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,

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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

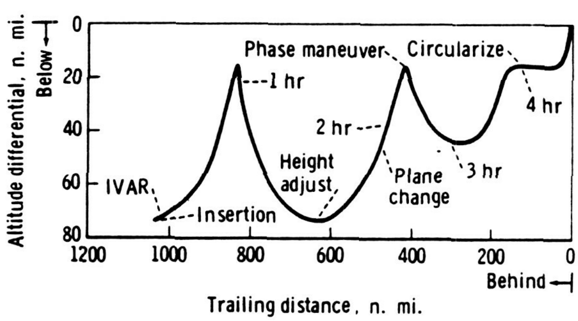

FIGURE 4–1.—Typical midcourse maneuvers.

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 consisted 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.

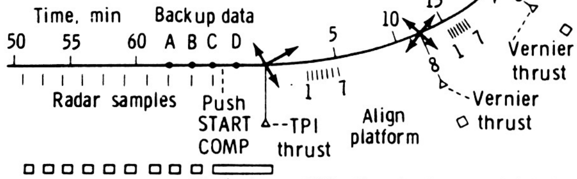

FIGURE 4–2.—Terminal-phase computer sequence.

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 $\Delta \dot{V}$ 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

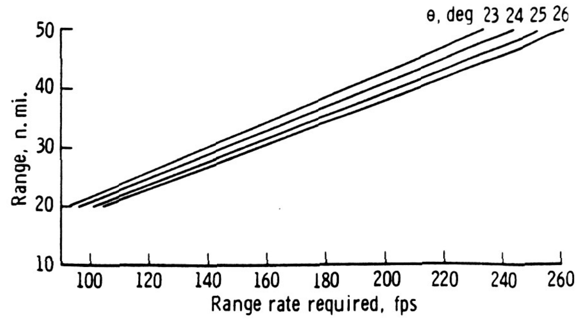

FIGURE 4–3.—Terminal-phase initiation range rate.

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

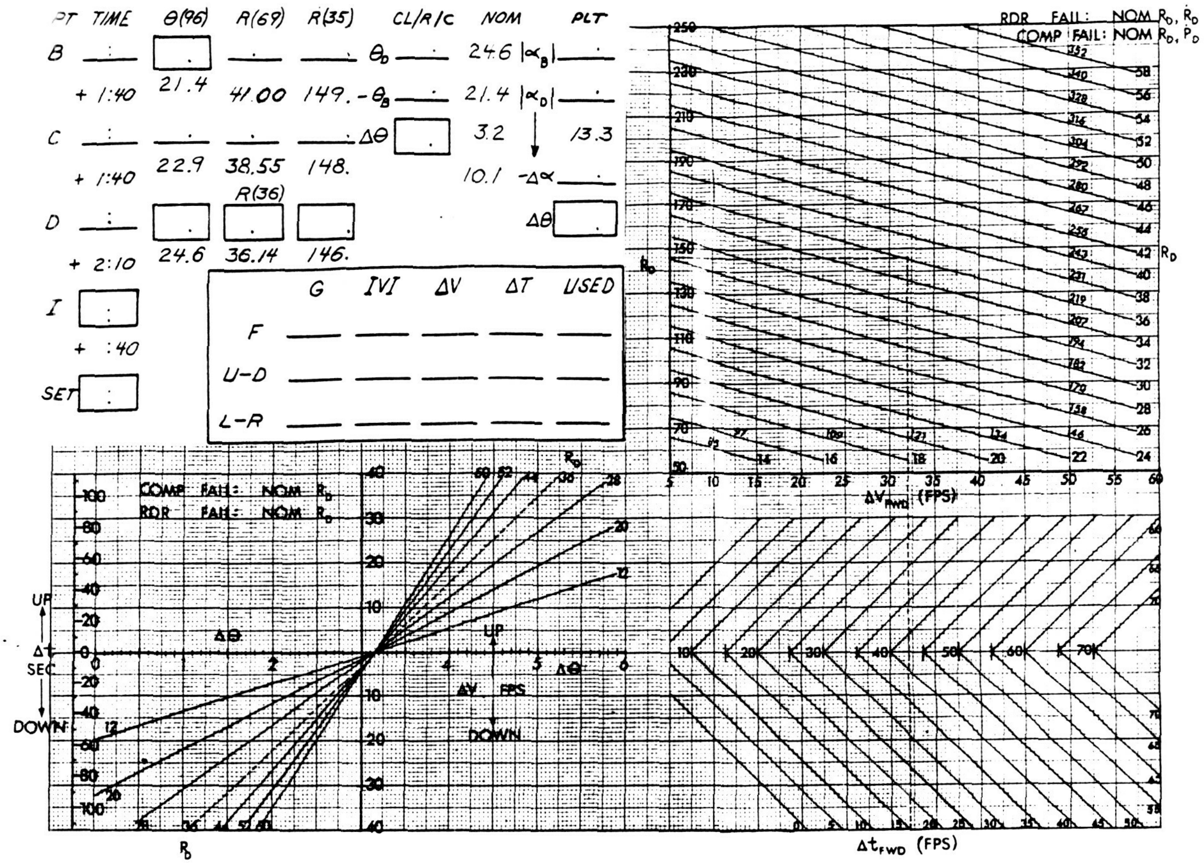

FIGURE 4–4.—Terminal-phase initiation.

(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 hand-held 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

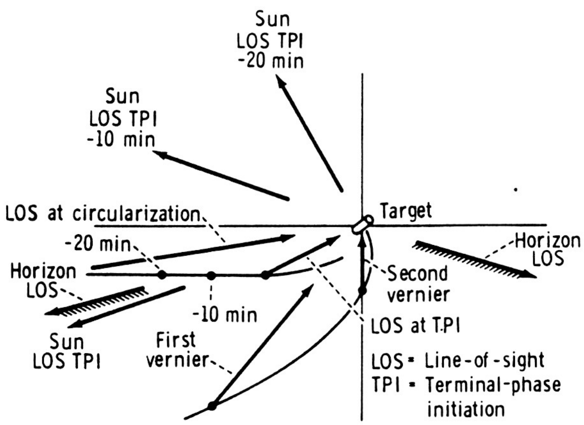

FIGURE 4–5.—Terminal-phase lighting conditions.

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

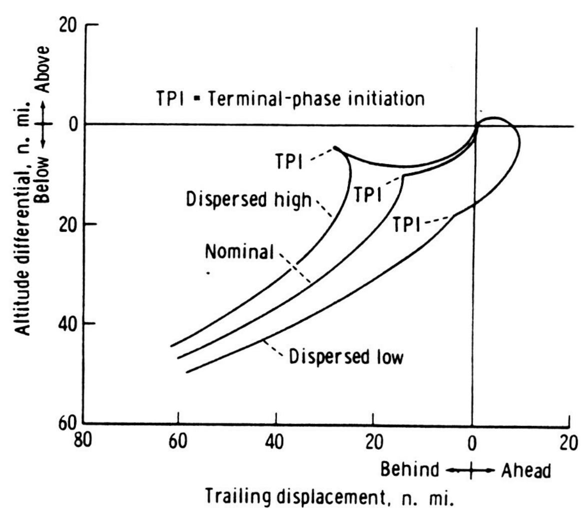

FIGURE 4–6.—First-orbit rendezvous trajectory.

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 aft	2 forward
4 down	1 up	10 down
2 left	5 left	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

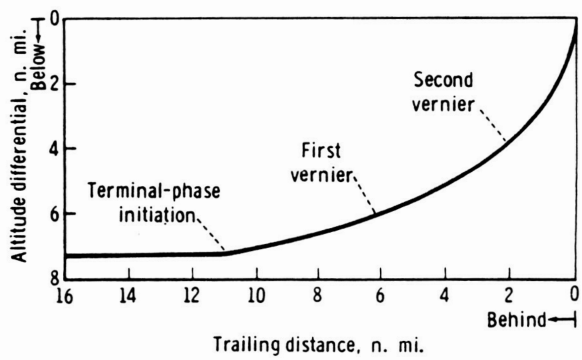

FIGURE 4–7.—Passive target rendezvous trajectory.

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.