2. GEMINI PROGRAM FEATURES AND RESULTS

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Summary

This introductory paper has the objective of highlighting some of the intrinsic features of the Gemini Program and relating general results to these features, thereby furnishing a background for the more detailed papers which follow.

Introduction

Less than 5 years ago, men ventured briefly into space and returned safely. These initial manned space flights were indeed tremendous achievements which stirred the imagination of people worldwide. They also served to provide a focus for the direction of future efforts. Gemini is the first U.S. manned space-flight program that has had the opportunity to take this early experience and carry out a development, test, and flight program in an attempt to reflect the lessons learned. In addition, Gemini has endeavored, from its conception, to consider the requirements of future programs in establishing techniques and objectives.

Gemini Program Features

The purpose of the Gemini Program has usually been stated in terms of specific flight objectives; however, somewhat more basic guidelines also exist, and these are described in the following paragraphs.

Reliable System Design

The first guideline, reliable system design, is an objective of all programs, but in the Gemini Program several aspects of the approach are worth noting. One is the concept of independence of systems in which, to the degree practical, systems are designed in modules than can be developed and tested as a single unit. In this manner the inherent reliability of a system is not obscured by complex interacting elements. Advantages of this approach also exist in systems checkout and equipment changeout.

A second factor in Gemini systems design is the use of manual sequencing and systems management to a large extent. This feature affords simplicity by utilizing man's capability to diagnose failures and to take corrective action. It facilitates flexibility in the utilization of necessary redundancy or backup configurations of the systems. For example, in the spacecraft electrical-power system, the redundancy involved would make automatic failure sensing, interlocking, and switching both complex and difficult, if not impossible.

As already implied, the use of redundant or backup systems is an important facet of the Gemini spacecraft design. An attempt has been made to apply these concepts judiciously, and, as a result, a complete range of combinations exists. For systems directly affecting crew safety where failures are of a time-critical nature, on-line parallel redundancy is often employed, such as in the launch-vehicle electrical system. In the pyrotechnics system, the complete parallel redundancy is carried to the extent of running separate wire bundles on opposite sides of the spacecraft. In a few time-critical cases, off-line redundancy with automatic failure sensing is required. The flight-control system of the launch vehicle is an example of this type. In most crew-safety cases which are not time critical, crew-controlled off-line redundancy or backup is utilized. In the spacecraft propulsion system, the backup attitude control is used solely for the reentry operation. This reentry propulsion in turn involves parallel redundancy because of the critical nature of this mission phase. Many systems not required for essential mission phases are basically single systems with internal redundancy features commensurate with the requirements for overall mission success. The spacecraft guidance system is an example of this application. Certain systems have sufficient inherent reliability, once their operation has been demonstrated, that no special redundant features are required. The heat protection system is one of this type.

Future Mission Applicability

In the selection of systems and types of operations to be demonstrated, a strong effort was made to consider the requirements of future programs, particularly the manned lunar landing. It was not anticipated that Gemini systems necessarily would be directly used in other programs; however, their operating principles would be sufficiently close that the concepts for their use would be validated.

Where possible and to minimize development time, systems that already had some development status were selected; the spacecraft guidance and control system (a simplified block diagram is shown in fig. 2–1) typically represents this approach. The system is capable of carrying out navigation, guidance, and the precise space maneuvers needed for such activities as rendezvous, maneuvering, reentry, and launch guidance. At the same time, such major elements of the system as the inertial platform,

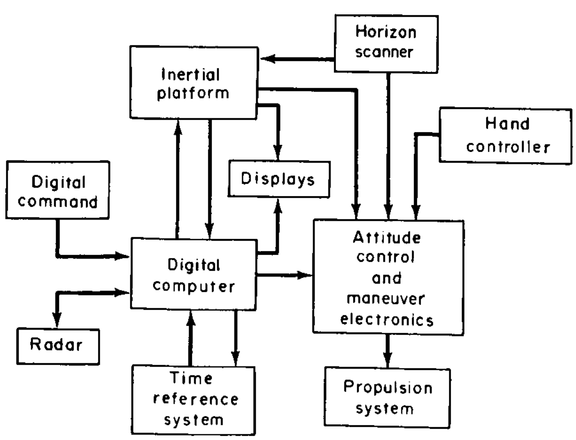

FIGURE 2–1.—Example of Gemini systems applicable to future programs and missions (guidance and control system shown).

the digital computer, the radar, and the flight-director display drew heavily on previous developments. Reliability, system operating life, and the sizing of consumables were also selected to afford durations corresponding to the requirements of oncoming programs.

These ground rules were applicable to many other systems. In the case of the Gemini launch vehicle, great benefit was obtained from the Titan II development program, even to the extent of validating certain Gemini-peculiar modifications in the test program prior to their use in Gemini.

Minimum Flight Qualification Tests

Because flying all-up manned space vehicles is expensive, time consuming, and exceedingly sensitive to failures, the Gemini development was based on the premise that confidence could be achieved through a properly configured program of ground tests and that a very limited number of unmanned flights could serve to validate the approach. With this in mind, a comprehensive ground program was implemented in the areas of development, qualification, and integrated systems tests. In addition, certain other measures were taken to further this approach, such as the utilization of the external geometric configuration and general heat protection approach of the Mercury spacecraft. The Titan II applicability has already been mentioned.

The ground-test program not only involved rigorous component and subsystems qualification and the usual structural testing, but also included many special test articles for integrated testing. These test articles included an airborne systems functional test stand for the launch vehicle and production spacecraft elements for ejection-seat tests, electrical and electronic compatibility tests, landing-system drop tests, at-sea tests, zero-g tests, and also a complete flight spacecraft for thermal-balance tests.

As indicated on figure 2–2, a high level of ground test effort commenced at the outset of the program and was sustained past the first several flights. The ability to fly with some qualification testing incomplete is related to the differences between the early spacecraft configurations and the long-duration and rendezvous spacecraft configurations. It was hoped that

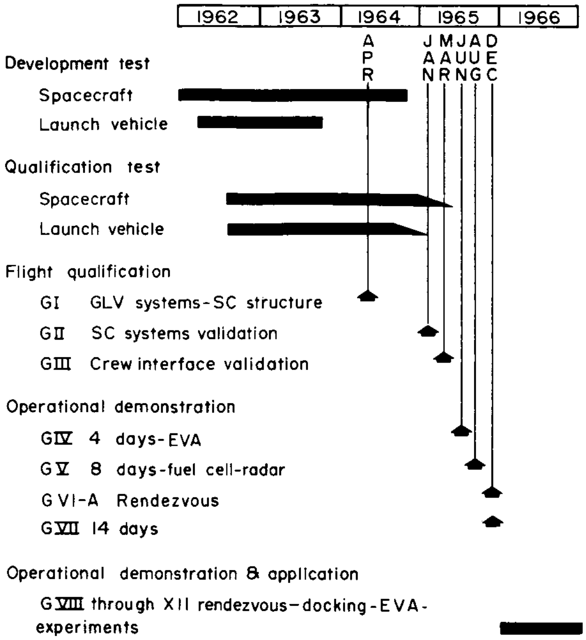

FIGURE 2-2.—Gemini test program.

the ground testing could be completed earlier, but the problems that were isolated and the required corrective action prevented earlier accomplishment. In spite of the great effort involved, it was better to utilize a ground-test program to ferret out problems than to encounter them in flight.

The ability to minimize flight qualification tests is also indicated in figure 2-2. Two unmanned flights were required prior to the first manned flight, and one manned flight test was required before proceeding into the operational program. No problems that significantly impacted following flights were encountered on these early flights.

Streamlined Launch Preparations

Activities aimed at streamlining the launch preparations and the other checkout activities commenced with the design. In the case of the spacecraft, the majority of equipment was placed outside the pressure vessel, with large removable doors providing a high percentage of equipment exposure during tests. Connectors were designed integral with each piece of equipment so that, when aerospace ground equipment was required for tests, the flight wire bundles need not be disconnected. These and similar features allow multiple operations to take place around the spacecraft and minimize damage while testing or replacing equipment.

Although repetitive testing still exists, it has been possible to curtail it because of the preservation of integrity features previously discussed and because of the improvement in test flow, to be discussed later. An outcome of the Gemini Program experience is that system reliability is achieved as a result of the basic development, qualification, and reliability testing; consequently, repetitive testing of the space vehicle need not be used for this purpose.

Another important aspect of the program is the delivery of flight-ready vehicles, including Government-furnished equipment, from the manufacturer's plant. This objective dictates complete integrated testing at the factory and includes crew participation in system tests, simulated flights, stowage reviews, and altitude-chamber runs. Equally important, it means the delivery of vehicles with essentially zero open items. All elements of the Gemini team, both launch vehicle and spacecraft, have worked extremely hard to achieve this end.

At Cape Kennedy the checkout plans have not been inflexible. They are continuously under review and are changed when the knowledge gained shows that a change is warranted. Some of the testing required for the first flights is no longer required or, in some cases, even desirable. Improvements in test sequences have also been achieved, and these avoid excessive cabling-up or cabling-down, or other changes in the test configuration. These alterations in test plans are carefully controlled and are implemented only after detailed review by all parties concerned.

Buildup of Mission Complexity

Although the Gemini flights have built up rapidly in operational capability, the planning endeavors have been orderly in order to make this buildup possible. The progressive buildup in mission duration is obvious from figure 2-2, but this philosophy also applies to most categories of the flight operations and will be discussed in more detail in subsequent papers. It can be stated that, from systems considerations alone, the 14-day flight of Gemini VII might not have been possible without the prior experience of the 8-day flight of Gemini V.

Another aspect of the buildup idea is the control of configuration to avoid flight-to-flight impact. The fuel cells and the cryogenic stowage of their reactants are by far the newest developments of all the Gemini systems. They were first flown "off-line" on Gemini II to obtain information on prelaunch activation and on their integrity in the launch and weightless environment. The next planned use was on Gemini V, where a fuel-cell power system was a mission requirement. To permit concentration on the basic flight objectives, the intermediate flights were planned with batteries as the source of electrical power. Similarly, the Gemini VI–A spacecraft utilized battery power so that possible results of the Gemini V flight would not impact on the first space rendezvous. This arrangement resulted in an excellent integration of these new systems into the flight program. The good performance of the fuel-cell systems now warrants their use on all subsequent flights.

Flight Crew Exposure

Gemini objectives require that complex operational tasks be demonstrated in earth orbit, but it is also desired to provide the maximum number of astronauts with space-flight experience. As a result, no flight to date has been made with crewmembers who have flown a previous Gemini mission. In fact, two significant flights, Gemini IV and VII, were made with crews who had not flown in space before. In the other three flights, the command pilot had made a Mercury flight. The results achieved attest to the character and basic capabilities of these men and also reflect the importance of an adequate training program. Again, a more detailed discussion of the subject will be presented in subsequent papers.

The flight crew require detailed familiarity with and confidence in their own space vehicle. This is achieved through active participation in the flight-vehicle test activities. The flight crews require many hours of simulation time to gain proficiency in their specific mission tasks, as well as in tasks common for all missions. With short intervals between missions, the availability of trained crews can easily become a constraint, and careful planning is necessary to avoid this situation. Much of this planning is of an advanced nature in order to insure the adequate capability and flexibility of simulation facilities.

Complex Mission Operations

The fundamentals of manned-mission operations were demonstrated in the Mercury Program where the flight-control functions of orbital insertion, orbit determination, systems monitoring, retrofire time, orbital landing-point prediction, and recovery were developed. These features also apply to Gemini flight control, but in a greatly expanded sense. There are many reasons for the increased requirements. On a rendezvous mission, the Gemini space vehicle is launched on a variable azimuth that is set-in just prior to launch, and the vehicle yaw-steers into orbit. These features affect both the flight-control function and the recovery operations for launch aborts. Also during rendezvous missions, flight control must be exercised over two vehicles in orbit at the same time, both of which have maneuvering capability. The orbit maneuvering further complicates the recovery operation by requiring mobility of recovery forces. These factors, combined with the relatively higher complexity of the Gemini spacecraft, require the rapid processing and display of data and a more centralized control of the operation. The maneuvering reentry is another aspect of the Gemini Program that complicates the flight control and recovery operations.

The long-duration missions have required shift-type operations on the flight-control teams and their support groups. This mode of operation increases the training task and introduces additional considerations, such as proper phasing from one shift to the other.

The Mission Control Center at Houston was designed to support these more complex functions, and these functions have been carried out with considerable success. It is felt that the implementation and demonstration of this part of the Gemini capability will be one of the largest contributions in support of the Apollo Program.

Flexible Flight Planning

Another facet of the Gemini flights is flexibility in flight planning and control. Requirements for flexibility have existed in both the preflight activities and in the manner in which the actual flight is carried out. The prime example of preflight flexibility is the implementation of the Gemini VII/VI–A mission subsequent to the aborted rendezvous attempt of the original Gemini VI mission. Although strenuous effort was required in all areas, these activities did take place essentially in accordance with the plan.

During actual flights, the need has often arisen to alter the flight plans. These changes have been implemented without affecting the primary objectives of the mission. They have also been initiated in a manner to obtain a high degree of benefit from the mission in terms of all the predetermined flight objectives. In some cases, new tasks have been incorporated in the flight plan during the flight, as was the phantom rendezvous and ground transponder interrogation on Gemini V when difficulties forced abandonment of the rendezvous-evaluation-pod exercise. While detailed premission flight planning is a requirement, the ability to modify rapidly has been of great benefit to the program.

Postflight Analysis and Reporting

In a manned operation, it is necessary to isolate and resolve problems of one flight before proceeding with the next. In the Gemini Program, an attempt has been made to establish an analysis and reporting system which avoids this potential constraint. The general plan is shown in figure 2–3. In targeting for 2-month launch centers, the publication of the mission evaluation report was set at 30 days. In turn, a major part of the data handling, reduction, and analyses activities takes place during a

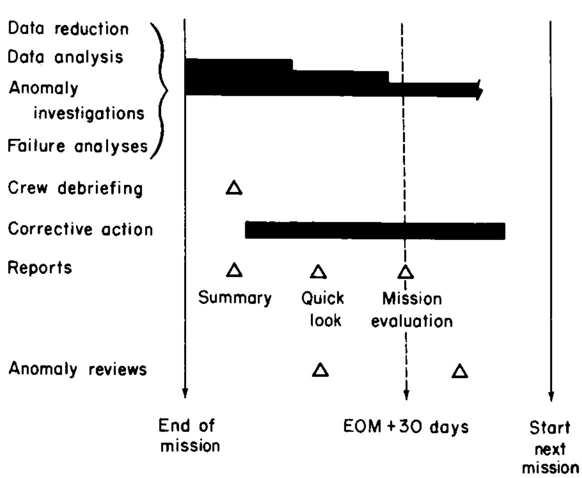

FIGURE 2–3.—Postflight analysis and evaluation.

period of approximately 2 weeks following each mission. All problems are not necessarily solved at the end of the 30-day period, but isolation of problems, evaluation of their impact, and initiation of corrective action have been possible.

In carrying out these activities, a formal task group is set up. Rather than having a permanent evaluation team, personnel are assigned who have been actively working in the specific areas of concern before the flight and during the flight. This approach provides personnel already knowledgeable with the background of the particular flight. Corrective action is initiated as soon as a problem is isolated and defined. At this point in the program, impact of one flight on another has not proved to be a major constraint.

Personnel Motivation

Although good plans and procedures are needed in a major program, well-motivated people must be behind it. Teamwork comes primarily from a common understanding through good communications. In the Gemini Program, an effort has been made to facilitate direct contact at all levels. Good documentation is necessary but should not constrain direct discussions. Individual people, right down to the production line, must fully realize their responsibility. This effort starts with special selection and training, but it is necessary to sustain the effort. With this in mind, a number of features directly related to the individual have been included in the flight-safety programs. The launch-vehicle program is an outstanding example of this effort. People working on Gemini hardware are given a unique badge, pin, and credentials. Special awards are presented for outstanding work. Special programs are held to emphasize the need for zero defects. A frequent extra feature of such programs is attendance and presentations by the astronauts. Much interest has been exhibited in this feature, and it serves to emphasize the manned-flight safety implications of the program.

Before leaving this subject, the effect of incentive contracts should also be pointed out. All major Gemini contracts, although differing in detail, incorporate multiple incentives on performance, cost, and schedule. The experience with these contracts has been very good in providing motivation throughout the contractor organization, and they have been structured to provide this motivation in the desired direction. The incentive features have served to enhance program visibility, both for the Government and for the contractors.

Gemini Flight Results

Gemini Objectives

At the outset of the Gemini Program, a series of flight objectives was set forth. As stated previously, these objectives were directed at the demonstration and investigation of certain operational features required for the conduct of future missions, particularly the Apollo missions. These original objectives include: long-duration flights in excess of the requirements of the lunar-landing mission; rendezvous and docking of two vehicles in earth orbit; the development of operational proficiency of both flight and ground crews; the conduct of experiments in space; and controlled land-landing. Several objectives have been added to the program, including extravehicular operations and onboard orbital navigation. One objective, controlled land-landing, has been deleted from the program because of development-time constraints, but an important aspect of this objective continues to be included—the active control of the reentry flight path to achieve a precise landing point. Initial demonstrations of most of these objectives have been made, but effort in these areas will continue in order to investigate the operational variations and applications which are believed to be important. In addition, the areas yet to be demonstrated, such as docking and onboard orbital navigation, will be investigated on subsequent flights.

Mission Results

The flight performance of the launch vehicle has been almost entirely without anomalies (fig. 2–4). There have been no occasions to utilize backup guidance or any of the abort modes. On two occasions, the Gemini II and VI–A missions, the automatic-shutdown capability was used successfully to prevent lift-off with launch-vehicle hardware discrepancies.

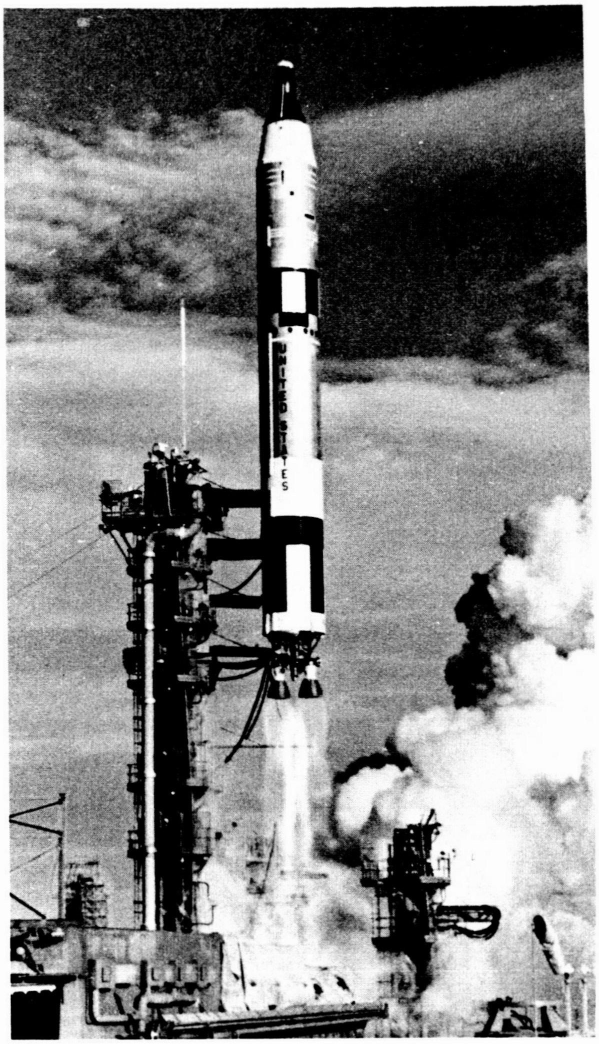

FIGURE 2–4.—Lift-off of Gemini space vehicle.

In orbital operations, all missions have taken place with no significant crew physiological or psychological difficulties (fig. 2–5). The proper stowage, handling, and restowage of equipment has been a major effort. There has been a tendency to overload activities early in the mission. This is undesirable because equipment difficulties are quite likely to become evident early in the mission. It has always been possible to develop alternate plans and to work around these equipment difficulties in carrying out the basic flight plan. The cabin environment has proved satisfactory, but pressure-suit comfort and mobility considerations make doffing and donning capabilities desirable. The performance of the spacecraft maneuvering and attitude control has been outstanding. Special orbital

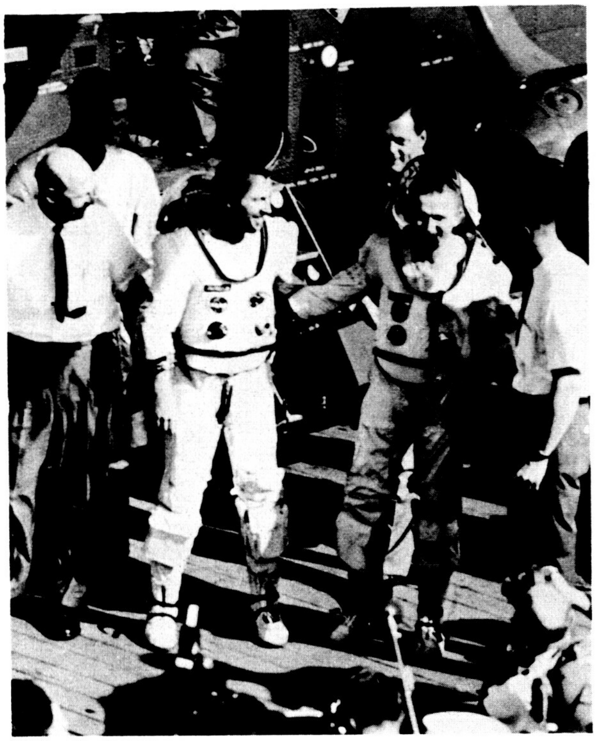

FIGURE 2-5.—Gemini VII flight crew onboard recovery ship.

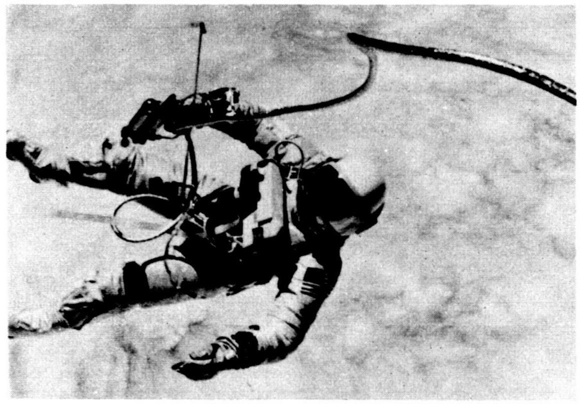

FIGURE 2-6.—Extravehicular activity during Gemini IV mission.

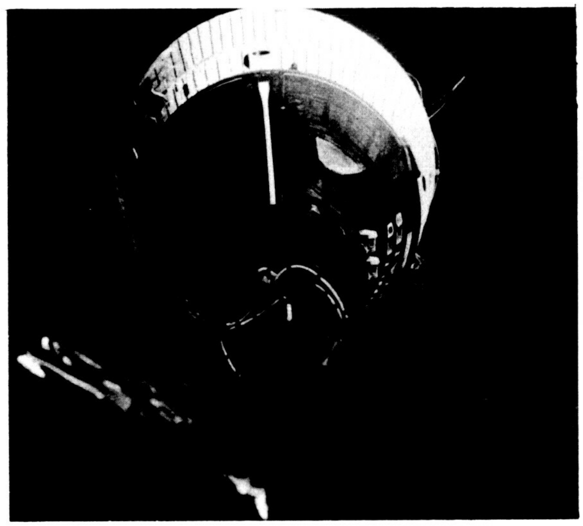

FIGURE 2-7.—Rendezvous during Gemini VI-A and VII missions.

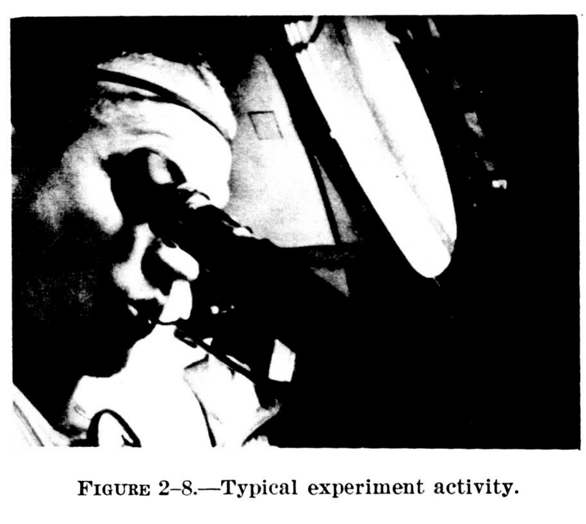

FIGURE 2-8.—Typical experiment activity.

tasks, such as extravehicular activities, rendezvous, and experiments, have been conducted very satisfactorily. During the extravehicular investigation on Gemini IV (fig. 2-6), no disorientation existed, and controlled maneuvering capability was demonstrated. This capability is felt to be a prerequisite to useful extravehicular operations. The straightforward manner with which the rendezvous was accomplished (fig. 2-7) does indeed reflect the extremely heavy effort in planning, analysis, and training that went into it.

The Gemini experiments have been of a nature that required or exploited man's capability to discriminate for the collection of data, and then retrieve the data for postflight evaluation. During the flights, 54 experiments were conducted (fig. 2-8). All of the experiment flight objectives, except for about three, have been accomplished.

All retrofire and reentry operations have been performed satisfactorily, although only the last two missions demonstrated precise controlled maneuvering reentry (fig. 2-9). In the Gemini VI-A and VII landings, an accuracy of about

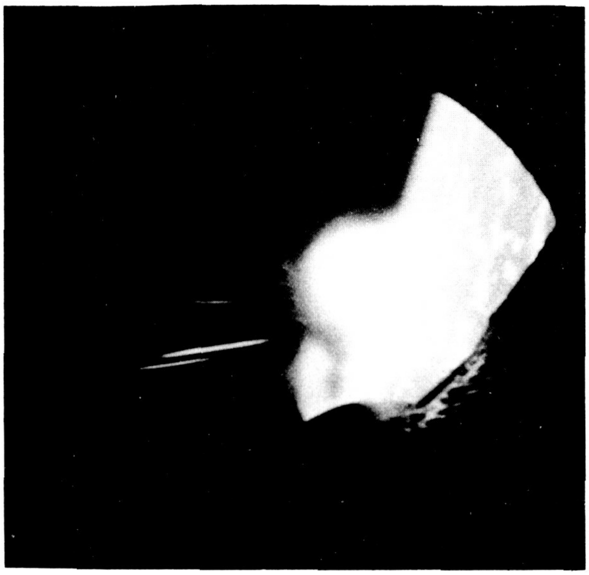

FIGURE 2-9.—View through spacecraft window during reentry.

6 miles was achieved, and this is approaching the capabilities of the system being utilized. Recovery has always been rapid, and the support of recovery by the Department of Defense has been excellent (fig. 2-10).

FIGURE 2-10.—Recovery operations.

Concluding Remarks

The Gemini design concepts and comprehensive ground test program have enabled the flight program to be conducted at a rapid pace and to meet program objectives. Much credit in this regard must be given to James A. Chamberlin, who spearheaded the conceptual effort on the Gemini Program.

Although flight operations have been relatively complex, they have been carried out smoothly and in a manner to circumvent difficulties, thereby achieving significant results from each flight.

The flights, thus far, have served to provide an initial demonstration of most of the Gemini flight objectives. Future flights will explore remaining objectives as well as variations and applications of those already demonstrated.

The Gemini team has worked exceedingly hard to make the program a success, and the special effort in developing teamwork and individual motivations has been of considerable benefit.