COLLECTIVE KNOWLEDGE GAINED FROM GEMINI

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Summary

The Gemini Program has comprised 12 space flights, 10 of which were manned operations. The information gained is difficult to summarize within a brief paper, but more detailed information has and will continue to be made available to those who have an interest in it. With minor exceptions, the objectives of the program were met, having been expanded well beyond original concepts and examined in considerably more depth than expected. Gemini leaves a legacy of results that, hopefully, will further accelerate man's efforts to explore and utilize the frontier of space.

I. Introduction

The Gemini Program with its series of manned space flights has been completed, and it is an appropriate time now to summarize and interpret the results of these flights. At the outset, the Gemini Program was based upon the exploration of several major objectives of manned operations. These objectives (listed in Fig 1) were to validate long-duration operations of several weeks, to demonstrate rendezvous and docking with another vehicle, and to develop a technique for controlled land landings. A great deal of concentration was placed on the first two objectives and those have been successfully accomplished. The third objective was partially accomplished with a number of demonstrations of precision maneuvering into a landing area, but land landing was not demonstrated.

ORIGINAL OBJECTIVES	ACHIEVED OBJECTIVES
RENDEZVOUS AND DOCK	RENDEZVOUS AND DOCK – INITIAL DEMONSTRATION – RENDEZVOUS VARIATIONS
LONG DURATION	LONG DURATION EXTRAVEHICULAR ACTIVITIES MANEUVERING WHILE DOCKED
CONTROLLED LAND LANDING	CONTROLLED REENTRY EXPERIMENTS TETHERED VEHICLE OPERATIONS NEW SYSTEMS FEASIBILITY

Figure 1. Objectives of the Gemini Program

As opportunities arose, the orginal objectives were expanded to include the investigation of extravehicular operations, the conduct of large orbital maneuvers using a docked stage, the conduct of scientific, medical, and technical experiments, and operations with two tethered vehicles. Substantial information in all of these areas has been obtained, particularily during the later half of the flight program.

Gemini has provided information in many other areas not entirely obvious from these statements of objectives. They include:

(1) Development of reliable systems configurations through the applications of redundancy, modular design, and simplifications afforded by the utilization of crew capabilities.

(2) Reduction in qualification flights, and rapid progression to an operational phase through use of a comprehensive ground-test program.

(3) Decrease in launch preparation times, and reduction in launch intervals by delivery from the manufacturers of thoroughly tested and flight-ready vehicles.

(4) Progressive buildup in flight complexity to achieve a logical extrapolation of the experience gained from previous flights.

(5) Flexibility in flight planning and operations to capitalize on successful flights and minimize the impact of flight problems.

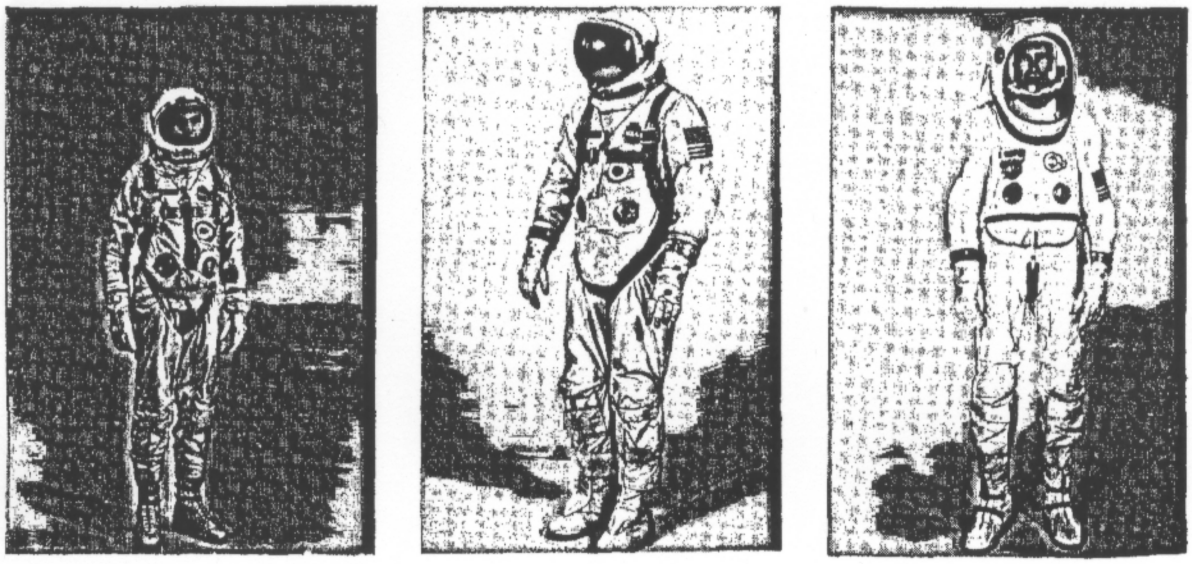
(6) Achievement of a high degree of proficiency of flight crews and ground personnel through experience gained from 10 manned flights.

These and other similar areas are discussed in References 1 and 2 and will not be discussed in detail herein. The intent will be to concentrate on flight results.

II. Long-Duration Flights

Results of long-duration flights are also reported in Reference 2, and those obtained subsequent to that report remain essentially unchanged. The weightless environment has not produced difficulties except during extravehicular activities (EVA), which will be discussed later. No evidence exists of significant physiological or psychological effects either noted or measured. Although some cardiovascular deconditioning is apparent on return to a one g environment, it has not affected crew function, and the condition is short-lived. No disorientation exists, and the flight crew can accurately perform systems management, control functions, and all other operations required onboard the spacecraft.

Confinement has been a surprisingly minor problem area even in the small volume of the Gemini spacecraft. The difficulties appear to be alleviated by the weightless state because of the absence of pressure points on the body. Pressure suits have some tolerable, but objectionable features, mainly caused by their bulk and clumsiness. The three types of suits used in the Gemini Program are shown in Figure 2. To circumvent possible difficulties during the 14-day flight of Gemini VII a special lightweight suit, which is also doffable, was developed. The astronauts found their comfort greatly enchanced in the doffed-suit condition, and the cabin provided



INTRAVEHICULAR STANDARD **EXTRAVEHICULAR** **LIGHTWEIGHT**

Figure 2. Three types of Gemini spacesuits

a completely satisfactory environment. The pressure suit also produces some subjective discomfort in that the mechanism of cooling primarily involves the evaporation of perspiration. Care must be exercised to maintain adequate water intake to avoid excessive dehydration.

The stowage, handling, and restowage of loose cabin equipment has been a tedious activity during all Gemini flights. This difficulty should be reduced in a larger spacecraft, but it probably will still be important. Typical items that must be stowed are shown in Figure 3, and Figure 4 gives categories and numbers of stowed items. Numerous planning reviews and stowage rehersals are required to establish proper locations, sequences of stowage and unstowage, and center of gravity changes so that a flight can be effectively carried out. The handling of waste articles (food bags, cleansing towels, urine bags, and the like) is particularly troublesome, and on recent flights special hatch openings have been programed to facilitate the maintenance of a clean and unobstructed cabin.

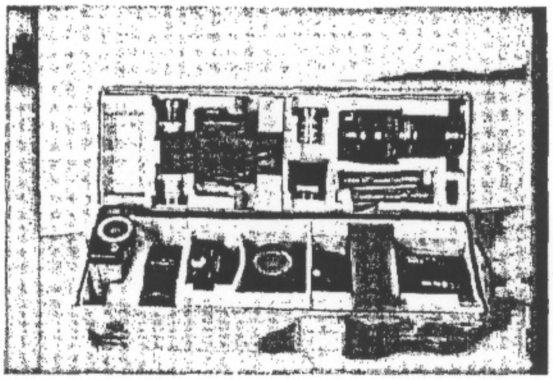
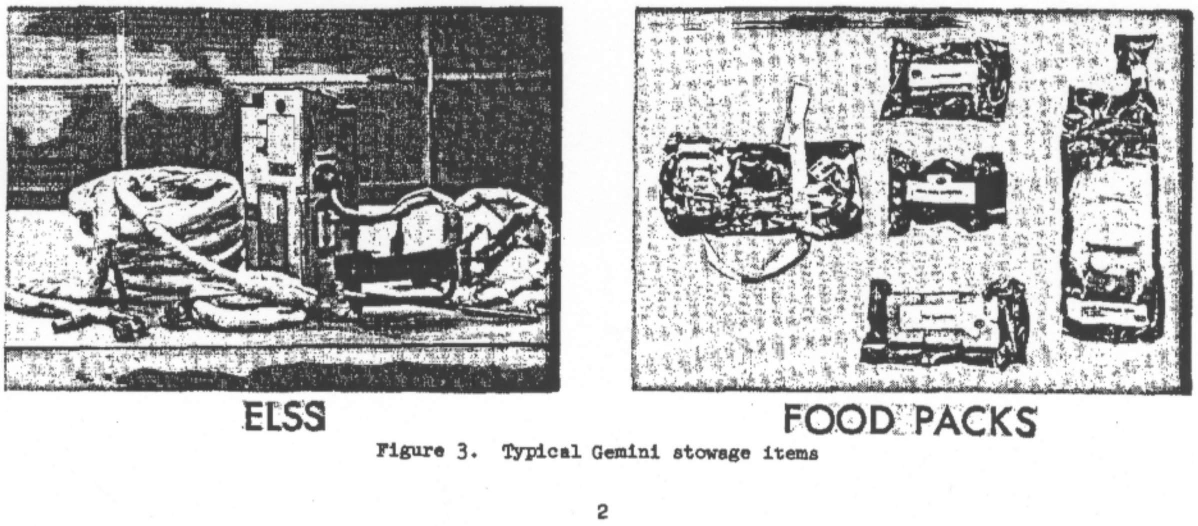


PHOTO EQUIPMENT STOWAGE



ELSS **FOOD PACKS**

Figure 3. Typical Gemini stowage items

Figure 3. Typical Gemini stowage items

Another aspect of space flight worthy of mention is the achievement of adequate sleep. Perhaps when flights become more routine, satisfactory sleep periods will be obtained. To the present, inadequate sleep in depth and length is invariably encountered during the first sleep period of a flight. Sleep adequacy also exhibits considerable variation on subsequent days, varying in a somewhat cyclic fashion as fatigue builds up. Typical sleep cycles as reflected in heart rate are shown in Figure 5. The depression in heart rate and the duration of the depression are a fairly good indication of the rest obtained. It is possible that medication may be a help in coping with this difficulty. In any case, flight planning should account for this condition such as by making the second day of a flight relatively less strenuous with respect to activities planned. In spite of this situation, Gemini astronauts have always returned from their flights in good physical condition, and from an overall standpoint they exhibited only light-to-moderate fatigue.

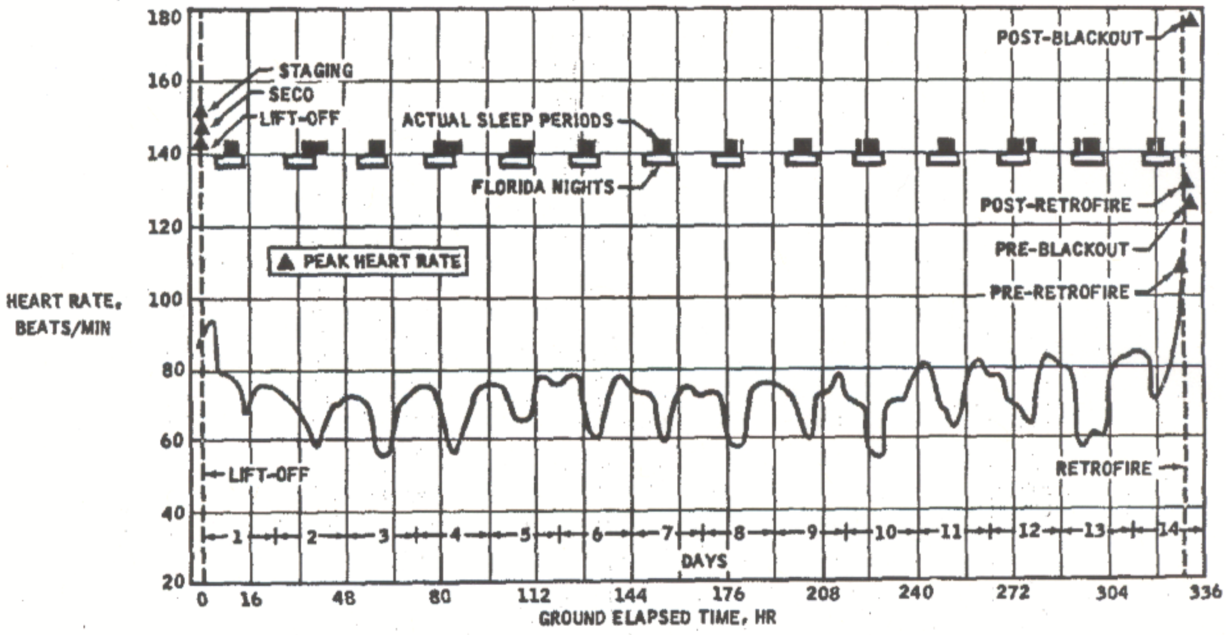


Figure 5. Typical sleep cycles as reflected in heart rate

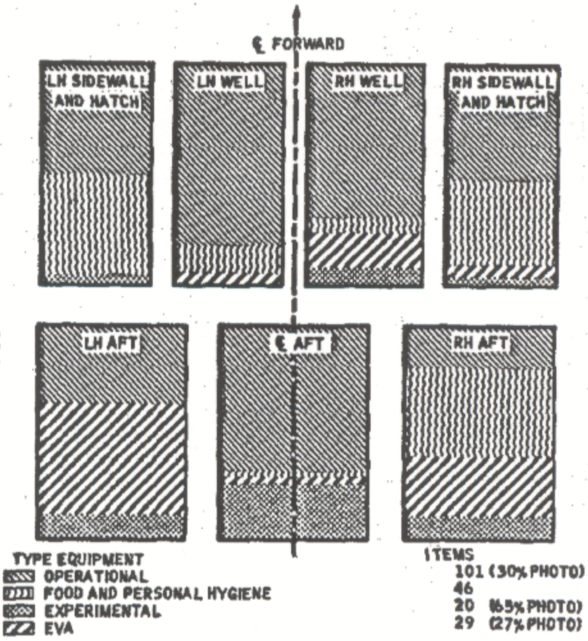


Figure 4. Categories and numbers of stowage items

III. Rendezvous Operations

Seven different types of rendezvous modes have been investigated during Gemini, most of which are indicated in Figure 6. Three types were used for the initial rendezvous after lift-off, three additional types were investigated using re-rendezvous techniques, and one was a dual rendezvous involving two different target vehicles. Each of these operations have been successful. This success has provided confidence in the ability to carry out such operations; however, rendezvous still is recognized as a highly precise task that is rather unforgiving

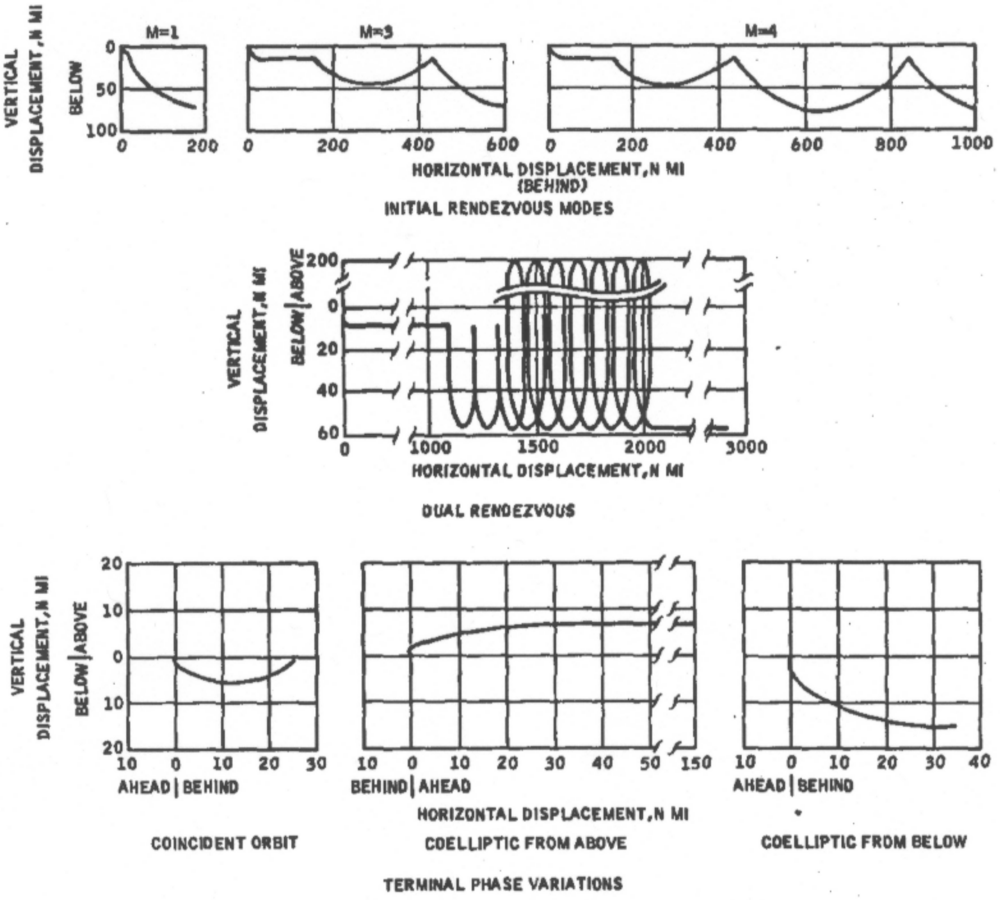


Figure 6. Relative trajectory plots showing rendezvous mode variations

of errors late in the operation because of the large energy expenditures involved in their correction.

Turning first to lift-off considerations, one interesting result is that the experience to date does not strongly indicate a need for extensive launch windows. As shown in Figure 7, the Gemini launches since Gemini V. have been essentially on time (or else the launch has been scrubbed). By suitable planning, minor problems can be easily absorbed in the count, and if major problems occur practical launch-window lengths are not particularly helpful. Although a simultaneous countdown of both vehicles has been extensively used in Gemini, there is nothing in the results to indicate that this is a necessity.

MISSION	LAUNCH ATTEMPTS	LAUNCH DATE	LAUNCH TIME DEVIATION
GI	1	APR 8, 1964	ON TIME
GII	2	JAN 19, 1965	-4 MIN
GIII	1	MAR 23, 1965	-24 MIN
GIV	1	JUN 3, 1965	-16 MIN
GV	2	AUG 21, 1965	ON TIME
GVI	1	SCRUB (AGENA FAILURE)	—
GVI A	2	DEC 15, 1965	ON TIME
GVII	1	DEC 4, 1965	ON TIME
GVIII	2	MAR 16, 1966	ON TIME
GIX	1	SCRUB (ATLAS FAILURE)	—
GIX A	2	JUN 3, 1966	ON TIME
GX	1	JUL 18, 1966	ON TIME
GXI	3	SEP 12, 1966	ON TIME
GXII	3	NOV 11, 1966	ON TIME

Figure 7. Gemini launch performance

Height adjust, plane change, and phasing maneuvers that position the spacecraft at an offset point from which the terminal phase is initiated have been accurately accomplished both under ground-control and by means of onboard guidance. Because of error propagation in the inertial guidance system rendezvous, accomplished soley from onboard information, are limited to fairly rapid operations. With the Gemini system it appears that this capability extends to rendezvous completed by the fourth revolution, and on Gemini XI a precise one-orbit rendezvous was accomplished during the first revolution based entirely on onboard computations. Ground control of rendezvous is highly effective when sufficient time is available for data gathering and processing. Rendezvous during the first revolution presented too rapid a maneuvering sequence for ground control, and in all cases corrections after initiation of the terminal phase have used onboard information.

The terminal phase of rendezvous commences with the initiation of transfer to the target from the offset point and concludes with the establishment of station keeping with the target. This phase involves precision maneuvers, and, finally, careful control of closing rates and line-of-sight rates. Fuel expenditures encountered during terminal operations are compared with the minimum possible in Figure 8. A considerable variation exists between the ratio of actual-to-minimum propellant for various

MISSION	TYPE OF RENDEZVOUS	CONDITIONS AT START OF TERMINAL PHASE	PROP USAGE - POUNDS		
			ACTUAL	MINIMUM	RATIO
G VI A	M=4	COELLIPTIC Δh=15 N. MI. ΔX=25 N. MI.	130	81	1.60
G VIII	M=4	COELLIPTIC Δh=15 N. MI. ΔX=25 N. MI.	160	79	2.02
G IX A	M=3	COELLIPTIC Δh=12 N. MI. ΔX=22 N. MI.	113	68	1.66
G IX A	EQUI-PERIOD	Δh=2.5 N.MI. ΔX=3.5 N. MI.	61	20	3.05
G IX A	REND. FROM ABOVE	Δh=-7.5 N. MI. ΔX=-10 N. MI.	137	39	3.51
G X	M=4	COELLIPTIC Δh=15 N. MI. ΔX=30 N. MI.	360	84	4.28
G X	OPTICAL TERMINAL PHASE	COELLIPTIC Δh=7 N. MI. ΔX=12 N. MI.	180	73	2.46
G XI	M=1	SC AT APOGEE OF 87/151 ORBIT Δh=10 N. MI. ΔX=15 N. MI.	290	191	1.52
G XI	COINCIDENT ORBIT	Δh=0 N. MI. Δh=25 N.MI.	87	31	2.81
G XII	M=3	COELLIPTIC Δh=10 N. MI. ΔX=20 N. MI.	112	55	2.04

Figure 8. Rendezvous propellant usage

types of terminal phase conditions, and also for different flights using the same or similar terminal phase conditions. This latter variation reflects the critical nature of this 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 may actually increase line-of-sight control requirements, and more time is spent controlling during the closing sequence. On the other hand, if high line-of-sight rates are encountered, braking has to occur early enough to allow correction of line-of-sight rates before this target is passed.

A number of terminal-phase operations have been satisfactorily completed by using optical 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 a very desirable device. During simulations, rendezvous have been effected without platform information, but success is of relatively low probability. Another point to note is the low theoretical (and actual) propellant consumption involved with the offset condition employed in the re-rendezvous on Gemini XI. The spacecraft is placed in the same orbit as the target vehicle, but with a trailing displacement. This type of terminal phase has generated considerable interest in its application to certain rendezvous operations, particularly where a ground system is used to set up the terminal phase.

IV. Station Keeping, Docking, and Docked Maneuvers

Station keeping with another vehicle encountered difficulties on Gemini IV, but, with a better understanding of constraints, this activity has proved to be straightforward on subsequent flights. Station keeping involves holding at a fixed position with respect to a target, using instinctive up-down, sideways, and fore - aft thrust applications. A nominal station-keeping range is about 50 feet; it continues to be easy out to 200 feet, becomes difficult at 600 feet, and practically impossible beyound. These figures apply when the spacecraft is operating at the same altitude as the target, and are somewhat reduced when the spacecraft operates above or below. Station keeping is easily accomplished at extremely short ranges (a matter of a few inches). Gemini IX operated within a few inches of a vehicle that was slowly rotating about all three axes in order to inspect a shroud failure. Gemini X maintained position within several feet of a slowly rotating vehicle, while an extravehicular astronaut transferred to that vehicle and recovered a micrometerorite experiment.

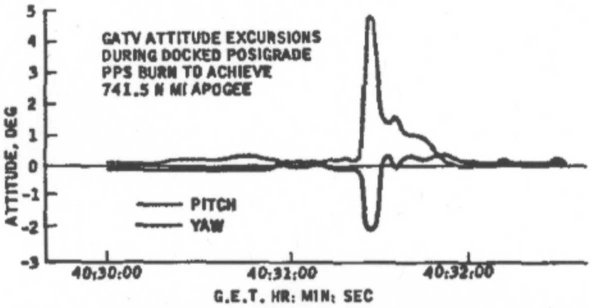
The most effective control during station keeping is to have the spacecraft attitude control in platform mode (automatic attitude hold), while the astronaut generates short pulses of the translation thrusters. Pulse mode of attitude control is effective, but it requires more attention, and rate command is also effective, but is a relatively high propellant user.

Because station keeping at short ranges has proved to be simple and accurate, no difficulty was anticipated in entering the target docking cone. This has generally been the case, although in one instance during Gemini XII a disturbance was encountered on inital contact. The spacecraft was backed away, the vehicles restabilized, and docking reinitiated. Eccentricity on docking contact can be held to a few inches, and angular alignment to less than 2°. Contact velocities have been less than 1 foot per second. Accelerations imported to either target or spacecraft have been insignificant. Impact shock is absorbed by hydraulic dampers, and a rigidizing operation ensues atuomatically, which draws the spacecraft nose section into hard points on the target docking adapter.

In the rigidized condition, the combined vehicle has been satisfactorily maneuvered both in attitude and translation. Attitude control can be exercised either with the spacecraft system or with the target-vehicle system. In the latter case, command is accomplished through a hard-line umbilical which is made during the docking operation. The system has a capability for 96 coded commands. Prior to docking, these commands can be sent to the target vehicle either from the spacecraft through an L-band radar link, or from the ground using another RF link. In the course of a flight, several thousand commands are sent involving these three input sources. All commands have been received and acted upon.

Docked translational maneuvers have utilized the Agena propulsion systems, the primary propulsion system (PPS)—16 000-pound thrust—for large maneuvers and the secondary propulsion system—400-pound thrust—for small maneuvers, or vernier corrections. The secondary system also employs still smaller thrusters—32-pound thrust—for ullage orientation prior to PPS burns.

Considerable analytical, testing, and simulation effort were expended to assure dynamically stable operations during primary propulsion system burns. This effort was necessary in light of the relatively high flexibility of the docked joint which has a natural frequency of the first bending mode of about four cycles per second. Fairly simple shaping networks were utilized to obtain stability. They produce a very low high-frequency gain with a long time constant. This approach resulted in significant attitude transients following engine start, as seen in Figure 9; however, it is acceptable, as seen by comparing the orbital parameters desired and achieved during the maneuvers carried out on Gemini XI (also shown on Fig 9). To adequately contain these transients, great care was exercised in the control of lateral center-of-gravity offset, engine-gimbal trim, and thrust vector orientation of the docked configuration. In future programs, it may be desirable to eliminate these constraints through use of more sophisticated shaping networks in the flight control system.



MANEUVERS	ΔV TOTAL FT/SEC		RESULTING ORBIT					
			APOGEE		PERIGEE		INCLINATION	
	PLAN	ACTUAL	PLAN	ACTUAL	PLAN	ACTUAL	PLAN	ACTUAL
OUT OF PLANE	110.0	109.8	166.5	164.2	157.6	154.6	28.85	28.85
POSIGRADE	920.0	918.0	739.4	741.5	156.5	156.3	28.82	28.85
RETROGRADE	920.0	917.6	164.1	164.2	156.4	156.0	28.86	28.83

Figure 9. Significant attitude transients

One of the main applications of redundancy in the target vehicle is to insure shutdown of the Agena engines at the proper point. The primary means for shutdown during a maneuver is through the use of a velocity meter. This is backed up in several ways: (1) by a stored program command set up to occur several seconds after the nominal duration of the burn, (2) by the command link where the crew monitors inertial velocity indicators in the spacecraft, and (3) by an arm-stop switch representing an independent and direct hardline control of the engine from the spacecraft. In addition, the engine is automatically shut down upon sensing a turbine-overspeed condition.

Undocking has also been a most straightforward operation. In the case of Gemini VIII, where uncontrolled rotations were encountered while docked, the undocking took place under rotational rates of about 5° per second in roll, and 3° per second in pitch and yaw. The undocking sequence is initiated on command from the spacecraft, and this undocking causes simultaneous urigidizing of the docking adapter and retraction of the latches. In general, aft spacecraft thrust has been applied, but in Gemini XI no thrust was used, and a smooth deployment of the spacecraft was obtained just utilizing the momentum from the unrigidizing operation. Because of the critical nature of undocking, several backup methods are employed. One is a completely independent control by hardline of the sequence by the crew, and the other is a pyrotechnic disengagement of the docking latches.

V. Extravehicular Activities

Extravehicular activities (EVA) are an aspect of the program that have been penetrated in considerably more depth than had been originally contemplated. A summarization of accomplishments is presented in Figure 10. The results of the initial extravehicular operations on Gemini IV were exceedingly satisfactory. The adequacy of the environmental protection that was provided for the EVA astronaut was demonstrated, the ability to maneuver about with a handheld unit was demonstrated, and no disorientation or other detrimental effects of this new operating regime were encountered. This was a brief exploratory operation that did not significantly involve complex and detailed work tasks.

GEMINI EVA ACCOMPLISHMENTS

- BASIC FEASIBILITY OF EVA
- EQUIPMENT DONNING
- DAY AND NIGHT OPERATIONS
- SURFACE TRANSIT
- WORK TASKS OF VARYING COMPLEXITY
- CREW TRANSFER TO ANOTHER VEHICLE
- USE OF MANEUVERING UNIT
- EQUIPMENT RETRIEVAL FROM PASSIVE SATELLITE DURING EVA
- FORMATION FLYING WITH PASSIVE VEHICLE DURING EVA
- EVA PHOTOGRAPHY
- TETHER DYNAMICS
- BODY RESTRAINTS

Figure 10. Gemini EVA accomplishments

It was not possible to investigate EVA further until Gemini IX, and this flight, indeed, was a very major extension of EVA operations. It involved a gross extension of time to over 2 hours, and, therefore, resulted in operations during day and night. It involved more extended evaluations of maneuvering with an umbilical, and also moving along the spacecraft using free-floating techniques, handholds, and handrails. It involved operations inside the equipment adapter of the spacecraft out of sight of the command pilot. More significantly, it involved complex close-in work tasks that had to be accomplished on a fairly tight schedule. These tasks included mounting equipment, retrieving equipment, and preparing and donning a sophisticated astronaut-maneuvering unit. Although, in the main, these activities were carried out, they were accompanied by a condition of excessively high workload. As a result, the demonstration of the astronaut maneuvering unit (AMU) had to be discontinued. This high workload involved difficulty in maintaining body position during the conduct of these tasks caused by inadequate restraints, and compounded by conditions of limited mobility in the pressurized suit, by the high thermal load encountered, and probably by other environmental factors.

The magnitude of the effort can be qualitatively deduced from heart-rate and respiration-rate levels encountered during this operation. These rates, presented as a time history in Figure 11, show sustained levels of the order of 150 beats per minute, and peak levels of 180 beats per minute during the AMU donning operation. These rates are comparable to those encountered during such activities as playing soccer or basketball, here on the ground, and, obviously, are not desirable when operations are sustained over a long period. Unfortunately, it is not possible to exactly correlate heart rate and workload because of unknown factors, such as thermal environment, carbon dioxide environment, emotional factors, and others.

These extremely high heart rates have not always been encountered during extravehicular operations. Also shown in Figure 11 are values obtained during the standup EVA and during the umbilical EVA on Gemini X. The standup EVA involved relative light-work tasks, such as photography, in a well-tethered condition. The umbilical EVA during Gemini X did involve some complex work tasks, such as the connection of a high-pressure fluid line for use with a handheld maneuvering unit, and the retrieval of a micrometeorite experiment mounted on another vehicle. However, these work tasks were less sustained, were more open-ended in nature, and did not present as restricted a time line. In this case heart rates were maintained below 135 beats per minute with an average sustained heart rate of 115 beats per minute, a completely satisfactory condition. Ingress produced somewhat higher pulses because of difficulties in handling the umbilical within the cockpit. Another factor of possible significance was that the standup EVA was programed before the umbilical EVA, allowing for some limited acclimatization to the EVA environment.

After the encouraging results of Gemini X, further difficulties in this area were encountered on Gemini XI. Although much engineering effort was expended to establish adequate body restraint and positioning methods in the equipment adapter area, it was not possible to evaluate these features because of fatigue encountered in a vehicle-to-vehicle tether-hookup operation which preceded this activity. The pitfall here was that extensive ground simulation and training activity had indicated that the tether hookup was easy to do. This result reflects the limitation of zero-g airplane-training because of the short duration of the zero-g environment available. It is not possible to accurately evaluate sustained operations that require periods of over 30 seconds. To circumvent this difficulty,

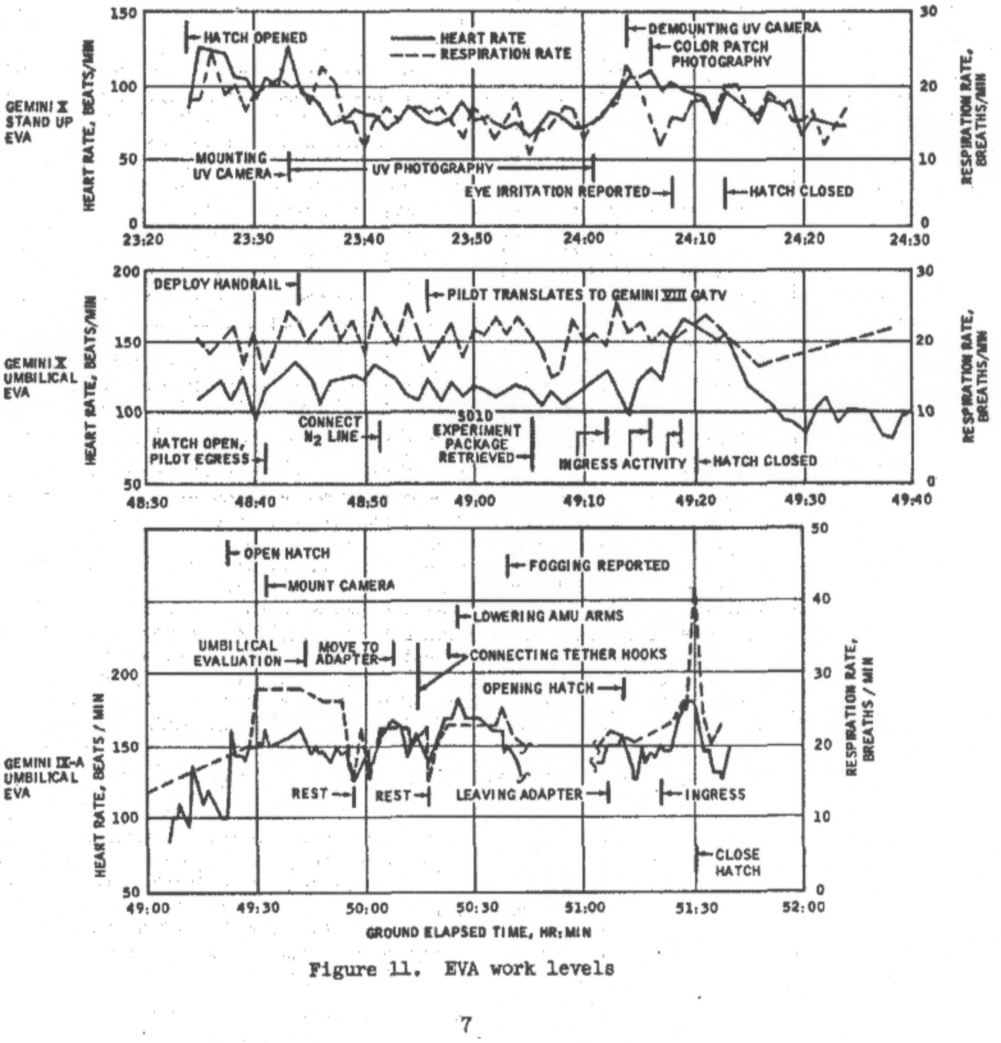
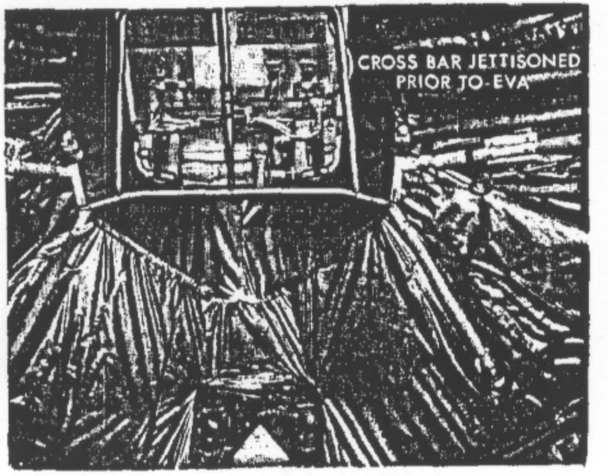


Figure 11. EVA work levels

much more emphasis has been placed on underwater neutral-buoyancy training for evaluation of close-in sustained work-tasks.

In the light of these prior results, the (EVA) on Gemini XII were approached with certain operational improvements in mind. These were to carefully engineer simple, but effective, restraints for each task involved; to train and carefully work out overall-task time-lines in underwater simulations, with frequently scheduled rest periods; to provide an open-ended approach to the total operations to allow good subjective evaluation of each task; to provide crew familiarization by conducting a standup EVA a day prior to the umbilical EVA; and to evaluate work tasks most likely to be of importance in future EVA applications. During the umbilical EVA, two work stations were provided, one near the nose of the spacecraft on the docking adapter of the target vehicle, and one aft of the spacecraft within its equipment adapter. The adapter configured for the EVA is shown in Figure 12. The activity in this area took place during a night-side pass. The work tasks involved, among others, breaking and making several different types of electrical and fluid connections; removing, installing, and torquing of bolts; cutting electrical wire bundles; connecting hooks and eyes of various sizes; evaluating portable handholds utilizing a Velcro attachment; installation and utilizing pip pins as body-tether attachments at various points in the vehicle; evaluating "Dutch-shoe"-type fixed-foot restraints; and using adjustable-length waist tethers.



GEMINI XII ADAPTER WORK AREAS

Figure 12. EVA adapter

With these features, the EVA astronaut, during the flight of Gemini XII, was able to go methodically through his work program during umbilical EVA and to operate for over 2 hours with very low heart and respiration rates, in a completely satisfactory thermal environment, and without encountering any significant level of fatigue. Heart rates except for one brief instance were about 125 beats per minute, and the sustained level was approximately 110 beats per minute. In fact, this astronaut was able to do additional tasks not formally in his time line, such as deploying an experiment package mounted on the target vehicle, and overcoming simple equipment malfunctions in two instances. These results provide considerable confidence in the ability of man to do useful work outside the spacecraft if adequate attention is given to restraint systems, aids for moving along the spacecraft, and proper simulation and training. Improved mobility of the pressure suit and similar features should enhance this capability even more.

VI. Tethered Vehicles

In spite of the fact that station keeping with another vehicle has proven to be precise and effective, this operation requires a continuous expenditure of propellant (about 20 pounds per revolution in the case of Gemini). Future operations can be envisioned in which undocked operations with vehicles in close proximity might be sustained for days or even longer.

Techniques for providing this capability without energy expenditure should be very useful; hence, part of the Gemini Program has been to investigate simple tethering of two vehicles for this purpose. Two approaches have been studied: (1) establishing a slow rotation of the two tethered vehicles using the centrifugal force to maintain a taut tether, and (2) carefully alining the two vehicles along the earth local vertical and providing a separating force from the earth gravity gradient.

During Gemini XI, the slow-spin technique was demonstrated; the results were quite similar to those predicted from analysis and simulations. The motions involved are shown in Figure 13. The spin was started with the target vehicle attitude-stabilized. The spacecraft was then maneuvered to extend the tether and the spin initiated by firing a lateral translational thruster using aft firing thrusters to maintain the tether more or less taut. Simulations revealed that starting accuracy is not particularly critical, although fairly large oscillations of the spacecraft can results. Conditions of alternate periods of slack and tension in the tether are also likely to be encountered for several cycles. After initiation of the spin, the control systems of both vehicles were shut down. The spacecraft oscillations were lightly, but positively, damped and reduced to half amplitude in about 1 hour without any attempts at crew control. Later in the test, small thrust applications by the crew were found to be effective in damping these oscillations more rapidly. After the oscillations damped to small values during the Gemini XI flight, the crew had complete confidence in the stability of this rotating system. The rotational rate initially achieved was 39° per second and was later increased to 55° per second. At these low rates, centripetal accelerations were not perceptible by the crew, but the use of higher rotational rates to produce artificial g is obvious.

To produce a gravity-gradient stabilized system requires extremely precise control of the relative velocities between the two vehicles. The amplitude of oscillations of this system, as a function of the relative velocity at their starting conditions (assuming initial alignment along the earth vertical) is presented in Figure 14. A relative velocity of 0.14 feet per second produces the ideal condition of a match with earth rates. Deviations beyond ±0.25 feet per second from this value

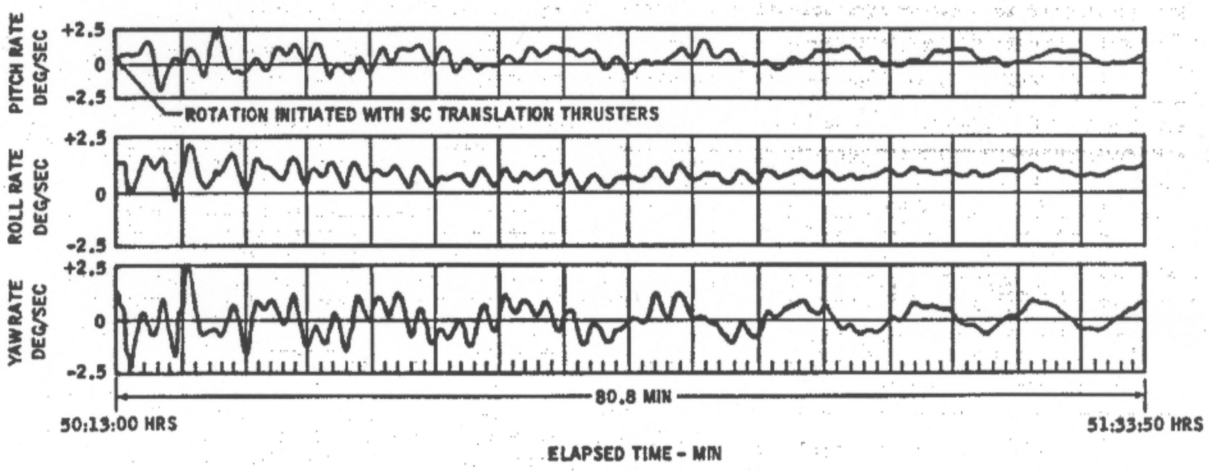


Figure 13. Spacecraft rates during tether exercise

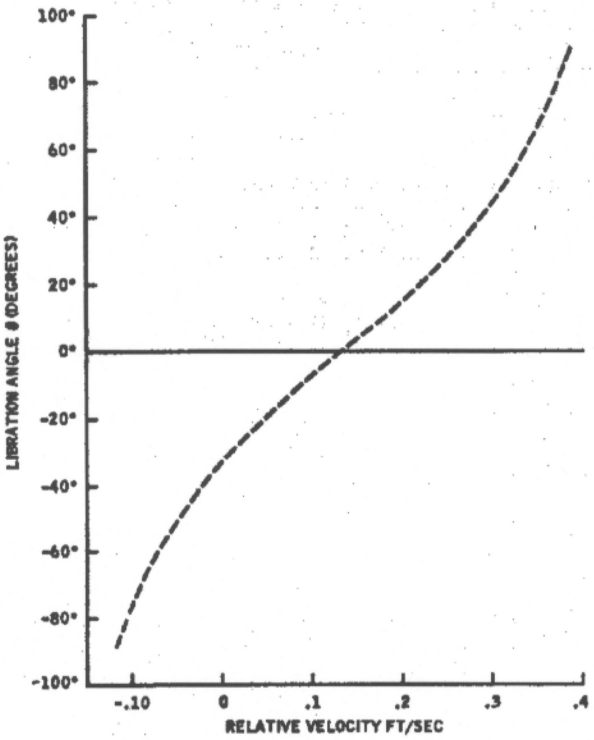


Figure 14. Oscillation amplitude versus relative velocities

excludes a condition of capture, and results in a rotating system.

During the Gemini XII flight, the docked combination was placed in a position with its longitudinal axis along the local vertical, and after the spacecraft was undocked, the 100-foot tether was deployed with the Agena control system activated to maintain its alinement. Because of degradation in the attitude thrusters of the spacecraft, the time spent in obtaining the velocity match was greater than would normally have been needed. Ultimately, an oscillation amplitude of ±45° was obtained indicating a velocity match to within 0.16 feet per second. It is felt that the accuracy of the velocity match would have been considerably better with a fully operational control system. The vehicle combination was maintained in this configuration with the control system off for several orbits, and disturbances from movements within the spacecraft did not appear to significantly affect the operation. Some disturbances could be noted during fuel-cell purges and other fluid venting, but even these did not upset the operations. Both the rotating system and the gravity-stabilized system, therefore, appear to be effective methods for maintaining two vehicles in close proximity. Which one is to be used would depend on the peculiar requirement of a mission.

VII. Experiments

Because of the variety and number of experiments carried out in the Gemini Program, it is not practical to comprehensively cover this activity within the scope of this paper. Some indication of the types of experiments conducted can be gleaned from the partial listing presented in Figure 15. The

SCIENTIFIC	
D-4	CELESTIAL RADIOMETRY
S-5	SYNOPTIC TERRAIN
S-8	VISUAL ACUITY
S-11	AIRGLOW HORIZON PHOTOGRAPHY
S-13	UV ASTRONOMICAL CAMERA
S-26	GEMINI ION WAKE MEASUREMENTS
TECHNICAL AND APPLIED TECHNICAL	
D-10	ION SENSING ATTITUDE CONTROL
D-15	NIGHT IMAGE INTENSIFICATION
MSC-1	ELECTROSTATIC CHARGE
MSC-2	PROTON ELECTRON SPECTROMETER
T-1	REENTRY COMMUNICATIONS
T-2	MANUAL NAVIGATION SIGHTINGS
MEDICAL	
M-1	CARDIOVASCULAR CONDITIONING
M-2	BIOASSAYS BODY FLUIDS
M-6	BONE DEMINERALIZATION
M-9	HUMAN OTHOLITH FUNCTION
S-4	RADIATION AND ZERO G ON WHITE BLOOD CELLS

Figure 15. Typical Gemini experiments

breakdown that is shown covers scientific, technical, and medical disciplines.

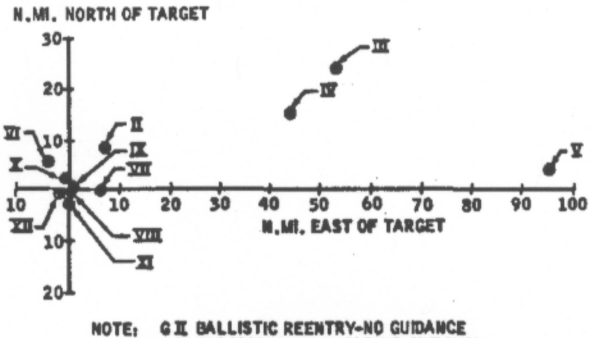
As indicated in Figure 16, 52 individual experiments were planned for the program, and 40 were actually conducted with satisfactory results. Most experiments were flown several times in the course of the program. Experiments are regarded as an extremely important aspect of the manned spaceflight program. The presence of the crew to exercise discrimination to set up and operate equipment, and to aid in the interpretation of results has proved extremely useful. With the many disciplines involved, the program of experiments required a rather heavy effort in systems integration, training, and flight planning, but, the financial expenditure for this activity was relatively low compared to the cost of developing and operating the vehicles.

TYPE	QUANTITY	MISSIONS COMPLETED OR PLANNED
SCIENTIFIC	17	44
MEDICAL	8	18
TECHNOLOGICAL	17	28
APOLLO SUPPORT	10	21
	52	111
COMPLETED	40	90

Figure 16. Summary of Gemini experiments

VIII. Controlled Reentry

Another phase of Gemini missions which requires precise guidance and control is the maneuvering reentry. This mission phase involves maneuvering in the hypersonic region through roll orientation of the lift vector to control the landing point to within a close tolerance of the desired position. Precise control into the landing point has been accomplished on all of the last seven flights (Fig 17). On prior flights, close-loop guidance was not attempted, except on Gemini V, in which an incorrect ground-update to the airborne computer produced a large landing-point error. Two mechanizations of guidance equations have been utilized, both of which have proven satisfactory. These methods are descirbed in Reference 1. The constant band-angle technique (with discrete bank angle reversals) is somewhat simpler in terms of the ability of the crew to monitor proper system operations, but it is fairly sensitive to center-of-gravity inaccuracies or other effects on lift-to-drag ratio. The technique involving a variable bank angle alternating with steady roll has been used during the last five flights, and excellent results have been obtained, both with the command pilot executing maneuvers based on cockpit displays of the guidance information, and also under conditions where the guidance signals are fed directly into the flight control system (hands-off operation). Although both procedures have proved adequate, the astronauts generally feel that their ability to monitor system operation is enhanced when they are in the loop, and executing the guidance commands. As in the case of rendezvous operations, the consistency of successfully controlled reentry has provided a high degree of confidence in the application to Apollo where landing footprint-shifts of hundreds of miles may be encountered.



NOTE: G II BALLISTIC REENTRY-NO GUIDANCE
G III PROGRAM BANK ANGLE-NO GUIDANCE
G IV BALLISTIC REENTRY-NO GUIDANCE
G V CLOSED LOOP REENTRY-WRONG GROUND UPDATE
G VI THRU G VIII CLOSED LOOP REENTRY

Figure 17. Gemini landing accuracies

References

1. The Gemini Program - Progress and Plans. Charles W. Mathews. Paper presented at AIAA/NASA 3rd Manned Space Flight Meeting, Houston, Tex., Nov., 1964.

2. Gemini Midprogram Conference. Including Experiment Results, NASA SP-121, Manned Spacecraft Center, Houston, Tex., Feb. 23-25, 1966.