22. GEMINI RESULTS AS RELATED TO THE APOLLO PROGRAM

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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-

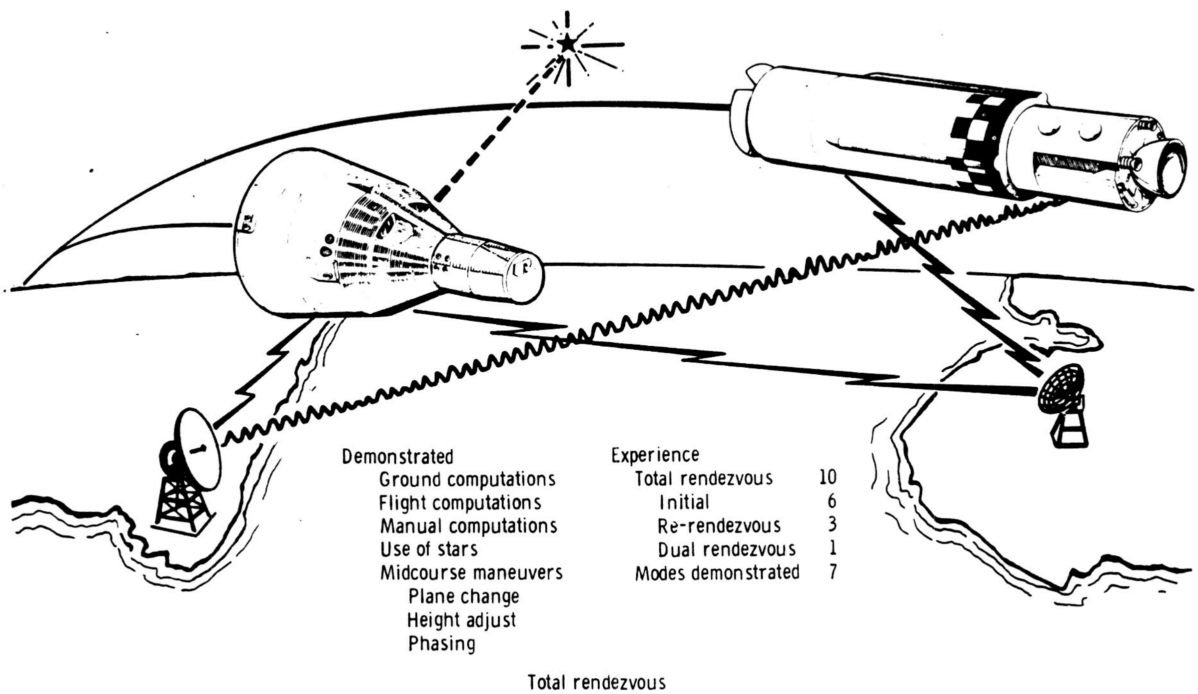

FIGURE 22–1.—Rendezvous.

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.

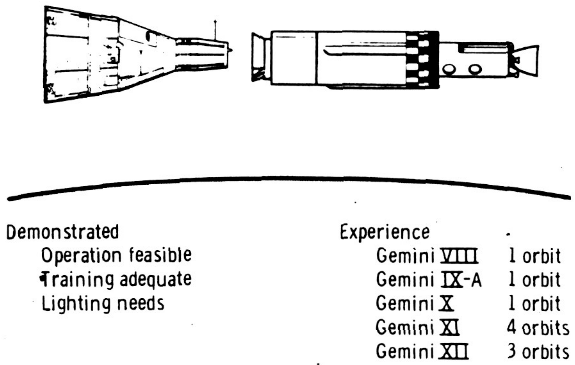

FIGURE 22–2.—Docking.

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,

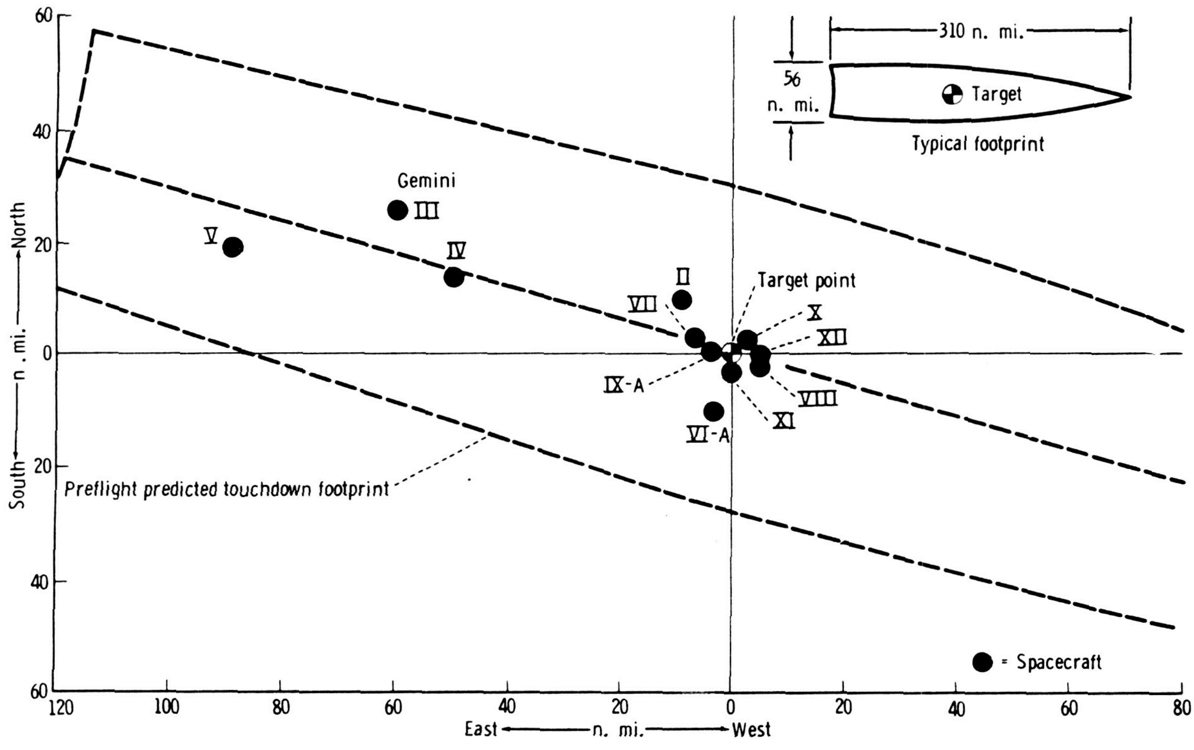

FIGURE 22–3.—Demonstration of landing accuracy.

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 applicability 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.