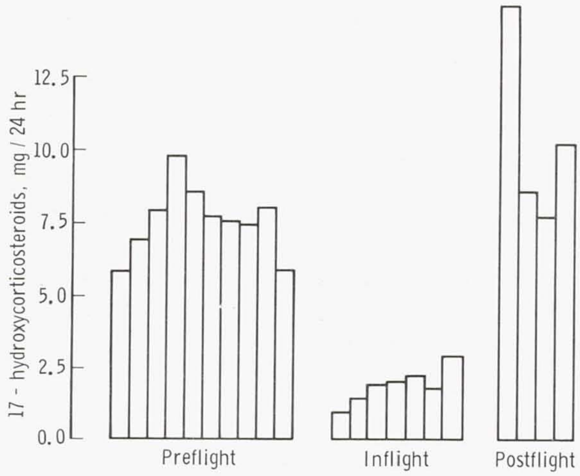


FIGURE 16-12.—Urine 17-hydroxycorticosteroids, Gemini VII command pilot.

The fourth group may be related to protein metabolism and tissue status. When total nitrogen was related to intake during flight, a negative balance was noted.

Gastrointestinal System

The design and fabrication of foods for consumption during space flights have imposed unique technological considerations. The volume of space food per man-day has varied in the Gemini missions from 130 to 162 cubic inches (2131 to 2656 cc). Current menus are made up of approximately 50 to 60 percent rehydratables (foods requiring the

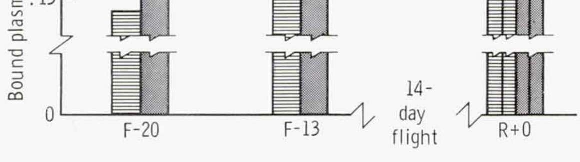


FIGURE 16-13.—Bound plasma hydroxyproline, Gemini VII.

addition of water prior to ingestion) ; therefore, food packaging is required that permits a method for rehydration and for dispensing food in zero gravity. The remaining foods are bite size; that is, food items which are ingested in one bite and rehydrated in the mouth. About 50 percent of the rehydratable and the bite-size foods are freeze-dried products; the remaining are other types of dried or low-moisture foods, some of which are compressed. A typical menu (table 16–VII) has an approximate calorie distribution of 17 percent protein, 32 percent fat, and 51 percent carbohydrate. Total calories provided and eaten per day varied from flight to flight. Food consumption during Gemini IV, V, and VII is summarized in figures 16–14 to 16–16. Food consumption during Gemini IV and VII was very good, but weight loss on the short-duration Gemini IV mission was definitely substantial. The anorexia of the Gemini V crew is unexplained, although many hypotheses could be presented. Although weight loss has occurred on all missions, it has not increased with mission duration (table 16–VIII). Obviously, more calories and water must be consumed in flight to maintain body weight at preflight levels.

Gastrointestinal-tract function on all missions has been normal, and no evidence exists of excess nutrient losses due to poor food digestibility during flight. Before the missions, the crews ate a low-residue diet; on all flights beginning with the Gemini V mission, an oral and usually a suppository laxative were used within 2 days of launch. On the shorter extravehicular missions, this preflight preparation has generally allowed the crew to avoid defecation in flight.

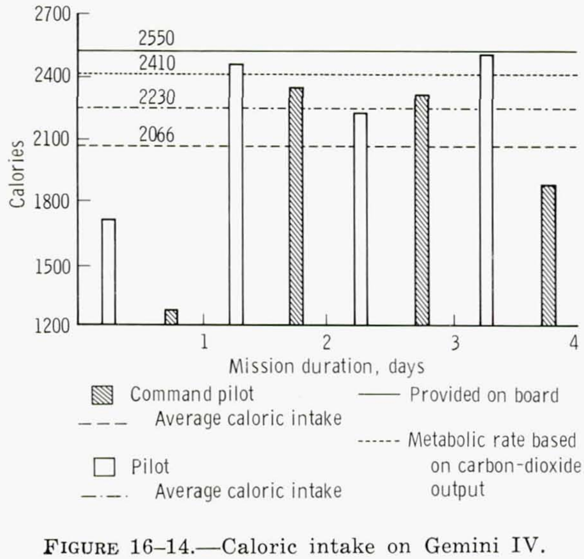


FIGURE 16–14.—Caloric intake on Gemini IV.

TABLE 16–VII.—*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

TABLE 16–VIII.—*Flight Crew Weight Loss to the Nearest Half Pound*

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
VIII	([a])	([a])
IX–A	5.5	13.5
X	3.0	3.0
XI	2.5	0
XII	6.5	7

[a] Not available.

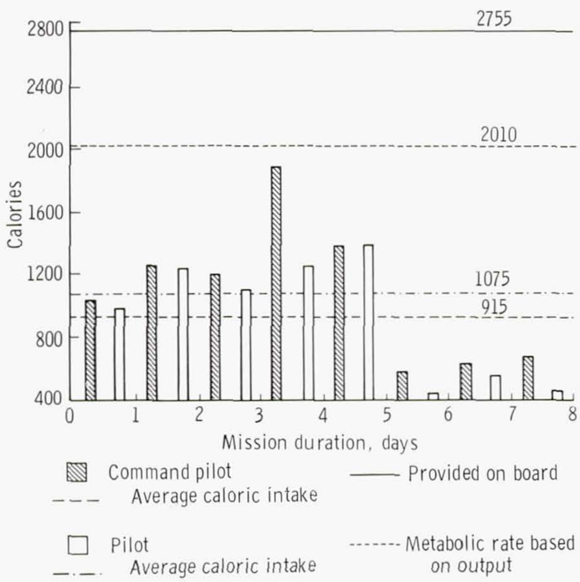


FIGURE 16–15.—Caloric intake on Gemini V.

Genitourinary System

There have been no difficulties involving the genital system. Urination has occurred normally both in flight and postflight, and there has been no evidence of renal calculi.

Musculoskeletal System

Here, again, interpretation of the information gathered to date on bone and muscle metabolism as affected by space flight must be cautious due to the very few subjects observed under varying dietary intakes and exposed to multiple flight stresses.

In figures 16–17 and 16–18, the bone demineralization (percent change in density) which occurred in the os calcis (heel) and phalanx 5–2 (little finger) during space flight is compared with the demineralization which occurred under equivalent periods of bedrest and analogous intakes of calcium. As compared with bedrest, the changes were definitely less in the 14-day flight where calcium intake approached 1000 mg per day and the crew routinely exercised. The phalanx changes are remarkable because significant differences in density have not been observed during 30 days of complete bedrest when calcium intake of over 500 mg per day has been adequate.

In all instances the data for the bones examined indicate a negative change, and the calcium-balance data collected on Gemini VII verify a negative balance trend. None of the changes are pathological, but indicate that further research is needed and that ameliorative methods for use during long-duration flights need to be examined.

The detailed 14-day inflight balance study revealed some loss in protein nitrogen.

Exercise Capacity Tests

Previous investigations have shown that a limitation of optimal cardiovascular and respiratory function exists when a heart rate of 180 beats per minute is reached during a gradually increased workload. With this in mind, an exercise capacity test was incorporated into the Gemini operational preflight and postflight procedures in order to determine whether changes occur in crew physiologic reaction to work.

The tests have been performed by the crewmembers of the Gemini VII mission and by the pilots of the Gemini IX–A, X, XI, and XII missions. All but one of the tested crewmen exhibited a decrease in exercise capacity as monitored by heart rate, and a concomitant reduction in oxygen consumption to a quantitated workload. These findings are graphically demonstrated in figure 16–19.

Additionally, the heart-rate/workload information collected preflight has been of value as a very rough index of the metabolic rate of crewmen during extravehicular activity. It is realized that many other stresses above and beyond the simple imposition of workload can and do affect heart rate. The heart rate as measured during extravehicular activity is not considered an exact index of the workload being performed, but rather as a reflection of total physiological and psychological strain.

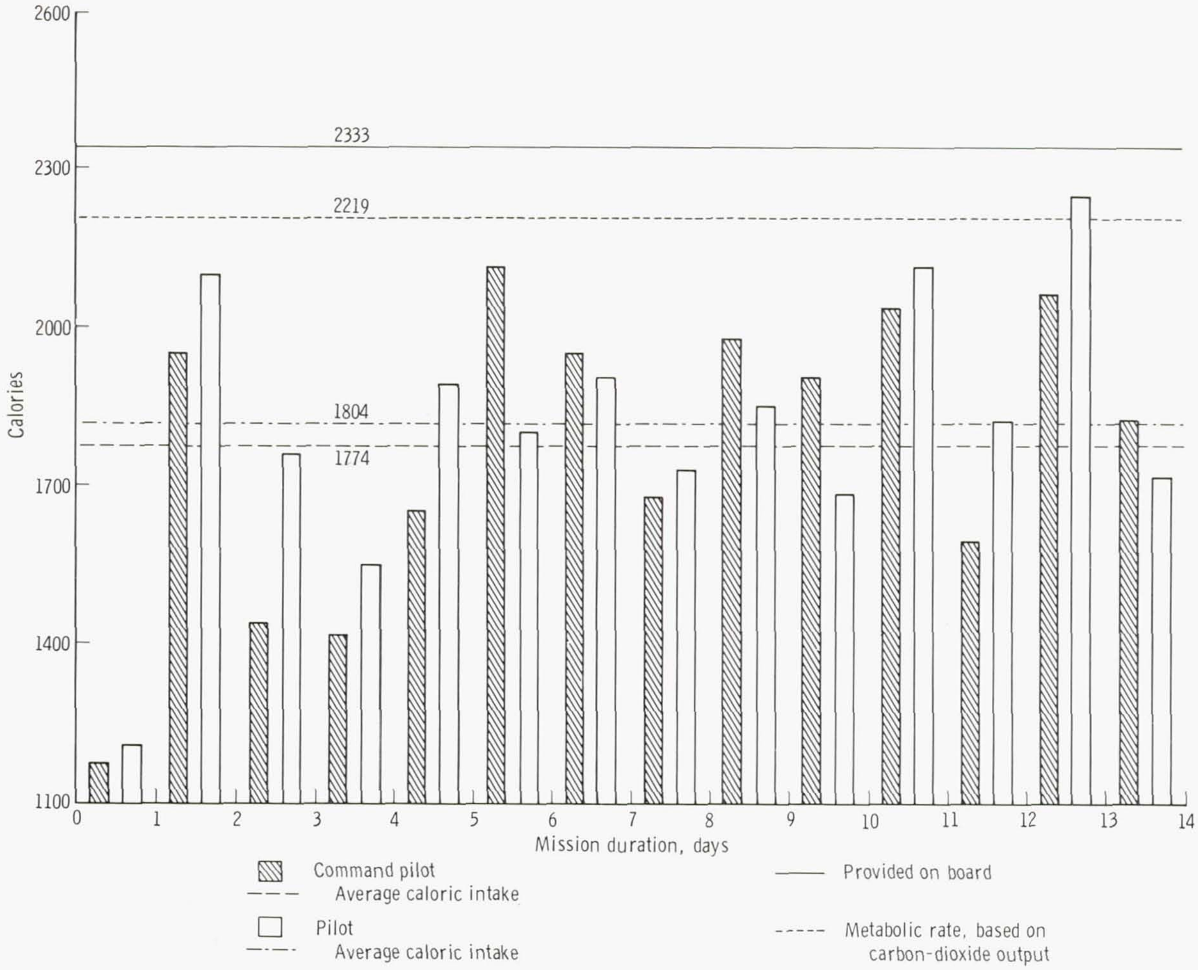


FIGURE 16-16.—Caloric intake on Gemini VII.

Inflight Metabolic Data

Metabolic measurement during U.S. space flights has been limited to the determinations of the total carbon-dioxide production by the chemical analysis of the spent lithium-hydroxide canister. This method is of value only in establishing the average heat-production rate for crewmen during space flight. Figure 16–20 shows close agreement between metabolic data from the U.S.S.R. and the American space flights. The higher metabolic rates observed during the Mercury flights are explained by the fact that these were short-duration flights in which the crewmen did not sleep.

Other Observations Concerning Weightless Flight

The crews have never slept well on the first night in space, and many factors other than weightlessness may be active in limiting the sleep obtained, regardless of flight duration. All crewmembers have reported a tendency to sleep with the arms folded at chest height and the fingers interlocked. The legs also tend to assume a slightly elevated position. On return to the 1g environment, the crews are aware of the readaptation period because they are aware for a short time that the arms and legs have weight and require effort to move. There has been some postflight muscle stiffness following the prolonged missions

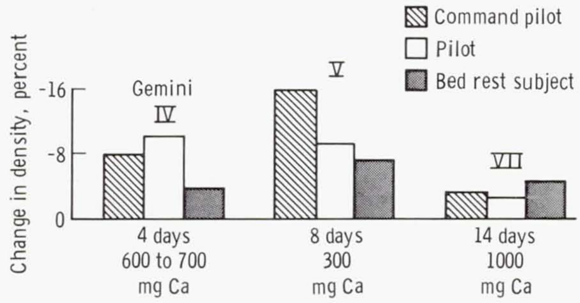


FIGURE 16-17.—Loss of os calcis density on Gemini IV, V, and VII missions.

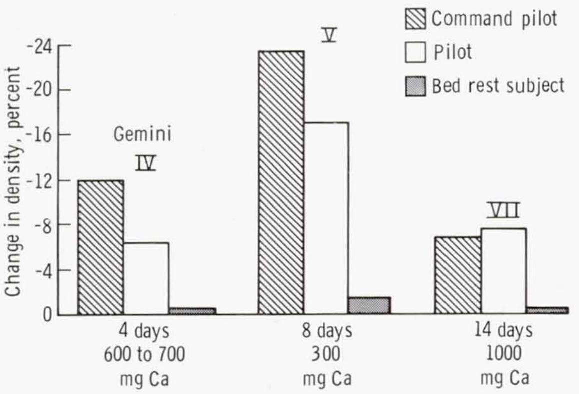


FIGURE 16-18.—Change in density of hand phalanx on Gemini IV, V, and VII missions.

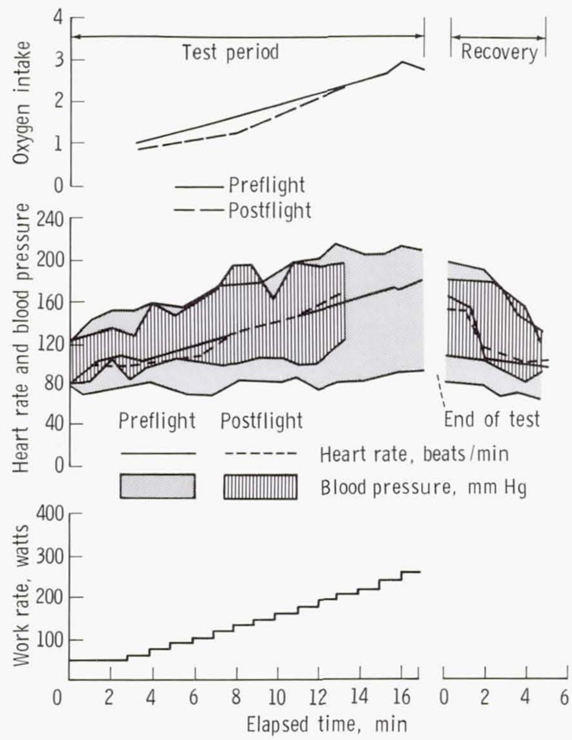


FIGURE 16-19.—Preflight and postflight exercise capacity test results, Gemini IX-A.

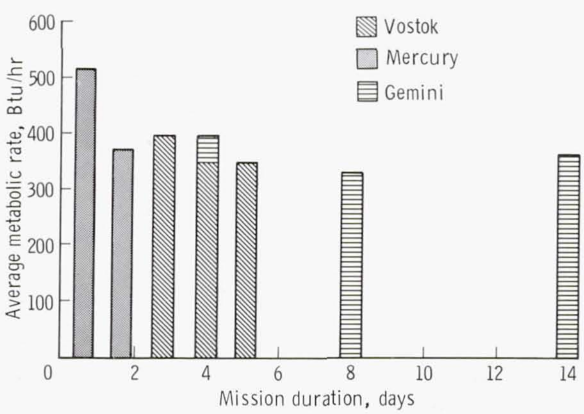


FIGURE 16-20.—Average metabolic rates during actual space flight.

that may be more associated with the confinement of the spacecraft than with weightlessness.

The amount of inflight exercise by the crew has varied even on the long-duration flights. On the 14-day mission, there were three 10-minute exercise periods programed and completed per day. On the short-duration flights with great demands upon the crew for rendezvous and extravehicular activity, no specific conditioning exercises have been conducted. There appears to be a need for a definite exercise regime on long-duration flights.

Crew Performance

Strange reactions to the isolation and the monotony of space flight were originally predicted. Hallucinations and a feeling of separation from the world, described as the break-off phenomenon, had also been predicted, along with space euphoria. The experience to date has shown no evidence of the presence of any of these responses. There have been no abnormal psychological reactions of any sort, and the flights have been far from monoto-

nous. In the single-man flights of the Mercury series, there was always ample ground contact and certainly no feeling of isolation or monotony. In the two-man Gemini flights, the same was true; and of course there has always been a companion crewman, thus avoiding isolation. The crews have exhibited remarkable psychomotor performance capabilities, and by performing a number of demanding tasks under stress they have demonstrated a high level of central nervous system function.

Drugs

A number of predictions were made that man would require the assistance of drugs to cope with the space-flight environment. In particular, sedation prior to launch and stimulation prior to reentry have been mentioned. As a result of the early planning for space flight, a drug kit was made available for inflight prescription. The crews have been pretested to each of the drugs carried; thus, the individual reaction to the particular drug is known. Aspirin and APC's have been used in flight for occasional mild headache and for relief of muscular discomfort prior to sleep. Dextroamphetamine sulfate has been taken on several occasions by fatigued crewmen prior to reentry. A decongestant has been used to relieve nasal congestion and alleviate the necessity for frequent clearing of the ears prior to reentry. The anti-motion-sickness medication has been taken in one instance prior to reentry to reduce motion sickness resulting from motion of the spacecraft in the water. An inhibitor of gastrointestinal propulsion has been prescribed when necessary to assist in avoiding inflight defecation. No difficulty has been experienced in the use of these medications which have produced the desired and expected effects. None of the injectors has been used in flight.

Inflight Disease

Preventive medicine enthusiasts have predicted the possible development of infectious disease in flight as a result of preflight exposure and the lack of symptoms or signs which can be detected in a preflight examination.

Quarantine of the crews for a period of time preflight has been discussed, and has been rejected as impractical in the missions to date. The immediate preflight period is very demanding of crew participation, and efforts have been directed at screening the contacts insofar as possible to reduce crew exposure to possible viral and bacterial infections, particularly the upper respiratory type. A number of short-lived flulike syndromes have developed in the immediate preflight period, as well as one exposure to mumps and one incident of betahemolytic streptococcal pharyngitis. Each situation has been handled without affecting the scheduled launch and, in retrospect, the policy of modified quarantine has worked well. Stricter measures may have to be adopted as longer flights are contemplated.

Fatigue

It was predicted that markedly fatigued flight crews would result from the discomfort of flight in a suited condition, a confined spacecraft, and inadequate rest. In reviewing the flight program to date, it appears that the crews obtained less sleep than in similar circumstances on the ground, but were not unduly fatigued. Intermittent periods of fatigue have resulted from the demanding mission requirements and from the fascination of the crew with the unique opportunity to view the universe. This has been cyclic in nature and on the long-duration flights has always been followed by periods of more restful sleep. No interference with performance has been noted due to inflight fatigue.

Medical Support

In preparing for the medical support of manned space flights, the possibility of in-

jury at the time of launch and recovery was carefully evaluated. A detailed plan of support involving medical and surgical specialists in the launch and recovery areas was evolved and modified as the program progressed. In retrospect, it might appear that the support of surgeons, anesthesiologists, and supporting teams in these areas has been overdone in view of the results. This is always a difficult area to evaluate, however, because none of the support is needed unless a disaster occurs. The best that can be said at the moment is that this support will be critically reviewed in the light of the experience to date and rendered more realistic in the demands placed on highly trained medical personnel.

When originally established, the preflight and postflight examinations were aimed at identifying gross changes in man resulting from exposure to the space-flight environment. The examinations have been tailored along standard clinical lines, and, although these techniques have been satisfactory, little in the way of change has been noted. The procedures have been modified to include more dynamic tests, such as bicycle ergometry, and to reduce the emphasis on those static tests which showed little or no change. Increased use of dynamic testing should continue in the support of future manned space-flight programs.

Concluding Remarks

There has been increased scientific interest in the effect of the space-flight environment on man. The scientific requirements for additional information on man's function must be evaluated in regard to operational and mission requirements and the effect upon future manned space flight. The input of the crews and the operations planners must be weighed along with the basic medical and scientific requirements, and a realistic plan must be established to provide needed medical answers at the proper time and allow projections of man's further exposure. This has been one of the most difficult tasks in the medical support area. The entire manned space-flight program has required the strictest cooperation and understanding between physician and engineer, and it is believed that this has been accomplished. The medical management of the diverse personnel necessary to provide proper medical support for manned space missions has provided experiences of great value to future progress.

In reviewing the flights, the orderly plan of doubling man's flight duration, and observing the results in relation to the next step, has been successful and effective. There is no reason to alter this plan in determining the next increments in manned space flight.

In general, the space environment has been much better than predicted. Additionally, man has been far more capable in this environment than predicted, and weightlessness and the accompanying stresses have had less effect than predicted. While all these items are extremely encouraging and are the medical legacy of the Gemini Program, it is important to concentrate on some of the possible problems of very long-duration future flights, and the application of Gemini knowledge. Consideration must be given to the following: (1) obtaining additional information on normal baseline reactions to stress in order to predict crew response; (2) determining psychological implications of long-duration confinement and crew interrelations; (3) solving the difficult logistics of food and water supply and of waste management; and (4) providing easy, noninterfering physiologic monitoring.

The first steps into space have provided a rich background on which to build. In addition to the information provided for planning future space activities, benefits to general medicine must accrue as smaller and better bioinstrumentation with wider applicability to ground-based medicine is developed; as normal values are defined for various physiologic responses in man; and as ground-based research is conducted, such as bedrest studies. These results should yield a large amount of information applicable to

hospitalized patients. It has been observed how the human body can adapt to a new and hostile situation and then readapt in a surprisingly effective manner to the normal 1g Earth environment. Continued observation of these changes will help determine whether the space environment may be utilized for any form of therapy in the future. The spaceflight environment will certainly prove to be a vital laboratory, allowing study of the basic physiology of body systems, such as the vestibular system. Even incidental findings, such as the red-cell membrane changes which are markedly applicable to hyperbaric applications in medicine, may be of benefit to general scientific and medical research.

GEMINI ONBOARD EXPERIMENTS

17. GEMINI EXPERIMENTS PROGRAM SUMMARY

By NORMAN G. FOSTER, *Test and Operations Office, Science and Applications Directorate, NASA Manned Spacecraft Center;* and OLAV SMISTAD, *Test and Operations Office, Science and Applications Directorate, NASA Manned Spacecraft Center*

Introduction

The Mercury Manned Space Flight Project emphasized the basic technological objective of placing a man in Earth orbit and returning him. Even during Project Mercury, man's potential in supporting and enhancing scientific activities in space was recognized. As a start toward the exploitation of man's capabilities, a few experiments, mostly of a visual or photographic nature, were accomplished during Project Mercury (ref. 1). Based on the limited experiences during Project Mercury, experiment programs of much greater scope were planned for the Gemini Program. The Gemini experiments were primarily additions to the basic spacecraft and missions.

The purpose of this paper on the Gemini Experiments Program is to describe briefly the general aspects, the operations, the scope, the integration of the experiments into the spacecraft and the mission, and selective experiment program summary data.

General Aspects

The selection of experiments for the program was based primarily on the requirement or desirability of crew participation. The planning phase and the management of experiment implementation at the Manned Spacecraft Center, Houston, progressed through several phases of development as the requirement for support expanded. In 1963, the Air Force Systems Command established a field office at the Manned Spacecraft Center with a primary purpose of providing central coordination for the experiments sponsored by the Department of Defense. The field office administered a spacecraft integration study to define and document the feasibility of incorporating 15 Department of Defense experiments into the Gemini missions.

In addition to the Department of Defense proposals, experiment proposals were also collected by the Manned Space Flight Experiments Board for potential experiment investigations submitted by the Manned Spacecraft Center, the Office of Space Science and Applications, the Space Medicine Office, and the Office of Advanced Research and Technology. The experiment proposals were transmitted to the Gemini Experiments Office of the Gemini Program Office for a determination of feasibility and for determination of which missions could best accommodate the experiments. Some of the proposals were for experiments which had either been flown on Mercury spacecraft or had been approved but not flown. Most of the experiments proposals, however, were for entirely new investigations.

The Gemini Program Office disseminated the proposals to other Manned Spacecraft Center organizations such as Recovery Operations, Flight Crew Support, Medical Office, and Flight Operations. The resulting comments and recommendations, plus engineering studies of integration of the experiment hardware into the spacecraft, were included in a final feasibility determination by the Gemini Program Office and subsequently presented to an Experiments Review Panel.

The Experiments Review Panel was comprised of representatives from all Manned

Spacecraft Center organizations concerned with experiments support. The Panel reviewed the block of experiment proposals and the comments from each affected organization concerning the experiments. Minutes of the panel meetings reflected the Manned Spacecraft Center position of incorporating each experiment studied into a particular mission. This information was presented to the Manned Space Flight Experiments Board along with the recommendations of the Office of Space Science and Applications, the Office of Advanced Research and Technology, the Medical Office, and the Department of Defense. After reviewing the material, this Board would make specific mission assignments for each approved experiment.

The number of experiment proposals increased as the program approached the operational phase. In recognition of the expanding workload and in order to firmly aline the organizational support to the principal investigators, in 1964 the Manned Spacecraft Center formed and staffed an Experiments Coordination Office in the Engineering and Development Directorate. The purpose of this Office was to manage the overall implementation of experiments into manned missions.

In June 1965, the Experiments Coordination Office and the Gemini Experiments Office were combined as part of the newly formed Experiments Program Office. The scope of responsibility of the Experiments Program Office included the Apollo experiments program and future experiments programs and planning. The Experiments Program Office became part of the Science and Applications Directorate in December 1966.

Operations

The first three formal Gemini experiments were conducted during the first manned mission, Gemini III, on March 23, 1965. All three required crew participation and real-time communications. The Langley Research Center proposed that a reentry communications experiment be conducted similar to one which had been approved but not performed during Project Mercury. The experiment was highly successful and proved that communication was feasible through the blackout phase during reentry. It was also evident from this experiment that an increased capability for real-time mission operation support was necessary for successful experiment accomplishments. A second experiment was supplied by the Atomic Energy Commission to determine synergism between weightlessness and radiation on human blood. The experiment was successfully conducted as planned, and results seemed to indicate that synergistic effects did exist.

The third experiment was conducted for the Ames Research Center to determine effects of weightlessness on sea urchin egg growth. The experiment utilized modified equipment originally constructed for an unmanned satellite. The manual handle manipulator failed during the mission, and an internal seal prematurely leaked fixative into some of the egg chambers. Objectives of the experiment were compromised, and the failure served to realine the objectives of the Gemini Experiments Office from integration of supplied experiments to a more comprehensive role of integrating and assuring successful experiment operations.

A functional verification review of experiments assigned to a particular mission was initiated and conducted prior to the particular mission flight-readiness review. All affected elements of the Manned Spacecraft Center were represented in the review. After detailed evaluations of the experiment equipment design and test history, the functional verification review panel determined flightworthiness of the experiment or additional operations required to make the experiment flightworthy.

Late in the preflight phase of Gemini IV, three Department of Defense experiments were canceled due to the addition of extravehicular activity. Although many Gemini experiments were planned for two missions, with the second mission serving as an alter-

nate, it became evident that the original objectives of some experiments had been expanded and required multiple missions. The Gemini IV experiment cancellations increased the emphasis on successfully accomplishing assigned experiments. Gemini IV also revealed that personnel involved with the development of an experiment and with a detailed understanding of the objectives must participate in real-time mission support so that continuity would not be lost and experiment objectives compromised. For the Gemini V mission, the Experiments Program Office increased the support to the crew-training program, and the Flight Operations organization included the Experiments Program Office in the decision-making cycle for the real-time mission planning related to experiments.

In the final preflight phase of Gemini VII, it was decided to incorporate equipment and crew procedures on the spacecraft to conduct a photographic study of dim-light phenomena. Photographic equipment for such a study was not readily available, and it was apparent that the stated objectives were not compatible with practical crew activity. Immediate action was taken to effect compatibility and the Gemini VII crew obtained the desired data.

Experience during Gemini showed that late perturbations to the general flight plan, to onboard equipment, and to crew activity should be expected. Since the nature of scientific investigations varies somewhat with the calendar and with the specific days in orbit, many of the perturbations are more directly related to the experiment-type activity than to the basic mission, and have to be resolved by the personnel concerned with the experiments program.

When Gemini VI–A was in the terminal phases of revised preflight planning for rendezvous with the Gemini VII spacecraft, the comet Ikey Seicki was discovered and was determined to be moving through the Sun's corona. It was decided to attempt to photograph the comet during the Gemini VI–A mission, and immediate preparations were made to perform this activity. However, the Gemini VI–A launch was delayed, and although the capability to photograph the comet was successfully accomplished, the actual launch time prevented the spacecraft from being in the correct location for obtaining photographs of the comet.

The Gemini VIII mission was prematurely terminated shortly after docking with the target vehicle. One onboard experiment package contained live frog eggs, and much data could be retrieved if certain onboard operations were conducted within a restrictive time period. Real-time operations proved successful in relaying information to the crew after the spacecraft had landed in the Pacific. Much of the experiment was saved by utilizing capabilities and supporting functions established as a result of knowledge gained from previous experiment missions.

Late in the Gemini XII preflight phase, the decision was made to obtain ultraviolet photographs of dust entering the Earth's atmosphere, to record information on an expected meteor shower as the Earth moved through the remains of the tail of a comet, and to rendezvous with the shadow of the Moon as it moved across the Earth. The Gemini XII mission had previously been extended from 3 to 4 days to accommodate the crew activity schedule. The personnel concerned with experiments assured availability of required equipment onboard the spacecraft, briefed the crew, and programed the mission for the added objectives without compromising previous mission planning. Subsequently, the launch was postponed until 2 days later than had been planned; however, it was decided to accomplish the objectives as previously planned. The immediate and effective response by operational personnel in adjusting the orbital mechanics displayed precision; the intricate rendezvous with the lunar eclipse was successful.

No experiment was deleted from a mission because of flight equipment not being available at launch time. The capability to sup-

port the experiments program was developed as necessary to meet expanding support requirements and was possible because of the flexible structure of the Manned Spacecraft Center organizations which allowed the Center to meet the demands of the program.

Scope of Program

The complement of experiments in the total Gemini Program numbered 52. In general, each experiment was flown several times to take advantage of varying flight conditions and resulted in 111 experiment missions, an average of 11 experiments per mission. The largest number of experiments, 20, was carried on the 14-day Gemini VII mission.

Table 17–I summarizes the experiments conducted during the Gemini Program. The large number of experiments, representing many disciplines, precludes a detailed description of all experiments in this paper. Reference 2 contains a brief description of the equipment and preliminary results of the experiments conducted during the Gemini III through VII missions.

The experiments were divided into three categories: scientific, technological, and medical. There were 17 scientific experiments conducted during the program. The 27 technological experiments were conducted in support of spacecraft development and operational techniques. The eight medical experiments were directed toward determining more subtle effects than might be determined from the regular operational medical measurements and preflight and postflight examinations.

TABLE 17–I.—*Experiment Program Summary*

Sponsoring agency	Number of experiments	Total experiment missions
Scientific:		
Office of Space Science and Applications	17	47
Technological:		
Office of Advanced Research and Technology	2	2
Office of Manned Space Flight, Manned Spacecraft Center	10	18
Department of Defense	15	26
Medical	8	18
Total	52	111

Principal Investigators and Affiliations

The Gemini experiments were proposed from many sources including universities, laboratories, hospitals, industry, and various Government agencies. Several investigators were often associated with a single experiment and they, in turn, may have had different affiliations. Table 17–II presents the principal investigators for the Gemini experiments and their affiliations, together with the missions for which the experiments were assigned.

Subsequent to the selections of the experiments and the principal investigators, a very close personal association was maintained among the experimenter, the spacecraft contractor, the crew, the mission planner, and the real-time operations personnel. Of these, the experimenter-crew relationship was of particular significance. The following paragraphs provide some insight into the integration of the experiments with the many program elements.

Experiment Equipment Integration

The selected experiments were integrated into the spacecraft on a minimum interference basis, based on the participation of the flight crew. Three specific examples illustrate the various categories. The simplest is the stowage category; the equipment is stowed in one of several areas or compartments, and is unstowed and operated according to a preplanned schedule. Examples of this type of equipment include the hand-held

TABLE 17–II.—*Principal Investigators and Affiliations*

Experiment description	Principal investigator	Affiliation	Mission No.
Scientific			
Office of Space Science and Applications:			
Zodiacal light photography	E. Ney	University of Minnesota	V, VIII, IX–A, X
Sea urchin egg growth	R. Young	NASA Ames	III
Frog egg growth	R. Young	NASA Ames	VIII, XII
Radiation and zero-g on blood	M. Bender	Atomic Energy Commission	III, XI
Synoptic terrain photography	P. Lowman	NASA Goddard	IV, V, VI–A, VII, X, XI, XII
Synoptic weather photography	K. Nagler and S. Soules	U.S. Weather Bureau	IV, V, VI–A, VII, X, XI, XII
Cloudtop spectrometer	F. Saiedy	Natl. Environ. Sat. Center	V, VIII
Visual acuity	S. Duntley	University of California	V, VII
Nuclear emulsion	M. Shapiro and C. Fichtel	NRL and NASA Goddard	VIII, XI
Agena micrometeorite collection	C. Hemenway	Dudley Observatory	VIII, IX–A, X, XII
Airglow horizon photography	M. Koomen	NRL	IX–A, XI, XII
Micrometeorite collection	C. Hemenway	Dudley Observatory	IX–A, X, XII
Ultraviolet astronomical camera	K. Henize	Dearborn Observatory, Northwestern University	X, XI, XII
Ion wake measurement	D. Medved	Electro-Optical Systems, Inc.	X, XI
Libration regions photographs	E. Morris	U.S. Geological Center	XII
Dim sky photographs orthicon	C. Hemenway	Dudley Observatory	XI
Daytime sodium cloud photography	Jacques-Emile Blamont	Centre Natl. de la Recherche Scientifique	XII
Technological			
Office of Advanced Research and Technology:			
Reentry communications	L. Schroeder	NASA Langley	III
Manual space navigation sighting	D. Smith and B. Creer	NASA Ames	XII
Office of Manned Space Flight:			
Electrostatic charge	P. Lafferty	NASA MSC	IV, V
Proton-electron Spectrometer	J. Marbach	NASA MSC	IV, VII
Triaxis fluxgate magnetometer	D. Womack	NASA MSC	IV, VII, X, XII
Optical communication	D. Lilly	NASA MSC	VII
Lunar ultraviolet spectral reflectance	R. Stokes	NASA MSC	X
Beta spectrometer	J. Marbach	NASA MSC	X, XII
Bremsstrahlung spectrometer	R. Lindsey	NASA MSC	X, XII
Color patch photography	J. Brinkman	NASA MSC	X
2-color Earth's limb photographs	M. Petersen	Massachusetts Institute of Technology	IV
Landmark contrast measurements	C. Manry	NASA MSC	VII, X

TABLE 17-II.—*Principal Investigators and Affiliations*—Concluded

Experiment description	Principal investigator	Affiliation	Mission No.
Department of Defense:			
Basic object photography	AF Avionics Lab	Wright-Patterson AFB	V
Nearby object photography	AF Avionics Lab	Wright-Patterson AFB	V
Mass determination	AFSC Field Office	NASA MSC (DOD)	VIII, XI
Celestial radiometry	AF Cambridge Lab	USAF-Hanscom Field	V, VII
Star occultation navigation	AF Avionics Lab	Wright-Patterson AFB	VII, X
Surface photography	AF Avionics Lab	Wright-Patterson AFB	V
Space object radiometry	AF Cambridge Lab	USAF-Hanscom Field	V, VII
Radiation in spacecraft	AF Weapons Lab	Kirtland AFB	IV, VI-A
Simple navigation	AF Avionics Lab	Wright-Patterson AFB	IV, VII
Ion-sensing attitude control	AF Cambridge Lab	USAF-Hanscom Field	X, XII
Astronaut Maneuvering Unit	AFSC Field Office	NASA MSC	IX-A
Astronaut visibility	S. Duntley	University of California	V, VII
UHF-VHF polarization	NRL	NRL	VIII, IX-A
Night image intensification	Air Development Center	U.S. Navy	VIII, XI
Power tool evaluation	AF Avionics Lab	Wright-Patterson AFB	VIII, XI
Medical:			
Cardiovascular conditioning	L. Dietlein	NASA MSC	V, VII
Inflight exerciser	R. Rapp	NASA MSC	IV, V, VII
Inflight phonocardiogram	R. Johnson	NASA MSC	IV, V, VII
Bioassays of body fluids	H. Lipscomb	NASA MSC	VII, VIII, IX-A
Bone demineralization	P. Mack	Texas Woman's University	IV, V, VII
Calcium balance study	D. Whedon	National Institutes of Health	VII
Inflight sleep analysis	P. Kelloway	Baylor Medical School	VII
Human otolith function	A. Graybiel	U.S. Navy, Naval Aerospace Medical Institute	V, VII

cameras used to conduct the zodiacal light, weather, and terrain photography experiments. Figures 17-1 and 17-2 are typical examples of stowage.

A second type of integration includes equipment mounted in the pressurized cabin area during the mission. This is exemplified by the radiation and zero-g effects on blood cells experiment (fig. 17-3) and the frog egg growth experiment (fig. 17-4), both of which were mounted on the spacecraft hatch.

The most complex type of integration involves equipment with some or all of the following requirements: structurally mounted; automatically deployed for taking measurements; thermally controlled; extensive data requirements involving onboard tape recordings of the measurement and radiofrequency transmission during the flight. These requirements are typified by the radiometry experiments D004 and D007. Figure 17-5 shows an outline of the spacecraft and the location of the elements of the equipment; figure 17-6 depicts the operational mission configuration of Gemini VII as viewed from Gemini VI-A.

FIGURE 17-1.—Photographic equipment stowage.

FIGURE 17–2.—Photographic equipment stowage compartment.

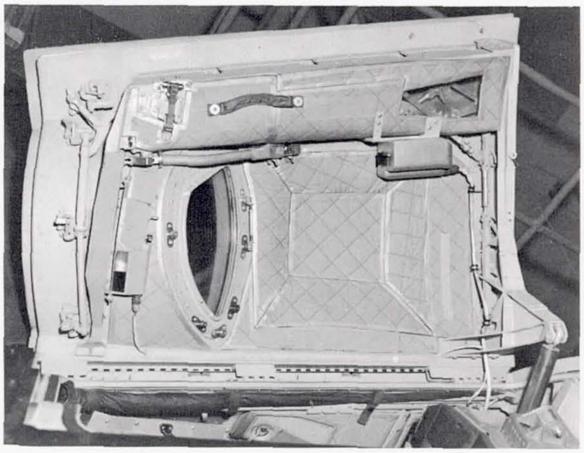


FIGURE 17–4.—Radiation and zero-gravity effects on frog-egg growth experiment package.

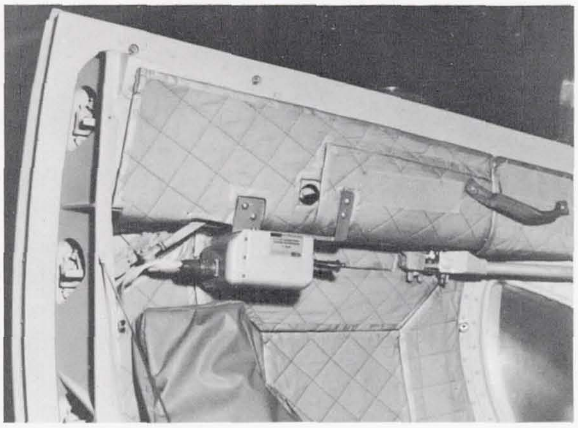


FIGURE 17–3.—Radiation and zero-gravity effects on blood cells experiment package.

Crew Integration

The diversity of the experiments required considerable training by the crew. The training began with briefings by the experimenter to explain the experiment, the proposed method of operation, the probable training required, and the expected results. It was often determined in such briefings that various constraints would prevent the spacecraft and/or crew from accomplishing the experiment in the manner originally desired. In these situations, either the crew or the engineering and operational specialists could generally propose and develop alternate techniques which allowed accomplishment of the experiment objectives within the capabilities of the crew and the spacecraft.

After the techniques were evolved for the various experiments, plans for crew training were developed. Planetarium briefings were included, as well as flight-simulator training with celestial backgrounds; aircraft flights to provide operational familiarity with hardware; zero-g aircraft flights for experiments requiring extravehicular activity; and baseline studies for medical and visibility experiments. These activities and others, coupled with continued discussions between crew and experimenters, were considered essential to the successful completion of the experiment. An understanding by the crew, not only of the mechanical operation of the experiment but also of the objectives and underlying principles, was required to allow the crew to exercise their selective and visual capabilities.

Mission Planning

In addition to integrating the hardware into the spacecraft, developing the experimental technique, and training the crew, the multitude of experimental operations had to

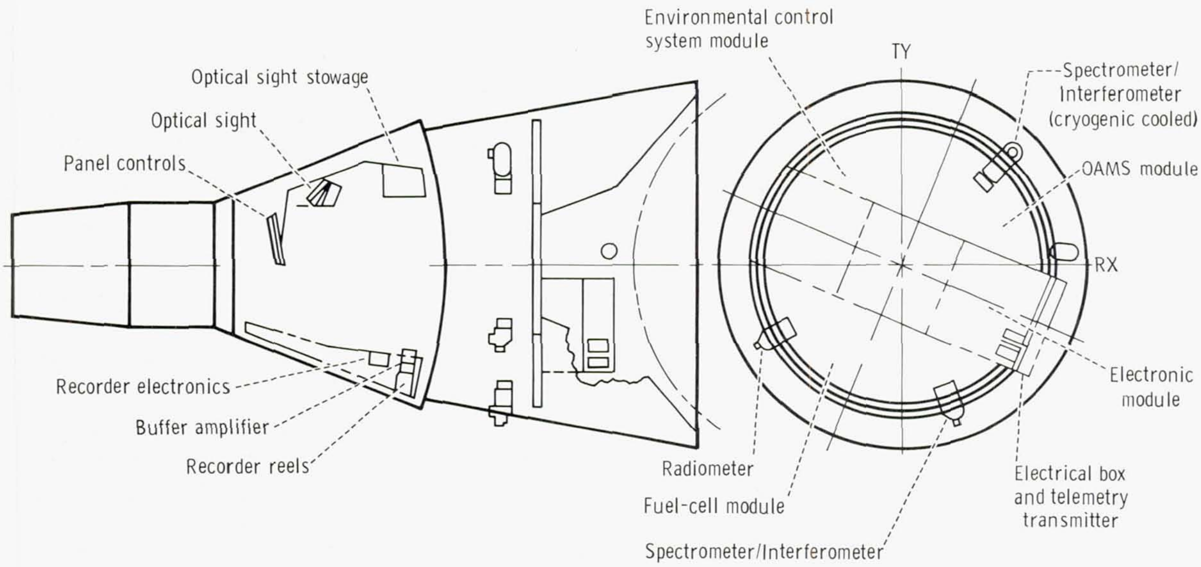


FIGURE 17–5.—Location of radiometry equipment for Experiments D004 and D007.

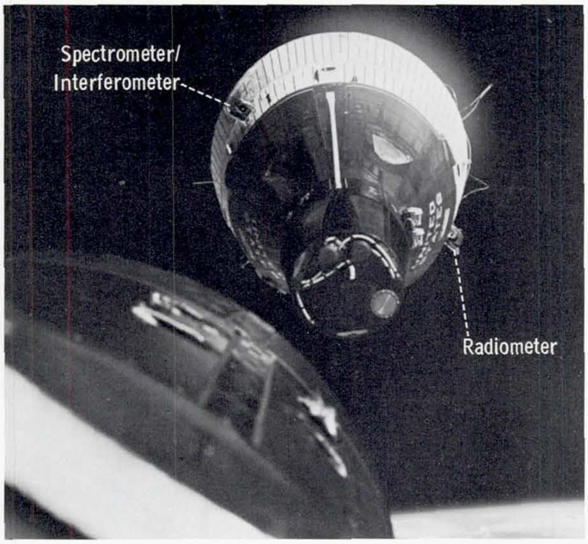


FIGURE 17–6.—Operational mission configuration for Experiments D004 and D007.

be integrated with the other primary mission activities. The experiments generally had a variety of requirements which often conflicted or interacted. The zodiacal light photography experiment was conducted only during nighttime conditions. The visual acuity experiment required clear skies and a constraining inclination angle above the ground patterns. The cloudtop spectrograph experiment cloud observations and recordings were performed in areas where airplanes could be deployed to make correlation measurements. During the Gemini VII mission, the radiometry experiments included a requirement for measurements at 36 different periods and locations. The conflicts and the potentially damaging interactions had to be resolved. The experimenter had a significant role in the planning. His knowledge of the flexibility in the experiment requirements maintained the integrity of the experiment without compromising the overall objectives. An optimum overall flight plan was thus achieved.

Prelaunch

The impact of experiments on the overall mission time line and spacecraft propellants is summarized in tables 17–III and 17–IV. The experiment hardware followed the same philosophy and supported the identical performance specifications and spacecraft checkout schedules as the operational spacecraft systems and crew-stowed operational equipment.

TABLE 17–III.—*Percentage of Mission Time Planned for Experiments*

Mission	Planned total mission time, hr[a]	Planned experiment activity time, hr[b]	Mission time planned for experiments, percent
III	9	0.5	5
IV	140	22	16
V	288	49	17
VI–A	66	8	12
VII	392	86	22
VIII	90	19	21
IX–A	90	19	21
X	90	33	37
XI	90	26	29
XII	122	37	30
Total	1377	299.5	22

[a] Two crewmen, less sleep time.

[b] Direct crew participation time only. Does not include total experiment equipment operating time.

TABLE 17–IV.—*Payload and Propellants for Experiment Activities*

Mission	Total experiment weight, lb[a]	Propellant allotted for experiments, lb
III	69	...
IV	67	63
V	206	68
VI–A	22	26
VII	243	85
VIII	237	49
IX–A	275	16
X	133	78
XI	251	153
XII	140	165
Total	1643	703

[a] Does not include mounting provisions or ballast.

As previously mentioned, the inflight failure of equipment involved in one of the experiments on the first manned mission resulted in added responsibility for the Manned Spacecraft Center to assure confidence in the equipment to successfully accomplish experiment objectives. Previously, mission and spacecraft integration responsibilities were the definitive interface responsibilities. The added responsibility resulted in an additional scope of monitoring and approval of environmental testing, and of a more extensive checkout interface involving actual flight hardware in the spacecraft, together with additional bench checks.

From a practical standpoint, checkout performed at the spacecraft contractor's plant and at Kennedy Space Center identified engineering problems which could affect hardware design and mission performance. In these cases, the combined experience of the experimenter, the Gemini Program Office, and the spacecraft contractor team enabled the experiment to be conducted with little or no change to hardware procedures or mission planning.

Real-Time Mission Support

During the mission, many of the experiments required considerable real-time support by ground personnel and the experimenter. The visual acuity experiment is an example. The experimenter was located at the Mission Control Center—Houston. The two ground-test sites to be viewed by the flight crew were located near Laredo, Tex., and in Australia. Special communications were established between these sites and the closest network stations, Corpus Christi, Tex., and Carnarvon, Australia. This allowed the experimenter to contact the sites to determine weather conditions; to direct changes in the ground-test pattern; to receive crew reports; to perform analyses based on these inputs; and to interact with the ground controllers, who in turn passed information to the crew for the continuation of the experiment.

In summing up the experiment integration activity and looking forward to the future, it can be concluded that the success of an experiment is highly dependent upon the participation of the experimenter in many

phases of the program. These phases include design integration, mission planning, crew training, checkout, and real-time support of the operation. Experiments requiring considerable amounts of integration activity can be accommodated and successfully implemented. Crew understanding is vital to achieve maximum benefit from man in space.

Experiment Performance

The overall success of the Gemini Experiments Program is indicated in numerical values in table 17–V. If mission problems are not considered, a remarkable success is indicated. Experiment equipment problems affected only 6 of the 111 experiments performed on all missions. This performance was the result of the close teamwork of all participants as well as the capability to readily incorporate equipment and mission modifications up to launch time.

Concluding Remarks

The success of the Gemini Experiments Program is measured by the new or confirmed information provided for engineering, management, and scientific disciplines. The experience gained from the Gemini Experiments Program has provided invaluable knowledge and experience for future manned space-flight programs.

TABLE 17–V.—*Experiment Performance Status*

Gemini mission	Number of experiments	Experiments accomplished [a]	Problems [b]
III	3	2	Experiment
IV	11	11	
V	17	16	Mission
VI–A	3	3	
VII	20	17	Experiment
VIII	10	1	Mission
IX–A	7	6	Mission
X	15	12	Mission
XI	11	10	Mission
XII	14	12	Experiment
Total	111	90	

[a] 80.3 per cent accomplished overall.

[b] 14.3 percent not accomplished due to primary mission problems; 5.4 percent not accomplished due to experiment equipment problems.

References

1. ANON: Mercury Project Summary, Including Results of the Fourth Manned Orbital Flight, May 15 and 16, 1963. NASA SP–45, 1963.
2. ANON: Gemini Midprogram Conference, Including Experiment Results. NASA SP–121, 1966.

18. SPACE PHOTOGRAPHY

By Richard W. Underwood, *Photographic Technology Laboratory, NASA Manned Spacecraft Center*

Introduction

The 10 manned Gemini flights produced a series of color photographs which are both striking in beauty and of immense scientific and academic value. Over 2400 photographs were secured and have demonstrated the value of space photography in such fields as geology, geography, oceanography, agriculture, hydrology, urban planning, environmental pollution control, meteorology, land management, cartography, and aerospace engineering. A representative selection of photographs from the various missions, as well as a short description of the informational content, are presented in this paper.

Camera Equipment

Figure 18–1 shows a selection of camera equipment used during the Gemini Program. The majority of the photographs were obtained with the NASA-modified 70-mm Hasselblad Camera, Model 500–C; both the 80-mm Zeiss Planar and 250-mm Zeiss Sonnar lenses were used. The Super Wide-Angle 70-mm Hasselblad Camera, Model SWA, was used on the Gemini IX–A through XII missions. Although designed primarily as an extravehicular activity device, the Model SWA camera recorded some of the most spectacular terrain photography of the program. The 70-mm Maurer Space Camera was also carried on Gemini IX–A through XII and permitted a unique versatility resulting from rapid interchangeability of components. The gray 80-mm Xenotar lens and magazine (50-frame capacity) secured conventional color photographs. The red f/0.95 Canon lens and magazine permitted scientific photography of very low light-level phenomena such as horizon airglow and libration regions. The blue lens, prism, grating, and magazine system were designed to work in the ultraviolet regions, primarily to record stellar spectrographs. Motion-picture equipment manufactured by J. A. Maurer, Inc., is also pictured. The 70-mm magazine especially built by Cine Mechanics, Inc., allowed the Hasselblad systems to secure 65 frames instead of the conventional 12. A second-generation Cine Mechanics magazine with a capacity of about 160 frames was used on Gemini XII.

Table 18–I indicates the various 70-mm films carried on Gemini flights. The thickness of the film varied from about 0.007 inch to 0.0025 inch. Most of the film had emulsion coatings and bases especially formulated to NASA specifications. Figure 18–2 shows the machine manufactured by Hi-Speed, Inc., to process the Ektachrome film. Great care was used in processing the Gemini flight film. Prior to processing the film, the machine was thoroughly cleaned and then checked for precise sensitivity control; this included checks of the various photographic processing chemicals, exact temperatures, cycle durations, and chemical replenishments. The flight films were sent through the processor singly; this required a considerable amount of time but allowed very close surveillance. No flight film was lost due to laboratory malfunctions.

Selected Photographs

The following representative photographs constitute about 2 percent of the total photographs secured during the Gemini Program, and contain information of value in

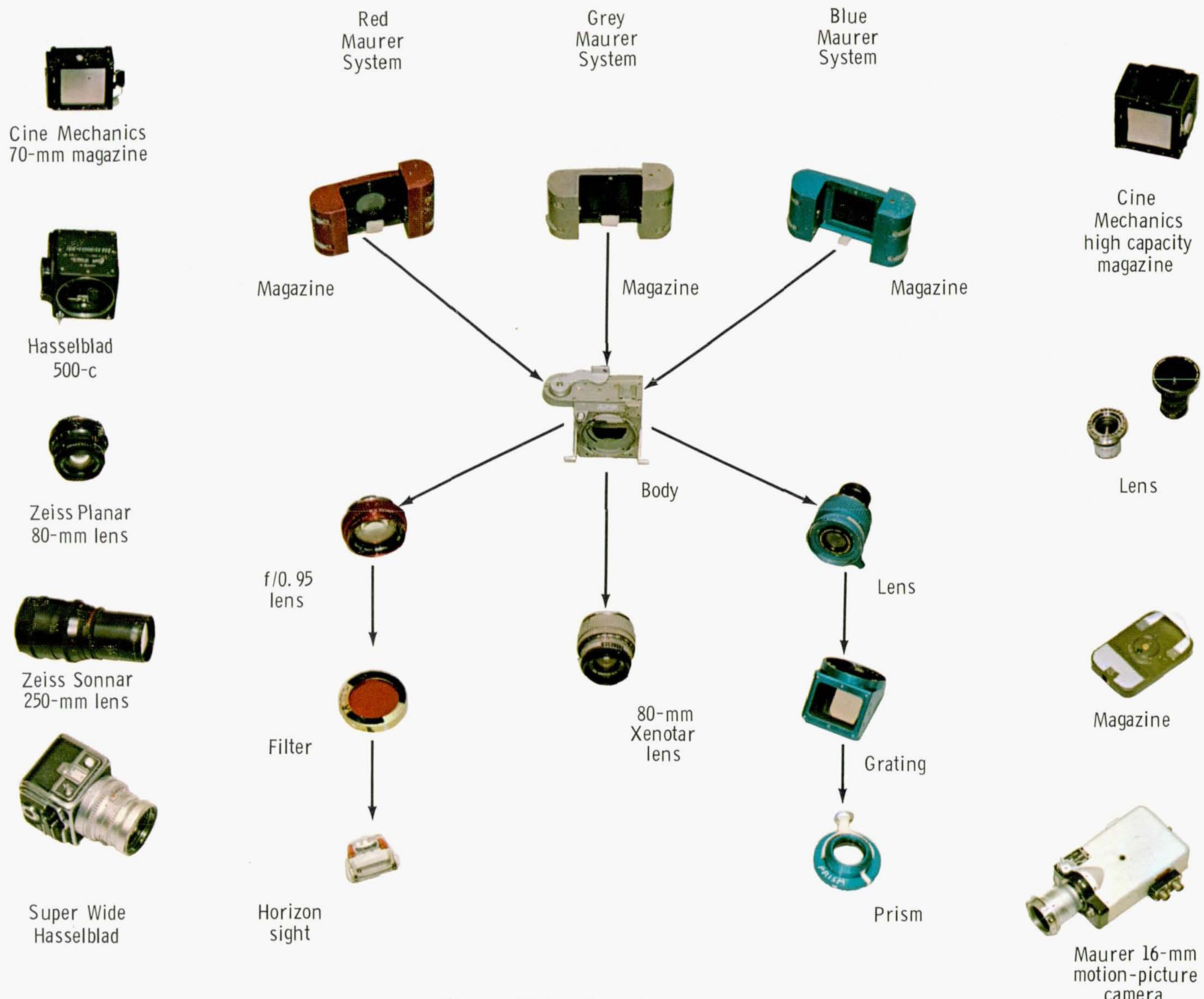


FIGURE 18–1.—Gemini camera equipment.

the various geoscientific or aerospace fields. The serious geoscientist would have to examine the entire collection in order to determine the total value to his field of interest.

TABLE 18–I.—*Gemini 70-mm Film*

Name	Type	Mission
S.O. 217	Ektachrome transparency	III, IV, V, VI–A, VII, VIII, IX–A, X
S.O. 368	Ektachrome transparency (improved)	XI, XII
D–50	Anscochrome transparency	V
8443	Ektachrome, infrared	VII
S.O. 166 (0–85)	Ultrahigh speed (ASA = 6000)	XI, XII
3400	Pan-Atomic X (ASA = 80)	VII
2475	High-speed (ASA = 1200)	VI–A, VII
103–D	Spectrographic (4500 Å–6100 Å)	IX–A, XI
I–0	Spectrographic (2500 Å–5000 Å)	X, XI, XII

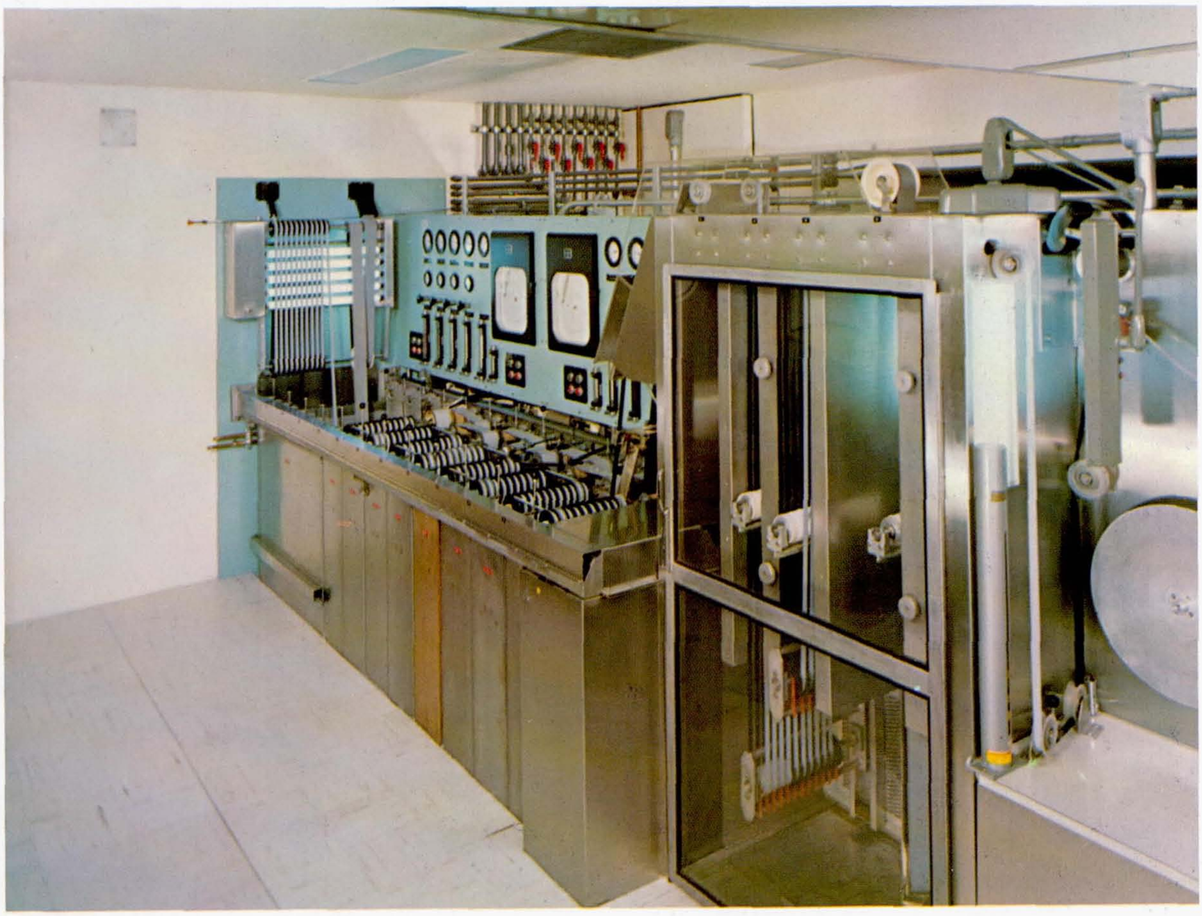


FIGURE 18–2.—Film processor.

Synoptic Terrain Photography

Figure 18–3 was taken from an altitude of 110 miles during the Gemini IV mission and has become a classic for obvious reasons. The Nile Delta is clearly visible, as well as the Sinai Peninsula, the Dead Sea, and the entire Suez Canal connecting the Red and Mediterranean Seas. The horizon is about 800 miles to the east, across Iraq and Saudi Arabia. The photograph shows both branches of the Nile River (Rosetta and Damietta) from Cairo, across the fertile and densely populated delta, to the Mediterranean Sea. Note the sharp contrast between the irrigated delta lands and the great deserts of Africa and Asia.

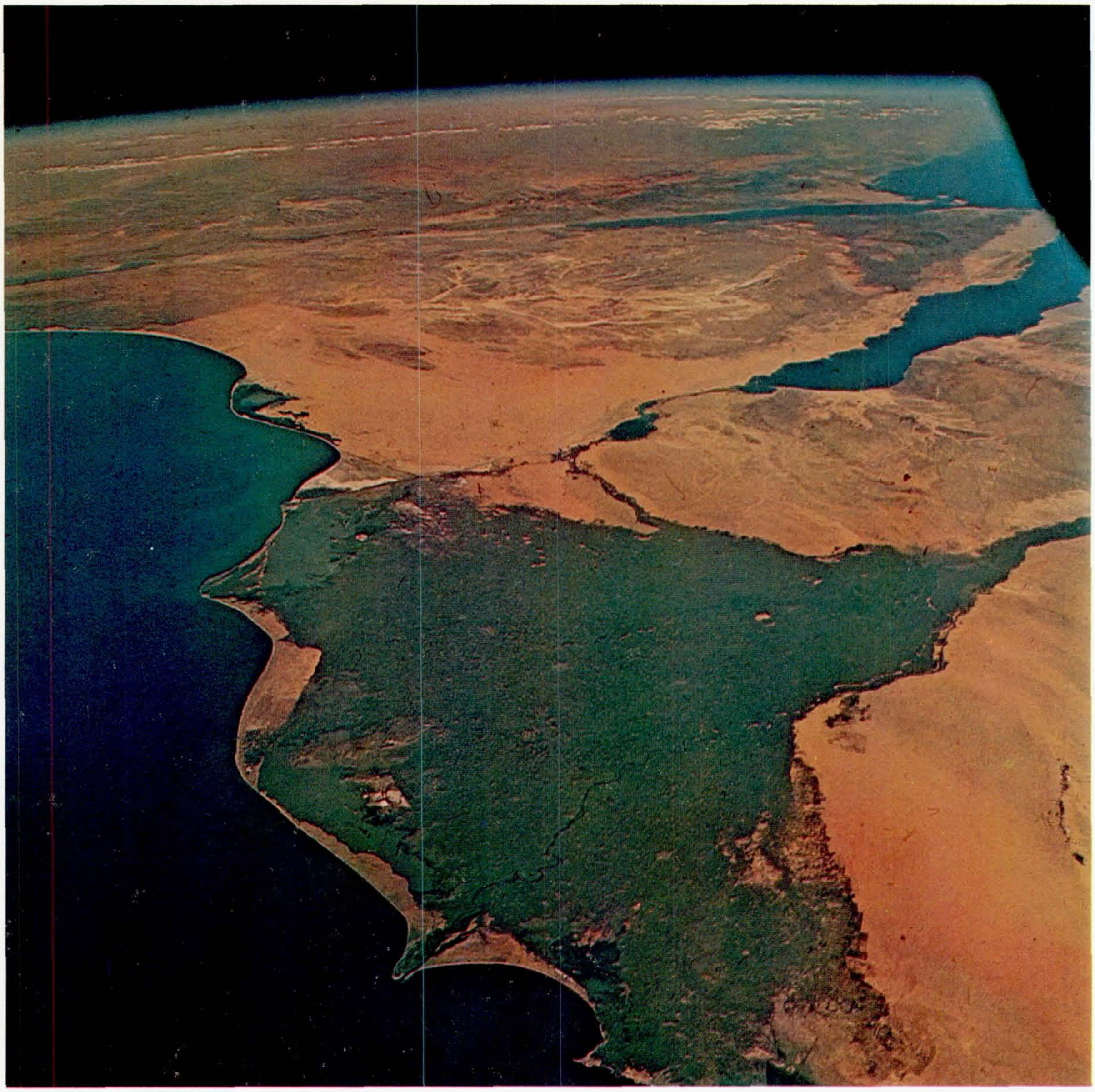


FIGURE 18–3.—Nile Delta.

FIGURE 18–4.—Nile River.

Figure 18–4 shows how the geology controls the course of the Nile River for some 200 miles in Sudan and the United Arab Republic. The river hugs the contact zone between the black basaltic intrusives east of the river and the sedimentary rocks to the west. Much of the area visible in this Gemini IV photograph will be inundated when the Aswan Dam is completed and the 400-mile-long Lake Nasser is created in the Sahara.

FIGURE 18–5.—Ras Al Hadd.

Figure 18–5 was taken during Gemini IV from an altitude of 120 miles. The Ras Al Hadd area of Muscat and Oman appears in fine detail; airport runways can also be seen at the point. Several oases are perceptible at the base of the pediment where ground water reaches the surface. Long seif dunes at the eastern extremities of the Rub Al Kahli (Empty Quarter) are visible and provide information of meteorologic value.

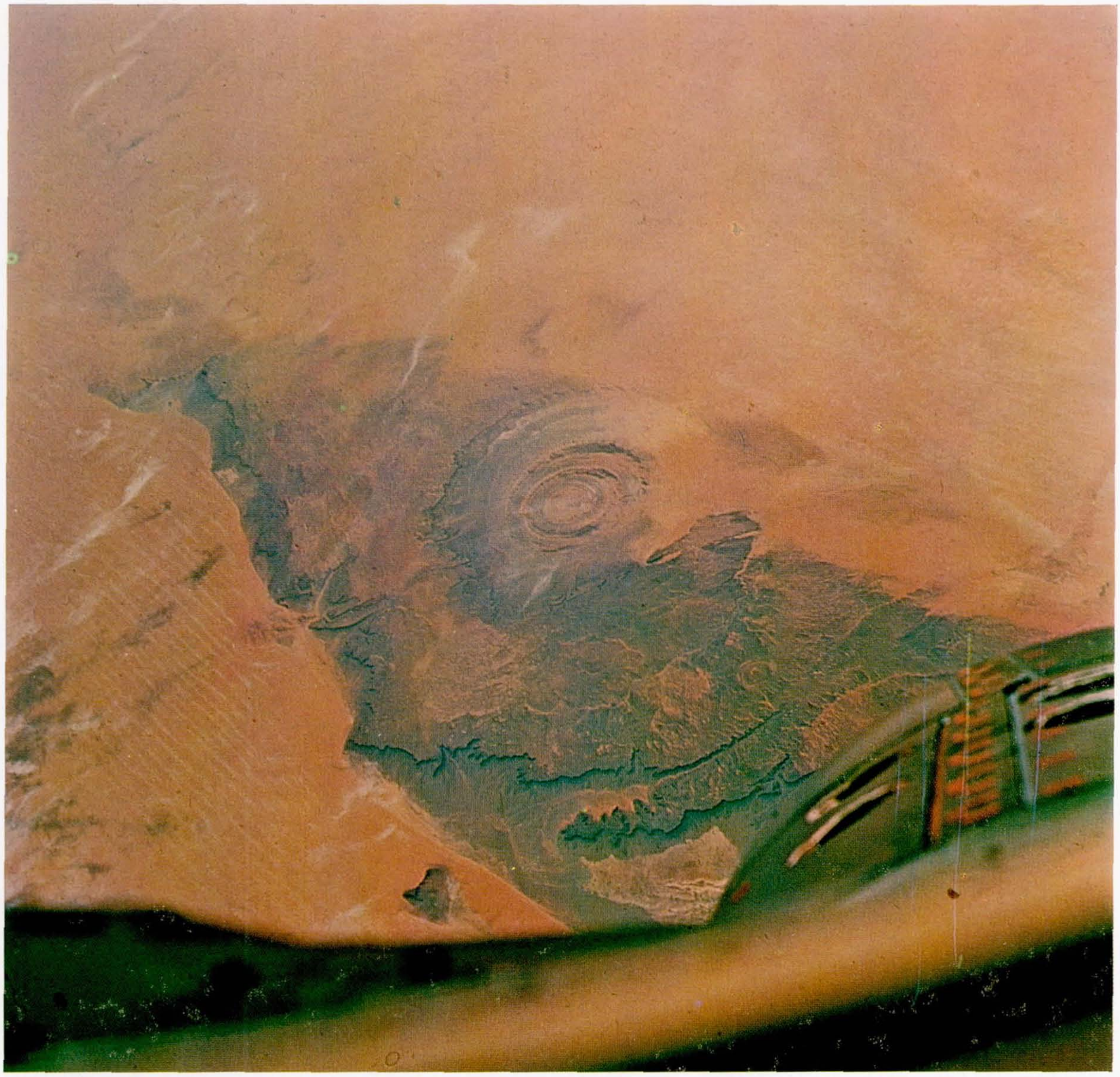


FIGURE 18–6.—Richat structure.

A view of large geologic structures can be captured in a single photograph such as figure 18–6 which shows Mauritania's Richat structure in excellent detail. The structure was possibly formed by a large meteorite-type impact, or possibly from the erosion of a volcanic plug or intrusion. This Gemini IV photograph has regenerated scientific interest in the structure in relation to the geology of the entire area.

FIGURE 18-7.—Florida Keys.

In figure 18–7, the Florida Keys are dramatically visible from the Gemini IV spacecraft at an altitude of 115 miles. The entire chain from Key Largo to Boca Chica Key is visible, thereby providing a regional study from a single photograph. The Overseas Highway, which is never more than 30 feet wide, can be clearly seen. Many boat wakes in the Florida Strait are emphasized in the solar highlight. A large portion of the Everglades is visible in the upper right. On the underwater reefs visible at the right, Florida has established the John Pennekamp State Park to preserve the ecology of the area.

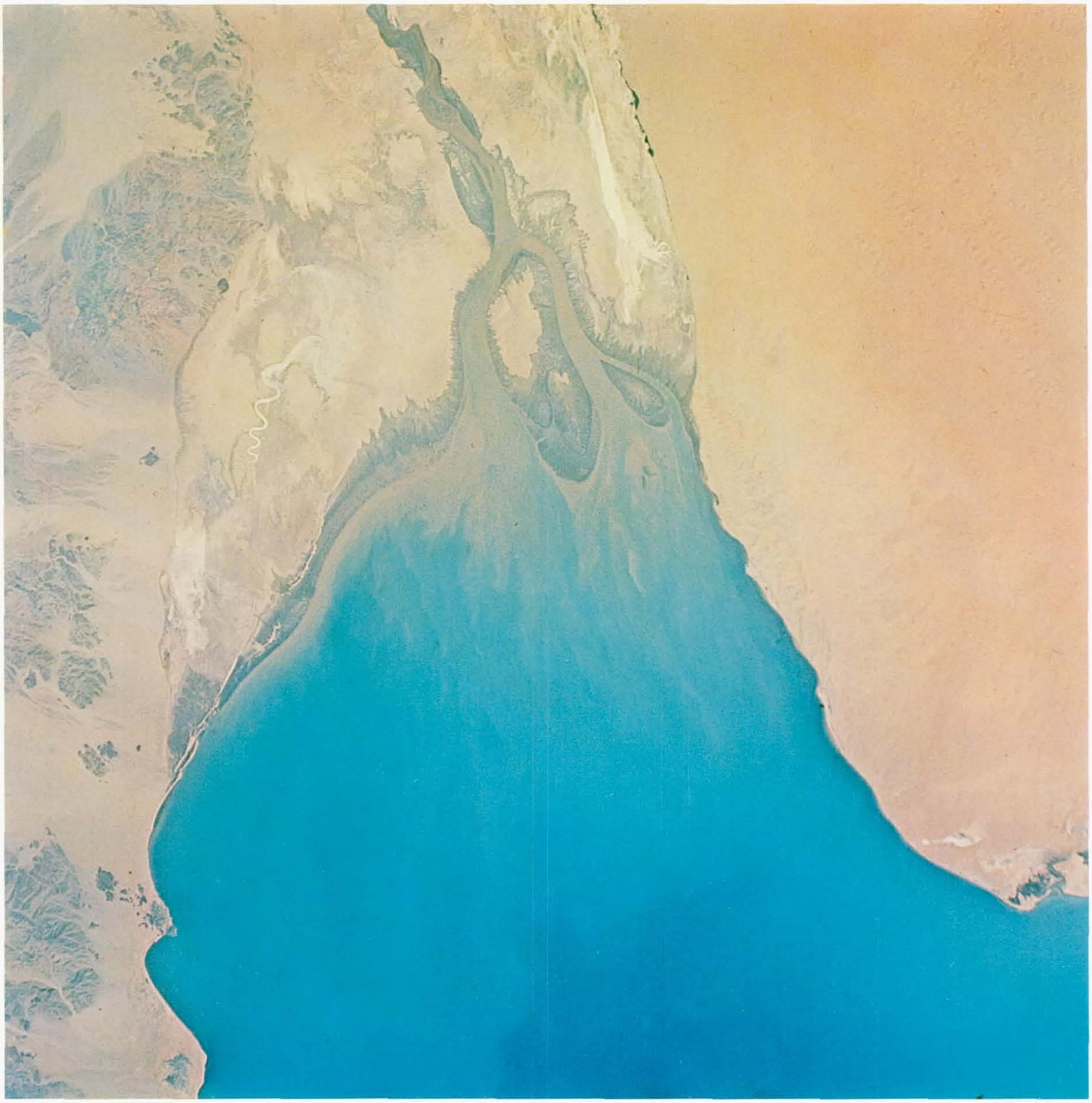


FIGURE 18–8.—Mouth of Colorado River.

Figure 18–8 was photographed during the Gemini IV mission, and shows quite clearly the mouth of the 1500-mile-long Colorado River and the related geology. The photograph, one of 39 made in a 4-minute rapid sequence between Baja California and central Texas, was taken from an altitude of 110 miles. The Mexican States of Baja California to the west and Sonora to the east, as well as the Gulfo de California, constitute the extent of the photograph. A white streak to the right of the river is the saltpan bed of the old river channel before upstream irrigation removed most of the water volume. A straight line just to the right (east) of the old channel is a portion of the San Andreas fault system. The distinct change in topography and in geologic structure is most evident, and was caused by the linear horizontal movement of the fault during the geologic past. To the right of the San Andreas fault are the sands of the Great Sonora Desert. The line of contact between the delta sediments brought down the river and the block-fault mountains and pediments of Baja California appears near the left (west) edge of the photograph. Suspended sediments carried down the river are clearly visible around the mouth.

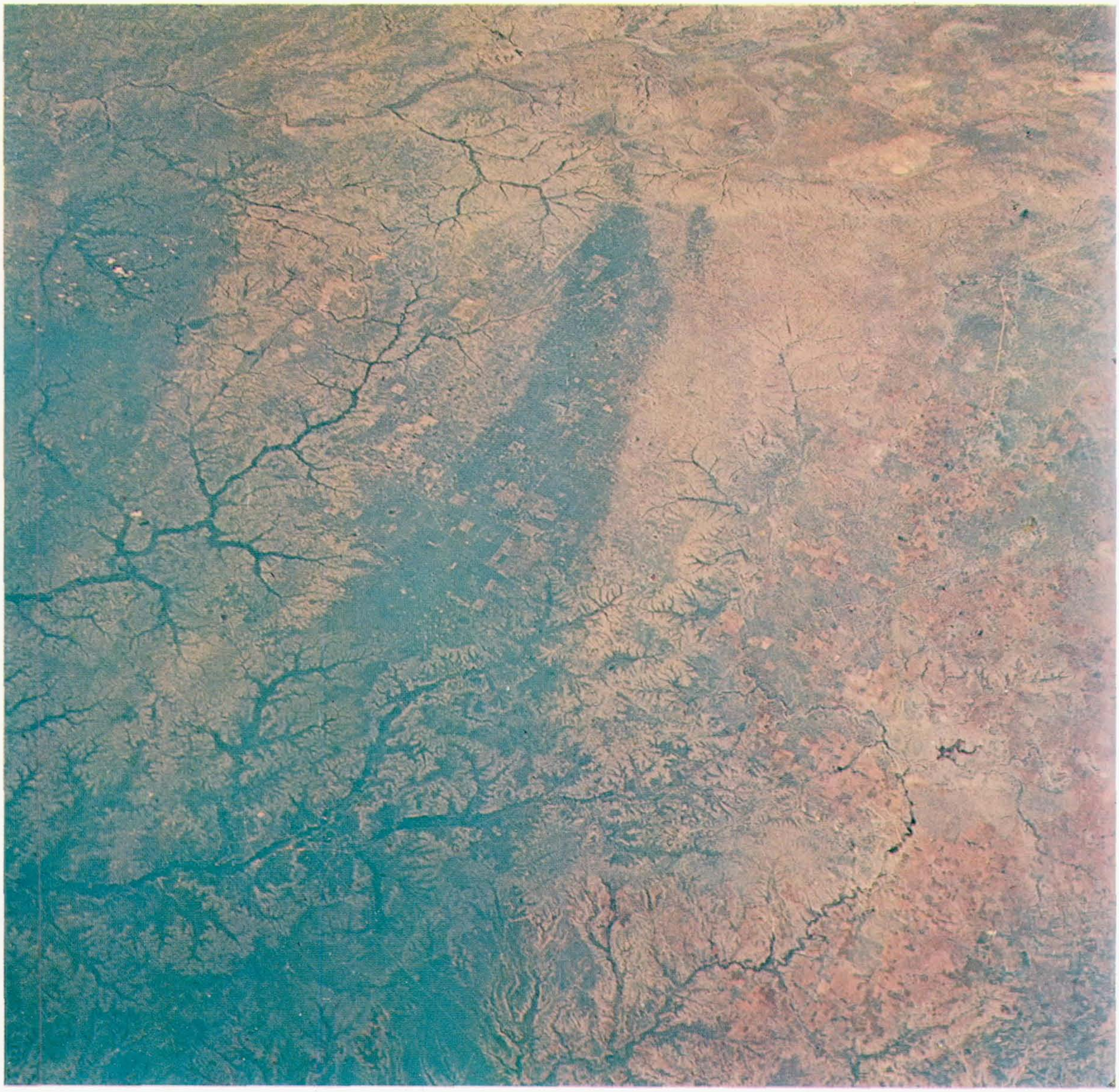


FIGURE 18-9.—West Texas.

Figure 18-9 is a portion of the Edwards Plateau area of Texas photographed during the Gemini IV mission. The view is to the west and shows the cities of Odessa, Midland, and Big Spring along the right edge. The unique darker areas in the left and lower left show the effect of a rain storm the previous evening, and how quickly vegetation demonstrates growth in a semiarid area. The dendritic drainage of the upper Concho system is quite evident due to the lush vegetation along these streams.

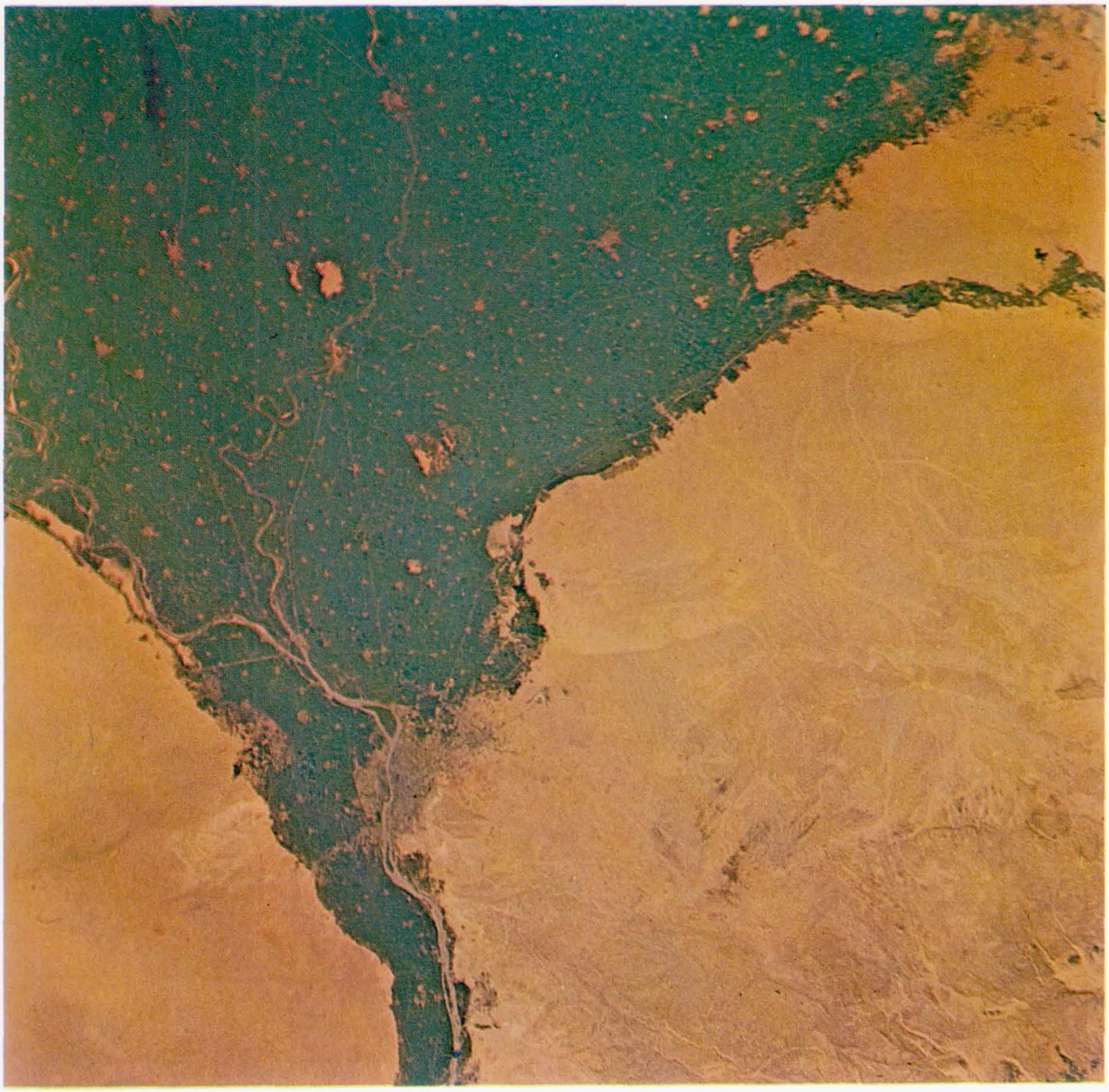


FIGURE 18–10.—Nile Delta.

Figure 18–10, showing a major portion of the Nile Delta, was taken during Gemini V from an altitude of 100 miles. With the 30 million people in the delta area and a high population growth rate, rapid regional information changes are most important. The photograph shows Cairo with a population of over 5 million; the distribution of cities and towns in the delta; and the networks of roads, railroads, and canals.

FIGURE 18–11.—Strait of Gibraltar.

Figure 18–11, photographed by the Gemini V crew, is a classic astronaut view of the Earth. The Strait of Gibraltar and the continents of Europe and Africa are pictured. The valley of the Guadalquivir River and the Sierra Morena in Spain, as well as Point Europa (Rock of Gibraltar), are clearly visible in the upper left. To the right are Morocco and Algeria. Unique cloud formations are visible on the Atlantic side of the strait.

FIGURE 18-12.—Southwest Africa.

A Gemini V photograph (fig. 18–12), taken from an altitude of 200 miles, clearly demonstrates the forces of wind and sea in the Namib Desert of Southwest Africa. This is one of the driest areas of the world, and the sole productivity is diamonds buried in the sands. The seif-type dunes extend over 100 miles across the southern part of the area. As the prevailing winds carry the sand into the Atlantic Ocean, the strong Benguela Current causes the northward waterborne migration of the sands and the formation of the three very large sand hooks. The northernmost hook is 50 miles long, and the port of Walvis Bay is located on the lee side. The area is known as the Skeleton Coast, a name that goes back nearly 500 years when early navigators in galleons attempted to use this route from Western Europe to Asia. In order to reprovision, they had to fight strong northward currents and prevailing winds from the mouth of the Congo River to the Cape of Good Hope in ships which sailed poorly to windward. Failure to reach their destination was disastrous for ship and crew. Navigators such as Columbus believed that the riches of Asia could be obtained with less hardship by sailing westward across the Atlantic.

FIGURE 18-13.—China basins.

The line of intersection of two large basins located in Szechwan Province, China, is visible in figure 18-13. The photograph was taken during the Gemini V mission and shows the Yangtze River along the right edge. The long folded sedimentary ridges with intermediate softer beds control the drainage pattern of the area. The synoptic view from orbital altitudes reveals much information which cannot be discerned from the lower altitudes attained by airplanes.

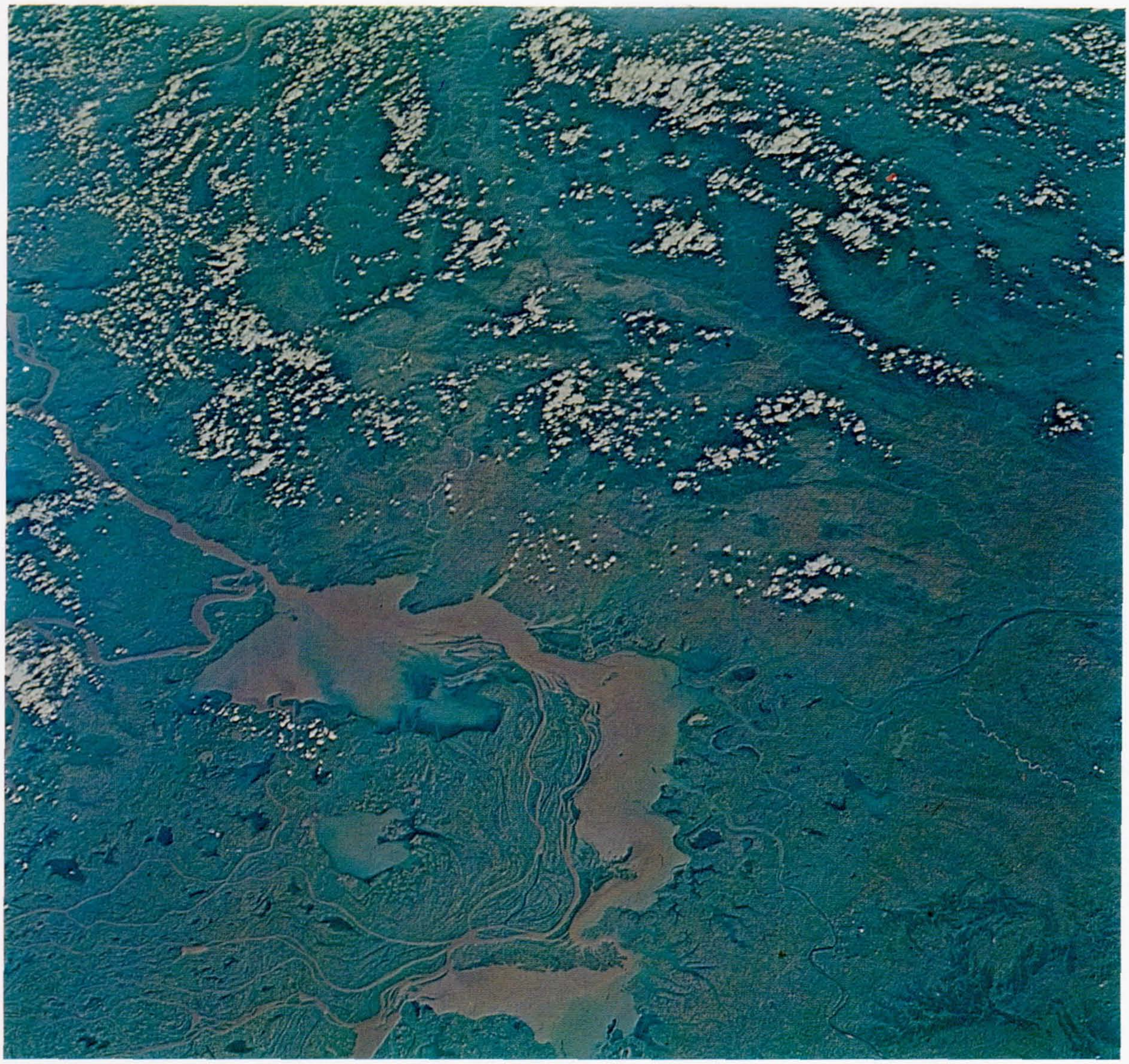


FIGURE 18–14.—Hunan Province, China.

Figure 18–14 was taken during the Gemini V mission, and shows a large natural floodway in Hunan Province, China, with the Yangtze River at left center. The open water of the floodway is Tung 'ting Hu, a lake about 100 miles long. The Hsiang River flows into the lake from the right and the photograph clearly shows the relationship of the floodway system to the surrounding topography.

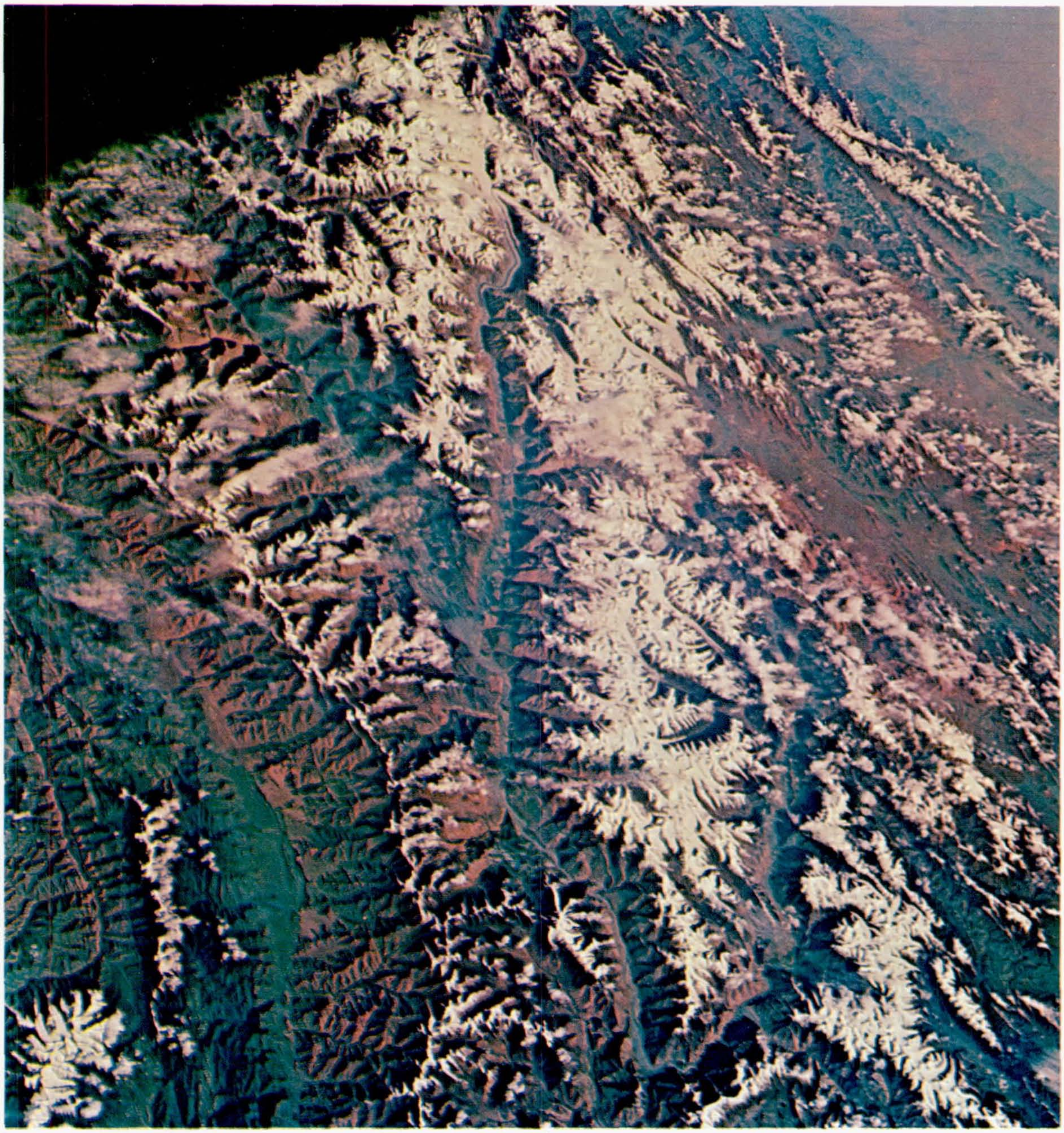


FIGURE 18-15.—Mount Godwin-Austen (K-2).

The boundaries of China (Sinkiang), India, Pakistan (Kashmir), Afghanistan, and U.S.S.R. (Tadzhik) meet in the Karakoram Range of the Himalayas (fig. 18-15). The mountains are snow covered above 20,000 feet. The world's second highest peak, Mount Godwin-Austen (K-2) with an elevation of 28,250 feet, is near the upper edge of the photograph and the Indus River is located in the lower portion. The upper right shows the basin of the distant Takla Makan Desert. The Gemini V photograph was

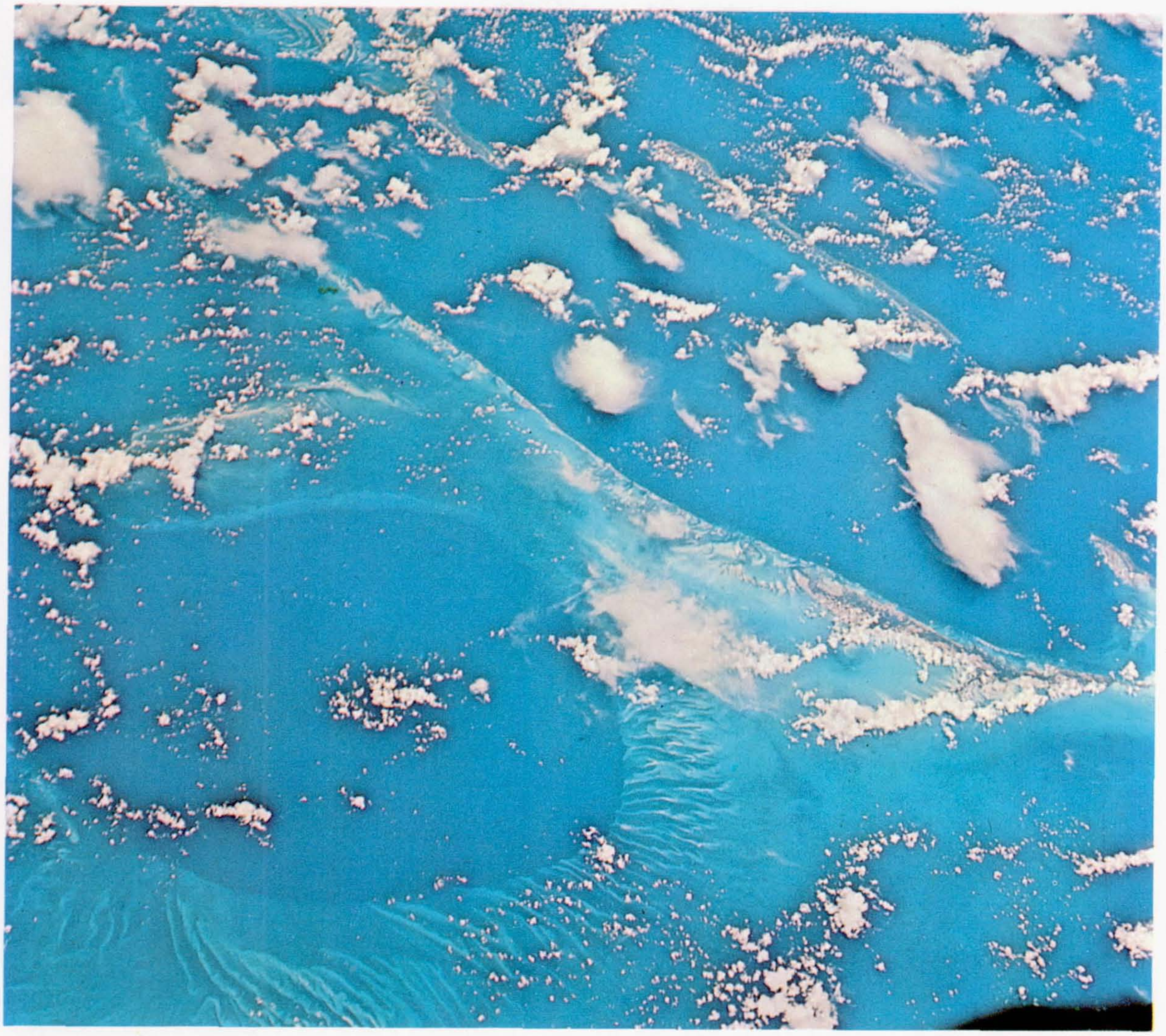


FIGURE 18–16.—Bahama Banks.

taken at the time of minimum snowcover, and indicates that space photography can provide data on the water runoff from snowfields of remote and poorly explored mountain ranges.

Oceanographers are interested in photographs such as figure 18–16, a view of the Great Bahama Bank taken from Gemini V. Except for the small land areas of Great Exuma Island, Cat Island, and Long Island, all the informational content concerns the floor of the ocean. Along the edge of the Tongue of Ocean, which is over a mile deep, the canyons cut in the coral banks are visible. Exuma Sound in the center drops abruptly from rocks awash to a depth of 8000 feet. Space photography for the first time affords an opportunity to photograph large areas of the world's oceans.

FIGURE 18-17.—Salton Sea.

Figure 18–17, taken by the Gemini V crew, shows the southwestern corner of the United States and portions of Baja California and Sonora in Mexico. The frontier cutting across the Imperial Valley is easily located due to the marked difference in the land division systems. The city of Mexicali on the border and the All-American Canal along the frontier are visible. A unique and unexplained gyre can be seen in the Salton Sea. The overall relationships of the many basins and ranges, which are the predominant geologic features of the area, can easily be studied. The Colorado River is visible from just above the mouth, through the entire Grand Canyon, to beyond Lake Powell in southeast Utah.

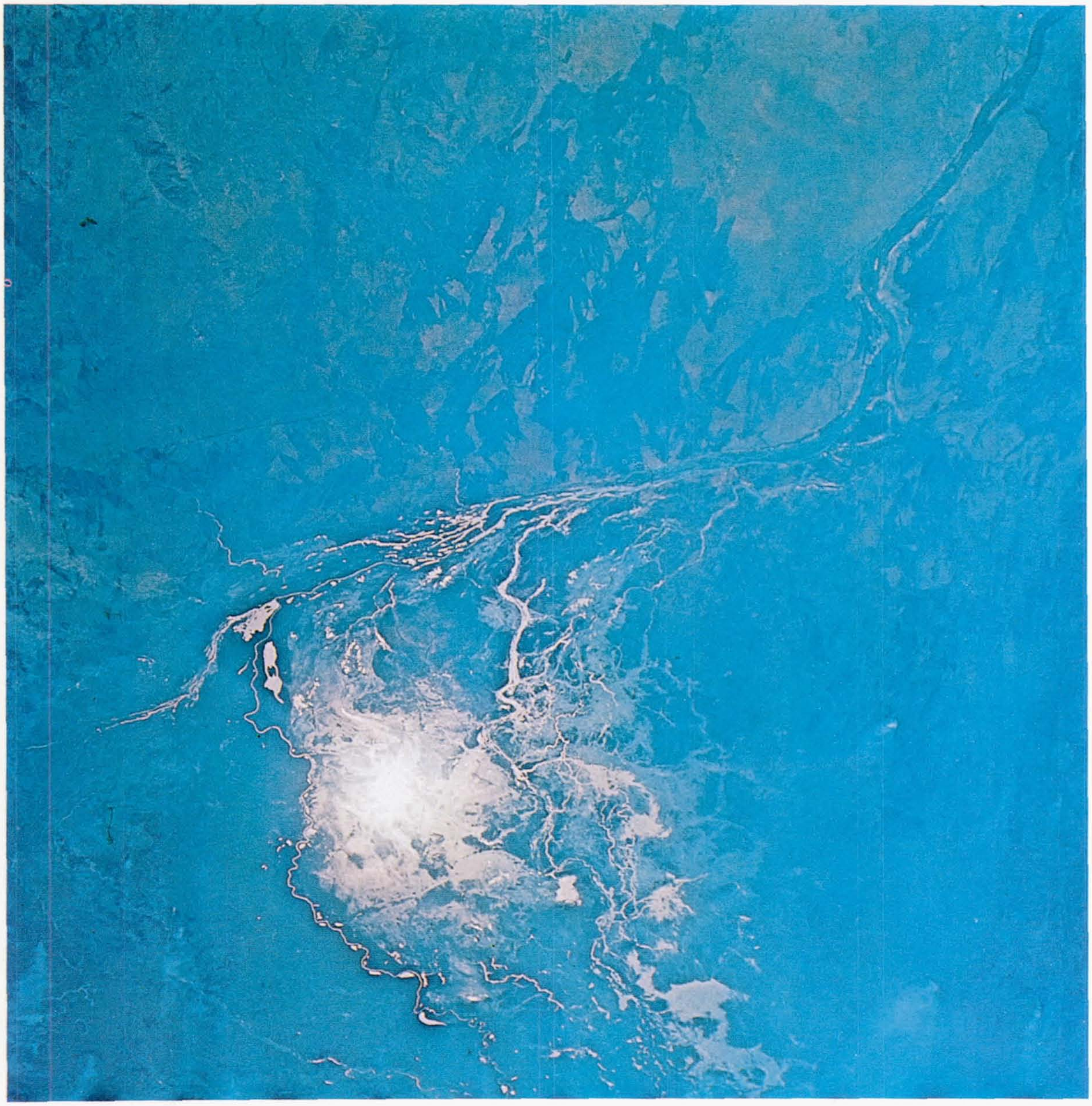


FIGURE 18–18.—The Sudd.

The area known as the Sudd, Arabic for the barrier or stopper, was dramatically photographed (fig. 18–18) from the Gemini VI–A spacecraft at an altitude of 185 miles. The main feature in the photograph is perhaps the world's largest swamp; the area is larger than the State of Pennsylvania. The White Nile flows out of the Great Rift Valleys of East Africa into Sudan and loses over 80 percent of its volume in a tangled mass of marsh, water hyacinth, and 15-foot papyrus grass. The river loses itself in many channels which open and close at random, as floating islands of papyrus block old and create new channels. Lightning often causes the grass to catch fire. The hostile terrain of this area has historically separated the cultures of Arab Africa from Negro Africa. Continued surveillance from manned spacecraft can provide much information on the river and the swamp vegetation, and may lead to an eventual triumph by man.

FIGURE 18–19.—Western Algeria.

The fine geologic details of the Sahara Desert in Western Algeria (fig. 18–19) were recorded by the Gemini VII flight crew. The dunes are long longitudinal ridges from 5 to 10 miles apart, 500 to 800 feet high, and up to several hundred miles long. A long ridge of upturned sedimentary beds is visible from the upper center to the lower right edge of the photograph. A wadi, a usually dry stream bed, follows the right edge of the ridge; just off the photograph, the wadi passes through a water gap and

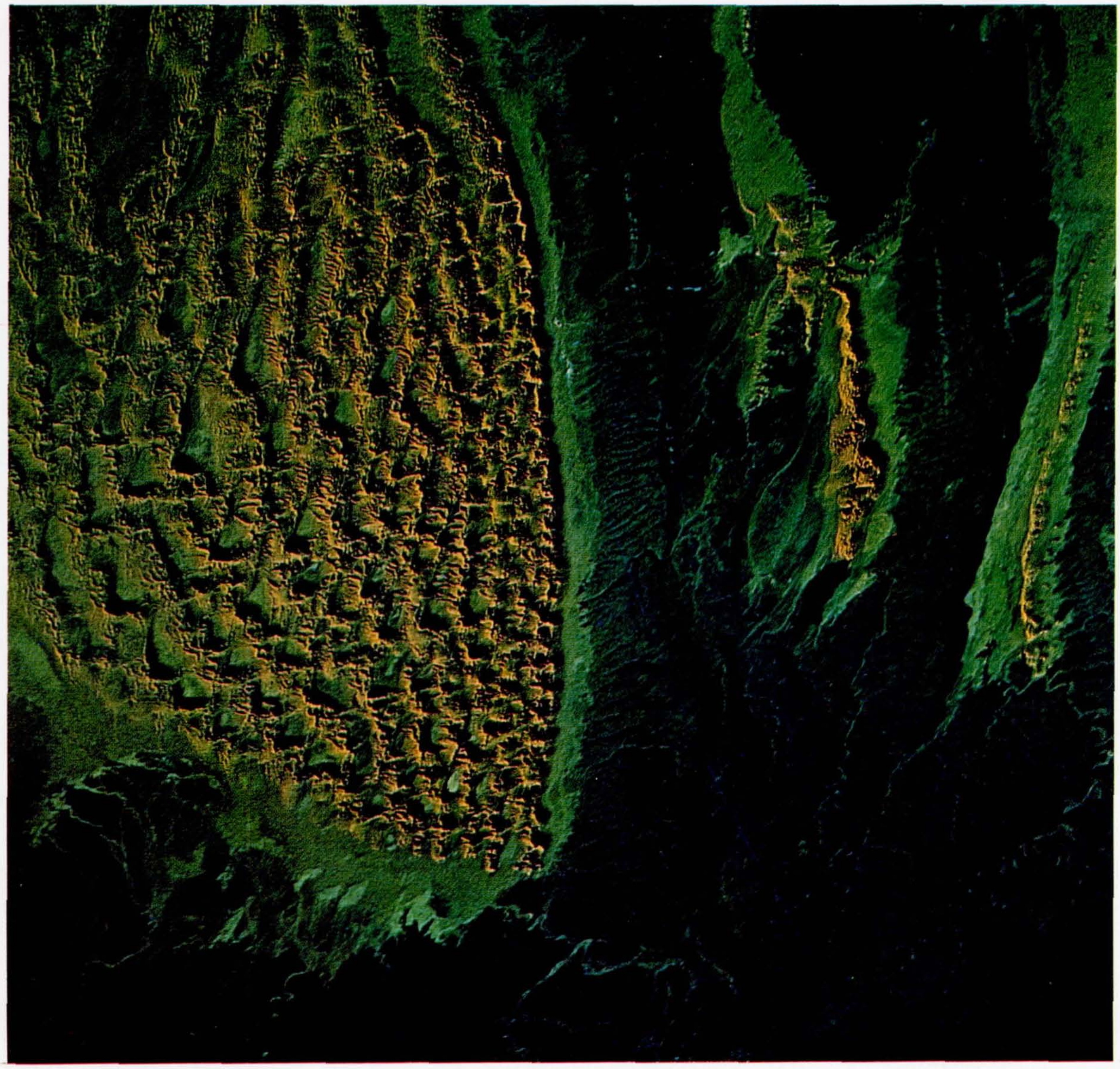


FIGURE 18–20.—Tifernine Dunes.

continues in the opposite direction down the other side of the ridge terminating in a large salt flat. The photographs of this usually dry country were made shortly after very heavy rains; the wadi is carrying surface water and the salt flat is inundated.

Figure 18–20 was obtained with a 250-mm Zeiss Sonnar lens, and shows the structure of a unique geologic feature, the Tifernine Dunes of Eastern Algeria. These dunes are probably the world's highest (1500 feet), and are trapped in a basin surrounded by mountains of basalt. The remote area had been poorly photographed prior to the Gemini VII mission.

FIGURE 18–21.—Kennedy Space Center, Florida.

The potential value of space photography to the urban planner is represented by figure 18–21. The Gemini VII crew photographed the Kennedy Space Center, Fla., and vicinity while directly overhead at an altitude of 140 miles. Launch Complex 19, where the spacecraft was launched 2 days before, can be clearly seen as part of Missile Row. Launch Complex 39, which includes the Vertical Assembly Building, the crawlerways, and the two launch pads, is partially obscured by a cloud. Other manmade features which are clearly visible include freeways, city streets, buildings, causeways, railroads, bridges, piers, runways, and taxiways. The channel of the Intracoastal Waterway can be located beside the series of white dots in the Indian River; the white dots are small islands of spoil piles resulting from dredging. Space photography can be utilized by urban planners to study and make important decisions regarding the fierce competition for land among industrial, commercial, residential, agricultural, and recreational users. Government personnel can update planning documents, such as master plans, or tax and transportation maps, and quickly see what changes have taken place in land use.

FIGURE 18–22.—Lake Titicaca, Peru.

Lake Titicaca, located between Peru and Bolivia at an elevation of 12 506 feet, was photographed (fig. 18–22) by the Gemini IX–A crew. The photograph also shows portions of Chile and Argentina, and the Pacific Ocean in the background. The snow-covered peaks of the Cordillera Real (Royal Mountains) rise to over 21 000 feet and are visible in the lower left. The high Salars or salt flats, on the left margin, are higher than any point in the continental United States and are as large as the Bonneville Salt Flats. Drainage, from the lower left, is about 3700 miles down the Amazon to the Atlantic Ocean.

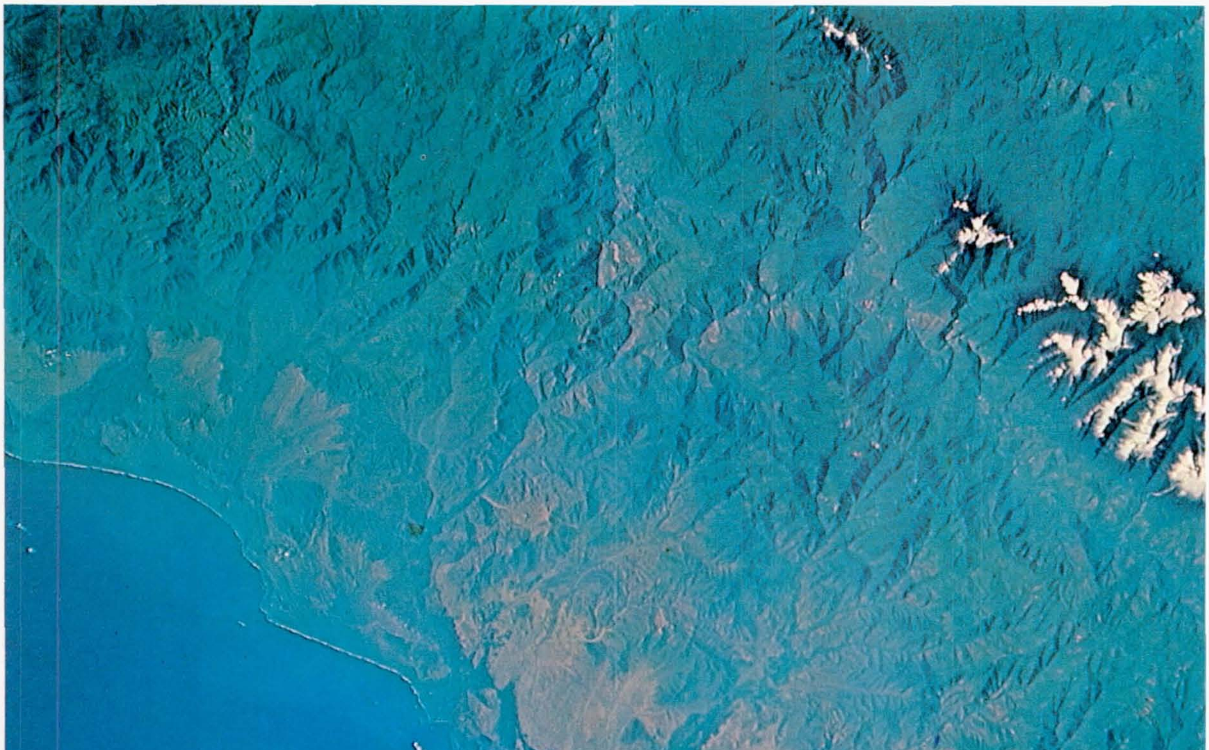


FIGURE 18-23.—Peru.

The Cordillera Blanca (White Mountains) of Peru were photographed (fig. 18–23) by the Gemini IX–A crew less than 1 minute prior to figure 18–22. Clearly visible is Huascaran Volcano (22 205 feet), the highest point in Peru; the snowline is at 18 000 feet. A thin white line down the west slope of the volcano marks the path of a destructive avalanche which killed several thousand people in the Santa River Valley in January 1962. Over 250 miles of the Pacific coast can be seen. The rivers in the upper right of the photograph flow down the Amazon system for over 3500 miles to the Atlantic. In areas which still require accurate and detailed mapping, space photography will be a valuable asset. Great effort is required to obtain accurate information on the amount of snow on these mountains and the predicted water runoff. Space photography can reduce the hardships encountered by topographic survey parties at altitudes in excess of 20 000 feet, and eliminate the frequent loss of life. In over 40 years of aerial photography, only a quarter of Peru has been photographed; the Gemini IX–A crew photographed over three-quarters in 3 minutes.

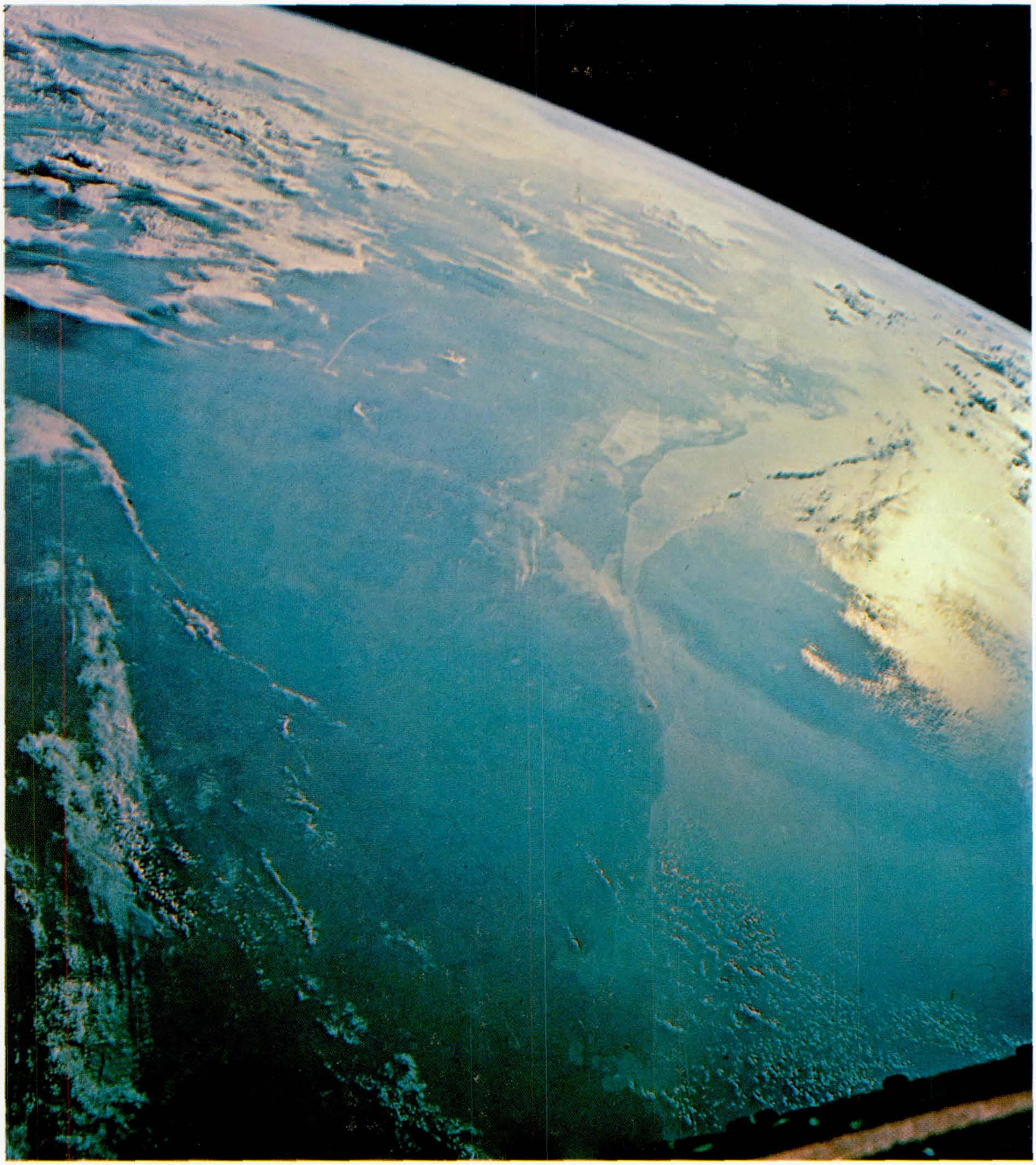


FIGURE 18-24.—Texas-Louisiana Gulf coast from Gemini XI.

Figure 18–24 is a very interesting study of the sources and distribution of air pollution along the Texas-Louisiana Gulf Coast. This photograph was taken through the open hatch of the Gemini XI spacecraft shortly after dawn. Large sources of air pollution can be seen originating from smokestacks in Houston, Texas City, Freeport, and Port Arthur, Tex., and in Lake Charles, Baton Rouge, and Bogalusa, La. As shown in the photograph, the air pollutants in the Houston area move northeastward at the lower levels until winds aloft carry the pollutants southward over the Gulf of Mexico. In the future, space photography will provide a worldwide aid in the detection of sources, and the collection and movement of airborne pollutants.

FIGURE 18-25.—Texas-Louisiana Gulf coast from Gemini XII.

Figure 18–25 was taken by the Gemini XII crew along the Texas-Louisiana Gulf Coast and shows Houston, the Manned Spacecraft Center, the Harris County Domed Stadium, the Houston Ship Channel, and many other features of the area. Of greater geoscientific importance, the distribution of very polluted water in Galveston Bay and other waterborne sediment in such passes as Bolivar Roads, Sabine, and Calcasieu can be clearly seen. The movement of currents in the Gulf of Mexico is also quite evident, and has afforded the oceanographer the opportunity to learn a great deal about the movement and distribution of larval commercial shrimp so important to area economy. The photograph also demonstrates the potential uses of space photography in the observation of causes and distribution of polluted water.

FIGURE 18–26.—Northern half of Mexico.

During the Gemini XII standup extravehicular activity, a striking panoramic series of photographs was obtained showing the entire length of Mexico from Guatemala to Arizona. Figure 18–26 shows the northern half of Mexico including the cities of Monterrey, Reynosa, Chihuahua, and Ciudad Juarez. Features visible in the United States include White Sands

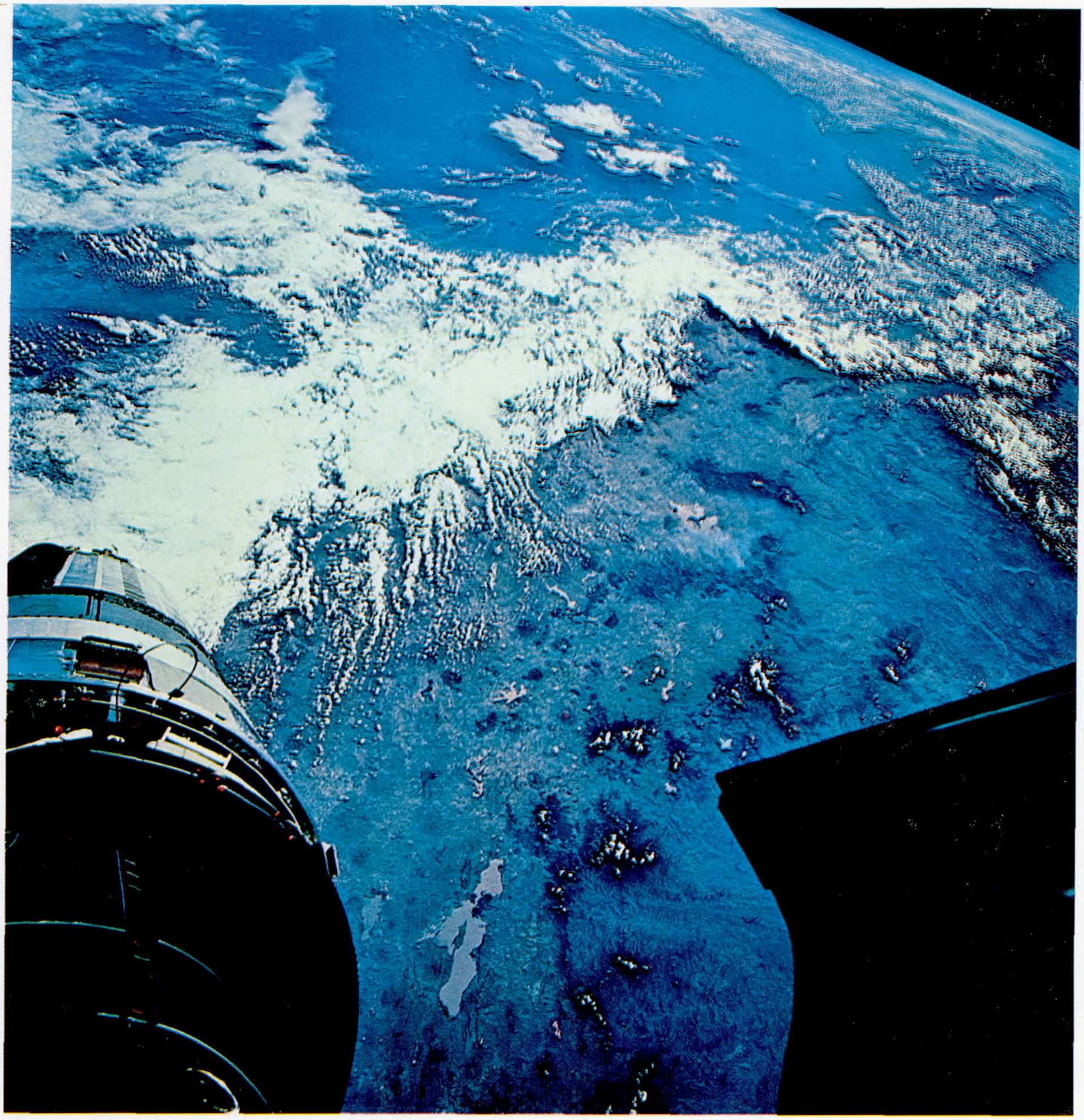


FIGURE 18–27.—Southern half of Mexico.

National Monument in New Mexico and Galveston Bay in Texas. Figure 18–27 taken a few seconds later shows the southeast half of the country including the Mexico City area (note the air pollution), the great snow-covered volcanoes such as Popocatepetl, the Isthmus of Tehuantepec, and the Yucatan Peninsula.

High-Apogee Photography

A series of superb photographs was taken by the Gemini XI flight crew while increasing the orbital altitude from 185 miles to a record 851 miles. Figure 18–28, taken approximately 200 miles above the Earth, shows a land area of almost 1 million square miles in the Sahara countries of Libya, United Arab Republic, Chad, Niger, Sudan, and Algeria. Clearly visible are the great sand deserts separated by mountains and escarpments of sedimentary or igneous origins. Two large volcanic areas, the Black Haruj and the Tibesti Mountains, are visible. The unique striations in rock and sand in the upper right demand more investigation by the geologist.

FIGURE 18–28.—Sahara area.

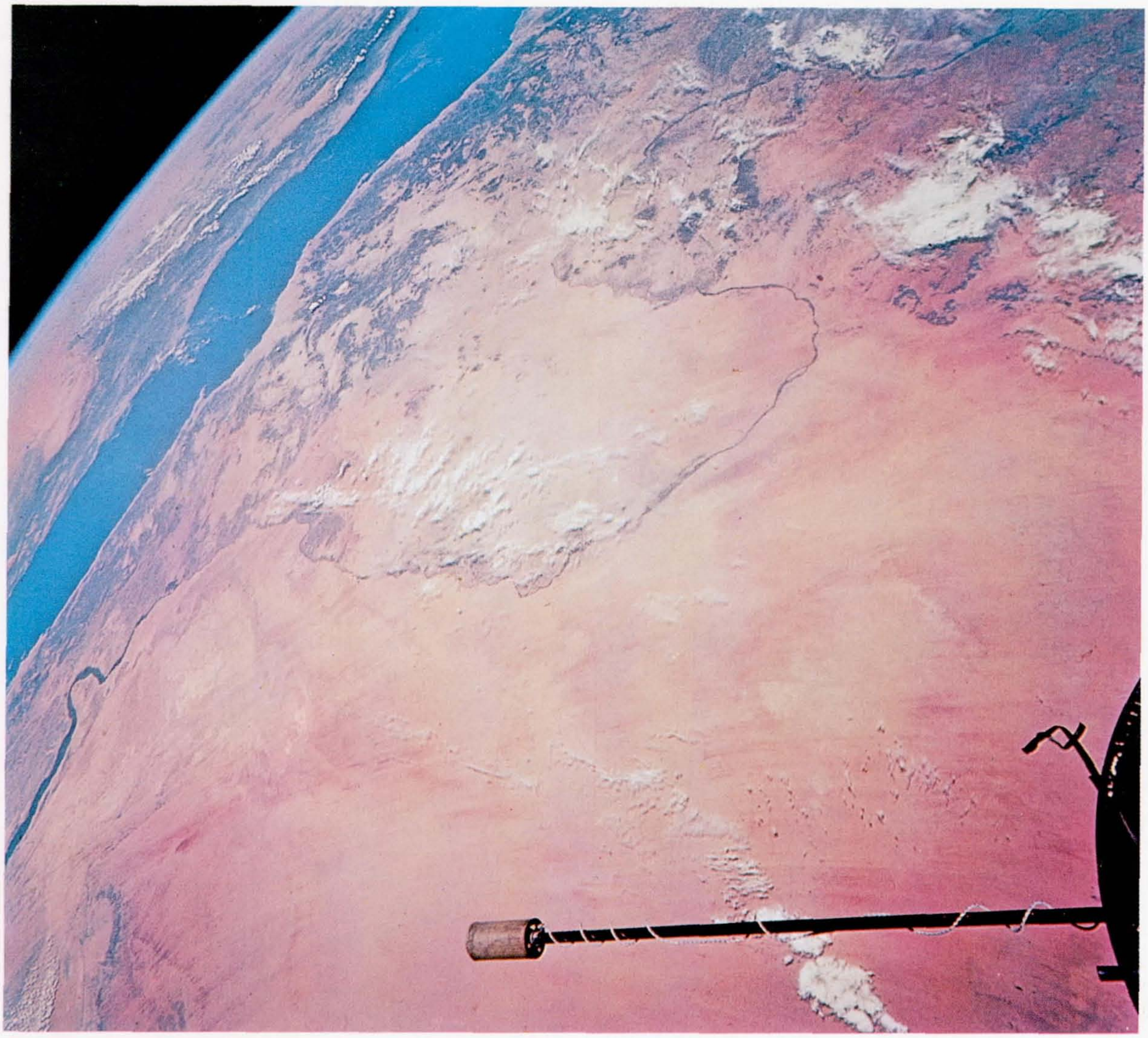


FIGURE 18–29.—Nile River.

Some 2 minutes later, the Gemini XI crew photographed approximately half of the 4200-mile-long Nile River (fig. 18–29). Taken from an altitude of about 220 miles, this synoptic view permits regional studies which cannot be accomplished by other means. The relationship of the world's longest river to the regional geology is clearly indicated from Bida (above Cairo) in the United Arab Republic southward to Kosti (above Khartoum) in the Sudan. The Red Sea and Arabia lie beyond.

FIGURE 18–30.—Middle East.

Figure 18–30 was taken during Gemini XI from an altitude of about 200 miles, and shows all of Israel and Jordan and portions of Turkey, Lebanon, Syria, Iraq, Saudi Arabia, and the United Arab Republic. The capitals of Beirut, Damascus, Baghdad, Amman, and Jerusalem, as well as the Red Sea terminus of the Suez Canal, are visible. The entire Sinai Peninsula and such sub-sea-level lakes as the Dead Sea and Sea of Galilee are visible. A break in the Trans-Arabian pipeline occurred near Badanah, Saudi Arabia, shortly before the photograph was made, and the resulting fire, smoke, and shadow are recorded in the upper right.

FIGURE 18–31.—Arabia-Somali.

From an altitude of about 410 miles, the Gemini XI crew photographed the junction of the Red Sea and the Gulf of Aden (fig. 18–31). Parts of Yemen, South Arabia Federation, Saudi Arabia, and the Muscat and Oman Sultanate are visible in the upper portions of the photograph, while parts of Somali, Ethiopia, and all of French Somaliland are in the foreground.

FIGURE 18–32.—India.

From an altitude of about 500 miles, the Gemini XI crew recorded a striking and beautiful view of the Indian subcontinent (fig. 18–32). The island of Ceylon is to the lower right. The climatic difference along the divide of the Western Ghats in India is clearly visible, with the lush jungle to the west and the semiarid regions to the east. Much valuable information is available concerning the meteorological conditions over such a vast area as the subcontinent and the adjacent Arabian Sea to the left and the Bay of Bengal to the right.

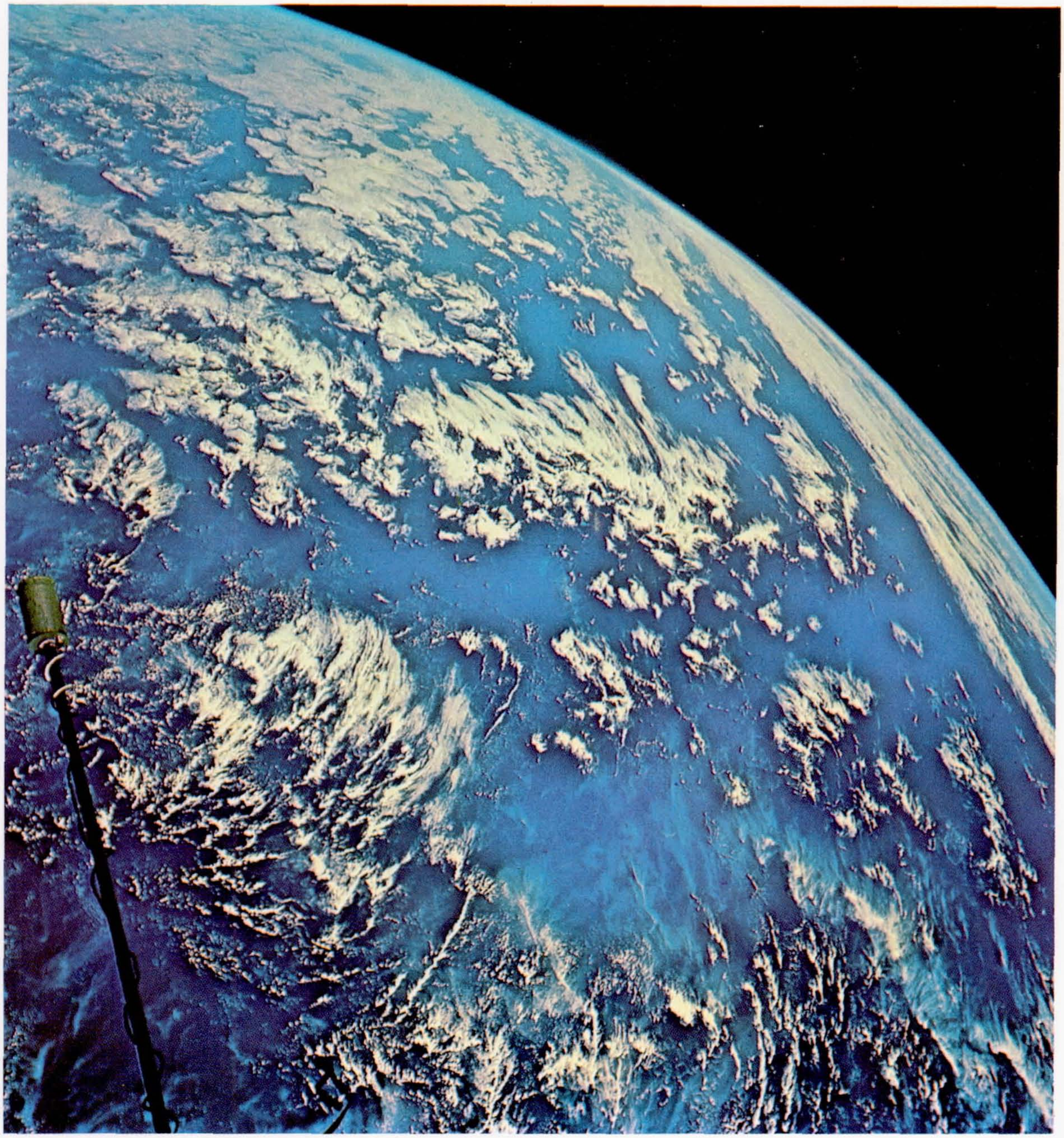


FIGURE 18–33.—Indonesia.

In figure 18–33, the cloud-covered Indonesian Islands were photographed during Gemini XI from about 740 miles above the Earth. The curved horizon is over 2000 miles to the east.

FIGURE 18–34.—Australia.

Figure 18–34 was taken while the Gemini XI spacecraft was 851 miles above the Earth, the highest altitude from which any photograph has been taken by man. The western half of Australia with the sunlit Indian Ocean beyond is visible. The horizon is nearly 3000 miles to the westward. The photograph was made near sunset, and ground detail is poor due to low light levels on the ground.

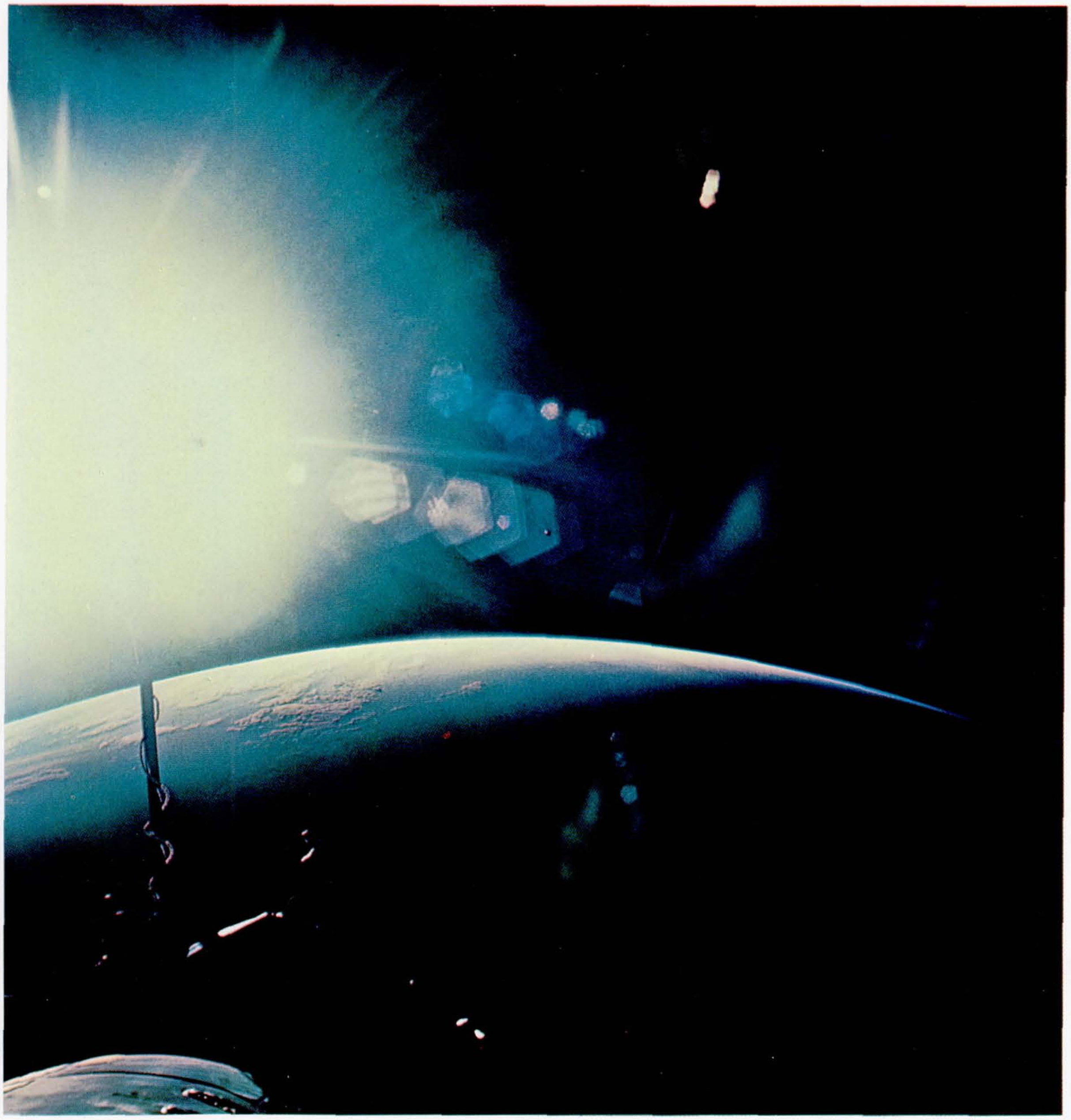


FIGURE 18–35.—Sunset.

The Gemini XI crew recorded the striking photograph of a sunset (fig. 18–35) from approximately 850 miles above the Earth. The sunset terminator is visible over 1000 miles to the west of the spacecraft and the Earth's limb about 3000 miles to the west. Due to the spacecraft altitude, however, the Sun is clearly visible well above the horizon.

Synoptic Weather Photography

The meteorologist has secured much valuable data from some 2000 Gemini photographs. The unmanned meteorological satellites are providing a great deal of valuable information and have been supplemented with the finer details and color of the photographs obtained from Gemini. The study of vortices is of particular importance in that the ultimate vortex may result in a destructive tornado, hurricane, or typhoon. Figure 18–36 was taken during the Gemini V mission, and shows the mile-high Mexican island of Guadalupe (200 miles off Baja California) interrupting the orderly flow of winds to create a bowed shockwave effect in the clouds to windward. Two vortices have developed to the lee of the island.

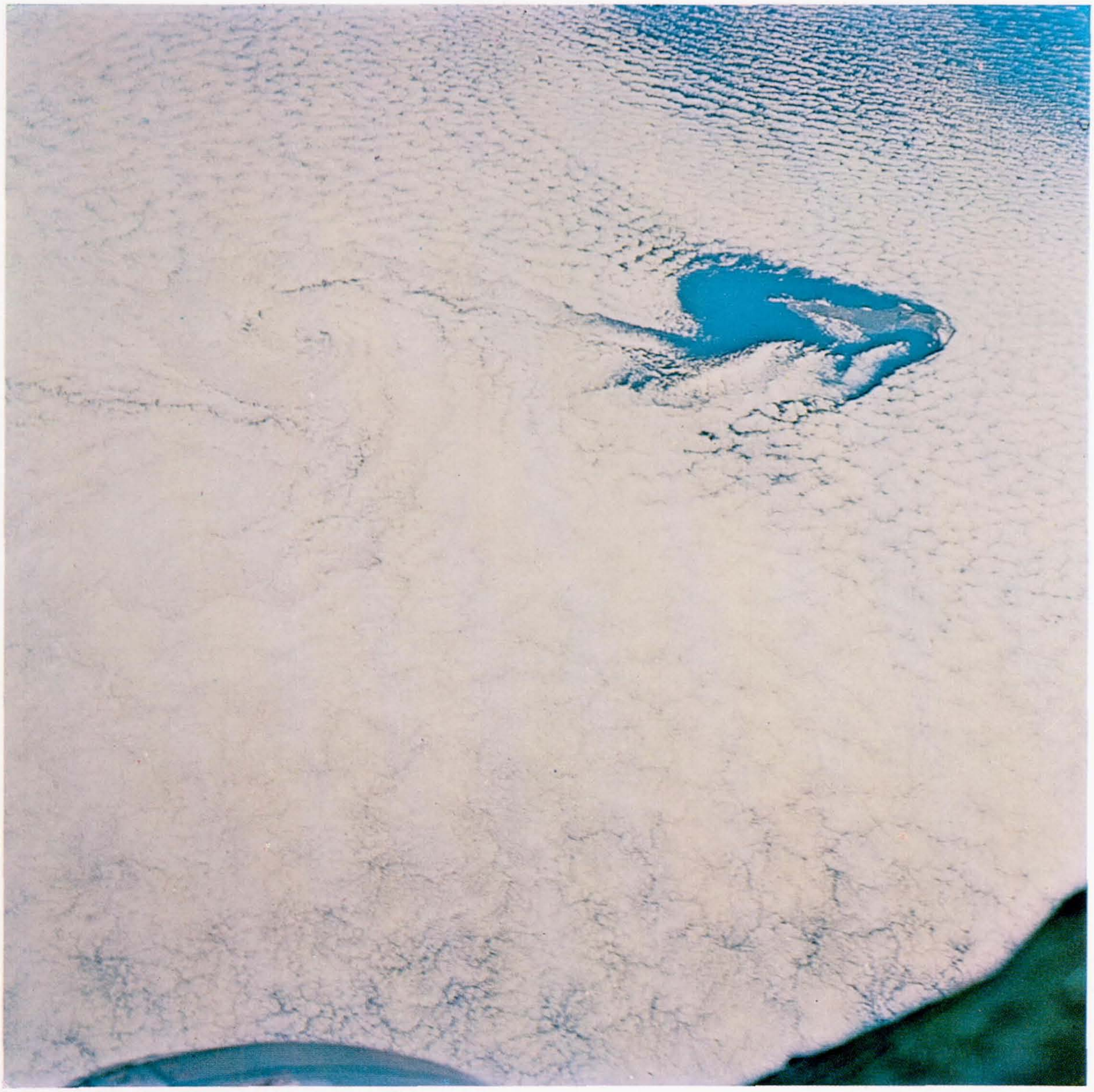


FIGURE 18–36.—Vortex off Mexico.

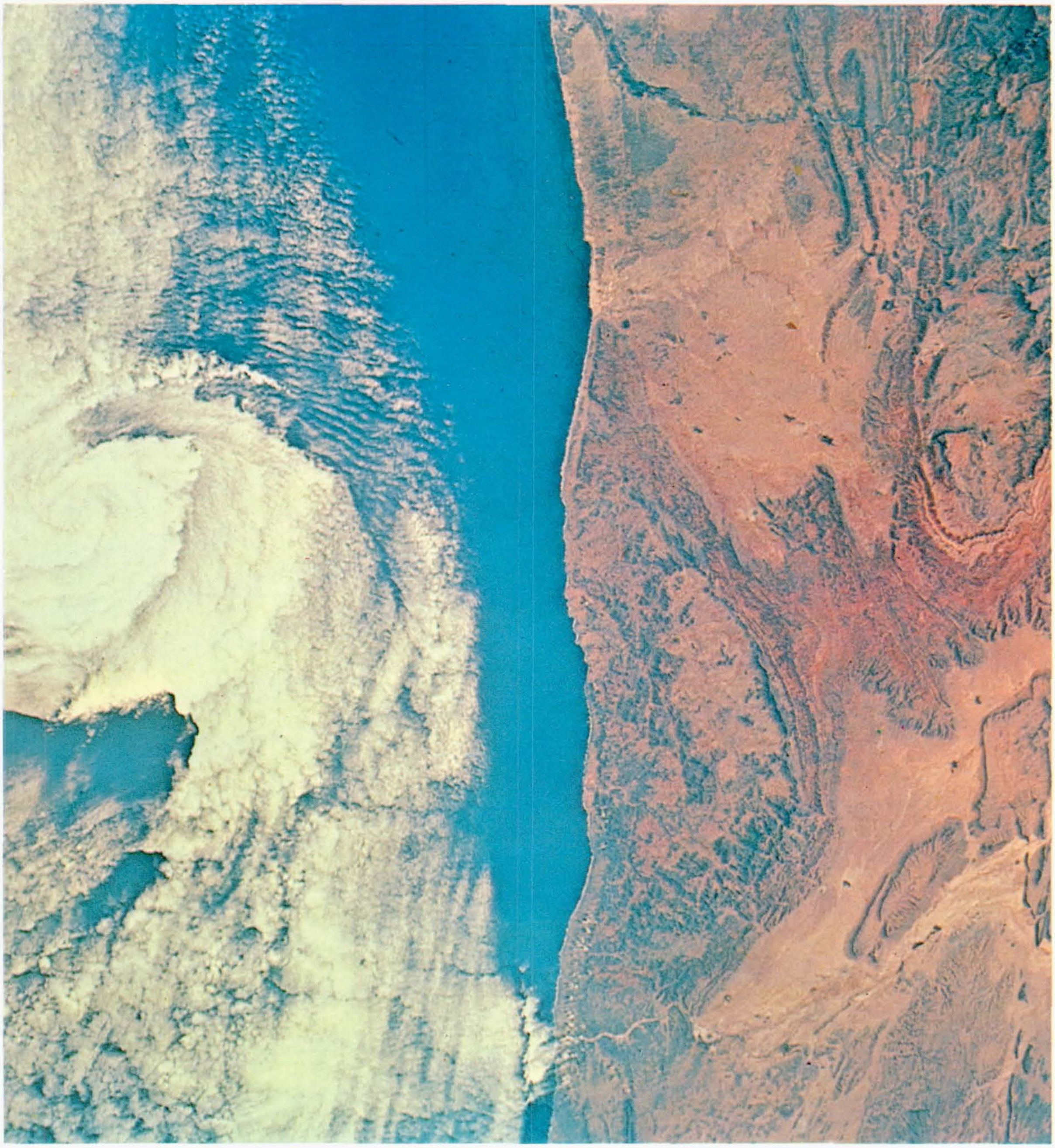


FIGURE 18-37.—Vortex off Morocco.

Figure 18–37 shows a very well developed vortex which has been caused by windshear at the coastal prominence of Ras Rhir in Morocco. The photograph clearly shows the eye of the vortex and the rotational effects on the periphery. This Gemini V photograph has become a classic example of the meteorological data which can be obtained from manned space-flight photography. It would be difficult to provide a machine with the ability to select and photograph phenomena of greatest value to the scientist.

FIGURE 18–38.—Typhoon in Pacific Ocean.

A large mature typhoon moving across the central Pacific Ocean was photographed (fig. 18–38) by the Gemini V crew. The diameter of the system was approximately 400 miles and the circular motion can be distinguished in the photograph.

Near-Object Photography

Figure 18–39 is of great interest to the aerospace engineer, and shows the first Gemini extravehicular activity. The cloud background is over the Pacific Ocean between Hawaii and California. This is one of 16 photographs of the Gemini IV extravehicular activity, and is evidence that much can be learned not only of the pilot but also of the maneuvering unit, camera, space suit, and umbilical cord.

FIGURE 18–39.—First extravehicular activity.

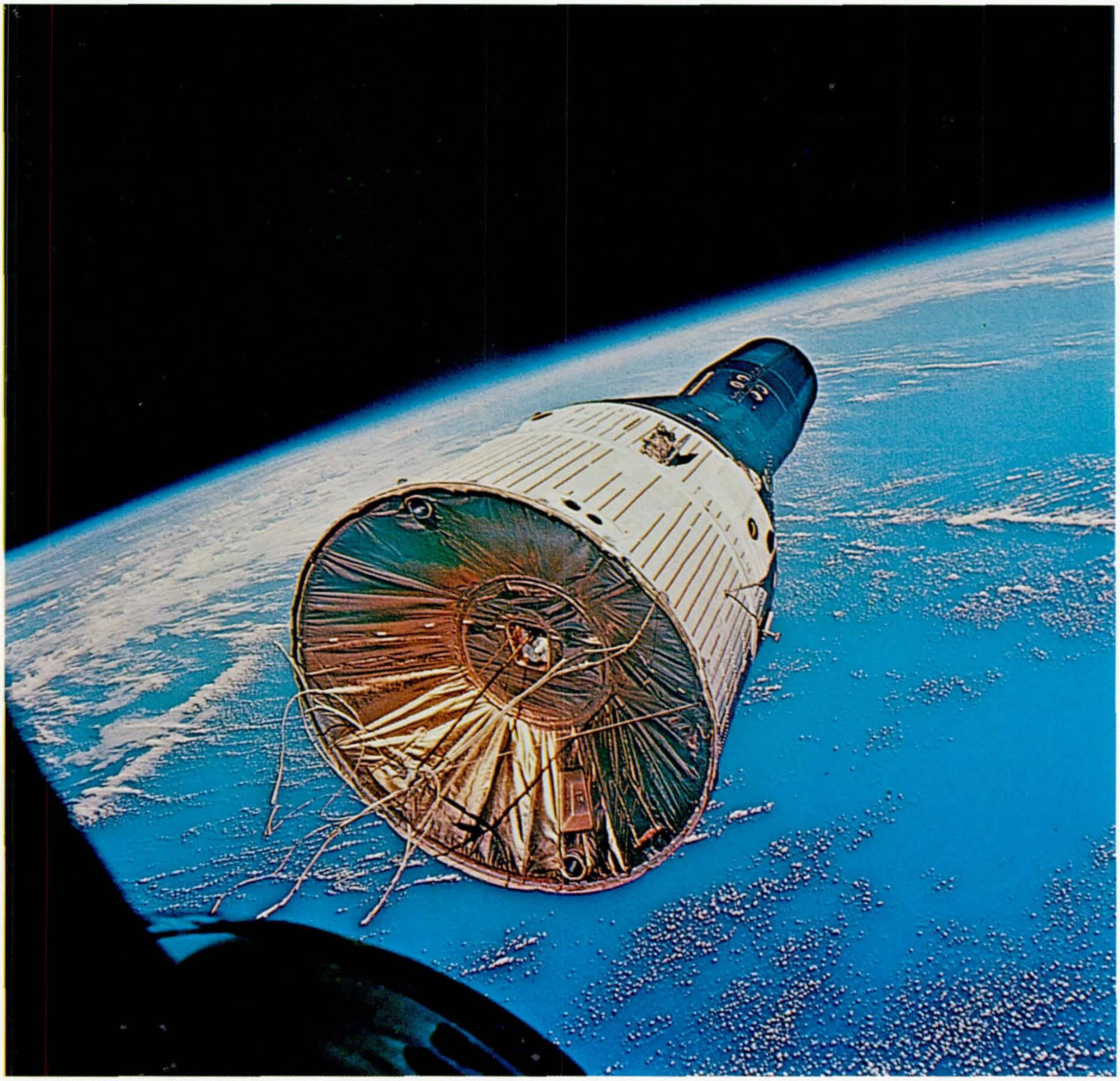


FIGURE 18-40.—Gemini VII from Gemini VI-A.

The historic first rendezvous of two manned space vehicles, Gemini VI–A and VII spacecraft, produced a series of 117 striking and informative still photographs and several hours of motion pictures. As the two vehicles moved through space some 185 miles above the Pacific Ocean, the Gemini VII spacecraft was photographed (fig. 18–40) from a distance of 20 feet by the Gemini VI–A flight crew.

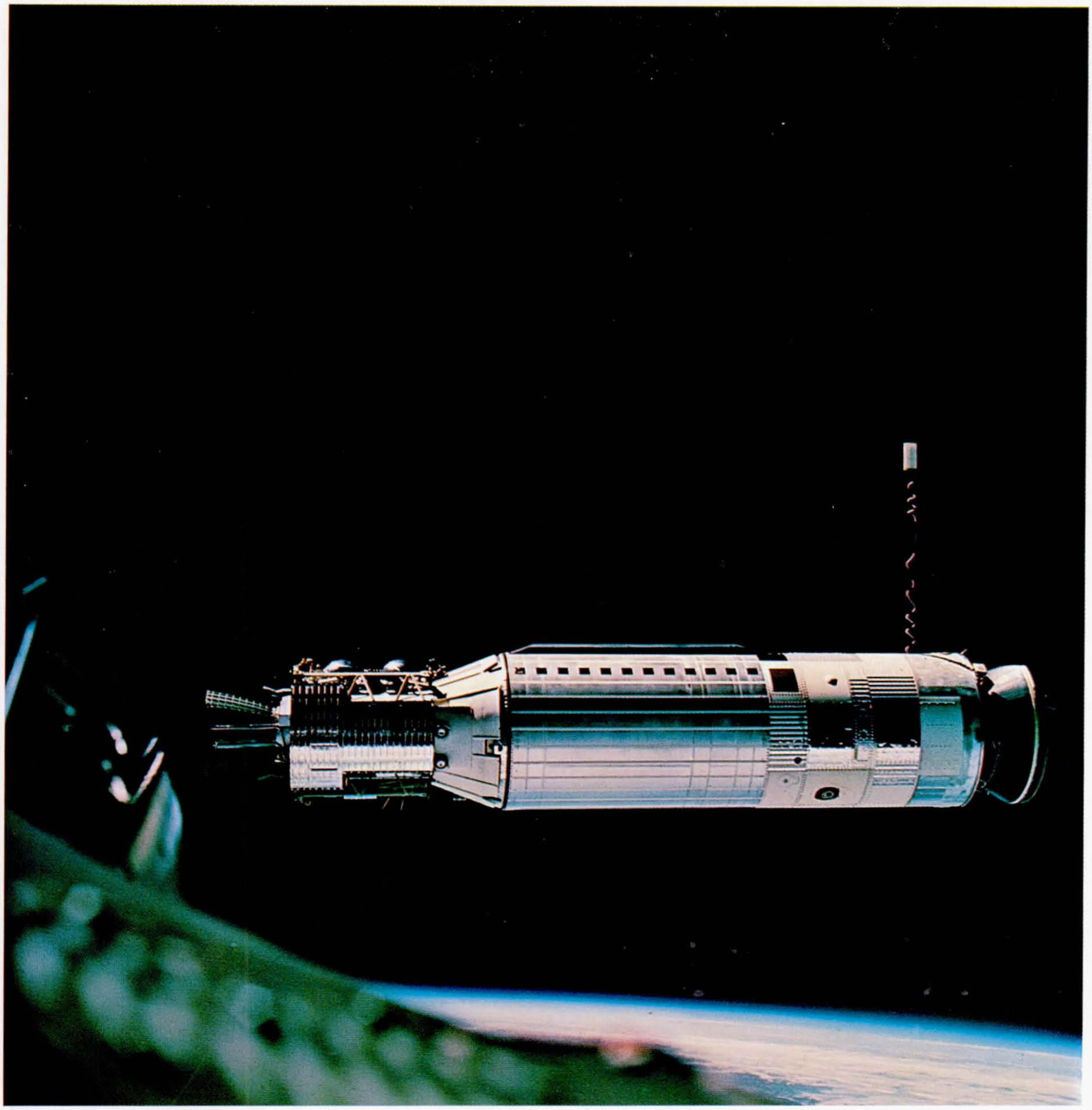


FIGURE 18–41.—Gemini VIII target vehicle.

Even though the Gemini VIII mission was terminated early due to a thruster malfunction, the aerospace engineering field has greatly benefited from the motion-picture and still photographic documentation of the first rendezvous and docking of a spacecraft with a target vehicle. In figure 18–41, the Gemini Agena Target Vehicle is approximately 50 feet from the spacecraft. This photograph was taken just prior to the docking maneuver and is one of a stereo pair which permits precise distance measurements. The motion-picture footage of the difficulties encountered at the time of undocking clearly illustrates the seriousness of the situation.

FIGURE 18–42.—Augmented Target Docking Adapter.

Figure 18–42 shows the Augmented Target Docking Adapter during one of three rendezvous accomplished by the Gemini IX–A crew. Docking could not be accomplished because the ascent shroud covering the docking adapter did not deploy after the vehicle was placed in orbit. The Gemini IX–A crew maneuvered the spacecraft to within inches of the Augmented Target Docking Adapter and secured 109 excellent photographs of the rendezvous and station-keeping activities. The ablative effect of launch heat on the shroud was photographed for the first time.

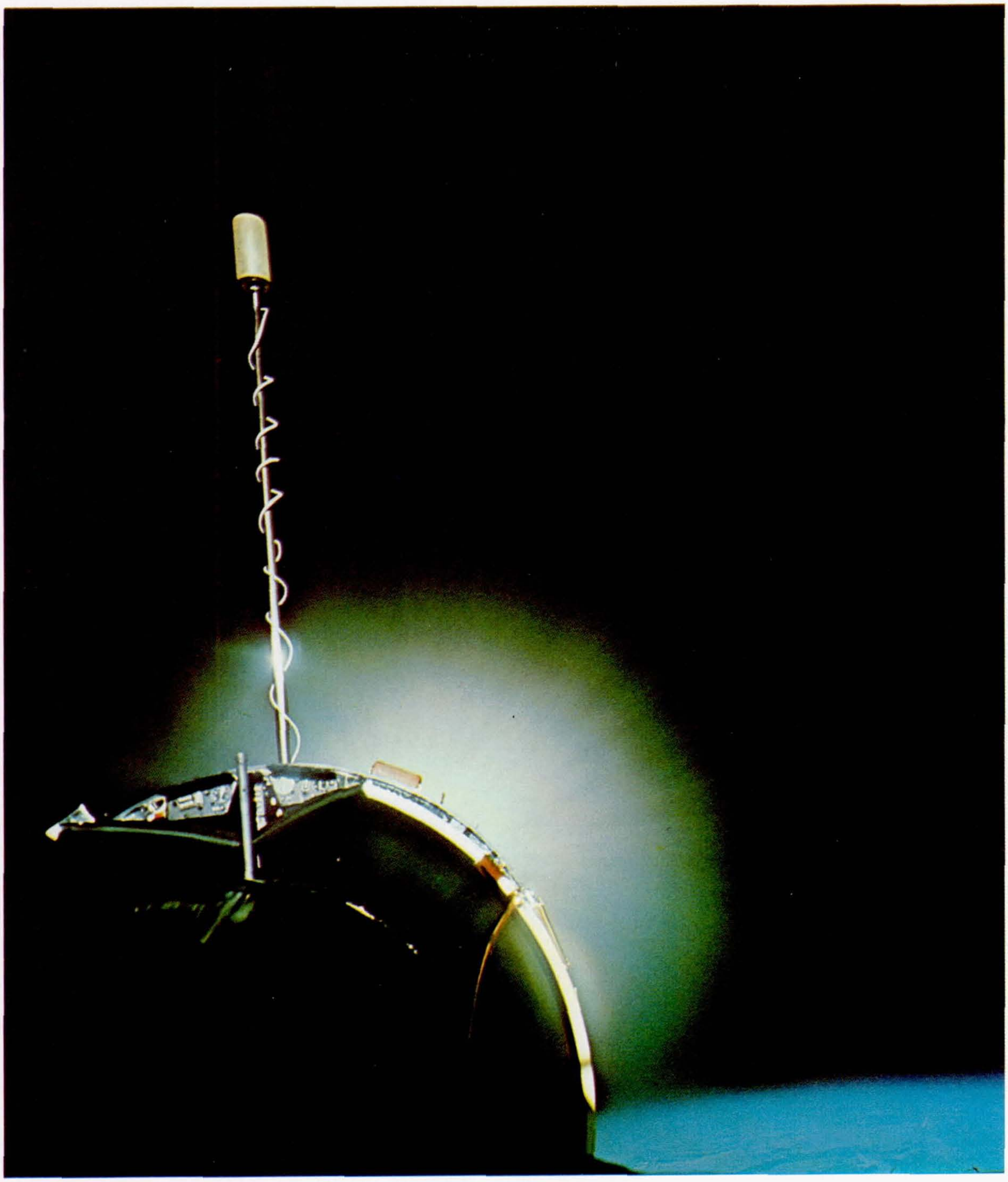


FIGURE 18–43.—Gemini X Primary Propulsion System firing.

Figure 18–43 is a photograph of the Gemini X spacecraft docked to the target vehicle with the target-vehicle status display panel and erected L-band antenna clearly visible. The glow around the target vehicle is caused by the firing operation of the Primary Propulsion System.

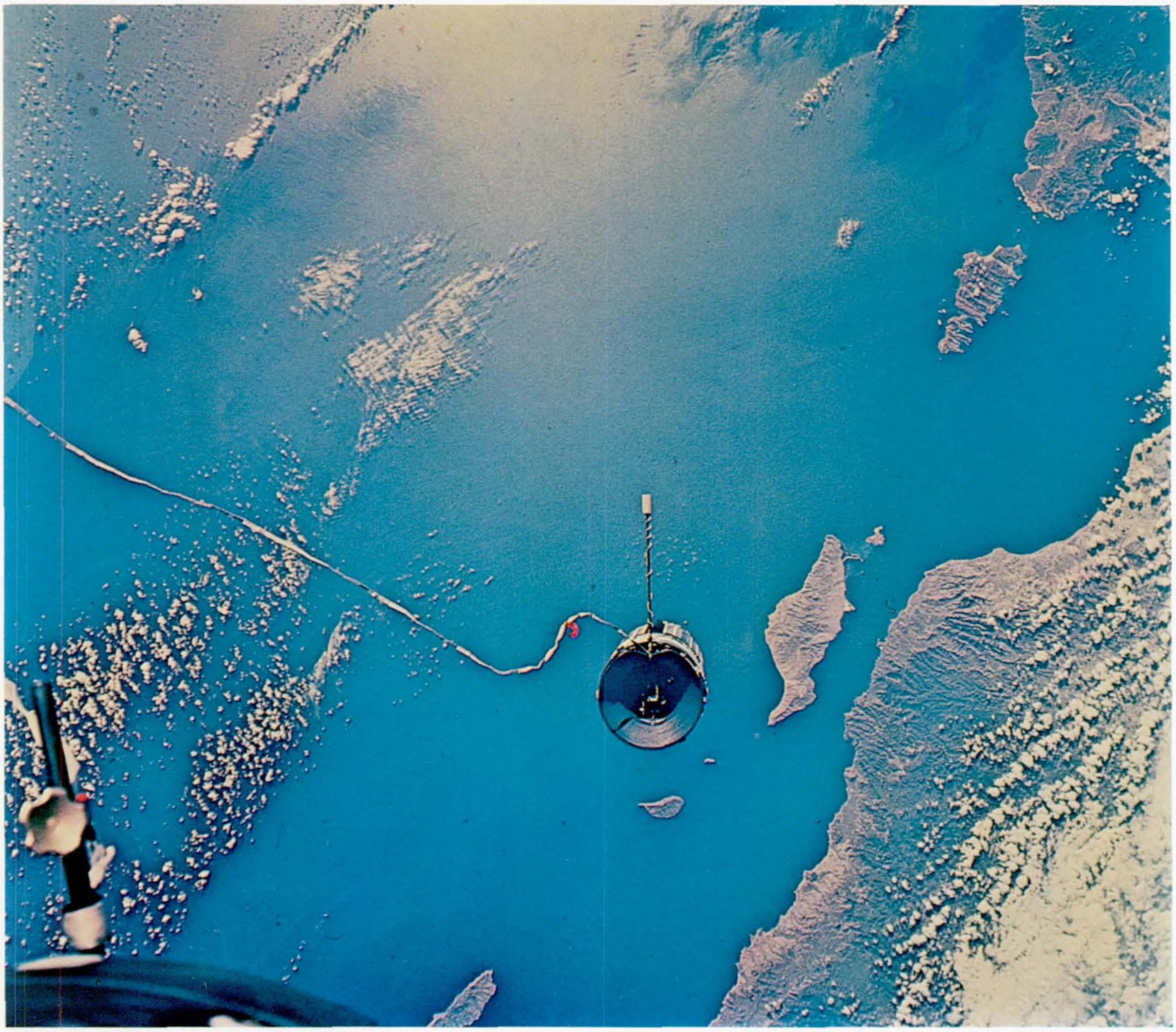


FIGURE 18–44.—Tethered target vehicle.

During the Gemini XI spacecraft/target-vehicle tether evaluation, a series of photographs was taken to show the exercise from the undocking and deployment of the tether until after the tether was jettisoned. Figure 18–44 was taken over Baja California at an altitude of about 185 miles and shows the target vehicle and the 100-foot Dacron tether.

FIGURE 18–45.—Extravehicular activity.

Figure 18–45 is one of a series of still and motion pictures taken of the Gemini XII extravehicular pilot working quite effectively while tethered to the target vehicle. This series of photographs demonstrates that man can do valuable and constructive work while extravehicular in space if the proper restraining devices are provided.

Concluding Remarks

The Gemini VII photograph of a distant full moon provides a fitting conclusion to a discussion of the photographic accomplishments of the Gemini Program (fig. 18–46). The 2400 exposures secured are all valuable, and a large number have provided information previously denied to the scientist. The two most important considerations furnished by this photographic record are found in the excellent historic documentation of the 10 manned missions, and in a clear demonstration of the feasibility of continuing with far more sophisticated photographic systems specifically designed to provide new and better information to the worldwide geoscientific community.

FIGURE 18–46.—Moon.

19. SCIENCE EXPERIMENTS SUMMARY

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Introduction

Results of the scientific experiments conducted during the Gemini Program through Gemini IX–A have been reported in a series of NASA publications (refs. 1 to 4) and in the scientific journals (refs. 5 to 7). This paper will therefore emphasize experiment results from the Gemini X, XI, and XII missions, but with some reference to results from earlier missions to emphasize the highlights of the program.

Gemini Science Experiments

Nineteen science experiments were flown during the Gemini Program (table 19–I). The table includes the principal investigators and their affiliations. The program was interdisciplinary in character, and was com-

TABLE 19–I.—*Gemini Science Experiments*

Number	Title	Principal investigator	Affiliation
S001	Zodiacal Light and Airglow Photography	E. P. Ney	University of Minnesota
S002	Sea Urchin Egg Growth Under Zero-G	R. S. Young	NASA Ames
S003	Frog Egg Growth Under Zero-G	R. S. Young	NASA Ames
S004[a]	Synergistic Effect of Zero-G and Radiation on White Blood Cells.	M. A. Bender	Atomic Energy Commission, Oak Ridge National Laboratory.
S005	Synoptic Terrain Photography	P. D. Lowman	NASA Goddard
S006	Synoptic Weather Photography	K. Nagler	U.S. Weather Bureau
S007	Spectrophotography of Clouds	F. Saiedy	U.S. Weather Bureau and University of Maryland.
S008	Visual Acuity in the Space Environment.	S. Q. Duntley	University of California, Scripps Institute.
S009	Nuclear Emulsions	M. M. Shapiro and C. Fichtel.	Naval Research Laboratory and NASA Goddard
S010	Agena Micrometeorite Collection	C. Hemenway	Dudley Observatory
S011	Airglow Horizon Photography	M. J. Koomen	Naval Research Laboratory
S012	Gemini Micrometeorite Collection	C. Hemenway	Dudley Observatory
S013	Ultraviolet Astronomical Photography	K. G. Henize	Dearborn Observatory
S026	Gemini Ion Wake Measurement	D. Medved	Electro-Optical Systems
S028[b]	Dim Light Photography	L. Dunkelman	NASA Goddard
S029	Libration Regions Photography	E. Morris	U.S. Geological Survey
S030	Dim Sky Photography/Orthicon	E. P. Ney and C. Hemenway.	University of Minnesota and Dudley Observatory.
S051	Sodium Cloud Photography	J. Blamont	Centre National de la Recherche Scientifique.
S064[c]	Ultraviolet Dust Photography	C. Hemenway	Dudley Observatory

[a] White blood cells and neurospora on Gemini XII.
[b] Flown on Gemini VI–A and VII as an operational experiment only.
[c] Flown on Gemini XII as an operational experiment only.

prised of investigations in the fields of astronomy, biology, geology, meteorology, and physics. Over half of the experiments were photographic in technique, indicating that the investigators wished to take advantage of the flight crew being available to guide and select the targets and to return the film for permanent record. A photograph frequently clarified data which otherwise were ambiguous.

Table 19–II shows the flight assignments of the science experiments and indicates that they were concentrated in the last half of the Gemini Program. There were 16 experiments with a total of 34 flight assignments in the last five Gemini missions.

Terrain and Weather Photography Experiments

Experiment S005, Synoptic Terrain Photography.—Experiment S005, Synoptic Terrain Photography, was devoted to a study of the Earth terrain, and was successfully performed on the Gemini IV, V, VI–A, VII, IX–A, X, XI, and XII missions; numerous useful pictures were also taken during Gemini III. Approximately 1400 color pictures were obtained, and are usable for geology, geography, or oceanography.

One of the most useful photographs (fig. 19–1), taken by the Gemini IV flight crew, shows an area about 80 miles wide of northern Baja California, Mexico. The geologic structure of this mountainous region is shown with remarkable clarity. For example, the Agua Blanca fault is visible as the series of alined valleys at lower left in the photograph, parallel to the frame of the spacecraft window. Numerous other faults, similarly expressed, are visible north of the Agua Blanca fault. The great need for more geologic information of this area is suggested by the fact that the Agua Blanca fault, one of the most prominent geologic structures in Baja California, was not discovered until 1956.

TABLE 19–II.—*Flights of Gemini Science Experiments*[a]

Experiment	Gemini mission										Number of flights
	III	IV	V	VI–A	VII	VIII	IX–A	X	XI	XII	
S001			+			–	+	+			4
S002	–										1
S003						–				+	2
S004	+								+		2
S005		+	+	+	+			+	+	+	7
S006		+	+	+	+			+	+	+	7
S007			+			–					2
S008			+		+						2
S009						–			+		2
S010						+	+	+		–	4
S011							+		+	+	3
S012							+	–		–	3
S013								+	+	+	3
S026								+	+		2
S028				+	+						2
S029										–	1
S030									+		1
S051										–	1
S064										–	1
Total											50

[a] + indicates experiment was successful; — indicates experiment was incomplete.

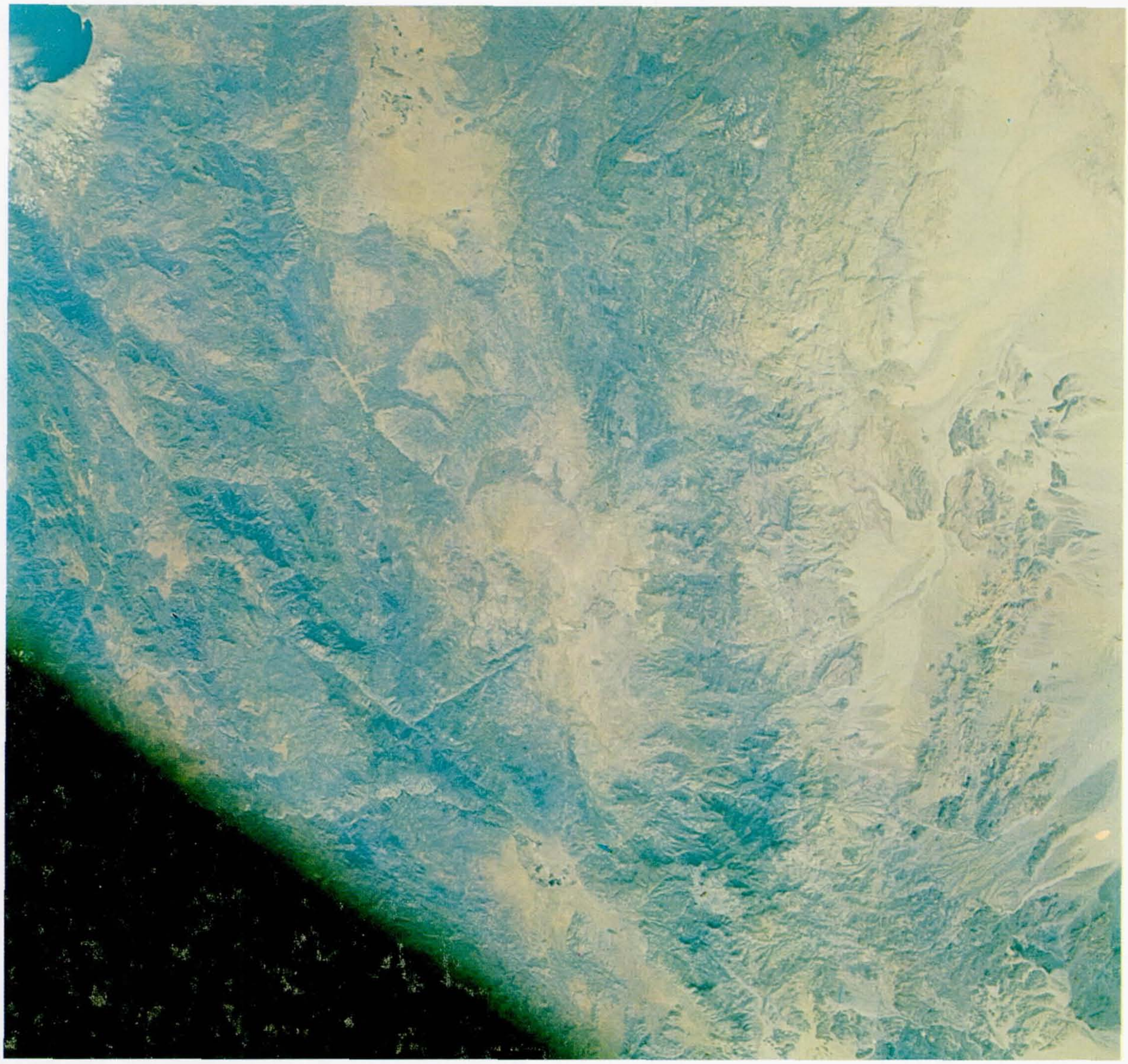

FIGURE 19-1.—Baja California.

One of the photographs (fig. 19–2) taken on Gemini XII appears to have considerable potential value in the study of continental drift. Proponents of this theory consider that the Red Sea, which structurally is a large graben or down-dropped block, represents incipient continental drift; that is, the Arabian Peninsula is considered to be drifting away from Africa and rotating. The photograph may provide new evidence on this possibility by providing a synoptic view of the regional geology.

Another Gemini XII photograph (fig. 19–3) demonstrates the potential value of orbital photography in studies of recent sedimentation. The portion of the Gulf of Mexico shown in the photograph has been extensively studied; and, when used in conjunction with the other photographs from space, may provide an extremely useful standard area for interpretation of similar pictures of other near-shore areas.

Experiment S006, Synoptic Weather Photography.—Figure 19–4 is a photograph

FIGURE 19-2.—Arabian Peninsula and the Red Sea.

taken during Experiment S006, Synoptic Weather Photography. The view is northwest over Camaguey Province, Cuba, and was taken August 23, 1965, by the Gemini V crew. A number of thunderstorms are visible along the southern coastline of Cuba. At the lower left of the photograph, some cumulus clouds off the northern coast appear to be

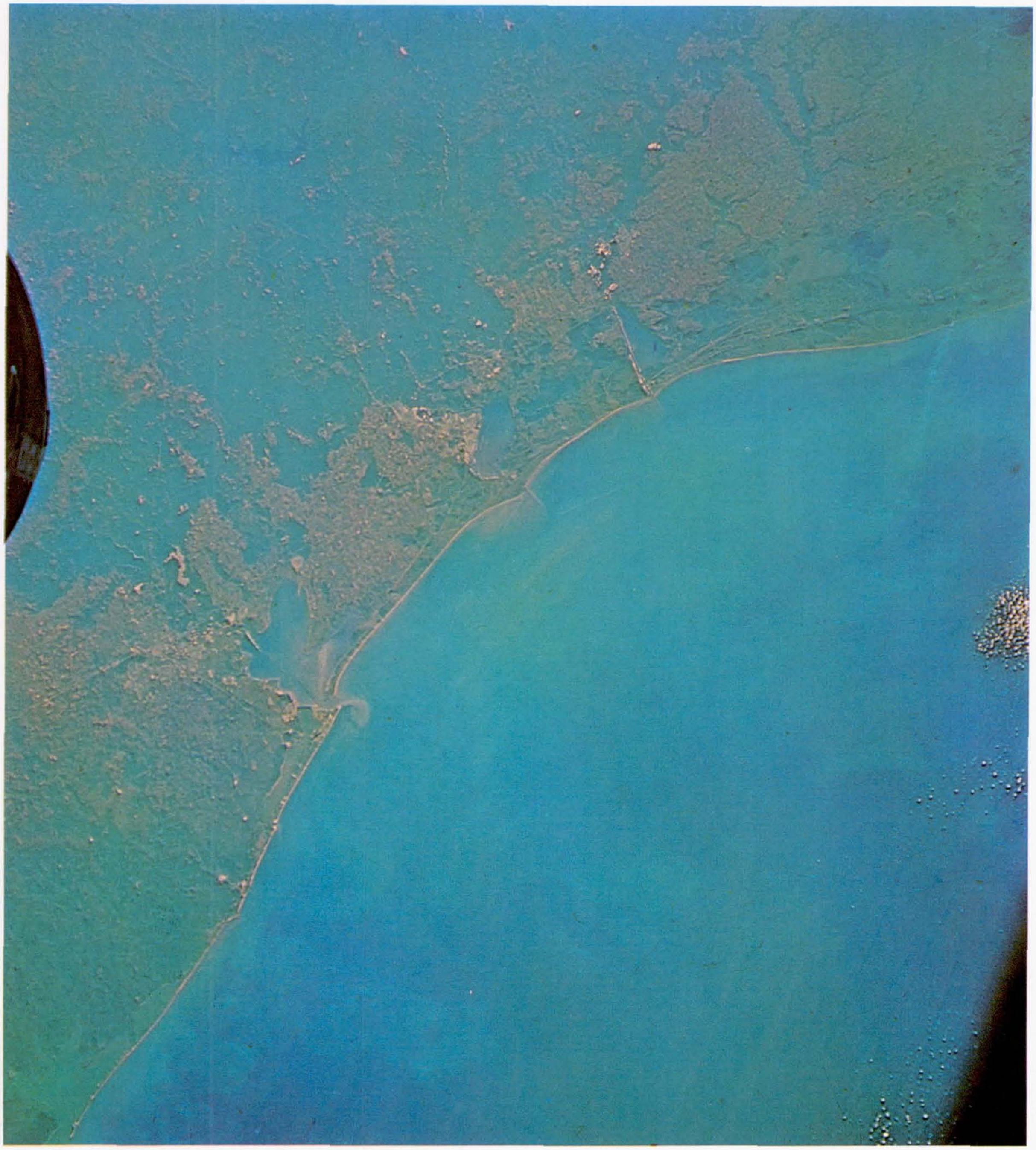

FIGURE 19-3.—Gulf of Mexico.

arranged in polygon-shaped, open cells. Several are hexagonal with taller cumulus clouds where the cell corners touch. The patterns illustrate a mesoscale cellular convection system that normally develops when relatively cool air passes over warmer water. Air is tending to sink within the cell and to rise near the borders where the cumulus clouds have formed. These open cells would be undetected by a standard satellite televi-

FIGURE 19-4.—Camaguey Province, Cuba.

sion picture because the cell walls are too thin, and the diameter is very small (ref. 8).

The photograph of southern India and Ceylon (fig. 19-5) was taken by the Gemini XI crew on September 14, 1966, with a superwide-angle lens attached to a 70-mm still camera. A clear zone, nearly free of clouds, and varying from 30 to 50 miles in width, extends along the west coast of India. The zone continues around the southern tip of India and into the Bay of Bengal where a line of convective clouds has formed several hundred miles offshore. The reason for the clear region is not entirely understood, but two possibilities have been suggested. First, the lack of clouds may be the result of drier air subsiding offshore which would have the tendency to suppress any cloud development. The sea breeze, or low-level winds which move the air toward land, may have caused

FIGURE 19–5.—India and Ceylon.

the air to descend in the clear region. Second, there may have been cold water welling up along the coast. Surface winds in India are northwesterly along the west coast and southwesterly along the east coast. The northwest winds will transport the surface water southeastward; however, the coriolis force will tend to deflect the water toward the southwest and away from the land. This would permit the welling up of cooler water along the coastline; also, the water temperature may have been sufficiently low to inhibit the development of cumulus clouds. A surface temperature change of about 1° may be enough to accomplish this. Southwest winds prevail to the east of India, and the coriolis force would act to transport the surface water in an easterly direction. Again, this would produce a favorable condition for water to well up near the coast. Measurements of seawater temperatures from ships are scarce, but the few available reports indicate that

the coastal waters were 1° or 2° cooler than sea-water temperatures farther west in the Arabian Sea.

Experiment S007, Spectrophotography of Clouds.—The objective of Experiment S007, Spectrophotography of Clouds, was to measure cloud-top altitudes. The experiment was first flown during Gemini V, and was also scheduled for Gemini VIII. Because of the early termination of the Gemini VIII flight, however, the experiment could not be accomplished. As a result, the National Environmental Satellite Center has designed a second-generation weather satellite that can measure cloud-top altitude and cloud thickness.

Experiment S051, Sodium Cloud Photography.—Experiment S051, Sodium Vapor Cloud, was flown on Gemini XII. The purpose of the experiment was to measure the daytime wind-velocity vector of the high atmosphere as a function of altitude between 62 and 93 miles. The measurements were to be obtained from the deformation of a rocket-made vertical sodium cloud. During the Gemini XII mission, two rockets were launched from Algeria. Although the second launching was easily visible from the ground, the sodium release was not seen by the flight crew. Even though they did not have visual sighting, the pilots photographed the region of the firing using a 70-mm still camera with a wide-angle lens. Unfortunately, shutter difficulties with the camera spoiled the exposed film. The experiment will be rescheduled for the Apollo Program.

Biological Experiments

Experiment S004, Synergistic Effects of Radiation and Zero-g on Blood and Neurospora.—Experiment S004, Synergistic Effect of Zero-g on White Blood Cells, was first carried during Gemini III, and was continued on Gemini XI with the addition of neurospora. A refrigeration unit was added to preserve the blood during the 4-day mission of Gemini XI. Gemini III was a three-orbit flight, and the blood could be recovered for analysis within 24 hours; therefore, refrigeration was not required.

An identical experimental package was established as a control in a laboratory at Cape Kennedy. It was activated simultaneously with the package in the spacecraft and was maintained under similar temperature conditions. Air-to-ground communications from the flight crew verified that the experiment was proceeding through the various stages exactly as planned.

The experiment was successfully conducted on the Gemini XI mission. The leukocyte-chromosome analysis of the blood showed no increase in the chromosome-deletion frequency in the flight samples over the ground control samples. The result does not confirm the preliminary results found on Gemini III. Preliminary results from the neurospora portion of the experiment carried on Gemini XI indicate no increase in the frequency of mutations in the flight samples. This part of the experiment analysis will require more time, but there now appears to be no observable synergism between radiation and space flight on white blood cells.

Experiment S003, Frog Egg Growth Under Zero-g.—The objectives of Experiment S003, Frog Egg Growth Under Zero-g, were to determine the effect of weightlessness on the ability of the fertilized frog egg to divide normally, and to differentiate and form a normal embryo. The experiment was performed in one package mounted on the right hatch in the spacecraft. The package had four chambers containing frog eggs in water with a partitioned section containing a fixative. Handles were provided on the outside of the package so the flight crew could activate the experiment.

During Gemini VIII, early cleavage stages were successfully obtained; however, the short duration of the flight did not permit formation of the later cleavage and developmental stages. During Gemini XII, the experiment was completely successful from a mechanical standpoint, and later embryonic stages were obtained. The 10 embryos in the fixation chambers appeared to be morpho-

logically normal. The five embryos which were unfixed were live, swimming tadpoles when the chamber was opened on board the recovery ship. Three of the embryos were morphologically normal; two were abnormal (twinning). The abnormalities, however, were not inconsistent with the controls, and no abnormalities can be ascribed to the flight at this time. The five surviving tadpoles died several hours after recovery, and were fixed for histological sectioning. The reason for death has not yet been ascertained; however, all the eggs will be sectioned for histological study to determine more conclusive results.

Visual Acuity Experiment

Experiment S008, Visual Acuity.—The ability of the flight crew to visually detect and recognize objects on the surface of the Earth was tested during Gemini V and VII in Experiment S008, Visual Acuity. Data from an inflight vision tester used during these flights showed no change in the visual performance of the crews. Results from the flight-crew observations of the ground site (fig. 19–6) near Laredo, Tex., confirm that visual performance during space flight was within the statistical range of the preflight visual performance, and that there was no degradation of the visual perception during space flight.

Astronomical Photography Experiments

Experiment S001, Zodiacal Light and Airglow Photography.—A series of excellent photographs for Experiment S001, Zodiacal Light Photography, was obtained during the Gemini IX–A flight. A photograph of the zodiacal light and the planet Venus is shown in figure 19–7. The apparent curvature of the airglow layer is due to the nature of the lens. The presence of Venus points out that the zodiacal light lies in the ecliptic plane. After sunset, a ground observer can see the zodiacal light. However, he must wait for twilight in order to see the dim-sky phenomena; even then the view is never free of the airglow, and not often of the glare from city lights. The photograph clearly distinguishes the cone-shaped zodiacal light from the narrow airglow layer visible just above the moonlit Earth. Heretofore, only an artist's drawing has been able to represent the zodiacal light as it would appear to a ground observer without the visual distractions of city lights, airglow, and faint sources of celestial light.

Experiment S011, Airglow Horizon Photography.—Experiment S011, Airglow Horizon Photography, was conducted during Gemini XI and XII as well as Gemini IX–A. The crews used the 70-mm general-purpose still camera in the f/0.95 configuration to photograph the night airglow layer with the Earth's limb. The camera was mounted so that exposures of 2 to 50 seconds could be obtained through the right hatch window. The objective was to obtain worldwide measurements of airglow altitude and intensity.

The camera filter system registered the spectral regions of 5577 angstroms (oxygen green) and 5893 angstroms (sodium yellow) side by side but separated by a vertical dividing line. Filter bandwidths were 270 and 380 angstroms, respectively. In figure 19–8, an example of the split-field photography taken during Gemini IX–A is shown. This is a 5-second exposure looking west. The corresponding star field is shown in figure 19–9, and the bright stars Procyon and Sirius are visible in the airglow layer. The pictures are being analyzed for possible height variations in the two layers.

During Gemini XI, an additional 6300-angstrom (red) filter with a bandwidth of 150 angstroms was provided to obtain photographs in a higher orbit; however, no photographs were obtained because of a camera malfunction. On Gemini XII, the split-field filter was removed, and the entire field was exposed with 40-angstrom-wide filters in alternate green and yellow bands. The 6300-angstrom filter was not used during Gemini XII because a high-altitude orbit could not be achieved. Much more work remains on airglow research, but the results obtained from Experiment S011 have demonstrated several useful lines of approach.

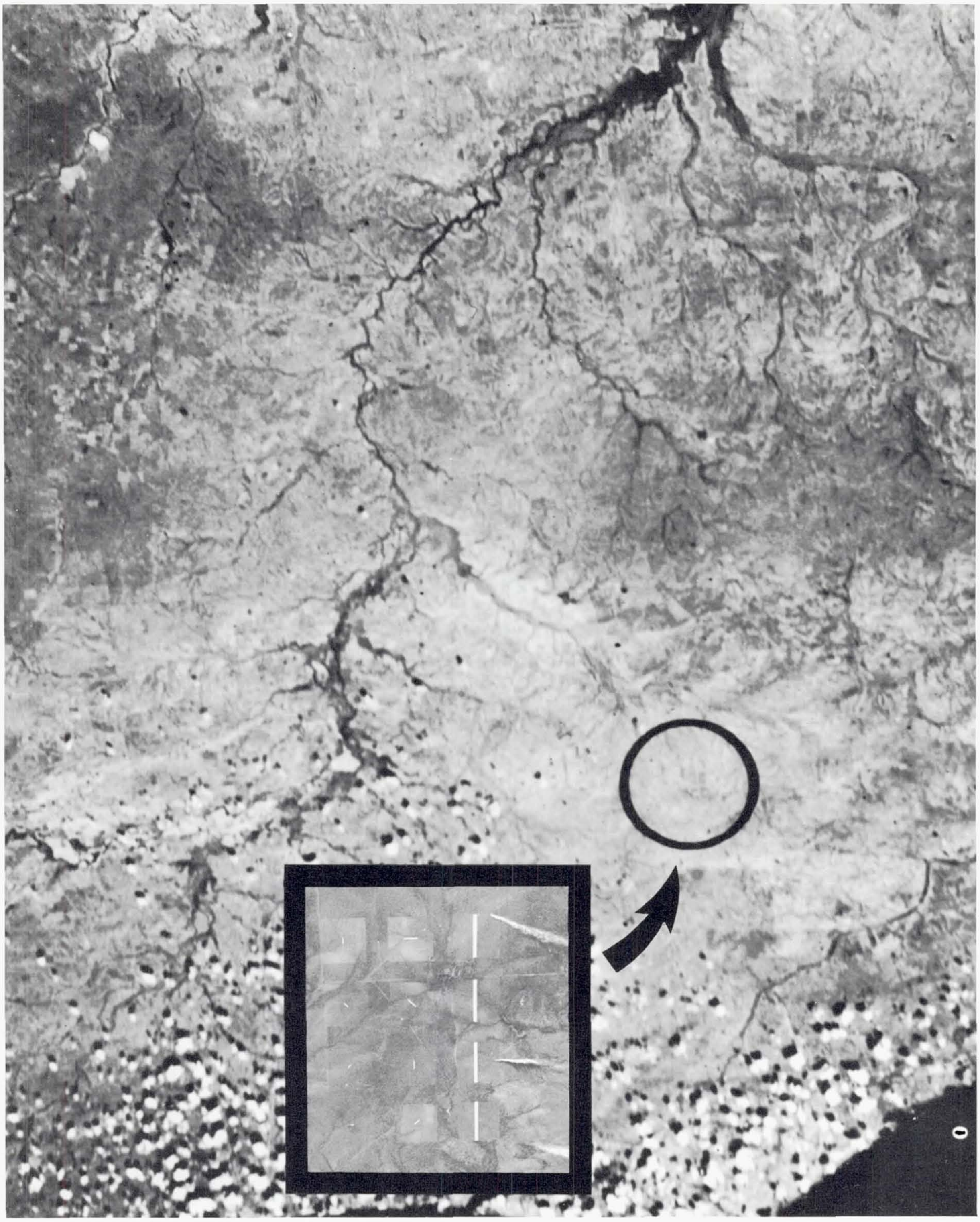

FIGURE 19-6.—Experiment S008 visual acuity ground pattern near Laredo, Tex. The inset area is an aerial photograph of the ground pattern.

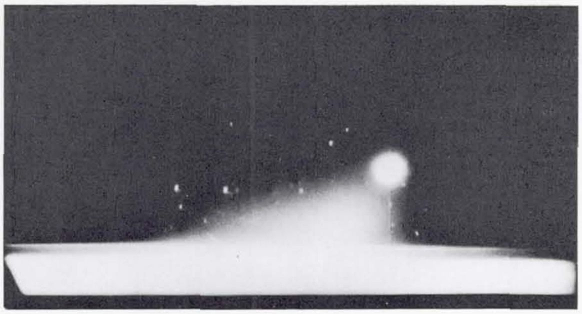

FIGURE 19–7.—Zodiacal light and planet Venus. Airglow is seen as a narrow band above the moonlit Earth.

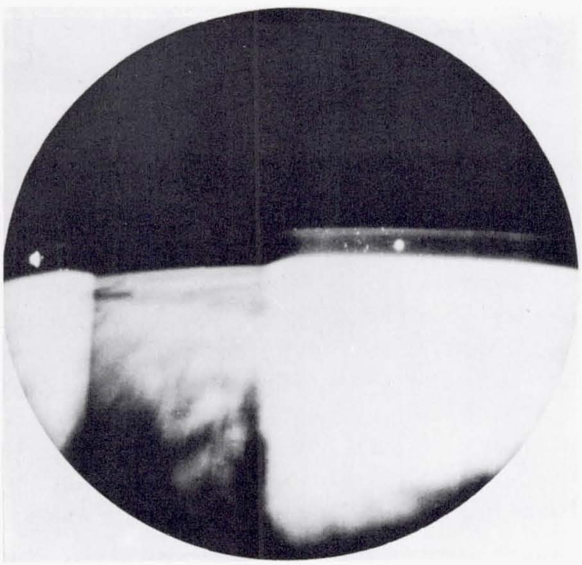

FIGURE 19–8.—Star field seen in airglow split-field filter photography.

Experiment S030, Dim Sky Photography/Orthicon.—Experiment S030, Dim Sky Photography/Orthicon, was conducted during Gemini XI. The image orthicon system of Experiment D015, Night Image Intensification, was used to obtain 415 pictures of airglow in a 360° sweep. At times, the image orthicon sensitivity was so great that these pictures were almost overexposed. There is some indication of a splitting of the airglow into two layers. The system had an automatic gain control with the sensitivity varying constantly; this makes calibration of the pictures difficult and time consuming. Figure 19–10 shows two sample frames. In figure 19–10(*b*), the blot above the airglow is due to the cathode tube.

Experiment S029, Libration Regions Photography.—The purpose of Experiment S029, Libration Regions Photography, was to investigate by photographic techniques the libration points of the Earth-Moon system to determine the possible existence of clouds or particulate matter orbiting the Earth in these regions. The Gemini XII mission was the first mission on which any libration region was available for photography. The 70-mm still camera with a wide-angle lens was used and the results are not immediately obvious, but appear to be less than satisfactory. Isodensitometry will be run on several exposures, but at this time the study is not expected to yield positive results.

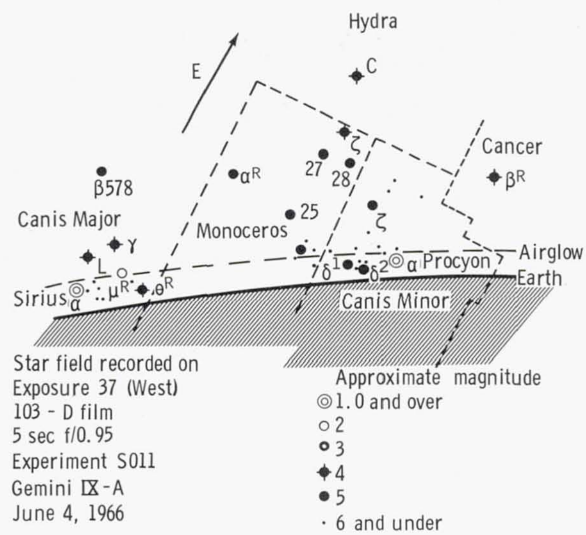

FIGURE 19–9.—Split-field filter photography showing Procyon and Sirius (from Norton's Atlas, maps 7 and 8).

Micrometeorite, Cosmic Ray, and Ion Wake Experiments

Experiment S010, Agena Micrometeorite Collection.—As part of Experiment S010, Agena Micrometeorite Collection, a package for recording micrometeorite impacts was installed on the Gemini VIII target vehicle.

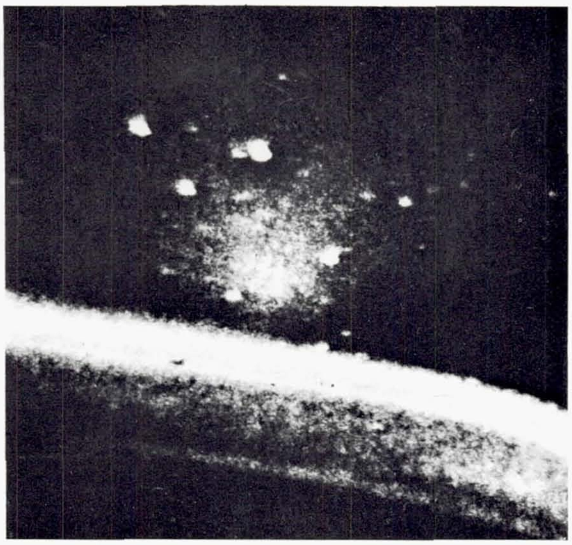

FIGURE 19–10.—Airglow photographs obtained from image orthicon system. (*a*) Near Canopus; (*b*) Near Arcturus.

After approximately 4 months in orbit, the package was recovered by the Gemini X flight crew. Optical scanning at the Dudley Observatory of the four stainless-steel slides on the outside of the box (protected from launch) have revealed at least four craters larger than 4 microns; these appear to be hyperballistic. Figure 19–11 shows one crater which has a diameter of 200 microns, a depth of 35 microns, and a lip height of 25 microns. This crater has been named Crater Schweickart for the astronaut who suggested that there be an outside collection area on the micrometeorite package on which micrometeorites could impact, even though the pilot did not open the package during extravehicular activity. The Dudley Observatory has installed a stereoscan electron microscope which will permit scanning the surface in the original form, thus minimizing sample contamination. Results of this work are not yet known.

During the Gemini XII mission, the extravehicular pilot opened the package on the Gemini XII target vehicle and exposed the sensitive collection plates to the space environment. The package was intended to be retrieved during some future mission; however, it is expected that the target vehicle will reenter the Earth's atmosphere before the package can be recovered.

Experiment S012, Gemini Micrometeorite Collection.—The package for Experiment S012, Gemini Micrometeorite Collection, was successfully recovered from the Gemini IX–A spacecraft adapter section after an exposure of over 16 hours. For comparison, another package was exposed for 6 hours during the Gemini XII flight (fig. 19–12). This experi-

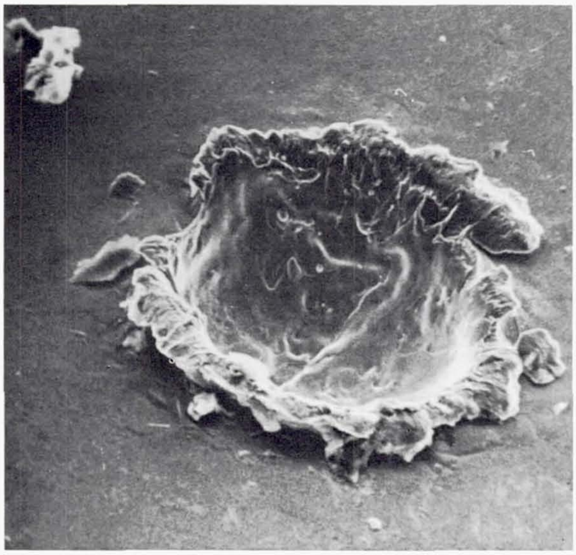

FIGURE 19–11.—Micrometeorite impact crater.

FIGURE 19-12.—Gemini XII pilot retrieving micrometeorite collection package.

ment had a number of guest investigators from the United States and abroad. A full report of the results can be made only after the impact craters have been carefully scanned with the electron microscope. A preliminary examination of 1 square centimeter of the surface of the Gemini XII package has revealed no impacts. Much work remains to be done to complete the analysis of this experiment.

Experiment S009, Nuclear Emulsions.—During the extravehicular activities of the Gemini XI mission, the pilot retrieved the package for Experiment S009, Nuclear Emulsions, from the exterior surface of the spacecraft adapter section. The Naval Research Laboratory has finished the initial scan of about one-fourth of the emulsion stacks, and has found about 700 tracks which must be sorted according to origin (either inside or outside the spacecraft) during activation of the experiment. It is estimated that about 200 of these tracks will belong to the experiment. If this percentage can be used throughout the analysis of the experiment, then it may be expected that between 1000 and 2000 usable tracks will have been recorded.

At the present time, the experimenters are performing a special kind of scan to obtain information on the appearance of the tracks in order that a preliminary report can be prepared on this aspect. Later, a detailed scanning, which is expected to require 1 to 2 years to complete, will provide information on the light nuclei. The experiment group at the Goddard Space Flight Center is concentrating on detailed scanning of the emulsion stacks in order to make progress on the analysis of the light nuclei, the main objective of the experiment.

Experiment S026, Gemini Ion Wake Measurement.—Experiment S026, Ion Wake Measurement, was conducted during Gemini X and XI. A great deal of ambient data were obtained during Gemini X, and all requested modes were performed during Gemini XI. Reduction of the data will be a rather painstaking task that will necessitate coordination of all available records of times and activities during the operation. It is believed that this experiment can result in a very useful method for mapping the actual wake of a vehicle.

Ultraviolet Photography Experiments

Experiment S064, Ultraviolet Dust Photography.—Experiment S064, Ultraviolet Dust Photography, was designed to provide ultraviolet photographs of dust in the Earth atmosphere, and was carried on Gemini XII. The experiment used black-and-white film in the 70-mm still camera with an ultraviolet lens. A series of sunrise photographs was made in the ultraviolet region; however, due to the many electrostatic marks in the film, very little information has been determined.

Experiment S013, Ultraviolet Astronomical Photography.—Experiment S013, Ultraviolet Astronomical Photography, used the 70-mm general-purpose still camera with an ultraviolet lens. Similar but less severe trouble was experienced with the electrostatic marks as on Experiment S064. An ultraviolet spectrum of the bright star Sirius was obtained on the Gemini XII mission (fig. 19-13). The Balmer series of hydrogen appears at the right. The Mg II doublet at 2800 angstroms and several other weak, sharp lines of Fe II appear at the left. The exposure was 20 seconds. Figure 19-14, a spectrum of

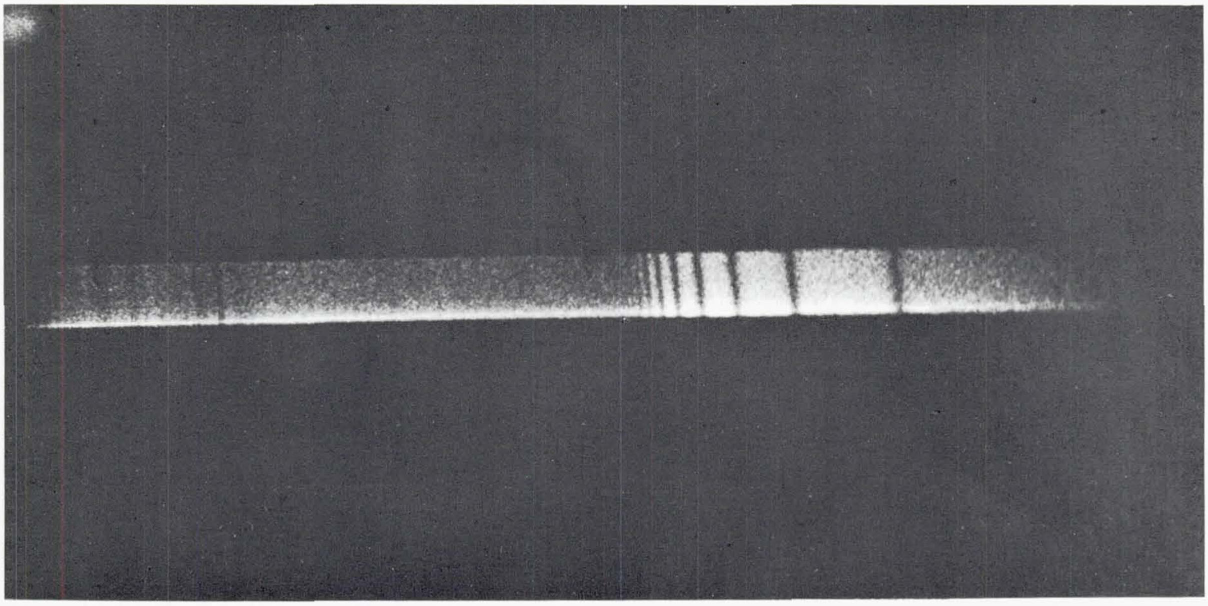

FIGURE 19–13.—Grating ultraviolet spectrum of Sirius.

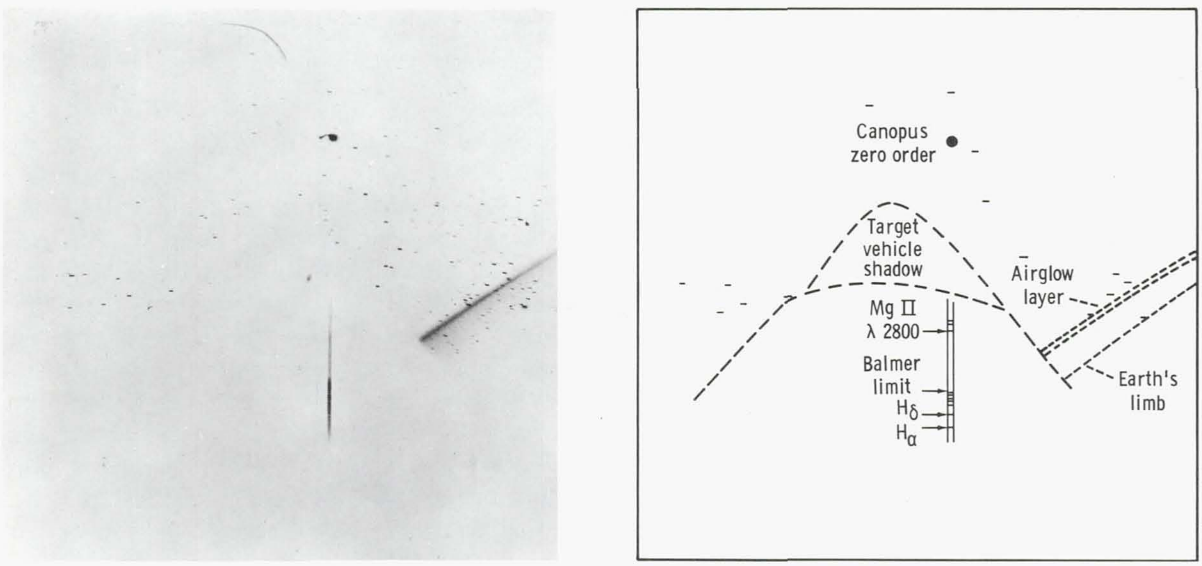

FIGURE 19–14.—Grating ultraviolet spectrum of Canopus.

the solar-type star Canopus, was obtained from Experiment S013, Gemini XI, frame 98, Dearborn Observatory, Northwestern University. This spectrum was especially useful for calibration purposes when compared with the solar spectra obtained from rockets.

In addition to the two remarkable grating spectrograms, several prism spectrograms were obtained. The prism resulted in a lower dispersion, but provided significant information on a large number of stars. The photographs recorded stars of fainter magnitude than was anticipated, and there will be work to be done on the ultraviolet energy curves for many months as a result of the photographs. Figure 19–15 is a reproduction of a

FIGURE 19-15.—Prism ultraviolet spectrogram of Cygnus region. The spacecraft shadow is on the left.

prism spectrogram of Cygnus and is typical of the exposures obtained during this experiment.

Since the spacecraft windows did not admit ultraviolet light, the experiment would not have been possible without the extravehicular capability of the pilot. Thus far, it has been possible to obtain only a few ultraviolet stellar spectra from rocket flights. During the three trials of this experiment during the Gemini Program, considerable ultraviolet information was obtained and should be especially useful in planning future ultraviolet experiments for manned flights.

Concluding Remarks

Significantly, Gemini experience has shown much about what can be done in the area of experiments for manned operations, and has uncovered some of the pitfalls. In summary, it seems clear that the same attention must be paid to all details of the experiments, crew procedures, and crew training that has been devoted to spacecraft operation. When this is possible, the return of new scientific information will increase. It is safe to say that scientific information has increased exponentially since Project Mercury, and is expected to continue to follow an upward curve. The interest the flight crew and the engineers have shown in the experiments has nearly matched the keen interest of the investigators, and will continue to be a large factor in future manned space-flight experiments.

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20. DOD/NASA GEMINI EXPERIMENTS SUMMARY

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Introduction

The DOD/NASA Gemini Experiments Program consisted of 15 experiments, sponsored by several development agencies of the Department of Defense. Experiments were selected which could be accomplished with minimum effect on the Gemini Program, and which would contribute to the solution of the evaluation of space technical development problems of interest to DOD. Participation in the experiments program provided a means for DOD elements to acquire data and operations experience for evaluation of the ability of man to accomplish missions in space, and provided a mechanism for the timely flow of manned space-flight development information between NASA and DOD.

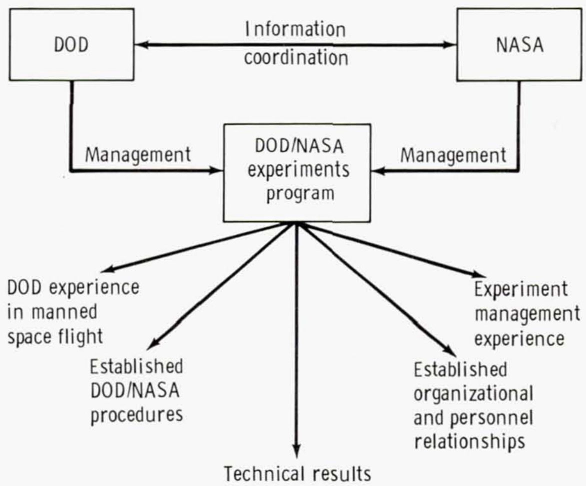

FIGURE 20-1.—DOD/NASA Gemini experiments program results.

Program Accomplishments

Although the technical result outwardly appeared to be the major program accomplishment, several other results of equal importance were obtained during the joint DOD/NASA implementation of the experiments program (fig. 20-1).

DOD Experience in Manned Space Flight

Through the experiments program, DOD participation was broadened to include experience in spacecraft, crew, and operational activities in addition to the experience acquired through program responsibilities for the Gemini Launch Vehicle, the Gemini Agena Target Vehicle, and the DOD Range Support. The direct working association with the Gemini Program permitted DOD development agencies at all levels to gain practical experience in manned space-flight development.

Procedures and Experience

Implementation of the DOD/NASA Gemini Experiments Program required the designation of responsibilities and development procedures for joint management. Organizational elements and procedures have been established for future joint activity, and experience has provided a better understanding of such joint activity for future planning.

Establishment of Organizational and Personnel Relationships

One of the most significant results of DOD participation in the Gemini Program was the development of organization knowledge and the establishment of personnel relationships which facilitate the flow of manned space-flight development information between DOD and NASA agencies. Active participation in the Gemini Program provided a working-level insight which facilitated the recognition

of information significant to DOD programs; and provided personnel and organizational rapport which expedited NASA/DOD support. The established relationships have been most beneficial in liaison with the Apollo and Apollo Applications Programs.

Experiment Management Information

The program has developed some specific conclusions related to management of experiments conducted as secondary objectives of a basic program. Although the following conclusions are of secondary importance as experiment program results, they are considered significant for future management planning.

Each experiment should be scheduled on at least two flights. The probability of successful attainment of experiment objectives on a single attempt is too low to risk high experiment development cost. Because experiments were considered as secondary mission objectives, successful experiments were highly dependent on the accomplishment of primary mission objectives. Occasions of higher-than-nominal fuel usage, of reduced electrical power, and of other mission problems resulted in the curtailment of experiment activities and the inability to obtain experiment objectives. A second experiment flight was essential to success in these cases.

The experiment interface with the spacecraft should be minimized. A simplified interface will generally result in higher reliability, in lower integration cost, in greater operational flexibility, and in reduced effect of basic spacecraft hardware change.

Colocation of the experiment manager with the agency accomplishing the basic program management provides a significant advantage for all experiments, and is essential for those experiments which have complex interfaces with the basic program. Experiments are developed concurrently and interact with the basic program development, and the experiment managers must develop detailed awareness of basic program effects and constraints to efficiently integrate the experiments. In dynamic development programs, this awareness can be developed only through day-to-day contact with the management personnel accomplishing the basic program.

The experimenter must emphasize the support of flight-crew training. The crew must represent the experimenter at a crucial point in what is normally an advanced experimental process; therefore, the crew must possess maximum understanding of experimental objectives and procedures. Training simulations using equipment identical to flight hardware are highly desirable. Direct contact between the experimenter and the crew during experiment training is essential.

Careful consideration should be given to scheduling the secondary experiments which require a large amount of crew operational time. Because such experiments have a greater probability of being affected by primary program contingencies, they have a lesser probability of success.

Technical Results

Program technical results were good. Of the 15 programed experiments, 11 were successfully completed (table 20–I). The four remaining experiments were carried on Gemini missions, but flight tests were not completed. Although flight test objectives of these four experiments were not completely attained, valuable data and experience were acquired during experiment development.

Experiments D001, D002, and D006, Basic Object, Nearby Object, and Surface Photography.—Photography accomplished during Project Mercury was oriented to a broad area of coverage with no specific pointing or tracking requirements. Experiments D001, D002, and D006 were designed to investigate the ability of man to acquire, track, and photograph objects in space and on the ground on a preplanned basis using photographic equipment with a small field of view. Acquisition of preplanned photographs of the Moon, planets, and points on the surface of the Earth clearly demonstrated the capability. The photograph of Love Field, Dallas, Tex. (fig. 20–2), is representative of the data acquired.

TABLE 20-I.—*DOD/NASA Gemini Experiments*

Experiment no.	Title	Flight	Result
D001	Basic Object Photography	V	Complete
D002	Nearby Object Photography	V	Incomplete
D003	Mass Determination	VIII, XI	Complete
D004	Celestial Radiometry	V, VII	Complete
D005	Star Occultation Navigation	VII, X	Complete
D006	Surface Photography	V	Complete
D007	Space Object Radiometry	V, VII	Complete
D008	Radiation in Spacecraft	IV, VI-A	Complete
D009	Simple Navigation	IV, VII	Complete
D010	Ion-Sensing Attitude Control	X, XII	Complete
D012	Astronaut Maneuvering Unit	IX-A	Incomplete
D013	Astronaut Visibility	V, VII	Complete
D014	UHF/VHF Polarization Measurements	VIII, IX-A	Incomplete
D015	Night Image Intensification	VIII, XI	Complete
D016	Power Tool Evaluation	VIII, XI	Incomplete

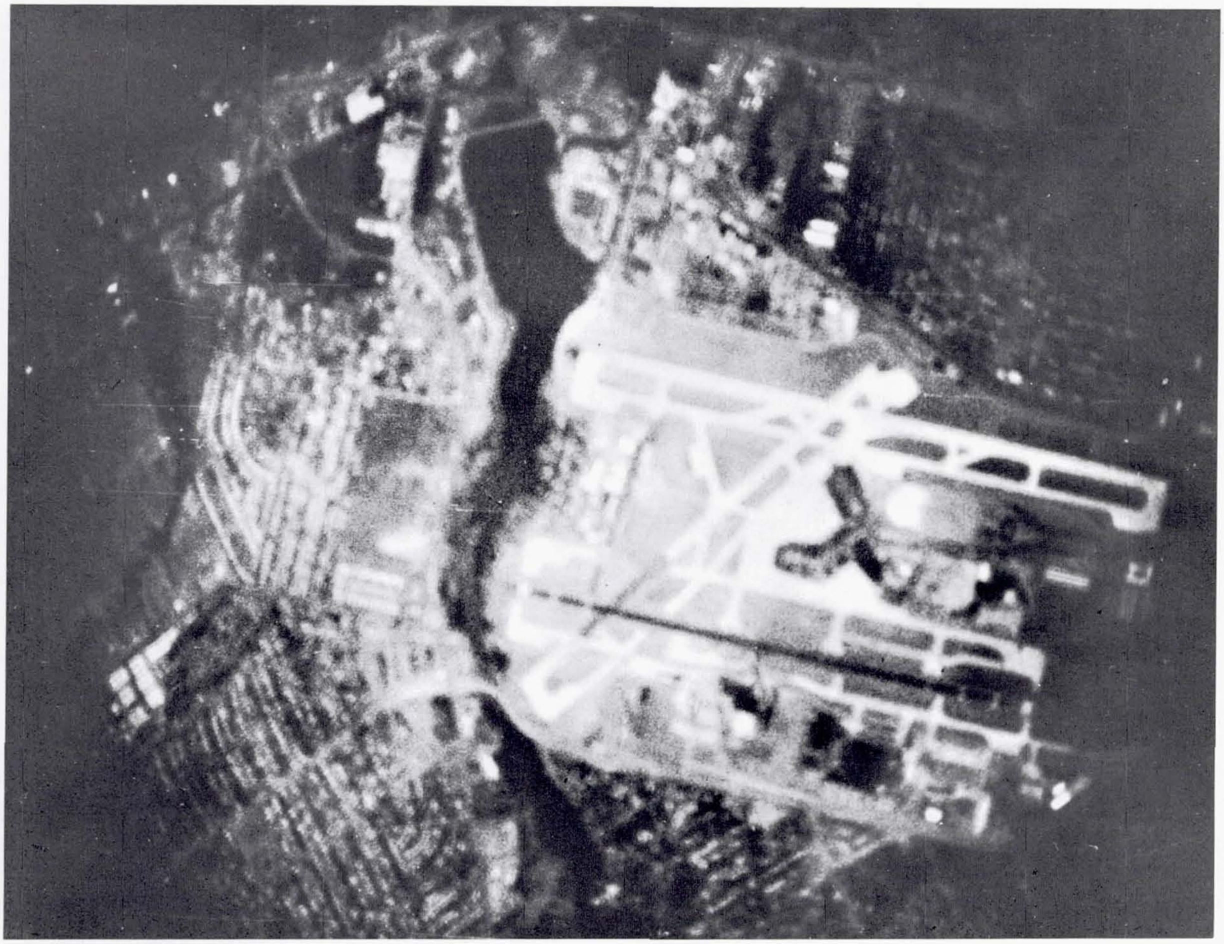

FIGURE 20-2.—Love Field, Dallas, Tex. Photograph taken during the Gemini V mission.

Experiment D003, Mass Determination.—Experiment D003 demonstrated the feasibility and the accuracy of determining the mass of an orbiting object by thrusting on it with a known thrust and measuring the resulting change in velocity. The experiment was conducted during the Gemini XI mission and used a Gemini Agena Target Vehicle as the orbiting object. The mass as determined from the experiment procedure was compared with the target-vehicle mass as computed from known launch weight and expendable usage to determine the accuracy of the method.

Experiment D003 investigated two methods of data acquisition. The Telemetry Method was based upon the telemetry data from the spacecraft computer and Time Reference System. The Astronaut Method was based upon data displayed by the spacecraft Manual Data Insertion Unit and the event timer, and recorded by the flight crew. In both cases, spacecraft thrust was determined from a calibration firing of the spacecraft propulsion system with the spacecraft and target vehicle undocked. Resulting spacecraft thrust F_c was computed from

$$F_c = \frac{M_G \Delta V}{\Delta t}$$

where

M_G=mass of spacecraft, slugs

ΔV=measured incremental velocity, ft/sec

Δt =measured thrusting time interval, sec

Data from the calibration and mass-determination firings for each method investigated are shown in figures 20–3 and 20–4, and in table 20–II. Using these data, the mass of the target vehicle was computed from

$$M_{A_c} = \frac{F_c(\Delta t)}{\Delta V} - M_{G_c}$$

where

M_{A_c}=target-vehicle mass, slugs

F_c =maneuvering thrust of the spacecraft, lb

Δt =measured thrusting time interval, sec

ΔV =measured incremental velocity, ft/sec

M_{G_c}=spacecraft mass, slugs

TABLE 20–II.—*Manually Observed Data, Astronaut Method*

Experiment operations	Time, sec	Velocity change, ft/sec
Calibration maneuver	11	9.8
Mass determination maneuver	7	2.94

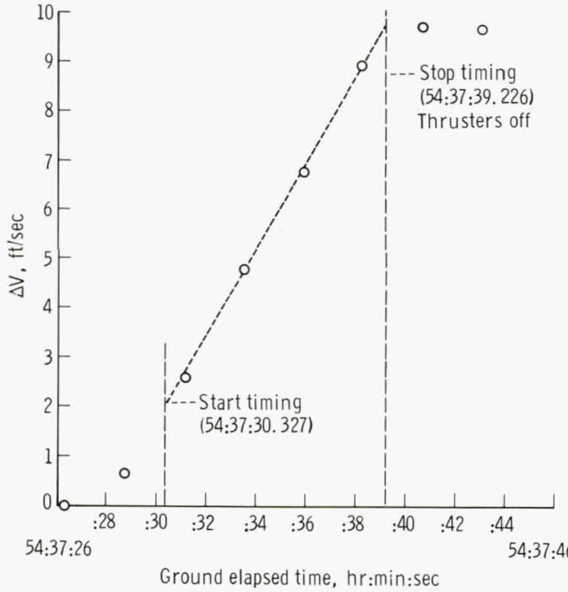

FIGURE 20–3.—Calibration maneuver. Experiment D003, Mass Determination, telemetry method.

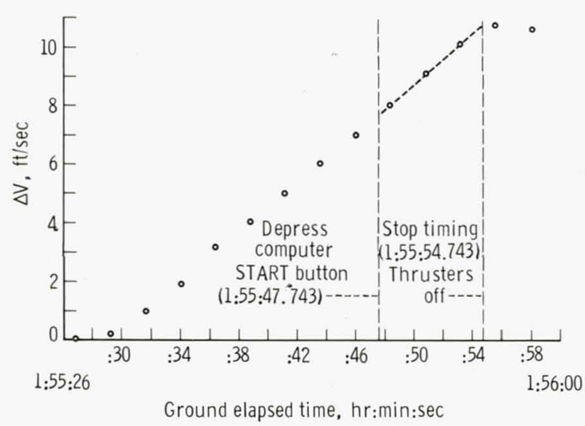

FIGURE 20–4.—Experiment D003, mass determination maneuver, telemetry method.

Comparison with target-vehicle mass as computed from launch weight and known expendables indicated a variation in results of 4.9 percent for the Telemetry Method and 7.6 percent for the Astronaut Method (table 20–III).

Experiment D004/D007, Celestial Radiometry/Space Object Radiometry.—Experiment D004/D007 was conducted during the Gemini V and VII missions. The spacecraft carried two interferometer spectrometers and a multichannel spectroradiometer for measurements of selected sources in the bands indicated in figure 20–5. Equipment characteristics are shown in tables 20–IV, V, and VI. Discrete measurements were made on 72 subjects such as the following:

(1) Gemini VI–A spacecraft thruster plume
(2) Rendezvous Evaluation Pod
(3) Gemini Launch Vehicle second stage
(4) Moon
(5) Stars
(6) Sky background
(7) Space void
(8) Star-to-horizon calibration
(9) Horizon-to-Earth nadir calibration
(10) Large ground fire
(11) Night and day, land and water subjects
(12) Sunlit cloudtops
(13) Moonlit cloudtops
(14) Lightning
(15) Missile-powered flight

TABLE 20–III.—*Weight of Target Vehicle Determined by Experiment D003*

Method	Actual weight, lb [a]	Calculated weight, lb	Variation in weight, lb	Percent
Telemetry	7268	6912	—356	—4.9
Astronaut	7268	7820	552	7.6

[a] Computed from launch weight and usage of consumables.

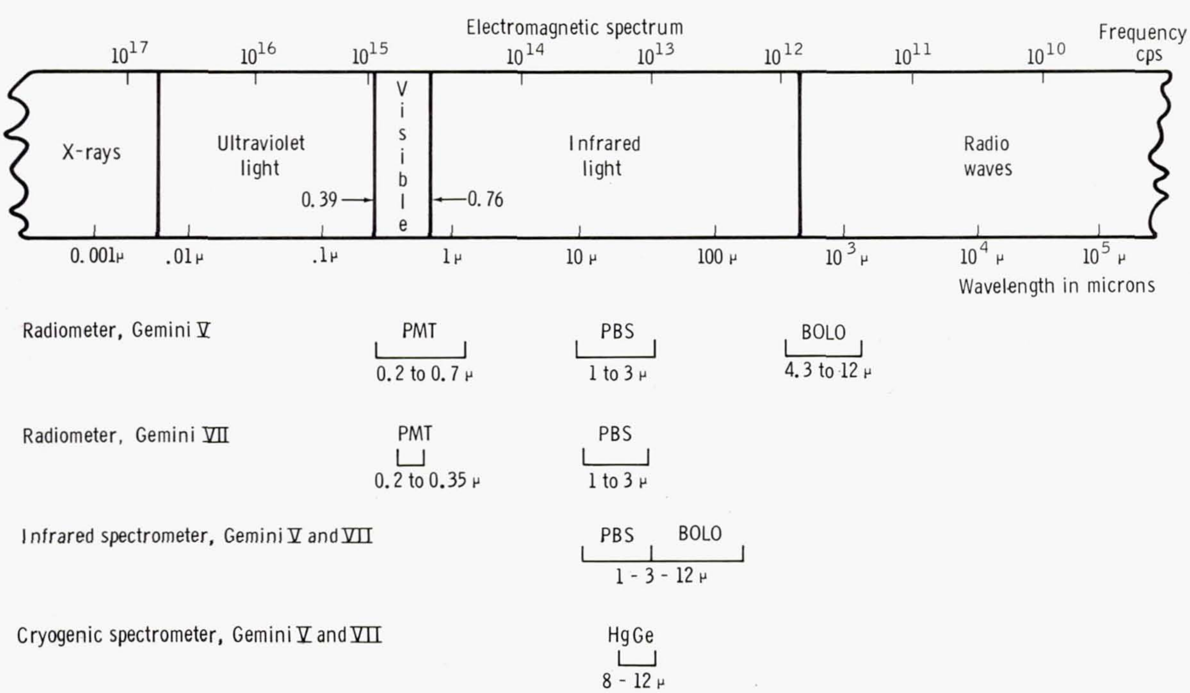

FIGURE 20–5.—Experiment D004/D007 equipment coverage.

TABLE 20–IV.—*Radiometer Instrument Parameters*

Weight, lb	17.5		
Power input, watts	14		
Field of view, deg	2		
Optics, in. Cassegrain	4		
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	.22	1.053	4.30
	.24	1.242	4.45
	.26	1.380	6.00
	.28	1.555	8.0
	.30	1.870	9.6
	.35	2.200	15.0
	.40	2.820	
	.50		
	.60		
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	Bolometer
Spectral band, μ	0.2–0.35	1.0–3.0	
Nominal filter width, μ	0.03	0.1	
Filters used, μ	.2200	1.053	
	.2400	1.242	
	.2500	1.380	
	.2600	1.555	
	.2800	1.870	
	.2811	1.900	
	.2862	2.200	
	.3000	2.725	
	.3060	2.775	
		2.825	
Dynamic range	10^5 in 4 discrete steps	10^3 log compressed	

TABLE 20–V.—*Parameters of the Cryogenic Interferometer/Spectrometer*

Weight (with neon), lb	33.5
Power input, watts	6
Field of view, deg	2
Optics, in. Cassegrain	4
Detector	Mercury-doped germanium
Spectral band, microns	8 to 12
Dynamic range	10^3 automatic gain changing
Coolant	Liquid neon

TABLE 20–VI.—*Parameters of the Infrared Spectrometer*

Weight, lb	18.5
Power input, watts	8
Resolution, cm^{-1}	40
Field of view, deg	2
Optics, in. Cassegrain	4

Detectors	Lead sulfide	Bolometer
Spectral band, μ	1–3	3–15
Dynamic range	10^3 automatic gain changing	10^3 automatic gain changing

The measurements on items (2), (3), (5), (7), and (8) were accomplished with the cryogenic-neon-cooled spectrometer which was successfully used in orbit for the first time during this experiment. New information was obtained on the development and the use of cryogenically cooled sensor systems for space application. Included in the experiment results were the first infrared measurements of a satellite made by a manned spacecraft outside the atmosphere (fig. 20–6). The experiment demonstrated the advantages of using manned systems to obtain basic data with the crew contributing identification and choice of target; choice of equipment mode; ability to track selectively; and augmenting, validating, and correlating data through on-the-spot voice comments.

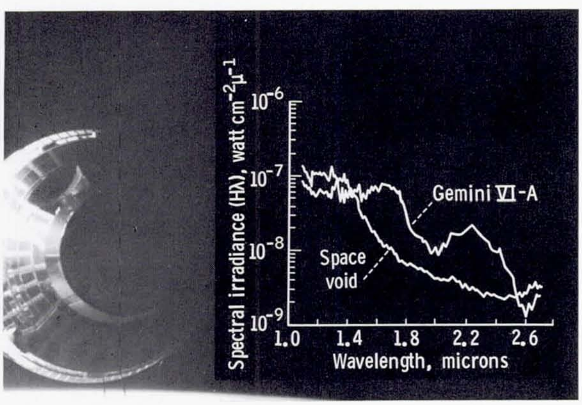

FIGURE 20–6.—Experiment D004/D007 measurement of Gemini VI–A in Earth-reflected sunlight.

Experiment D005, Star Occultation Navigation.—Experiment D005 was conducted to determine the usefulness of star occultation measurements for spacecraft navigation, and to establish a density profile for updating atmospheric models for horizon-based systems. Data analysis has not yet been completed; but preliminary evaluation indicates that the atmospheric density profile is sufficiently stable to provide photometer data for determining spacecraft position with an accuracy of ±1 nautical mile. Typical occultation data are shown in figure 20–7. The photometer developed and tested during this experiment is available for future applications.

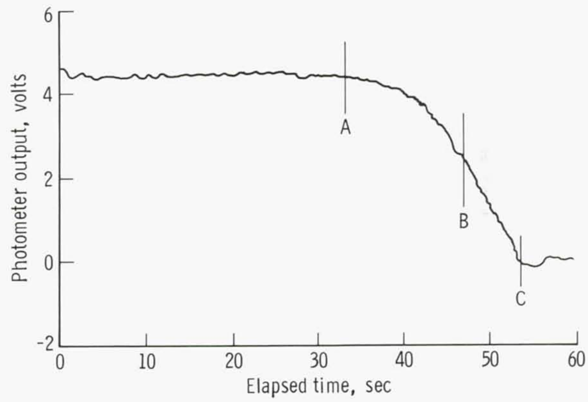

FIGURE 20–7.—Experiment D005, Gemini X. Measurement of Vega occultation.

Experiment D008, Radiation in Spacecraft.—Experiment D008 provided an active tissue equivalent ionization chamber system and passive dosimeters including thermoluminescent devices, film-emulsion packs, and activation foils to record cosmic and Van Allen belt radiation within the Gemini spacecraft. Excellent agreement was found between data from the active and the passive dosimetry. The active dosimeter incorporated a portable sensor to measure radiation dose rate at various points within the spacecraft and about the body of each crewman. The measurements indicated that the total dose received on the Gemini IV mission was 82 millirads; the major portion was Van Allen belt radiation. On Gemini VI–A, a total dose of only 20 millirads was computed. The integrated dose per pass through the South Atlantic anomaly is shown in table 20–VII. On Gemini IV, the instantaneous dose rate reached a level of 107 millirads/hour during revolution 7 (fig. 20–8); the highest dose rate recorded on Gemini VI–A was 73 millirads/hour during a pass through the inner Van Allen belt. Typical cosmic radiation levels for the Gemini orbits are shown in figure 20–9.

The spacecraft shielding influenced dose levels by more than a factor of 2 on both

TABLE 20–VII.—*Radiation Dose Experienced During South Atlantic Anomaly Passes*

Mission	Revolution	Integrated dose per anomaly revolution, mrad
Gemini IV	6	3.0
	7	8.4
	8	10.45
	9	3.5
	21	2.87
	22	7.10
	23	[a]6.0
	24	[a]3.0
	36	3.32
	37	5.90
	38	3.26
	39	2.50
	51	1.72
	52	2.26
	53	[a]2.0
	54	2.0
Total		67.28
Gemini VI–A	5	1.0
	6	6.0
	7	5.5
	8	2.5
	9	1.5
Total		16.5

[a] These data are not measured, but are extrapolated from dose-rate plots of similar type revolutions.

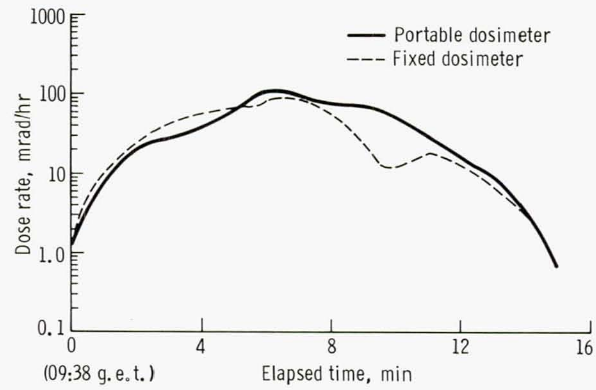

FIGURE 20–8.—Dose rate, South Atlantic anomaly pass, Gemini IV, revolution 7.

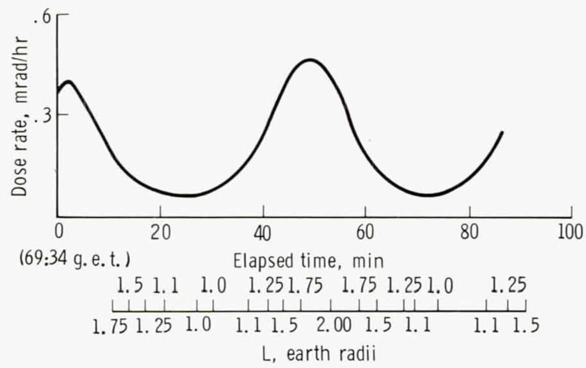

FIGURE 20–9.—Cosmic radiation dose levels within Gemini IV as a function of orbital time and L-values for revolution 45.

missions. Film-emulsion data, coupled with special shielding experiments conducted using the active dosimeters, show that the doses received on the Gemini IV and VI–A missions were predominantly a result of the energetic proton component of the inner Van Allen belt; although radiation levels were well within acceptable limits, the data indicated the problems of manned operations deeper in the radiation belts. Equipment developed and tested during this experiment is available for future space applications.

Experiment D009, Simple Navigation.—Experiment D009 developed data on observable phenomena and procedures which can be used for manual spacecraft navigation. A space sextant was developed and tested; the use of the sextant in an autonomous navigation system proved feasible. The observable horizon for sextant measurements was determined to average 14.9 miles above the mean Earth horizon. Typical errors in star coaltitude determination were less than 0.10°. Measurements of angles to 51° were made with ease. Table 20–VIII compares some Gemini VII essential orbital elements computed from ground track data and from sextant data. The calculated uncertainty for the position determined from sextant sightings was 10.1 nautical miles along the track, and 6.3 nautical miles across the track. This compared favorably with the accuracy of the

TABLE 20-VIII.—*Orbit Parameter Comparison for Experiment D009*

Star set no.	Inclination, deg		Right ascension of ascending node, deg	
	Ground track	Sextant	Ground track	Sextant
4	28.90	28.71	192.03	191.85
8	28.90	29.03	192.06	192.37
12	28.87	28.92	192.01	192.20
16	28.90	28.72	192.02	191.84

spacecraft position computed from radar tracking data. A flight-qualified sextant is available for future operational use.

Experiment D010, Ion-Sensing Attitude Control.—Experiment D010 developed and tested equipment which used specially adapted ion sensors to indicate spacecraft yaw and pitch angles relative to the flight path. The flight crew confirmed that the system provided an excellent indication of attitude. Data from the ion sensors are compared with data from the Gemini X spacecraft inertial sensor in figures 20–10 and 20–11. The system has excellent possibilities for future attitude indication/control applications.

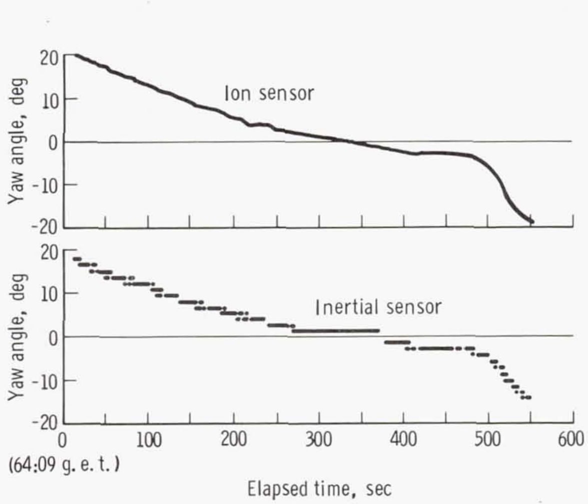

FIGURE 20–10.—Comparison of ion sensor and inertial system yaw-angle measurements, Gemini X.

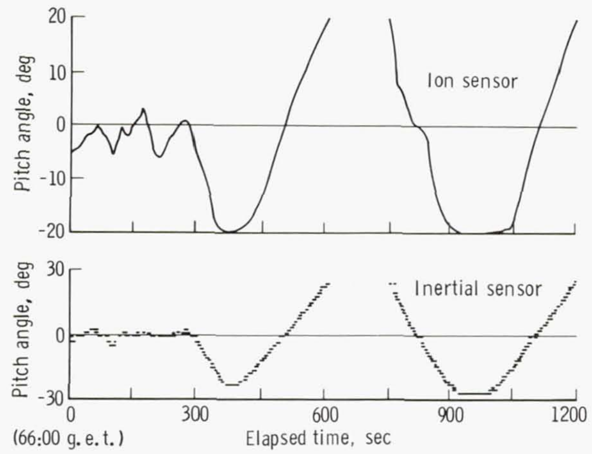

FIGURE 20–11.—Comparison of ion sensor and inertial system pitch-angle measurement, Gemini X.

Experiment D012, Astronaut Maneuvering Unit.—Experiment D012 was not completed due to the inability to accomplish the planned flight tests on Gemini IX–A and XII. The Astronaut Maneuvering Unit was carried in the Gemini IX–A spacecraft, but flight testing was terminated prior to separation of the Astronaut Maneuvering Unit when visor fogging obstructed the vision of the extravehicular pilot. Preparation of the Astronaut Maneuvering Unit for donning demonstrated for the first time that extravehicular work tasks of significant magnitude could be accomplished, and that adequate astronaut restraint provisions were required to maintain the workload within acceptable levels. Extravehicular activity evaluation through Gemini XI indicated that progress of extravehicular activity development was less than desired. Therefore, the final Gemini XII extravehicular activity was devoted to investigation of basic extravehicular activity tasks rather than to testing of the Astronaut Maneuvering Unit. Although flight tests were not completed, the experience and data acquired during design fabrication, testing, and training will be valuable in the planning and future development of personal extravehicular maneuvering units. The Astronaut Maneuvering Unit, the Gemini space suit, and the

Extravehicular Life-Support System (chest pack) are shown in figure 20–12.

FIGURE 20–12.—The Astronaut Maneuvering Unit, Gemini space suit, and Extravehicular Life-Support System.

Experiment D013, Astronaut Visibility.—In conjunction with the scientific visual acuity experiment (S008) which investigated the effects of the space environment on visual acuity, Experiment D013 confirmed a technique for predicting capability of the flight crew to discriminate small objects on the surface of the Earth in daylight. In the experiment, the crew observed and reported ground rectangles of known size, contrast, and orientation as shown in the photograph of the array at Laredo, Tex. (fig. 20–13). Simultaneous measurements were taken of light scattering caused by the spacecraft window and of conditions over the array. The crew reported correctly on the rectangles that earlier predictions indicated they should see.

Experiment D014, Ultrahigh-Frequency/Very High-Frequency Polarization Measurements.—The flight test of Experiment D014 was not completed. The experiment was scheduled for the Gemini VIII and IX–A missions. The experiment was not attempted during Gemini VIII due to control problems which forced early termination of the mission. The experiment was accomplished on Gemini IX–A, but the number of measurements was limited because of other experiments and mission constraints. The success of the experiment required a representative number of measurements; since only a limited number were acquired, objectives were not completely attained. Experiment equipment operation was satisfactory, and experiment technique was successfully demonstrated.

Experiment D015, Night Image Intensification.—In Experiment D015 image intensification equipment was used for the first time on a manned spacecraft to view the Earth in darkness. The crew reported that geographic features (bodies of water, coastlines, and rivers) were observed under starlight conditions, with no Moon. Cloud patterns were especially prominent, indicating a possibility for mapping weather patterns at night. The experiment results provided a basis for evaluating future applications of image intensification equipment in space flight.

Experiment D016, Power Tool Evaluation.—Experiment D016 was not completed due to the inability to complete the planned flight tests. Spacecraft control problems of the Gemini VIII mission prevented evaluation of the minimum-reaction power tool (fig. 20–14). Pilot fatigue necessitated early termination of extravehicular activity during Gemini XI, and evaluation of the power tool was not attempted. Although flight testing was not completed, development and testing of the power tool provided experience and data of value to future development of space maintenance activities.

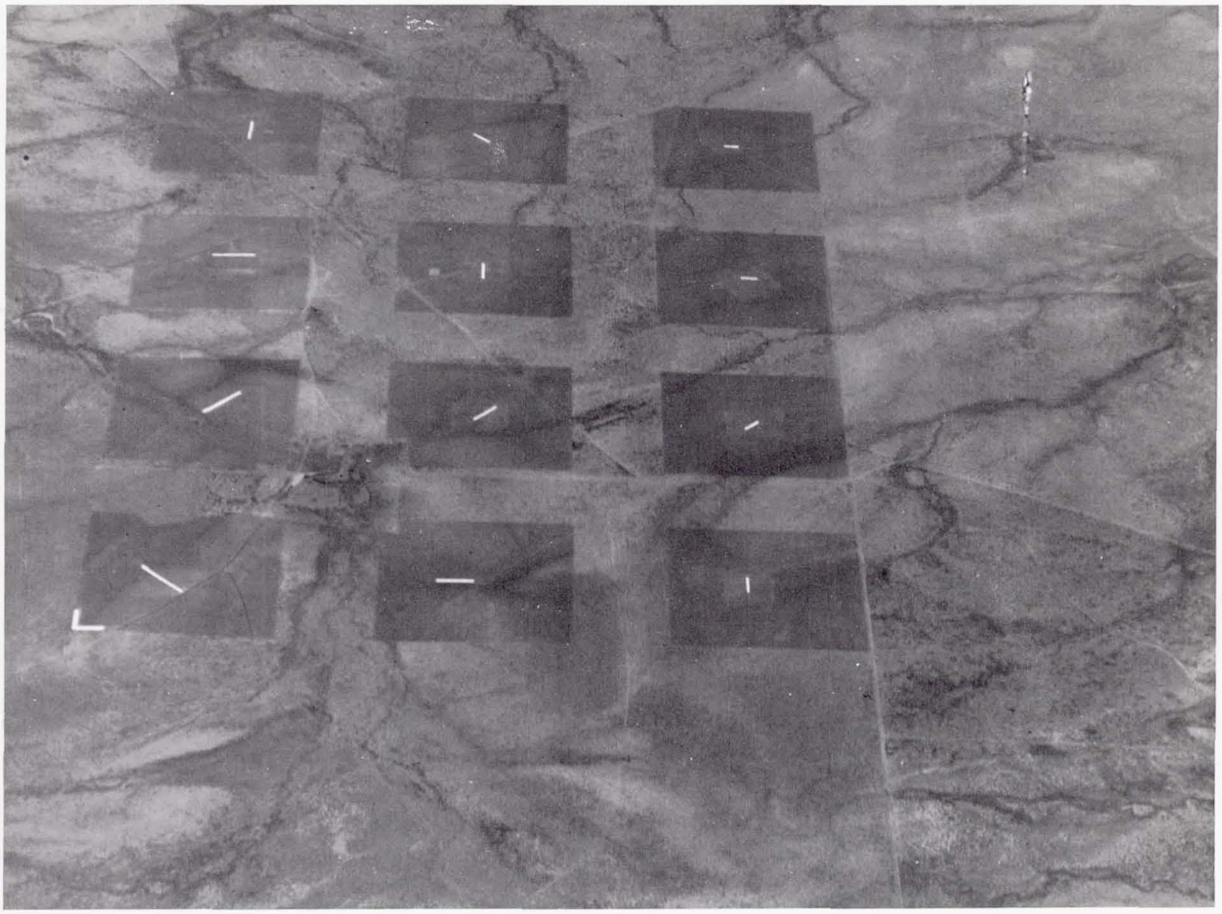

FIGURE 20-13.—Aircraft photograph of Experiment D013, ground array, Laredo, Tex.

FIGURE 20-14.—Experiment D016, minimum reaction power tool.

Conclusion

Overall evaluation of the DOD/NASA Gemini Experiments Program indicates that the program was successful. Some basic capabilities of man in space which were unknown or uncertain at the beginning of the experiments program are now understood in specific terms. Such understanding will be valuable in the planning of future manned space systems.

GEMINI SUMMARIZATION

21. ASTRONAUT FLIGHT AND SIMULATION EXPERIENCES

By THOMAS P. STAFFORD, *Astronaut, Astronaut Office, NASA Manned Spacecraft Center; and* CHARLES CONRAD, JR., *Astronaut, Astronaut Office, NASA Manned Spacecraft Center*

Summary

This presentation will be a discussion of the flight simulations and of the actual flight experiences of the Gemini Program. The program has proven that precise flight-crew responses during orbital flight is critically dependent upon the fidelity of the simulation training received prior to flight. All crews utilized a variety of simulators in preparing for their specific missions. Flight experiences have shown that the majority of the simulators were of a high fidelity and that, in most cases, the simulators produced accurate conditions of the actual flight. The few minor discrepancies between the responses, controls, and displays in the simulator and in the actual spacecraft had no noticeable effect on flight-crew performance.

Introduction

The presentation will be categorized into specific areas of the missions, and will compare the fidelity of flight simulations with actual flight experience. The areas will be discussed in the chronological sequence in which they occurred during flight.

Launch

The launch phase encompassed powered flight from lift-off through orbital insertion. The first phase of training for the launch sequence was conducted by the flight crew in the Dynamic Crew Procedures Simulator located at the Manned Spacecraft Center, Houston. The simulator provided sound, motion, and visual cues to the crew (figs. 21–1 and 21–2). During this phase of training, all launch and abort procedures were exercised and revised when necessary. After completing initial practice runs in the Dynamic Crew Procedures Simulator, the crew practiced the launch phase of flight at the start of each Gemini Mission Simulator Session. The initial training was conducted in a shirt-sleeve environment and later with each crewman wearing a full pressure suit. The Gemini Mission Simulator was of the exact configuration of the spacecraft to be flown, and provided both visual displays and sound cues (figs. 21–3 and 21–4).

As the training progressed, launch-abort simulations were practiced with the Gemini Mission Simulator integrated with the Mission Control Center. During these simulations, the Mission Control Center was manned by the mission flight controllers. The majority of the later runs were conducted with the crew suited in either training or flight suits. A final series of runs in the Dynamic Crew Procedures Simulator was conducted approximately 3 weeks prior to launch.

The data displayed in the Dynamic Crew Procedures Simulator and in the Gemini Mission Simulator proved very realistic when compared with the data experienced in flight. Quantitative statistical data and qualitative flight-crew debriefings all correlated this fact. A comparison of Gemini Mission Simulator and actual flight data from the powered-flight phase of the Gemini VI–A mission is shown in figures 21–5 to 21–8. An analysis of the plots indicates a close agreement between the two sources of data. During the debriefing sessions after each flight, the crews have indicated that the response of the simulator controls and displays had an extremely close correlation with the responses observed in flight.

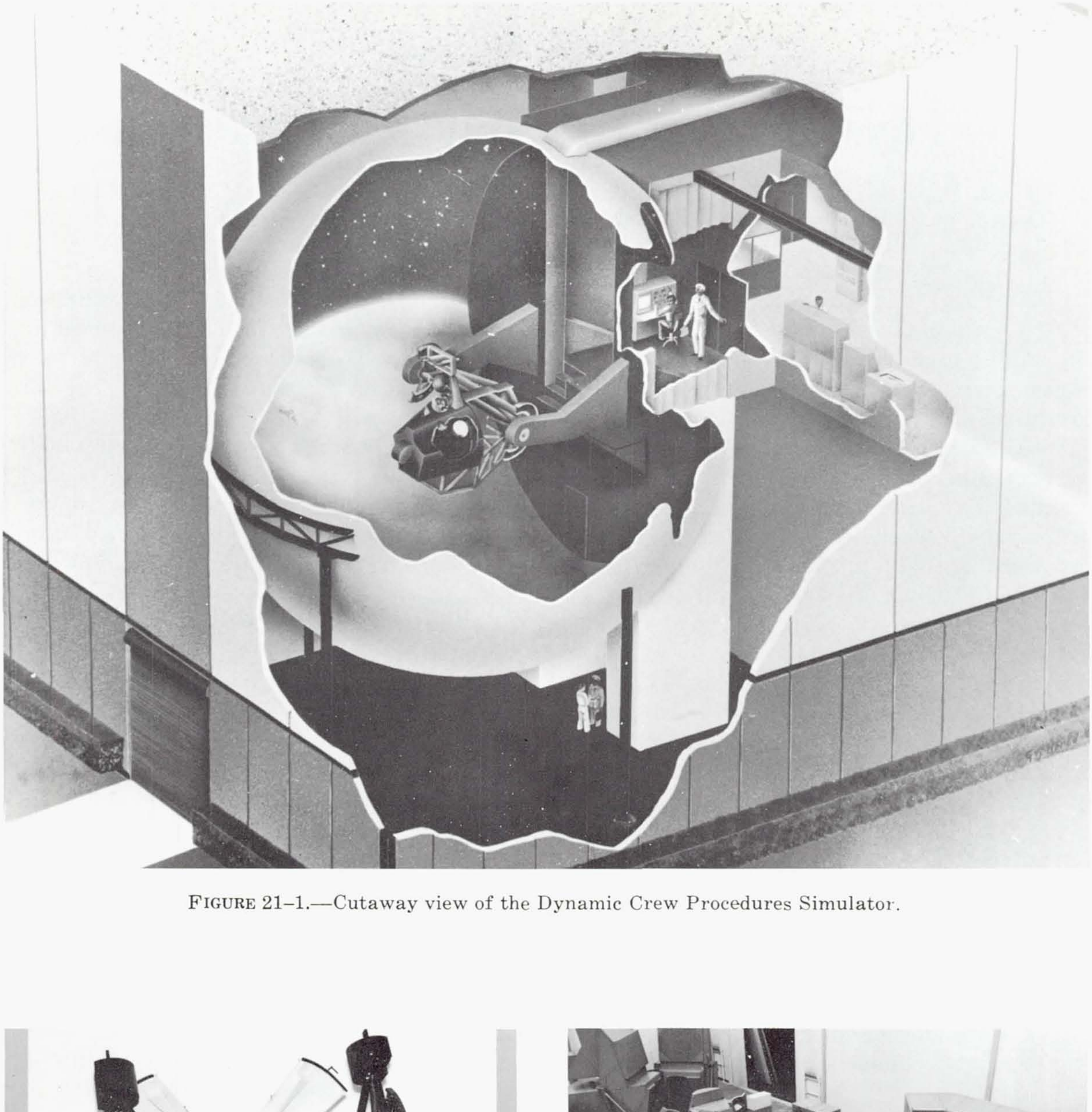

FIGURE 21-1.—Cutaway view of the Dynamic Crew Procedures Simulator.

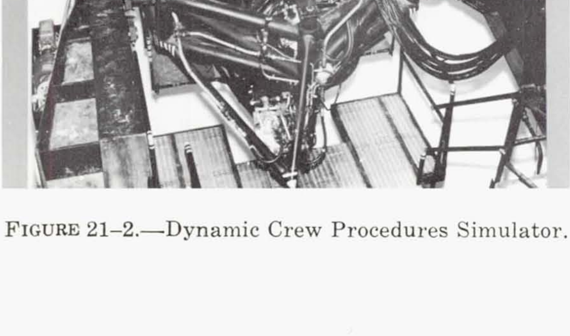

FIGURE 21-2.—Dynamic Crew Procedures Simulator.

FIGURE 21-3.—Gemini Mission Simulator console area.

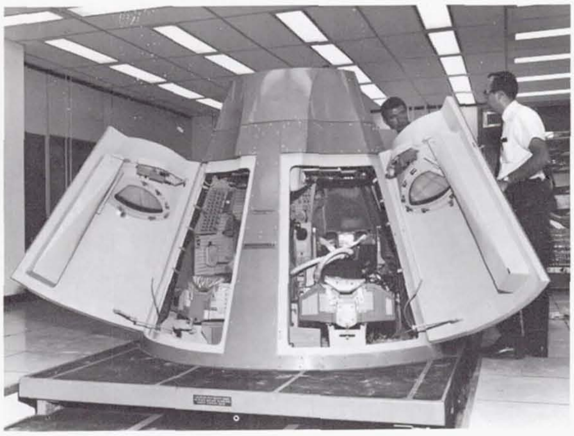

FIGURE 21-4.—Gemini Mission Simulator crew station.

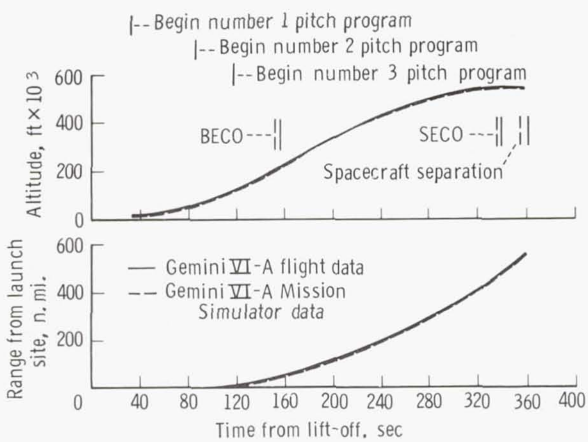

FIGURE 21-5.—Time history of altitude and range during launch phase.

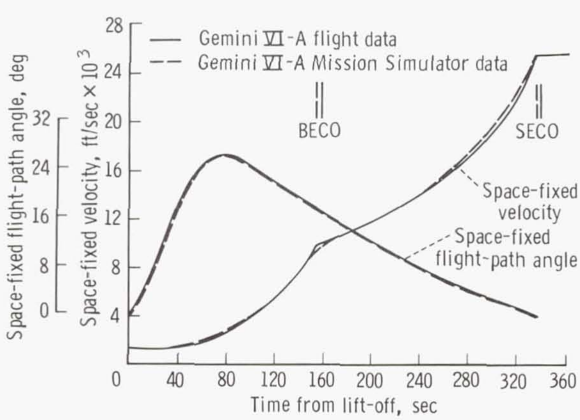

FIGURE 21-6.—Space-fixed velocity and flight-path angle.

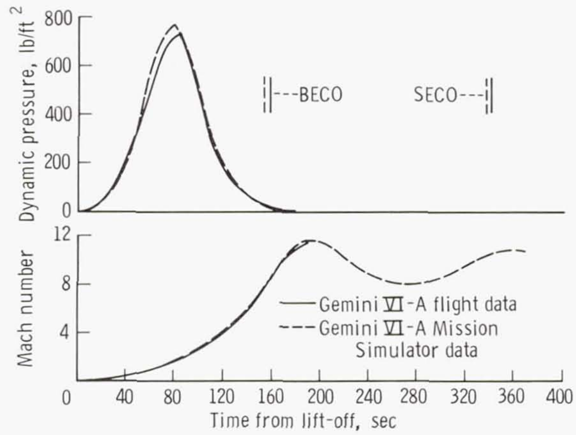

FIGURE 21-7.—Dynamic pressure and Mach number.

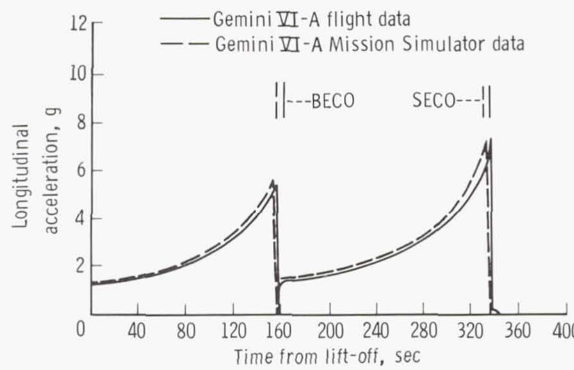

FIGURE 21-8.—Comparison of longitudinal acceleration.

One simulation problem that continually recurred during the early phases of the Gemini Program was that of providing guidance and control functions that were accurate and repeatable. The Gemini III crew received a reentry simulation that approached the flight computer outputs only 2 weeks prior to flight. This situation slowly improved and the Gemini VI crew received accurate launch and reentry data approximately 1 month prior to flight. The Gemini VIII and subsequent crews were provided with accurate guidance and navigation simulations for the entire training period.

Rendezvous

The initial phase of the training for rendezvous operations was conducted on the

Hybrid Simulator at the spacecraft contractor facility. The simulator contained the flight controls and displays of the spacecraft Guidance and Control System and of the Propulsion System, with a mockup for the remainder of the cockpit (figs. 21–9 and 21–10). Procedures for normal, backup, and failure modes were developed during the early part of the training period. The crews performed this phase of rendezvous training in a shirt-sleeve environment. Various instructors were able to stand alongside the simulator to observe and make comments during the run. The Hybrid Simulator visual display had a random star-field background which provided a satisfactory inertial reference for this phase of training. Accurate data on attitude and maneuver fuel were obtained, and indicated a close correlation with the inflight data.

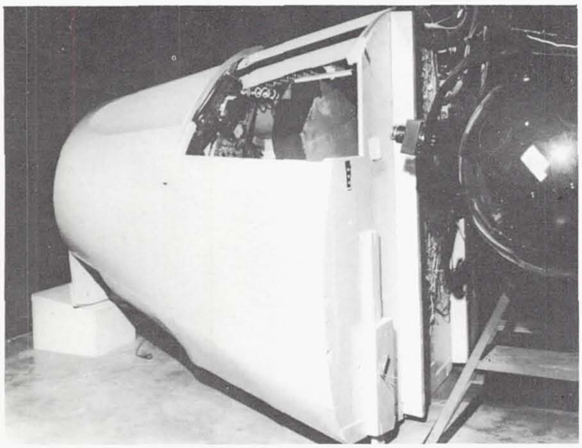

FIGURE 21–9.—Exterior view of Hybrid Simulator.

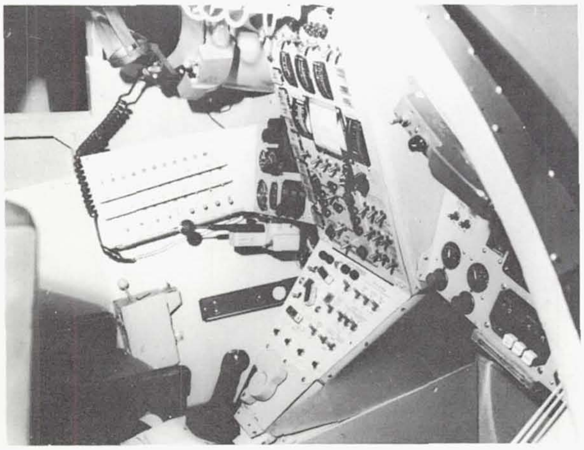

FIGURE 21–10.—Hybrid Simulator crew station.

The training progressed to the Gemini Mission Simulator at the Kennedy Space Center where the total spacecraft configuration was available. The runs were conducted first in a shirt-sleeve environment and later progressed to the suited condition. Approximately 20 percent of the simulator runs during the later phase of rendezvous training were conducted with the crew wearing training suits and then flight suits. The rendezvous phases of the flight plans were also refined during the runs. The third orbit ($M=3$) and the first orbit ($M=1$) rendezvous missions required that considerable effort be expended in practicing unstowage of gear, and in cockpit configuration management. This was a significant item in obtaining a smooth work flow during a time-critical period.

After the predicted launch date and time were determined, the simulator optical system was programed to provide the precise star and constellation field. The day/night cycle was also included in this part of the program. Flight experience indicated that the visual simulations were extremely accurate with respect to the celestial field, but somewhat lacking with respect to the magnitude and sharpness of the acquisition lights on the Gemini Agena Target Vehicle. Starting with the Gemini VI–A mission, the Gemini Mission Simulator and the Mission Control Center were integrated for rendezvous network simulations; however, not until the Gemini IX simulations could a satisfactory rendezvous be achieved on a target generated by the Mission Control Center. While wearing space suits, the flight crew performed all of the network rendezvous simulations and unstowed equipment in the same manner as they would in flight. To facilitate the rendezvous phase of the mission, the information obtained from the network rendezvous simulations frequently resulted in

minor changes in the stowage configuration.

Basic failure modes of the guidance and navigation system were presented to the crew during training, and the knowledge acquired by the crew contributed to their confidence in performing the entire rendezvous maneuver. Several reset points were available for specific parts of the maneuver; for example, the period after the completion of the final midcourse maneuver through the entire braking routine. These runs were used to perfect the pilot techniques required for specific maneuvers.

The Gemini Mission Simulator provided accurate trajectory and fuel data for mission planning. Figures 21–11 and 21–12 compare the simulator and flight data for the Gemini VI–A rendezvous mission. Figure 21–13 compares hybrid simulation, Gemini mission simulation, and flight data for the Gemini IX–A mission. The hybrid simulation and the Gemini mission simulation were conducted at 15 nautical miles differential altitude. The flight was conducted at 12.1 nautical miles differential altitude. The hybrid simulation incorporated system errors. The Gemini mission simulation was nominal.

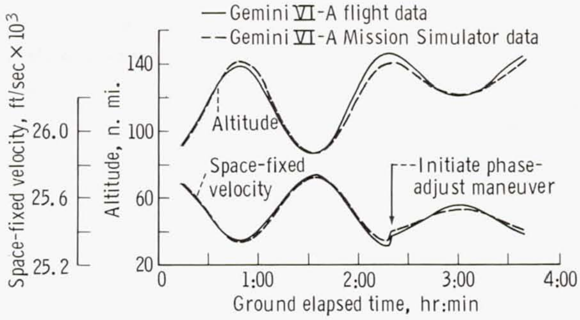

FIGURE 21–11.—Altitude and space-fixed velocity during orbit.

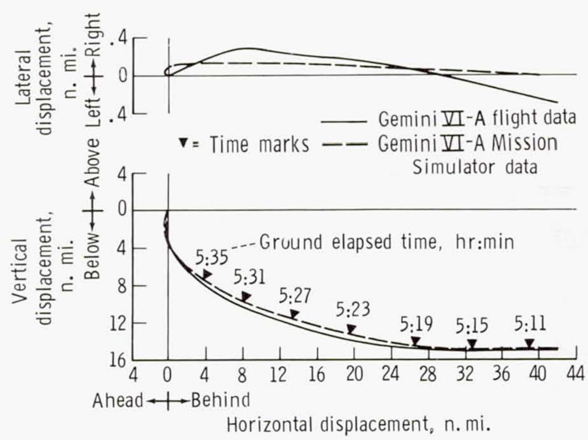

FIGURE 21–12.—Relative trajectory profile during terminal phase.

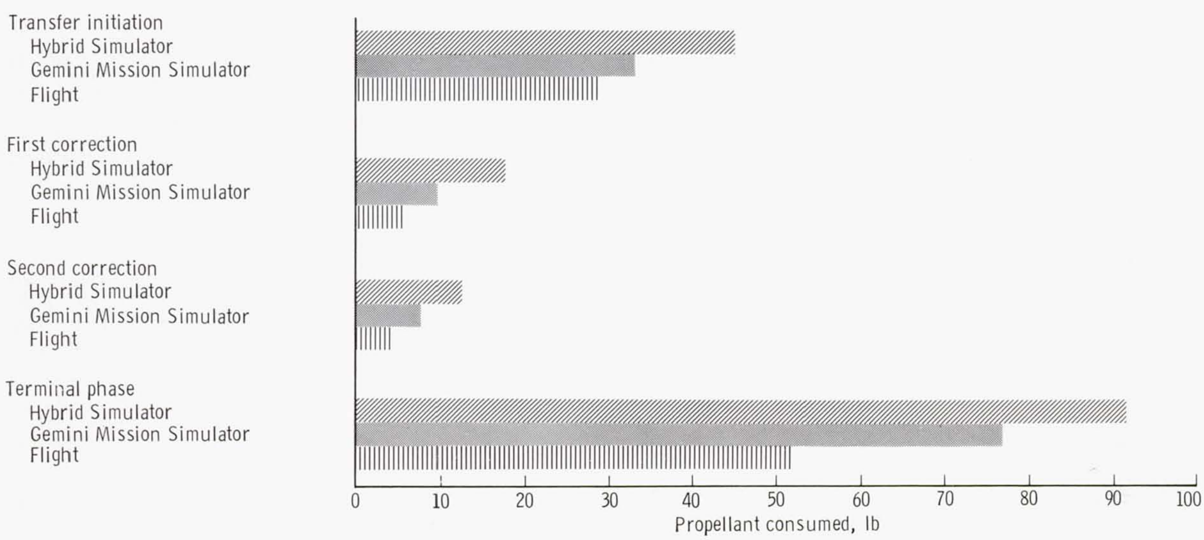

FIGURE 21–13.—Gemini IX–A rendezvous propellant comparison.

Special Tasks

Experiment Training

Training equipment identical to the actual flight hardware was provided for each Gemini experiment. The individual pieces of experiment hardware were first used for training in the spacecraft mockups at the spacecraft contractor facility and at the Manned Spacecraft Center. Later, the same hardware was used for training in the Gemini Mission Simulators. Camera equipment and other experiment hardware were often used by the Gemini flight crews while flying T–33 and T–38 aircraft. Operating the specific gear in this environment provided excellent training in the use of the individual pieces of hardware. To accomplish specific tasks for individual experiments that required precise tracking, spacecraft pointing commands and nulling of attitude rates were practiced. Flight experience indicated that the time lines and control tasks were very similar to those experienced in the Gemini Mission Simulator. The required updating and engineering changes of the experiment equipment frequently resulted in the flight crew not having the training hardware at a specified time to complete training. In certain isolated instances, the actual experiment hardware was not received until just prior to launch. This placed a difficult workload on the crew in trying to concentrate on new hardware and procedures in the last few days prior to flight.

Gemini Agena Target Vehicle Training

The Gemini VIII through XII missions were scheduled to include docking and various maneuvers involving the Gemini Agena Target Vehicle. The Gemini Mission Simulator provided a visual target vehicle that responded to commands from the Gemini crew station and from the simulator instructor station. All target-vehicle commands in both the docked and the undocked configurations were available. Commands were initiated for practicing attitude maneuvers as well as maneuvers with the target-vehicle Primary and Secondary Propulsion Systems. The response of the simulated target vehicle to the input commands accurately simulated the response of the actual target vehicle during flight. Target-vehicle failure modes were included during certain training periods to provide the crew with the maximum available training for systems malfunction.

The Gemini docking trainer, located at the Manned Spacecraft Center, provided the majority of the actual docking-sequence training. All control modes of the spacecraft and of the target vehicle were simulated in this facility. The lighting configuration was varied to simulate the conditions that were encountered during flight. All flight crews indicated that the final contact and docking-engage maneuver was somewhat easier than that experienced in the simulator. The control task difference was explained by the difficulty in simulating a dynamic 6-degree-of-freedom motion precisely equal to the orbital flight condition.

Tether Dynamics

The Dynamic Crew Procedures Simulator at the Manned Spacecraft Center was configured to provide a realistic simulation of the tethered-vehicle evaluations performed during the Gemini XI and XII missions. The basic time lines and control task for the tether maneuver were developed on this facility. The ability of the crew to cope with the large attitude excursions can be directly attributed to simulation training. The tether evaluation again demonstrated that an exercise could be generated with only a specific task involved; the use of this technique contributed greatly to the success of many of the Gemini missions.

Systems Operation

The flight-crew training for normal and emergency engineering procedures was first practiced on the Gemini Mission Simulator in conjunction with spacecraft systems briefings at the Manned Spacecraft Center. After

the crew moved to the Kennedy Space Center, practice for the normal procedures was emphasized; and less emphasis was placed on emergency procedures in order to concentrate on the planned mission. Final systems briefings were conducted at the Kennedy Space Center, and training in the operation of all spacecraft systems was accomplished in the Gemini Mission Simulator. Network simulations involving the Mission Control Center provided practice for all types of system failures, and provided vehicle training for both ground and flight crews. A few minor simulator discrepancies were noted in the display responses when a system condition was changed. The differences between the simulator display and the actual spacecraft responses were small and did not produce any noticeable effect on the training program or the crew reaction in flight.

Reentry-Phase Training

The training for the reentry phase was conducted initially at the Manned Spacecraft Center on the Gemini Mission Simulator, and later at the Kennedy Space Center. Two types of reset points were available for training, one just prior to retrofire, and the other at an altitude of 400 000 feet. The reset points provided the crew considerable flexibility in perfecting procedures and techniques for the retrofire and reentry sequence.

The exact constellation position for the night retrofire sequence was programed for each mission. This feature of the Gemini Mission Simulator provided excellent training for the actual mission. The Mission Control Center simulations were performed in both the shirt-sleeve and the suited configurations.

The computer updates for reentry were performed by updata link and by voice link. The exact procedures used in flight were practiced many times in the simulator by the flight crews and in the Mission Control Center by the flight controllers during network reentry simulations.

The Gemini Mission Simulator data and the actual flight data for the Gemini VI–A mission are shown in figure 21–14. The curve shows a close correlation between simulation and flight data. Any variances between actual flight data and simulation data were considered insignificant for crew training.

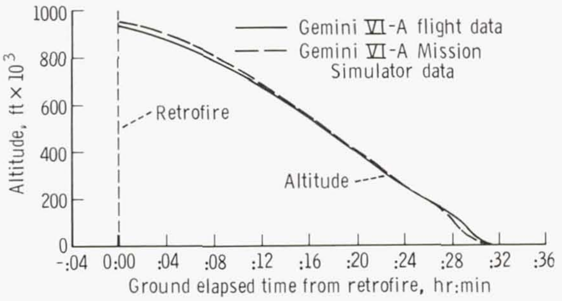

FIGURE 21–14.—Altitude during reentry.

Concluding Remarks

The variety of simulations available to the Gemini flight crews produced conditions that closely approximated those encountered in flight. Certain simulators were of the hybrid design and encompassed only specific systems. However, the simulation of the spacecraft operation of the individual systems produced excellent flight-crew training to accomplish specific tasks such as launch, rendezvous and docking, and reentry. The few discrepancies between simulator and actual spacecraft systems had no noticeable effect on the overall training program or orbital performance. The success with which the flight crews accomplished each Gemini mission was a direct result of high-fidelity simulation training.

Thus it can be concluded that the wealth of knowledge gained in the Gemini Program will provide the simulation and training guidelines for the Apollo Program. High-fidelity Apollo simulations and adequate flight-crew training can allow us to complete the lunar landing mission with a minimum number of actual space flights. The only phase of the lunar mission that has not been previously experienced to a great degree in the

Gemini Program is that of the lunar descent and landing. This phase cannot be experienced in flight until the actual landing takes place. Thus we can extrapolate from present knowledge that an accurate simulation can be provided to give the flight crews a realism that will closely approximate the actual lunar landing.

22. GEMINI RESULTS AS RELATED TO THE APOLLO PROGRAM

By WILLIS B. MITCHELL, *Manager, Office of Vehicles and Missions, Gemini Program Office, NASA Manned Spacecraft Center;* OWEN E. MAYNARD, *Chief, Mission Operations Division, Apollo Spacecraft Program Office, NASA Manned Spacecraft Center; and* DONALD D. ARABIAN, *Office of Vehicles and Missions, Gemini Program Office, NASA Manned Spacecraft Center*

Introduction

The Gemini Program was conceived to provide a space system that could furnish answers to many of the problems in operating manned vehicles in space. It was designed to build upon the experience gained from Project Mercury, and to extend and expand this fund of experience in support of the manned lunar landing program and other future manned space-flight programs. The purpose of this paper is to relate some of the results of the Gemini Program to the Apollo Program, and to discuss some of the contributions which have been made.

The objectives of the Gemini Program applicable to Apollo are: (1) long-duration flight, (2) rendezvous and docking, (3) post-docking maneuver capability, (4) controlled reentry and landing, (5) flight- and ground-crew proficiency, and (6) extravehicular capability. The achievement of these objectives has provided operational experience and confirmed much of the technology which will be utilized in future manned programs. These contributions will be discussed in three major areas: launch and flight operations, flight-crew operations and training, and technological development of subsystems and components. While there is obvious interrelation among the three elements, the grouping affords emphasis and order to the discussion.

Launch and Flight Operations

Gemini experience is being applied to Apollo launch and flight operations planning and concepts. Probably the most significant is the development and understanding of the rendezvous and docking process. The Apollo Program depends heavily upon rendezvous for successful completion of the basic lunar mission. The Lunar Module, on returning from the surface of the Moon, must rendezvous and dock with the Command and Service Module. In addition, the first Apollo mission involving a manned Lunar Module will require rendezvous and docking in Earth orbit by a Command and Service Module placed in orbit by a separate launch vehicle. During the Gemini Program, 10 rendezvous and 9 docking operations were completed. The rendezvous operations were completed under a variety of conditions applicable to the Apollo missions.

The Gemini VI–A and VII missions demonstrated the feasibility of rendezvous. During the Gemini IX–A mission, maneuvers performed during the second re-rendezvous demonstrated the feasibility of a rendezvous from above; this is of great importance if the Lunar Module should be required to abort a lunar-powered descent. During the Gemini X mission, the spacecraft computer was programed to use star-horizon sightings for predicting the spacecraft orbit. These data, combined with target-vehicle ephemeris data, provided an onboard prediction of the rendezvous maneuvers required. The rendezvous was actually accomplished with the ground-computed solution, but the data from the onboard prediction will be useful in developing space-navigation and orbit-determination techniques.

The passive ground-controlled rendezvous demonstrated on Gemini X and XI is important in developing backup procedures for equipment failures. The Gemini XI first-orbit rendezvous was onboard controlled and provides an additional technique to Apollo planners. The Gemini XII mission resulted in a third-orbit rendezvous patterned after the lunar-orbit rendezvous sequence, and again illustrated that rendezvous can be reliably and repeatedly performed.

All of the Gemini rendezvous operations provided extensive experience in computing and conducting midcourse maneuvers. These maneuvers involved separate and combined corrections of orbit plane, altitude, and phasing similar to the corrections planned for the lunar rendezvous. Experience in maneuvering combined vehicles in space was also accumulated during the operations using the docked spacecraft/target-vehicle configuration when the Primary Propulsion System of the target vehicle was used to propel the spacecraft to the high-apogee orbital altitudes. During the Gemini X mission, the Primary Propulsion System was used in combination with the Secondary Propulsion System to accomplish the dual-rendezvous operation with the passive Gemini VIII target vehicle. These uses of an auxiliary propulsion system add another important operational technique.

In summary, 10 rendezvous exercises were accomplished during the Gemini Program, including 3 re-rendezvous and 1 dual operation (fig. 22–1). Seven different rendezvous modes were utilized. These activities demonstrated the capabilities for computing rendezvous maneuvers in the ground-based computer complex; the use of the onboard radar-computer closed-loop system; the use of manual computations made by the flight crew; and the use of optical techniques and star background during the terminal phase and also in the event of equipment failures. A variety of lighting conditions and background conditions during the terminal-phase maneuvers, and the use of auxiliary lighting devices, have been investigated. The rendezvous operations demonstrated that the com-

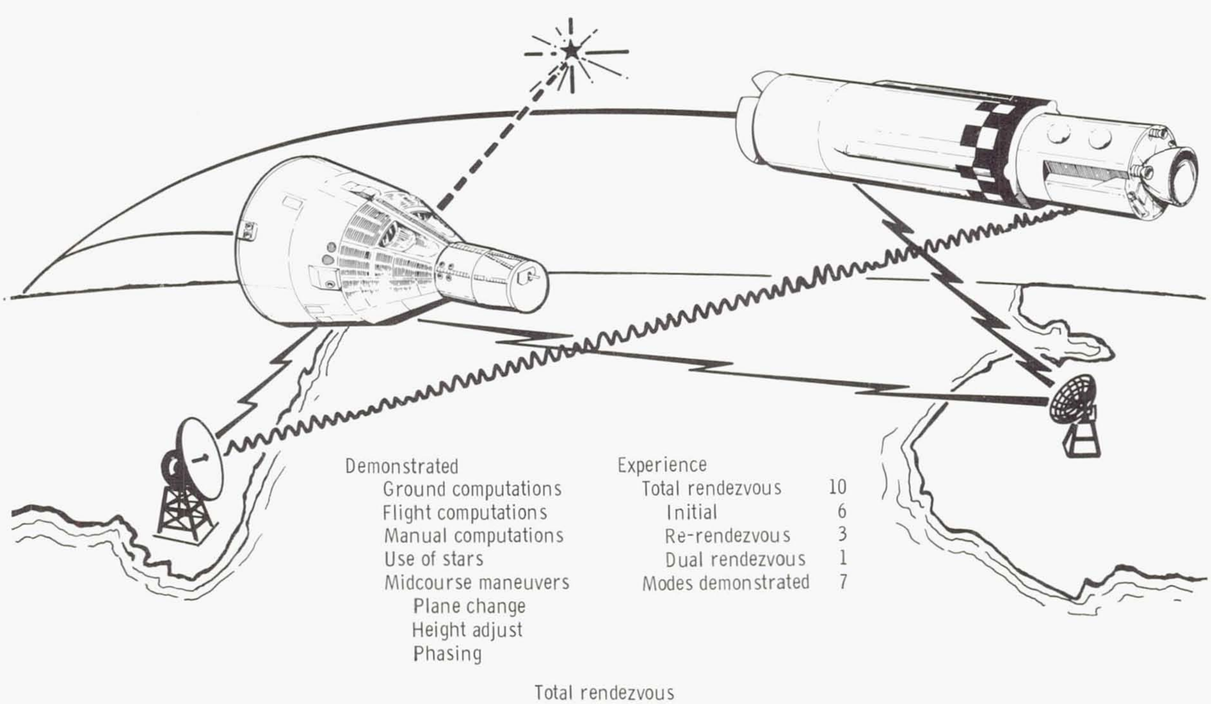

FIGURE 22–1.—Rendezvous.

putation and execution of maneuvers for changing or adjusting orbits in space can be performed with considerable precision.

The nine docking operations during Gemini demonstrated that the process can be accomplished in a routine manner, and that the ground training simulation was adequate for this operation (fig. 22–2). The Gemini flight experience has established the proper lighting conditions for successful docking operations. Based on the data and experience derived from the Gemini rendezvous and docking operations, planning for the lunar-orbit rendezvous can proceed with confidence.

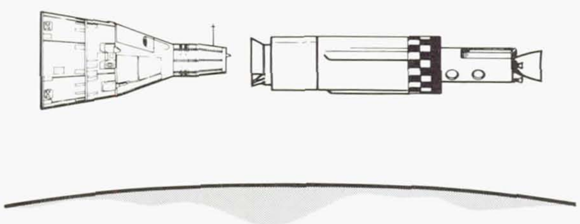

FIGURE 22–2.—Docking.

Extravehicular Activity

Extravehicular activity was another important objective of the Gemini Program. Although extensive use of extravehicular activity has not been planned for the Apollo Program, the Gemini extravehicular experience should provide valuable information in two areas. First, extravehicular activity will be used as a contingency method of crew transfer from the Lunar Module to the Command Module in the event the normal transfer mode cannot be accomplished. Second, operations on the lunar surface will be accomplished in a vacuum environment using auxiliary life-support equipment and consequently will be similar to Gemini extravehicular operations. For these applications, the results from Gemini have been used to determine the type of equipment and the crew training required. The requirements for auxiliary equipment such as handholds, tether points, and handrails have been established.

Controlled Landing

From the beginning of the Gemini Program, one of the objectives was to develop reentry flight-path and landing control. The spacecraft was designed with an offset center of gravity so that it would develop lift during the flight through the atmosphere. The spacecraft control system was used to orient the lift vector to provide maneuvering capability. A similar system concept is utilized by the Apollo spacecraft during reentry through the Earth atmosphere.

After initial development problems on the early Gemini flights, the control system worked very well in both the manual and the automatic control modes. Spacecraft landings were achieved varying from a few hundred yards to a few miles from the target point (fig. 22–3). The first use of a blunt lifting body for reentry control serves to verify and to validate the Apollo-design concepts. The success of the Gemini guidance system in controlling reentry will support the Apollo design, even though the systems differ in detail.

Launch Operations

The prelaunch checkout and verification concept which was originated during the Gemini Program is being used for Apollo. The testing and servicing tasks are very similar for both spacecraft, and the Gemini test-flow plan developed at the Kennedy Space Center is being applied. The entire mode of operation involving scheduling, daily operational techniques, operational procedures, procedures manuals, and documentation is similar to that used in the Gemini operation. Much of the launch-site operational support is common to both programs; this includes tracking radars and cameras, communications equipment, telemetry, critical power,

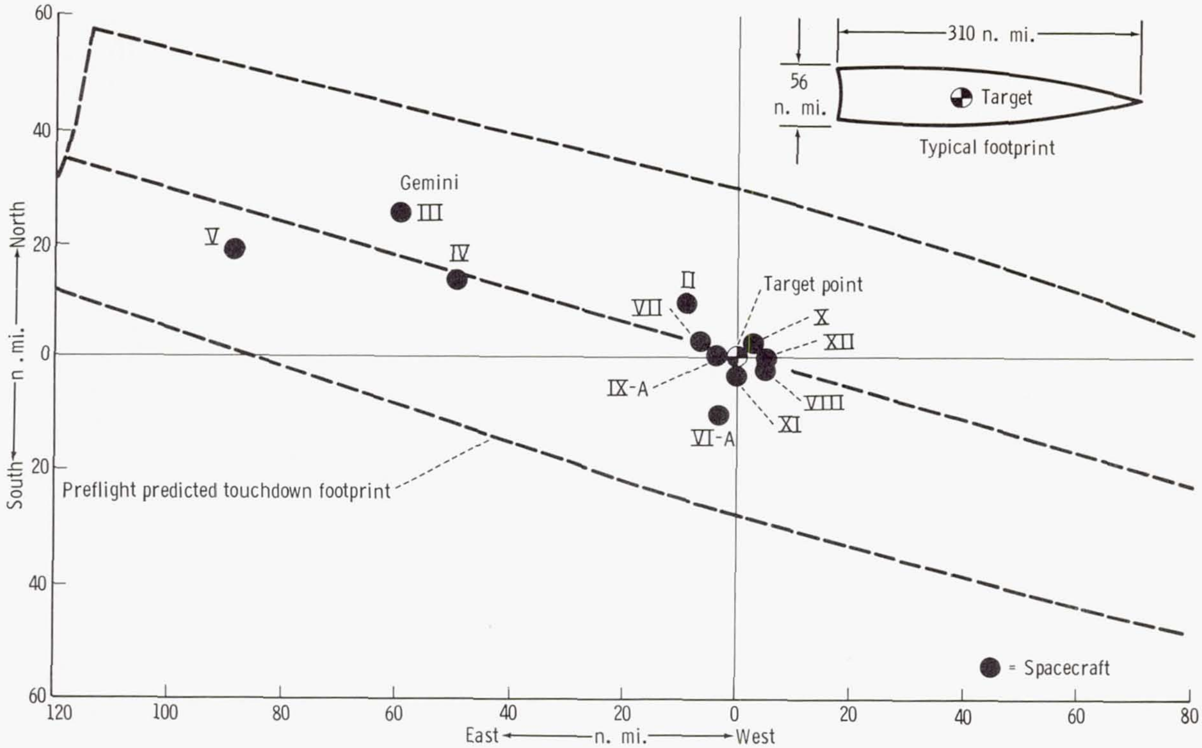

FIGURE 22–3.—Demonstration of landing accuracy.

and photography. The requirements for this equipment are the same in many cases, and the Gemini experience is directly applicable. The Apollo Program will use the same mission operations organization for the launch sequence that was established during Project Mercury and tested and refined during the Gemini Program.

Mission Control

The Gemini mission-control operations concepts evolved from Project Mercury. These concepts were applied during the Gemini Program and will be developed further during the Apollo missions, although the complexity of the operations will substantially increase as the time for the lunar mission nears. The worldwide network of tracking stations was established to gather data concerning the status of the Mercury spacecraft and pilots. The Mercury flights, however, involved control of a single vehicle with no maneuvering capability.

The Gemini Program involved multiple vehicles, rendezvous maneuvers, and long-duration flights, and required a more complex ground-control system capable of processing and reacting to vast amounts of real-time data. The new mission-control facility at the Manned Spacecraft Center, Houston, was designed to operate in conjunction with the Manned Space Flight Network for direction and control of Gemini and Apollo missions, as well as of future manned space-flight programs. Much of this network capability was expanded for Gemini and is now being used to support the Apollo missions. Gemini has contributed personnel training in flight control and in maintenance and operation of flight-support systems. As the Gemini flights progressed and increased in complexity, the capabilities of the flight controllers increased, and resulted in a nucleus of qualified control personnel.

The development of experienced teams of mission-planning personnel has proved extremely useful in the preparation for future manned missions. Mission plans and flight-crew procedures have been developed and exercised to perform the precise inflight maneuvers required for rendezvous of two vehicles in space, and to perform flights up to 14 days in duration. The techniques which were evolved during Gemini have resulted in flight plans that provide the maximum probability of achieving mission objectives with a minimum usage of consumables and optimum crew activity. The development of satisfactory work-rest cycles and the acceptance of simultaneous sleep periods are examples of learning which will be carried forward to the Apollo planning. The mission planning procedures developed for Gemini are applicable to future programs, and the personnel who devised and implemented the procedures are applying their experience to the Apollo flight-planning effort.

Flight-Crew Operations and Training

Crew Capability

The results of the Gemini Program in the area of flight-crew operations have been very rewarding in yielding knowledge concerning the Gemini long-duration missions. The medical experiments conducted during these flights have demonstrated that man can function in space for the planned duration of the lunar landing mission. The primary question concerning the effect of long-duration weightlessness has been favorably answered. Adaptation to the peculiarities of the zero-g environment has been readily accomplished. The results significantly increase the confidence in the operational efficiency of the flight crew for the lunar mission.

The Apollo spacecraft is designed for cooperative operation by two or more pilots. Each module may be operated by one individual for short periods; however, a successful mission requires a cooperative effort by the three-man crew. The multiple-crew concept of spacecraft operation was introduced for the first time in the United States during the Gemini Program and cooperative procedures for multipilot operations were developed.

The Gemini Program has established that man can function normally and without ill effect outside the spacecraft during extravehicular operations.

Crew Equipment

Most of the Gemini technology regarding personal crew equipment is applicable to Apollo. The Block I Apollo space suit is basically the same as the Gemini space suit. The Block II Apollo space suit, although different in design, will have familiar Gemini items such as suit-design concepts, locking mechanisms for connectors, and polycarbonate visors and helmets. The Gemini spacesuit support facilities at the Manned Spacecraft Center and at the Kennedy Space Center, plus the ground-support equipment, will be fully utilized during Apollo.

A considerable amount of personal and postlanding survival equipment will be used for Apollo in the same configuration as was used for Gemini. Some items have minor modifications for compatibility, others for improvements based upon knowledge resulting from flight experience. Specific examples include food packaging, water dispenser, medical kits, personal hygiene items, watches, sunglasses, penlights, cameras, and data books.

Many of the concepts of crew equipment originated in Gemini experience with long-duration missions and recovery: food and waste management; cleanliness; housekeeping and general sanitation; and environmental conditions such as temperature, radiation, vibration, and acceleration. Although the Apollo approach may differ in many areas, the Gemini experience has been the guide.

Flight-Crew Training

The aspects of crew training important to future programs include preflight preparation of the crews for the mission and the

reservoir of flight experience derived from the Gemini Program. Apollo will inherit the training technology developed for the Gemini flight crews. The technology began with Project Mercury, and was developed and refined during the training of the Gemini multiman crews. There now exists an organization of highly skilled specialists with a thorough understanding of the training task. Adequate crew preparation can be assured in all areas, from the physical conditioning of the individual crewmembers to the most complicated integrated mission simulation.

One highly developed aspect of flight-crew training is the use of simulators and simulation techniques. A significant result of the Gemini rendezvous experience was the verification of the ground simulation employed in flight-crew training. The incorporation of optical displays in the Gemini simulations was an important step in improving the training value of these devices. Using high-fidelity mission simulators to represent the spacecraft and to work with the ground control network and flight controllers was instrumental in training the pilots and ground crew as a functional team that could deal with problems and achieve a large percentage of the mission objectives.

The Gemini Program resulted in an accumulated total of 1940 man-hours of flight time distributed among 16 flight-crew members. This flight experience is readily adaptable to future programs since the Gemini pilots are flight qualified for long-duration flights and rendezvous operations, and are familiar with many of the aspects of working in the close confines of the spacecraft. This experience is of great value to future training programs. The experience in preparing multiman crews for flight, in monitoring the crew during flight, and in examining and debriefing after flight will facilitate effective and efficient procedures for Apollo.

Technological Development of Systems and Components

Gemini and Apollo share common hardware items in some subsystems; in other subsystems, the similarity exists in concept and general design. The performance of Gemini systems, operating over a range of conditions, has provided flight-test data for the verification of the design of related subsystems. These data are important since many elements of Apollo, especially systems interactions, cannot be completely simulated in ground testing. The Apollo Spacecraft Program Office at the Manned Spacecraft Center, Houston, has reviewed and analyzed Gemini anomalous conditions to determine corrective measures applicable to Apollo. The Apollo Program Director has established additional procedures at NASA Headquarters to promote rapid dissemination and application of Gemini experience to Apollo equipment design.

The Gemini missions have provided background experience in many systems such as communications, guidance and navigation, fuel cells, and propulsion. In addition, a series of experiments was performed specifically for obtaining general support information applicable to the Apollo Program.

In the communications systems, common items include the recovery and flashing-light beacons; similar components are utilized in the high-frequency and ultrahigh-frequency recovery antennas. Reentry and postlanding batteries and the digital data uplink have the same design concepts. The major Apollo design parameters concerned with power requirements and range capability have been confirmed.

In the area of guidance and navigation, the use of an onboard computer has been demonstrated and the Gemini experience with rendezvous radar techniques has been a factor in the selection of this capability for the Lunar Module. The ability to perform inplane and out-of-plane maneuvers and to determine new space references for successful reentry and landing has been confirmed by Gemini flights. The control of a blunt lifting body during reentry will also support the Apollo concept.

In the electrical power supply, the use of the Gemini fuel cell has confirmed the appli-

cability of the concept. The ability of the cryogenic reactant storage system to operate over a wide range of off-design conditions in flight has verified the design, which is similar for Apollo. The performance of the Gemini system has provided a better understanding of the system parameters over an operating range considerably in excess of the range previously contemplated. The design of the cryogenic servicing system for Apollo was altered after the initial difficulties experienced by early Gemini flights. Consequently, a fairly sophisticated system now exists which will eliminate the possibility of delays in servicing. The ability to estimate the power requirements for the Apollo spacecraft equipment is enhanced by the Gemini operational data.

In the propulsion area, the ullage control rockets of the Apollo-Saturn S–IVB stage are the same configuration as the thrusters used for the Gemini spacecraft Orbital Attitude and Maneuver System; the thrusters of the Apollo Command Module Reaction Control System are similar. Steps have been taken to eliminate the problems which occurred in the development of the Gemini thrusters, such as the cracking of the silicon-carbide throat inserts, the unsymmetrical errosion of the chamber liners, and the chamber burn-through. The tankage of the Reaction Control System is based upon the Gemini design, and employs the same materials for tanks and bladders. The propellant control valves were also reworked as a result of early problems in the Gemini system.

The Lunar Module ascent engine also benefited from the Gemini technology: the contractor for this engine also manufactured the engines for the Gemini Agena Target Vehicle. Following the inflight failure of the target-vehicle engine during the Gemini VI mission, a test program verified the inherent danger in fuel-lead starts in the space environment. Consequently, the Lunar Module ascent engine and the Gemini target-vehicle engine were changed so that the oxidizer would enter the engine before the fuel. The problem had been indicated during ascent-engine testing, but was not isolated until the required definitive data were furnished by Project Sure Fire on the target-vehicle engine.

In addition to medical experiments, several other types of experiments were conducted during Gemini and have supplied information and data for use by the Apollo Program. The experiments included electrostatic charge, proton-electron spectrometer, lunar ultraviolet spectrometer, color-patch photography, landmark contrast measurements, radiation in spacecraft, reentry communications, manual navigation sightings, simple navigation, radiation and zero-g effects on blood, and micrometeorite collection. Although the direct effects of these experiments on Apollo systems are difficult to isolate, the general store of background data and available information has been increased.

Concluding Remarks

The Gemini Program has made significant contributions to future manned space-flight programs. Some of the more important contributions include flight-operations techniques and operational concepts, flight-crew operations and training, and technological development of components and systems. In the Gemini Program, the rendezvous and docking processes so necessary to the lunar mission were investigated; workable procedures were developed, and are available for operational use. The capability of man to function in the weightless environment of space was investigated for periods up to 14 days. Flight crews have been trained, and have demonstrated that they can perform complicated mechanical and mental tasks with precision while adapting to the spacecraft environment and physical constraints during long-duration missions.

Additionally, the development of Gemini hardware and techniques has advanced spacecraft-design practices and has demonstrated advanced systems which, in many cases, will substantiate approaches and concepts for future spacecraft.

Finally, probably the most significant contributions of Gemini have been the training of personnel and organizations in the disciplines of management, operations, manufacturing, and engineering. This nucleus of experience has been disseminated throughout the many facets of Apollo and will benefit all future manned space-flight programs.

23. CONCLUDING REMARKS

By George M. Low, *Deputy Director, NASA Manned Spacecraft Center*

With the preceding paper, one of the most successful programs in our short history of space flight has ended. The Gemini achievements have been many, and have included long-duration flight, maneuvers in space, rendezvous, docking, use of large engines in space, extravehicular activity, and controlled reentry. The Gemini achievements have also included a host of medical, technological, and scientific experiments.

The papers have included discussions of many individual difficulties that were experienced in preparation for many of the flight missions and in some of the flights. The successful demonstration that these difficulties were overcome in later missions is a great tribute to the program, to the organization, and to the entire Gemini team.

A period of difficulty exists today in the program that follows Gemini, the Apollo Program. Yet, perhaps one of the most important legacies from Gemini to the Apollo Program and to future programs is the demonstration that great successes can be achieved in spite of serious difficulties along the way.

The Gemini Program is now officially completed.

APPENDIXES

APPENDIX A

NASA CENTERS AND OTHER GOVERNMENT AGENCIES

This appendix contains a list of Government agencies participating in the Gemini Program.

NASA Headquarters, Washington, D.C., and the following NASA centers:
- Ames Research Center, Moffett Field, Calif.
- Electronics Research Center, Cambridge, Mass.
- Flight Research Center, Edwards, Calif.
- Goddard Space Flight Center, Greenbelt, Md.
- Kennedy Space Center, Cocoa Beach, Fla.
- Langley Research Center, Langley Station, Hampton, Va.
- Lewis Research Center, Cleveland, Ohio
- Manned Spacecraft Center, Houston, Tex.
- Marshall Space Flight Center, Huntsville, Ala.

Department of Defense, Washington, D.C.:
- Department of the Army
- Department of the Navy
- Department of the Air Force

Department of State, Washington, D.C.

Department of Commerce, Washington, D.C.

Department of the Interior, Washington, D.C.

Department of Health, Education, and Welfare, Washington, D.C.

Department of the Treasury, Washington, D.C.:
- U.S. Coast Guard

Atomic Energy Commission, Washington, D.C.

Environmental Science Services Administration, Washington, D.C.

U.S. Information Agency, Washington, D.C.

APPENDIX B

CONTRACTORS, SUBCONTRACTORS, AND VENDORS

This appendix contains a listing of contractors, subcontractors, and vendors that have Gemini contracts totaling more than $100 000. It represents the best effort possible to obtain a complete listing; however, it is possible that some are missing, such as those supporting activities not directly concerned with Manned Spacecraft Center activities. These contractors, subcontractors, and vendors are recognized as a group.

Contractors

Acoustica Associates, Inc., Los Angeles, Calif.
Aerojet-General Corp., Sacremento, Calif.
Aerojet-General Corp., Downey, Calif.
Aerospace Corp., El Segundo, Calif.
AiResearch Manufacturing Co., division of Garrett Corp., Torrance, Calif.
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Analytical Mechanics Associates, Westbury, N.Y.
Arde-Portland, Inc., Paramus, N.J.
Avco Corp., Stratford, Conn.
Bechtel Corp., Los Angeles, Calif.
Beckman Instruments, Inc., Fullerton, Calif.
Bell Aerosystems Co., division of Bell Aerospace Corp., Buffalo, N.Y.
Bissett-Berman Corp., Santa Monica, Calif.
Burroughs Corp., Paoli, Pa.
CBS Labs, Inc., Stamford, Conn.
David Clark Co., Inc., Worcester, Mass.
Cook Electric Co., Morton Grove, Ill.
Cutler-Hammer, Inc., Long Island, N.Y.
Electro-Optical Systems, Inc., Pasadena, Calif.
Farrand Optical Co., Inc., Bronx, N.Y.
Federal Electric Corp., Paramus, N.J.
Federal-Mogul Corp., Los Alamitos, Calif.
General Dynamics/Astronautics Division, San Diego, Calif.
General Dynamics/Convair Division, San Diego, Calif.
General Dynamics/Convair Division, Fort Worth, Tex.
General Electric Co., Syracuse, N.Y.
General Motors Corp., Milwaukee, Wis.
General Precision, Inc., Link Division, Binghamton, N.Y.
General Precision, Inc., Pleasantville, N.Y.
B. F. Goodrich Co., Akron, Ohio
Honeywell, Inc., Minneapolis, Minn.
Honeywell, Inc., West Covina, Calif.
Hughes Aircraft Co., Culver City, Calif.
International Business Machines Corp., Owego, N.Y.
International Business Machines Corp., Bethesda, Md.
Ling-Temco-Vought, Inc., Dallas, Tex.
Lockheed Missiles & Space Co., Sunnyvale, Calif.
Martin Co., division of Martin-Marietta Corp., Baltimore, Md.
Martin Co., division of Martin-Marietta Corp., Denver, Colo.
J. A. Maurer, Inc., Long Island City, N.Y.
McDonnell Aircraft Corp., St. Louis, Mo.
Melpar, Inc., Falls Church, Va.
D. B. Milliken, Inc., Arcadia, Calif.
North American Aviation, Inc., Rocketdyne Division, Canoga Park, Calif.
North American Aviation, Inc., Space and Information Systems Division, Downey, Calif.
Philco Corp., Philadelphia, Pa.
Philco Corp., WDL Division, Palo Alto, Calif.
Razdow Lab., Newark, N.J.
Scientific Data Systems, Inc., Santa Monica, Calif.

Space Labs, Inc., Van Nuys, Calif.
Sperry Rand Corp., Sperry Phoenix Co. Division, Phoenix, Ariz.
Sperry Rand Corp., Washington, D.C.
Texas Institute for Rehabilitation and Research, Houston, Tex.
Thiokol Chemical Corp., Elkton, Md.
Thompson Ramo Wooldridge, Inc., Redondo Beach, Calif.
Todd Shipyards Corp., Galveston, Tex.
Western Gear Corp., Lynwood, Calif.
Whirlpool Corp., St. Joseph, Mich.

Subcontractors and Vendors

ACF Industries, Inc., Paramus, N.J.
ACR Electronics Corp., New York, N.Y.
Advanced Technology Laboratories, division of American Radiator & Standard Corp., Mountain View, Calif.
Aeronca Manufacturing Corp., Baltimore, Md.
AiResearch Manufacturing Co., division of Garrett Corp., Torrance, Calif.
American Machine & Foundry Co., Springdale, Conn.
Argus Industries, Inc., Gardena, Calif.
Astro Metallic, Inc., Chicago, Ill.
Autronics Corp., Pasadena, Calif.
Avionics Research Corp., West Hempstead, N.Y.
Barnes Engineering Co., Stamford, Conn.
Beech Aircraft Corp., Boulder, Colo.
Bell Aerosystems Co., Buffalo, N.Y.
Bendix Corp., Eatontown, N.J.
Brodie, Inc., San Leandro, Calif.
Brush Beryllium Co., Cleveland, Ohio
Brush Instrument Corp., Los Angeles, Calif.
Burtek, Inc., Tulsa, Okla.
Cadillac Gage Co., Costa Mesa, Calif.
Calcor Space Facility, Inc., Whittier, Calif.
Cannon Electric Co., Brentwood, Mo.
Cannon Electric Co., Phoenix, Ariz.
Captive Seal Corp., Caldwell, N.J.
Central Technology Corp., Herrin, Ill.
Clevite Corp., Cleveland, Ohio
Clifton Precision Products Co., Clifton Heights, Pa.
Collins Radio Co., Cedar Rapids, Iowa
Comprehensive Designers, Inc., Philadelphia, Pa.
Computer Control Co., Inc., Framingham, Mass.
Consolidated Electrodynamics Corp., Monrovia, Calif.
Cook Electric Co., Skokie, Ill.
Cosmodyne Corp., Hawthorne, Calif.
Custom Printing Co., Ferguson, Mo.
Day & Zimmerman, Inc., Los Angeles, Calif.
De Havilland Aircraft, Ltd., Downsview, Ontario, Canada
Dilectrix Corp., Farmingdale, N.Y.
Douglas Aircraft Co., Inc., Tulsa, Okla.
Douglas Aircraft Co., Inc., Santa Monica, Calif.
Eagle-Picher Co., Joplin, Mo.
Edgerton, Germeshausen & Grier, Inc., Boston, Mass.
Electro-Mechanical Research, Inc., Sarasota, Fla.
Electronics Associates, Inc., Long Branch, N.J.
Emerson Electric Co., St. Louis, Mo.
Emertron Information and Control Division, Litton Systems, Inc., Newark, N.J.
Engineered Magnetic Division, Hawthorne, Calif.
Epsco, Inc., Westwood, Mass.
Explosive Technology, Inc., Santa Clara, Calif.
Fairchild Camera & Instrument Corp., Cable Division, Joplin, Mo.
Fairchild Controls, Inc., division of Fairchild Camera & Instrument Corp., Hicksville, N.Y.
Fairchild Hiller Corp., Bay Shore, N.Y.
Fairchild Stratos Corp., Bay Shore, N.Y.
General Electric Co., Pittsfield, Mass.
General Electric Co., West Lynn, Mass.
General Electric Co., Waynesboro, Va.
General Precision, Inc., Link Division, Binghamton, N.Y.
General Precision, Inc., Little Falls, N.J.
Genistron, Inc., Bensenville, Ill.
Giannini Controls Corp., Duarte, Calif.
Goodyear Aerospace Corp., Akron, Ohio
Gray & Huleguard, Inc., Santa Monica, Calif.
Gulton Industries, Inc., Hawthorne, Calif.

Hamilton-Standard, division of United Aircraft Corp., Windsor Locks, Conn.
Hexcel Products, Inc., Berkeley, Calif.
Honeywell, Inc., Minneapolis, Minn.
Honeywell, Inc., St. Petersburg, Fla.
Hurletron Corp., Wheaton, Ill.
Hydra Electric Co., Burbank, Calif.
International Business Machines Corp., Owego, N.Y.
Johns-Mansville Corp., Mansville, N. J.
Kinetics Corp., Solvana Beach, Calif.
Kirk Engineering Co., Philadelphia, Pa.
Leach Corp., Compton, Calif.
Leach Relay Corp., Los Angeles, Calif.
Lear-Siegler, Inc., Grand Rapids, Mich.
Linde Co., Whiting, Ind.
Lion Research Corp., Cambridge, Mass.
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Marotta Valve Corp., Boonton, N.J.
Meg Products, Inc., Seattle, Wash.
Missouri Research Laboratories, Inc., St. Louis, Mo.
Moog, Inc., Buffalo, N.Y.
Motorola, Inc., Scottsdale, Ariz.
National Water Lift Co., Kalamazoo, Mich.
North American Aviation, Inc., Rocketdyne Division, Canoga Park, Calif.
Northrop Corp., Ventura Division, Newbury Park, Calif.
Northrop Corp., Van Nuys, Calif.
Ordnance Associates, Inc., South Pasadena, Calif.
Ordnance Engineering Associates, Inc., Des Plaines, Ill.
Palomar Scientific Corp., Redmond, Wash.
Pneumodynamics Corp., Kalamazoo, Mich.
Pollak & Skan, Inc., Chicago, Ill.
Powerton, Inc., Plainsville, N.Y.
Radcom Emerton, College Park, Md.
Radiation, Inc., Melbourne, Fla.
Raymond Engineering Laboratory, Inc., Middletown, Conn.
Reinhold Engineering Co., Santa Fe Springs, Calif.
Rocket Power, Inc., Mesa, Ariz.
Rome Cable Corp., division of Alcoa, Rome, N.Y.
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Servonics Instruments, Inc., Costa Mesa, Calif.
Space Corp., Dallas, Tex.
Sperry Rand Corp., Tampa, Fla.
Sperry Rand Corp., Torrance, Calif.
Speidel Co., Warwick, R.I.
Talley Industries, Mesa, Ariz.
Teledyne Systems Corp., Hawthorne, Calif.
Texas Instruments, Inc., Dallas, Tex.
Thiokol Chemical Corp., Elkton, Md.
Union Carbide Corp., Whiting, Ind.
Vickers, Inc., St. Louis, Mo.
Weber Aircraft Corp., Burbank, Calif.
Westinghouse Electric Corp., Baltimore, Md.
Whiting-Turner, Baltimore, Md.
Wyle Laboratories, El Segundo, Calif.
Yardney Electric Corp., New York, N.Y.
H. L. Yoh Co., Philadelphia, Pa.

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GEMINI SPACECRAFT FLIGHT HISTORY

MISSION	DESCRIPTION	LAUNCH DATE	MAJOR ACCOMPLISHMENTS
Gemini VIII	Manned 3 days Rendezvous and dock Extravehicular activity	Mar. 16, 1966	Demonstrated rendezvous and docking with Gemini Agena Target Vehicle, controlled landing and emergency recovery, and multiple restart of Gemini Agena Target Vehicle in orbit. Spacecraft mission terminated early because of an electrical short in the control system.
Gemini IX	Manned 3 days Rendezvous and dock Extravehicular activity (Canceled after failure of Target Launch Vehicle)	May 17, 1966	Demonstrated dual countdown procedures.
Gemini IX-A	Manned 3 days Rendezvous and dock Extravehicular activity	June 3, 1966	Demonstrated three rendezvous techniques, evaluated extravehicular activity with detailed work tasks, and demonstrated precision landing capability.
Gemini X	Manned 3 days Rendezvous and dock Extravehicular activity	July 18, 1966	Demonstrated dual rendezvous using Gemini Agena Target Vehicle propulsion for docked maneuvers, and demonstrated removal of experiment package from passive target vehicle during extravehicular activity. Evaluated feasibility of using onboard navigational techniques for rendezvous.
Gemini XI	Manned 3 days Rendezvous and dock Tether evaluation Extravehicular activity	Sept. 12, 1966	Demonstrated first-orbit rendezvous and docking, evaluated extravehicular activity, demonstrated feasibility of tethered station keeping, and demonstrated automatic reentry capability.
Gemini XII	Manned 4 days Rendezvous and dock Tether evaluation Extravehicular activity	Nov. 11 1966	Demonstrated rendezvous and docking, evaluated extravehicular activity, demonstrated feasibility of gravity-gradient tethered-vehicle station keeping, and demonstrated automatic reentry capability.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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