Gemini VI-A Rendezvous Mission Planning, E.C. Lineberry, "Gemini Mid-Program Conference"

28. GEMINI VI–A RENDEZVOUS MISSION PLANNING

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Summary

This paper discusses the mission planning effort for the Gemini VI–A mission which applied directly to rendezvous. Included are a discussion of the basic design criteria and a brief history of the considerations which led to the selection of the particular Gemini VI–A mission plan. A comparison between the nominal and actual flight trajectories is also presented.

Introduction

The basic Gemini VI–A mission design criteria were, in effect, quite simple. Consideration was given almost exclusively to the development of a plan which would provide the highest probability of mission success. The desire was to develop a plan which could routinely depart from the nominal in response both to trajectory dispersions and to spacecraft systems degradation, while minimizing dispersed conditions going into the terminal phase of rendezvous. More specifically, the plan would provide flexibility without introducing undue complexity; that is, the flight controllers would have the capability, in the event of dispersed conditions, to select alternate maneuver sequences that would not be dissimilar to the basic maneuver sequence.

Selection of the Basic Mission Plan

Prior to the selection of the Gemini VI–A mission plan, three significantly different plans (fig. 28–1) were analyzed to the extent necessary to permit a realistic choice consistent with the desired flexibility criteria. The first of these was the tangential mission plan. The salient feature of this plan was a final tangential approach to the target vehicle, preceded by several orbits during which midcourse maneuvers would be commanded from the ground. The last maneuver in the ground-controlled sequence would be designed to place the spacecraft on an intercept trajectory. The onboard system would be utilized to correct this final trajectory to effect rendezvous. The second plan investigated the coelliptic plan, utilized the same midcourse-maneuver sequence as the tangential plan, except that the final maneuver in the ground-controlled sequence would be designed to place the spacecraft in an orbit with a constant differential altitude below the target orbit. The onboard system in this plan would be utilized to establish an intercept trajectory departing from the coelliptic orbit. The third plan which was investigated incorporated a rendezvous at the first spacecraft apogee. In effect, a nominal insertion would place the spacecraft on

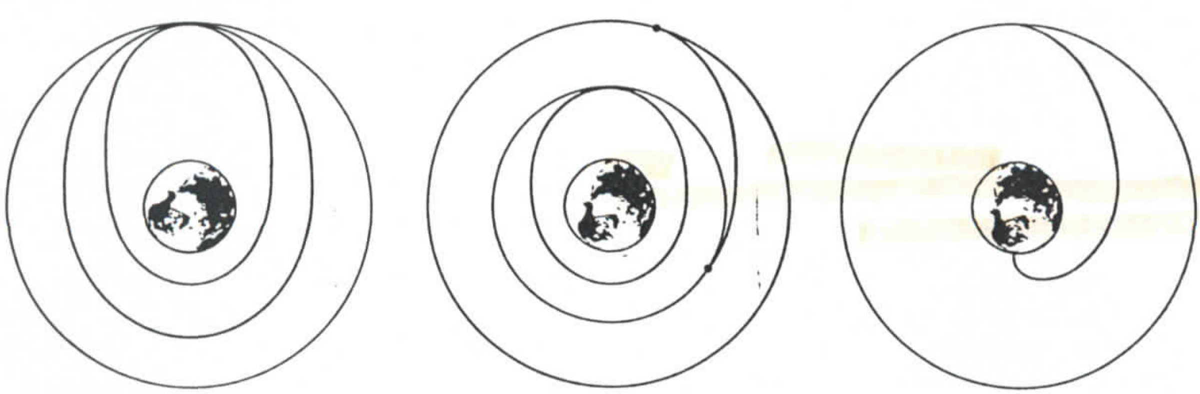

Figure 28–1.—Rendezvous mission plan development.

an intercept trajectory, and the onboard system would be utilized to correct for dispersed conditions, thereby placing the spacecraft on a final intercept trajectory.

As can be seen, two of these three plans incorporated a parking-orbit mode of operation prior to the establishment of a final intercept trajectory, whereas the third plan incorporated a direct intercept mode. Based upon various analyses conducted for the plans, a recommendation was made to adopt the coelliptical mission plan. Two major considerations, as well as a number of lesser ones, influenced this recommendation.

First of all, the mission plan for rendezvous at first apogee was eliminated as a contender, as compared with the other plans, for the Gemini VI-A mission because of its increased spacecraft propellant requirements for reasonable trajectory dispersions. Secondly, the terminal-phase initiation conditions of the coelliptical plan afforded a certain advantage over the tangential plan. Without going into detail, the basic desired feature of the coelliptical plan is that the relative terminal-phase trajectory of the spacecraft with respect to the target is not particularly affected by reasonable dispersions in the midcourse maneuvers. On the other hand, it is grossly affected when initiating from the tangential approach. More simply stated, the coelliptical approach affords a standardized terminal-phase trajectory, yielding obvious benefits in the establishment of flight-crew procedures and training. Another benefit derived from this plan is that the rendezvous location can be controlled to provide the desired lighting conditions. As a consequence of these advantages, the coelliptical mission plan was selected.

Terminal-Phase Considerations

The above discussion leads naturally to a consideration of the terminal phase, because it was this portion of the mission plan which governed the plan selection. These considerations also dictate the targeting conditions of the preterminal-phase midcourse activity controlled by the ground. The most basic consideration was to provide a standardized terminal-phase trajectory which was optimized for the backup procedures—that is, those procedures developed for use in the event of critical systems failure. It was possible to optimize the trajectory for the backup procedures with no degradation of the primary inertial-guidance-system closed-loop rendezvous-guidance technique.

Since it is possible to select any particular transfer trajectory to serve as a standard, extensive analyses were performed to provide a transfer trajectory with certain desired characteristics. It was desired, first of all, that the transfer initiation maneuver for a nominal coelliptical trajectory be alined along the line of sight to the target. This procedure has the obvious advantage of providing the crew with an excellent attitude reference for this critical maneuver, should it be needed. The second characteristic desired in the transfer trajectory was a compatibility between the closed-loop guidance mode and the final steering and braking performed manually by the flight crew. Based upon the transfer initiation criteria, the desired feature in the resultant trajectory would be a situation in which the nominal trajectory would create low inertial line-of-sight rates during the time period prior to and including braking. Such a trajectory would be consistent with the steering technique utilized by the flight crew to null the line-of-sight rate to zero. The analyses resulted in a choice of 130° orbital travel of the target vehicle between the terminal-phase initiation and braking. As can be seen in figure 28-2, the 130° transfer trajectory not only satisfies the second desired characteristic, but also fulfills a third desired condition, in that the approach of the spacecraft, relative to the target, is from below, thus assuring a star background which could be utilized as an inertial reference.

After the selection of the transfer trajectory, the differential altitude between the two orbits was the next decision point. Analyses were

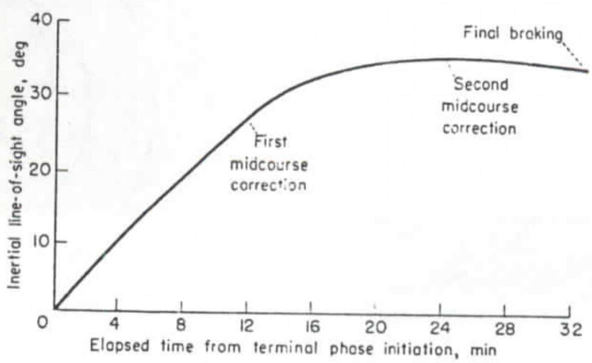

FIGURE 28-2.—Gemini 130° transfer trajectory.

carried out and resulted in a decision to utilize a 15-nautical-mile differential altitude between the orbits of the two vehicles. This choice resulted from a trade-off between a desire to be close enough to insure visual acquisition of the target prior to terminal-phase initiation, and a desire to minimize the influence of dispersions in the previous midcourse maneuvers on the desired location of terminal-phase initiation. Figure 28–3 shows that the effect of dispersions on the terminal-phase initiation time increases as the differential altitude is decreased. For the selected differential altitude of 15 nautical miles, the 3-sigma dispersion of the timing of the terminal-phase initiation maneuver is on the order of ±8 minutes. Factors governing the choice of the desired lighting condition for terminal-phase initiation cannot be considered here: however, the decision was made for the nominal initiation time to be 1 minute into spacecraft darkness. This condition and the selected differential altitude of 15 nautical miles established the targeting conditions for the ground-controlled maneuvers at the time of the coelliptical maneuver.

Ground-Control Midcourse-Phase Considerations

As previously noted, the intention was to provide a plan as insensitive to dispersions and spacecraft systems degradation as possible. This led to the provision of three spacecraft revolutions in the nominal plan, with preestablished maneuver points to compensate for any of the dispersions likely to occur either in target altitude and ellipticity or in spacecraft insertion. Emphasis was given to minimizing the demands of this phase of the mission on the spacecraft propulsion system. Because the propulsion requirements for the terminal rendezvous phase could increase significantly from degraded systems performance, it was imperative that the maximum amount of spacecraft propulsion capability exist at the time those activities were initiated. These decisions were reflected in the following mission plan characteristics:

(1) Maneuvers were carried out with the Gemini VII spacecraft to provide the best possible launch opportunities and optimum orbital conditions for rendezvous.

(2) The Gemini launch vehicle was targeted to provide a differential altitude of 15 nautical miles between the two orbits at first spacecraft apogee. The launch vehicle was targeted also to launch the spacecraft into the target plane; that is, launch-vehicle guidance was utilized to fly a dog-leg launch trajectory in order to minimize spacecraft propulsion requirements in orbit for making a plane change.

(3) During the first orbit the flight crew were left free of rendezvous activity. This period of time was used for spacecraft systems checks. It was also used by the Mission Control Center—Houston to determine the precise spacecraft 6 orbit.

(4) Ground tracking, computation and display, and command capability were provided to carry out the ground-controlled midcourse maneuvers.

Since it was necessary to plan for nonnominal situations such as delayed lift-off, a real-time mission planning capability was implemented in the Mission Control Center. This capability consisted of various computer-driven displays which would permit the flight controllers to assess any particular situation and select a maneuver sequence which was compatible with the mission constraints.

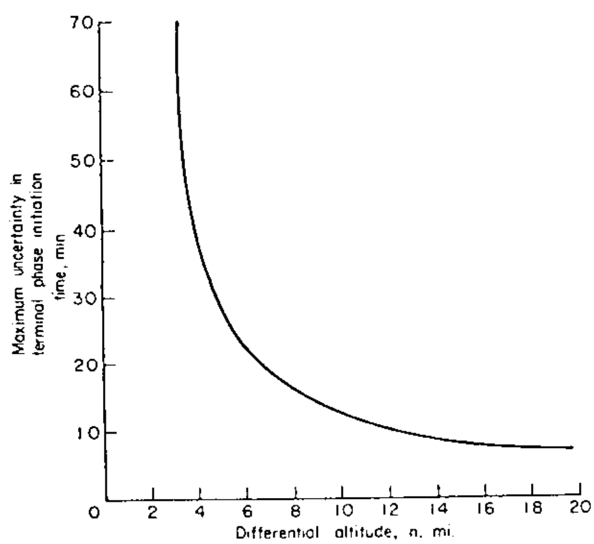

FIGURE 28–3.—Terminal phase maneuver time dispersion analysis.

Comparison Between Prelaunch Nominal and Actual Gemini VI–A Mission Trajectories

Prior to launch of the Gemini VI–A spacecraft, the maneuver plan selected consisted of two nonzero maneuvers: (1) A phase-adjustment maneuver to be performed at the second spacecraft apogee to raise the perigee to approximately 117 nautical miles; and (2) the coelliptical maneuver to be made at the third spacecraft apogee. However, in order to account for insertion dispersions, two additional maneuver points were established: (1) a height-adjustment maneuver to be made at first spacecraft perigee following first apogee; and (2) a plane-change maneuver to be performed at a common node following the phase-adjustment maneuver. Since the launch vehicle was targeted to achieve the correct differential altitude and plane location, these two maneuvers were nominally zero.

Ground network tracking during the first orbit revealed an underspeed condition at insertion, as well as a small out-of-plane condition. This can be seen in figure 28–4. Whereas the targeted condition for first apogee was a differential altitude of 15 nautical miles, the actual value which resulted was approximately 23 nautical miles. Consequently, the height-adjustment maneuver at first perigee (fig. 28–5) was 14 feet per second. The additional refinement of the spacecraft orbit following the height-adjustment maneuver indicated that a second height adjustment would be required, and the maneuver sequence was altered to include this adjustment at the second spacecraft perigee. The phase-adjustment maneuver to be performed at second spacecraft apogee was adjusted accordingly (fig. 28–6). Because of the underspeed condition at insertion, the Gemini VI–A spacecraft was actually catching up too fast; therefore, during the phase-adjustment maneuver at second apogee, the prelaunch nominal value of 53 feet per second was changed to 61 feet per second. This maneuver adjusted the catchup rate to establish the correct phasing condition at the time of the coelliptical maneuver.

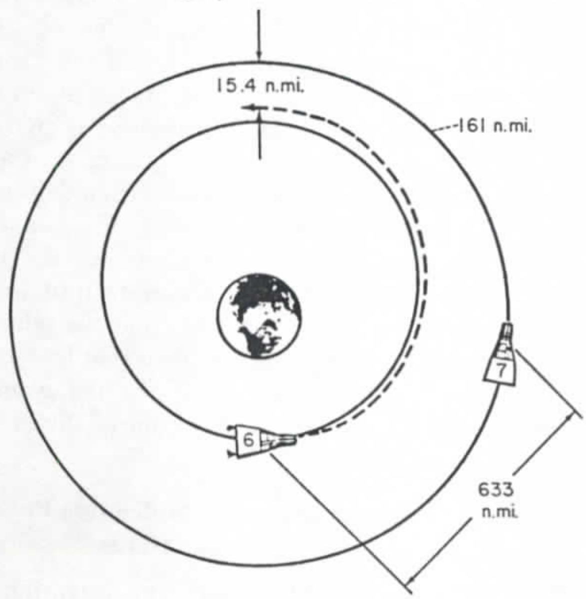

FIGURE 28–5.—Gemini VI–A first adjustment.

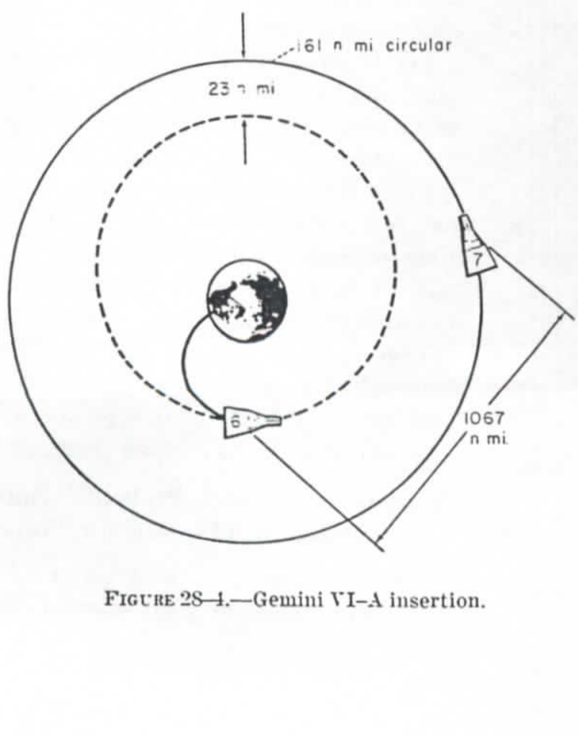

FIGURE 28–4.—Gemini VI–A insertion.

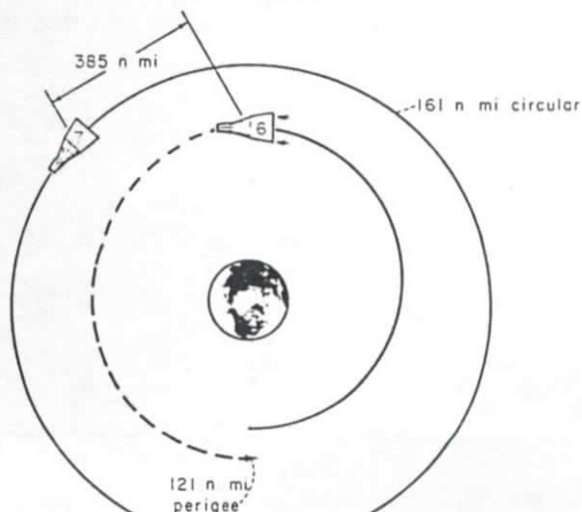

FIGURE 28–6.—Gemini VI–A phase adjustment and plane change maneuvers (common node) at second apogee.

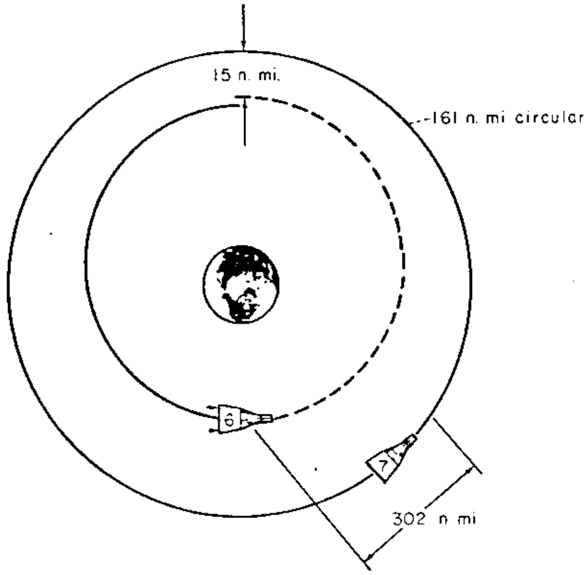

FIGURE 28–7.—Gemini VI–A second height adjustment maneuver at second perigee.

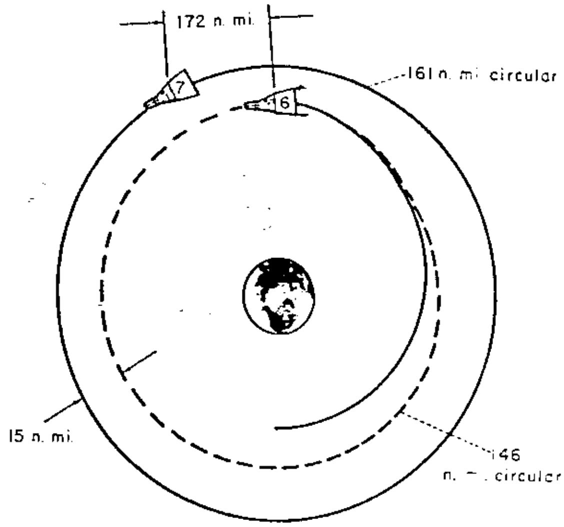

FIGURE 28–8.—Gemini VI–A coelliptical maneuver at third apogee.

Following the phase-adjustment maneuver, a plane change of 34 feet per second was performed to place the Gemini VI–A spacecraft in the plane of the Gemini VII spacecraft. At the next spacecraft perigee, the second height-adjustment maneuver of 0.8 foot per second was performed to correctly adjust the differential altitude to 15 nautical miles (fig. 28–7). At the third spacecraft apogee, a coelliptical maneuver of 43 feet per second was performed (fig. 28–8). Following this maneuver, radar tracking indicated a downrange-position error of approximately 2 miles at the time of the coelliptical maneuver, so that the actual downrange displacement was approximately 172 nautical miles, compared with the desired value of 170 nautical miles. The result, as determined on the ground, was a predicted slip of approximately 2 minutes in the terminal-phase-initiation maneuver. This information, as well as a ground-computed terminal-phase-initiation maneuver, was passed to the flight crew to serve as a comparative value with onboard computations.

Concluding Remarks

The discussion dealing primarily with the terminal-phase portion of the mission will be discussed in the following paper. The Gemini VI–A mission-planning effort resulted in the successful rendezvous with the Gemini VII spacecraft.

Rendezvous of Gemini VII and Gemini VI-A, T.P. Stafford et al., op. cit.

29. RENDEZVOUS OF GEMINI VII AND GEMINI VI–A

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Summary

A description of the rendezvous techniques, procedures, and flight data charts developed for the Gemini VI–A mission is presented in this paper. The flight data charts and crew timeline activities were developed over an 8-month period.

Successful rendezvous is critically dependent on the presentation to the flight crew of sufficient information developed onboard the spacecraft. The Gemini VI–A flight crew used this information to evaluate the rendezvous progress by several different methods and made critical decisions based on their evaluation. The system combination found most effective in making these evaluations was the range-rate data from the radar, and the angle data from the platform.

Introduction

The Gemini spacecraft was designed to use four subsystems in determining the rendezvous maneuver and presenting information to the crew. These subsystems are the radar, computer, platform, and cockpit displays. In all cases, the crew has independent operational control over each system and performs the function of selecting how these systems will be integrated.

The Gemini VI–A rendezvous flight plan was based on the use of flight data displayed to the crew in a manner to allow monitoring and backup for each spacecraft maneuver. The philosophy of maximum manual backup capability begins with the mission profile in which a coelliptical spacecraft-catchup orbit is employed prior to initiation of rendezvous. This permits use of a standard transfer change in velocity (ΔV) in both magnitude and direction, with the time of initiation determined by the elevation angle of the target line of sight above the local horizontal. Thus, the transfer maneuver varies only because of dispersions in the catchup orbit, and these are corrected by angle and range measurements.

The discussions that follow apply to that time period from the start of circularization thrusting to a point where the Gemini VI–A spacecraft was within 100 feet of the Gemini VII spacecraft, and had no attitude rates and less than 0.5-foot-per-second relative velocity in all translational axes (station keeping). Although the closed-loop guidance technique is considered the primary method to accomplish rendezvous, backup guidance techniques were developed to assure rendezvous in the event of equipment failures. Accordingly, the procedures are presented for both the closed-loop guidance technique and the backup guidance techniques required in the event of radar, computer, or platform failure. In addition, flight data charts were developed specifically for the Gemini VI–A mission. These charts provide a means for determining the proper transfer maneuver and midcourse corrections, for monitoring the performance of closed-loop guidance, and for the calculation of the required backup maneuvers in the event of equipment malfunctions or failures.

Optical tracking of the target is a mandatory requirement in case a radar or platform failure is encountered. Thus the day-night cycle becomes an increasingly important parameter for the rendezvous mission. Lighting conditions for the terminal-phase maneuver were investigated after the coelliptical mission plan, involving a 130° transfer trajectory, was developed. At an altitude of 161 nautical miles, the target is in daylight for 55 minutes and in darkness for 36 minutes. The lighting conditions, displayed in figure 29–1, are planned so that the crew can track the target by reflected sunlight just prior to transfer to obtain data for the transfer maneuver. During the transfer maneuver and all subsequent maneuvers, the crew tracks the target's artificial lighting with respect to the stars for inertial angular measurement or uses platform angles when the optical sight is boresighted on the target. The braking maneuver occurs just as the target becomes lighted at sunrise. Thus it can be seen that the rendezvous initiation is normally planned to occur at 1 minute after sunset and the braking maneuver to occur at a range of 3000 feet when the target is starting to be illuminated by sunlight.

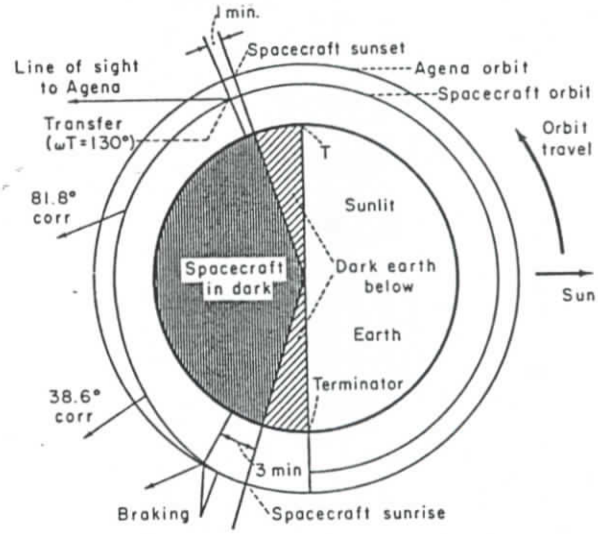


FIGURE 29-1.—Terminal-phase lighting conditions.

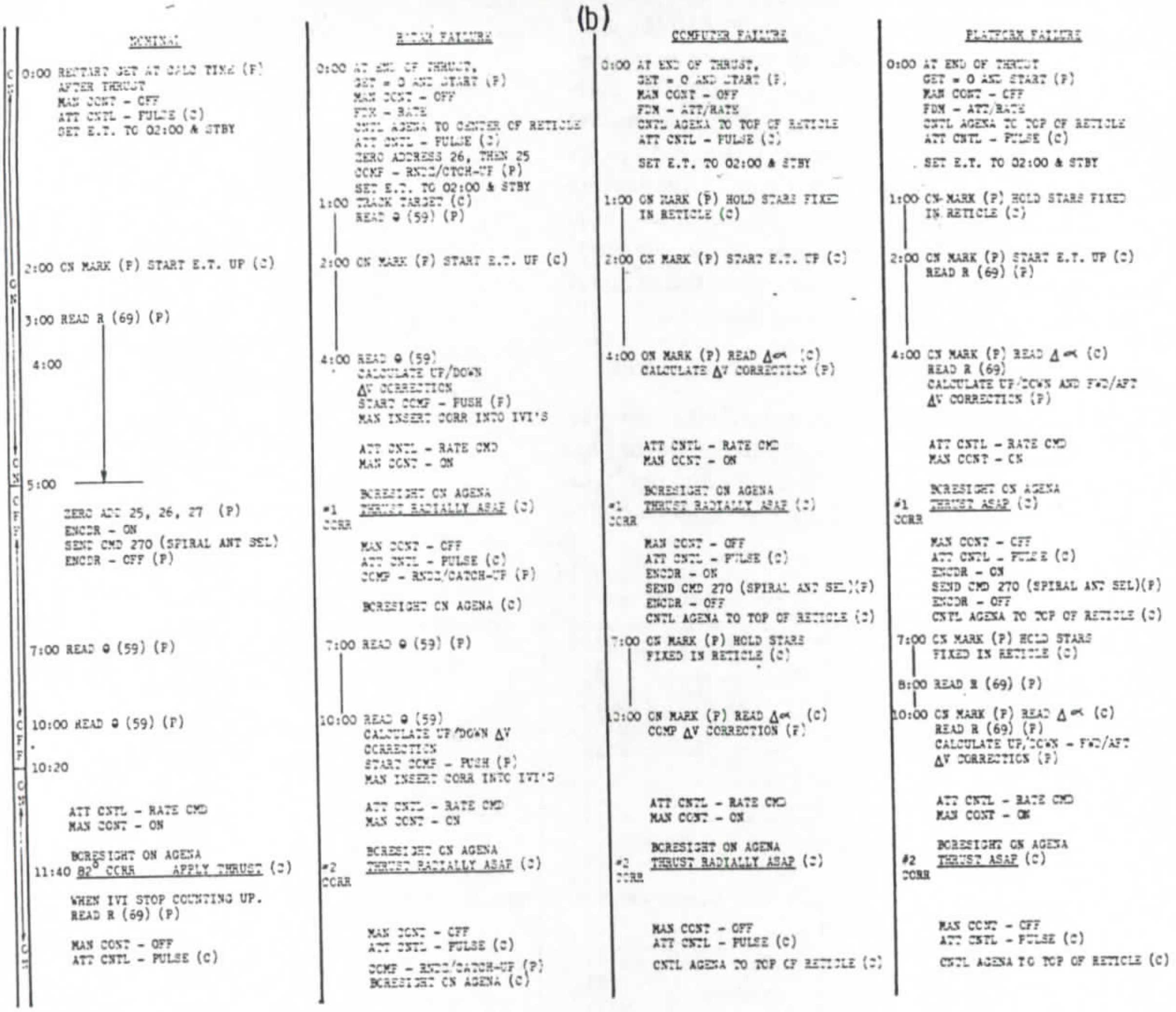
Closed-Loop Rendezvous Procedures

Closed-loop rendezvous procedures are presented in the left column of figure 29-2; they are listed in the exact order that the crew performs them. Cockpit responsibility is assigned by the

(a)

NOMINAL	RADAR FAILURE	COMPUTER FAILURE	PLATFORM FAILURE
INITIATION CUE - ANGLE/MDC OUTPUT	INITIATION CUE - ANGLE/MDC INPUT COMPUTER - CATCH-UP AT FAILURE ZERO ADD 25, 26, 27	INITIATION CUE - "8" BALL	INITIATION CUE - RANGE (MDC) OUTPUT COMPUTER - CATCH-UP AT FAILURE
0:00 APPLY CIRCULARIZATION TRANS (C) START GET (P) AT 0,0,0 ATT, APPLY THRUST TO ZERO READOUTS FROM ADD 80,81,82 GO TO RDR ACQ ATT, ACQUIRE LOCK-ON FDR - RDR FDM - ATT	0:00 APPLY CIRCULARIZATION TRANS (C) START GET (P) AT 0,0,0 ATT, APPLY THRUST TO ZERO ADD 80, 81, 82 (C) ZERO ADD 25, 26, 27 (P) COMPUTER - RNDZ/CTCH-UP (P) FDR - COMP FDM - ATT	0:00 APPLY CIRCULARIZATION TRANS (C) START GET (P) GO TO RDR ACQ ATT, ACQUIRE LOCK-ON FDR - RDR FDM - ATT/RATE	0:00 APPLY CIRCULARIZATION TRANS (C) START GET (P) GO TO RDR ACQ ATT, ACQUIRE LOCK-ON FDR - RDR FDM - ATT/RATE
ATT CNTL - PULSE MAN CONT - OFF	ATT CNTL - PULSE MAN CONT - OFF	ATT CNTL - PULSE MAN CONT - OFF	ATT CNTL - PULSE MAN CONT - OFF
SET E.T. TO 4:00 BORESIGHT ON AGENA BY NULLING FDI'S (C)	SET E.T. TO 4:00 (C)	SET E.T. TO 4:00 BORESIGHT ON AGENA BY NULLING FDI'S (C)	SET E.T. TO 4:00 BORESIGHT ON AGENA BY NULLING FDI'S (C)
4:00 ON MARK (P) START E.T. UP (C) COMPUTER - RNDZ (P)	4:00 ON MARK (P) START E.T. UP (C)	4:00 ON MARK (P) START E.T. UP (C)	4:00 ON MARK (P) START E.T. UP (C)
NOTE READ Θ (59) AND R (69) (EACH 100 SEC PT) (P)	NOTE CONTROL Θ TO NOMINAL UNTIL AGENA IS VISIBLE, THEN CONTROL S/C TO KEEP AGENA AT CENTER OF RETICLE.	NOTE WHEN VISIBLE, CONTROL S/C TO KEEP AGENA AT TOP OF RETICLE.	NOTE WHEN VISIBLE, CONTROL S/C TO KEEP AGENA AT TOP OF RETICLE.
INPUT WT = 93:13000; ΔWT = 93:04820 (P)		MONITOR RANGE ON R - Ṙ METER (C) MONITOR "8" BALL (P)	READ R (69) (EACH 100 SEC PT) MONITOR RANGE ON R - Ṙ METER (C)
VERIFY ADD 83, 93, 54, 53, 24, 92 IF REQ (P)	MONITOR Θ (59) EVERY 100 SEC WHEN Θ = 19°, READ Θ (59) EVERY 10 SEC		WHEN R = 43.00 N.M. READ EVERY 10 SEC
NOTE Θ WHICH EXCEEDS 20.1° AND CIRCLE IT. IF CIRCLED Θ IS NEARER 20.1° THAN 21.4°, LABEL IT PT A. IF NOT, LABEL IT PT B AND THE PREVIOUS ONE PT A. ADD 3:20 TO PT A TIME TO OBTAIN TIME OF PT C. CALCULATE GET RESET TIME BY ADDING 4:30 TO PT C TIME (P).	RECORD TIME WHEN Θ = 20.1° (59) (LABEL POINT A)	WHEN ATT BALL READS 15.5° (P) SELECT STAR PATTERN ON MARK (P) HOLD STARS FIXED IN RETICLE (C) START WATCH (P) ON MARK (P) READ Δα OVER 01:40 (C)	WHEN R ≤ 41.00 N.M. SELECT STAR PATTERN ON MARK (P) HOLD STARS FIXED IN RETICLE (C) START WATCH AND READ R (69) (P) ON MARK FROM (P) READ Δα OVER 01:40 (C) READ R (69) (P)
3:20 AFTER PT A (PT C), READ Θ (59) AND R (69) (P) AFTER PT C, START COMP - PUSH CALCULATE ΔṘ & ΔΘ CORR (P)	ADD 3:20 AND RECORD Θ (59) AT THIS TIME (LABEL POINT C) (P)	CALCULATE UP/DOWN ΔV CORR (P) FWD ΔV NOMINAL	CALCULATE UP/DOWN AND FWD ΔV (P)
	INPUT: 25:00284; 26:90147; 27:00000 (P) NULL FDI'S (COMP) (ATT) START COMP - PUSH (C)	BORESIGHT ON AGENA (C)	MONITOR R (69) EVERY 10 SEC (P) BORESIGHT ON AGENA (C)
	CALCULATE UP/DOWN ΔV CORR (P) FWD ΔV NOMINAL SET UP/DOWN IVI BY MAN KNOBS (C)		
ATT CNTL - RATE CMD MAN CONT - ON (C)	ATT CNTL - RATE CMD MAN CONT - ON (C)	ATT CNTL - RATE CMD MAN CONT - ON (C)	ATT CNTL - RATE CMD MAN CONT - ON (C)
COMP LITE ON NOMINALLY 03:50 AFTER PT C, THEN START THRUST TO ZERO IVI (C) (S/C BORESIGHT ON AGENA)	WHEN AGENA IN CENTER OF RETICLE (Θ = 27.4°) START THRUST TO ZERO IVI (C)	WHEN BALL READS 27.5° (P) START THRUST (C)	WHEN R = 32.96 (P) START THRUST (C)

(*a*) Determination of terminal phase initiation.
FIGURE 29-2.—Closed-loop and backup rendezvous procedures.



(*b*) Determination of 82° correction.
FIGURE 29–2.—Continued.

letters C for command pilot and P for pilot. The procedures start with the initiation of the circularization maneuver. The stopwatch feature of the clock, which is located on the pilot's instrument panel, is started and is used throughout the remainder of the rendezvous phase as the basic time reference for crew procedures. The event timer, which is located on the command pilot's instrument panel, is synchronized to the pilot's time and is used as a reference for the command pilot's critical events.

At 4 minutes after the circularization maneuver, the event timer is synchronized, and the computer is switched to the rendezvous mode. The command pilot controls the spacecraft attitude to boresight on the target, while the pilot verifies the pertinent computer constants, and, at the specific times requested by the charts, he records elevation angle and range to the target vehicle. This is continued until the initiation cue is reached.

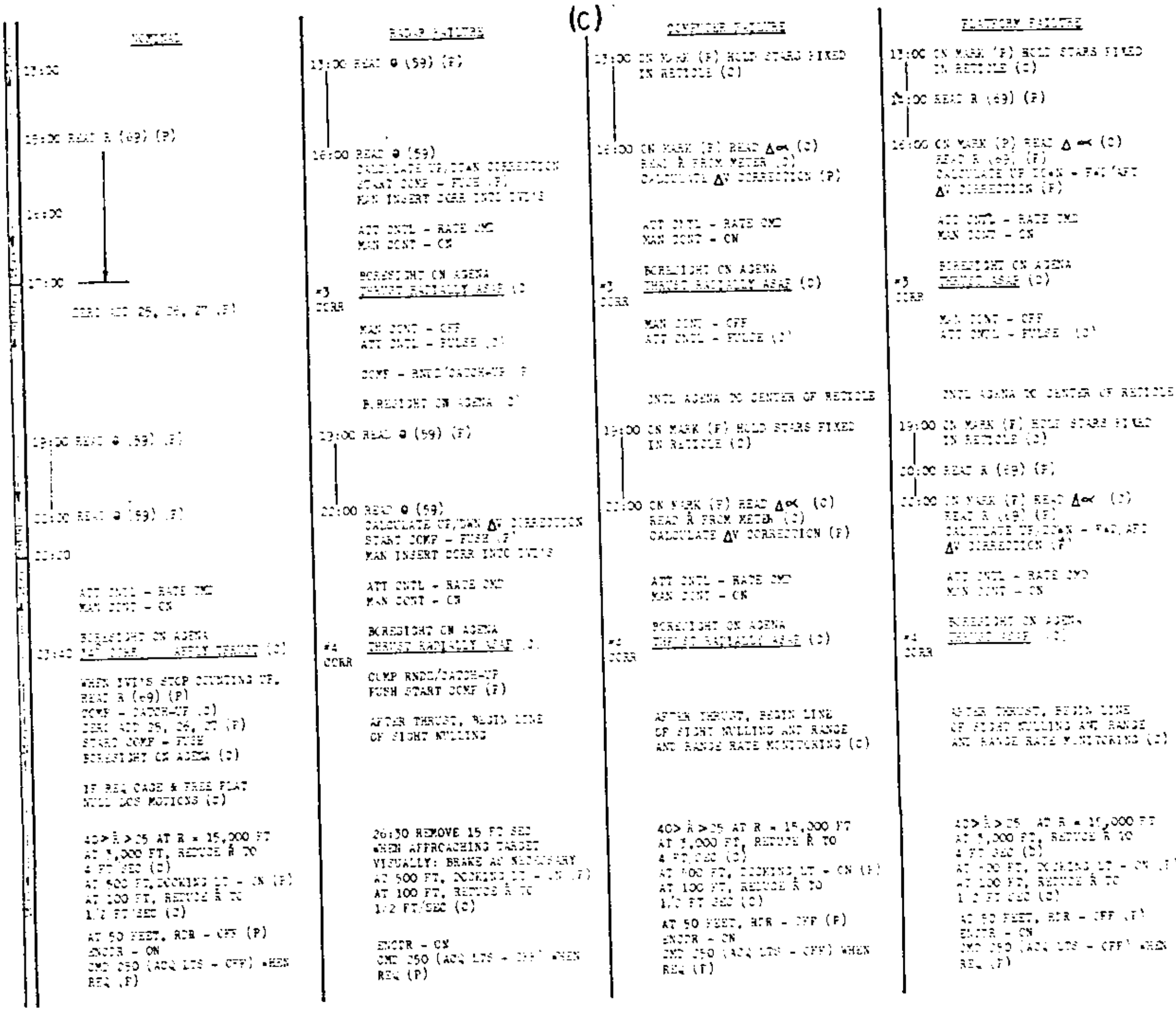
The initiation cue was selected to provide the thrust application along the elevation angle of the line of sight to the target vehicle. Two of the reasons for this decision were that radar lock-on could be maintained continuously, and, secondly, that this provided a convenient pointing reference for use during the thrusting maneuver. The reasons were valid whether radar pointing commands or the optical sight was used. An additional procedural advantage to this technique was that it was not necessary for the command pilot to switch his flight director reference from radar to computer during the rendezvous. However, this approach meant that, in most cases, the command pilot would have some small velocity components to thrust-out individually in the lateral and vertical axes. This disadvantage was deemed an insufficient reason to sacrifice a reference which could be the same for all modes of operation.

After the initiation point is determined, the pilot initiates the closed-loop guidance sequence by depressing the START COMP button. The pilot then calculates the thrust required for the transfer maneuver from the flight data recorded on the charts. The data used are pitch angle and range. The purpose of this calculation is to check the onboard computer solution and to provide backup data in case a system should fail.

After the initiation point for transfer has been selected and backup solutions have been calculated, the pilot then determines when the clock is to be resynchronized with the onboard computer.

When the START COMP button is depressed, the required change in velocity is presented on a cockpit display. When the START COMP light comes on, the command pilot applies thrust to bring the displayed velocity values to zero and, at the same time, maintains boresighting on the target. This event completes the transfer maneuver. At the previously described time, the pilot resets the stopwatch to zero to synchronize it with the computer for the remainder of the rendezvous.

After the transfer maneuver, the command pilot remains boresighted on the target vehicle, and between the 3- and 5-minute period the computer collects radar data at intervals of 20 seconds to be used for the first midcourse cor-



(c) Determination of 34° correction, and braking.

FIGURE 29-2.—Concluded.

rection. During this time, the pilot interrogates the computer to obtain the necessary data to analyze closed-loop guidance and trajectory parameters. This information is recorded on a monitor sheet (fig. 29–3). When the radar data collection is completed by the computer at 5 minutes, the START COMP light goes off, indicating that the computer is sequencing to the next part of its program. The crew now has an option of alining the platform during the next 5 minutes 20 seconds or of ignoring it. Their decision is based upon premission rules regarding accuracy requirements of the platform. The pilot then takes certain data from the computer in order to obtain the change in velocity requirements for a backup solution to the first midcourse maneuver. The first midcourse correction occurs at a point in the trajectory where 81.8° central angle travel of the target remains until intercept. Just prior to the first midcourse maneuver, the spacecraft must be boresighted for a final radar data collection by the computer. As soon as this occurs, the required velocities for the first midcourse correction are displayed. The command pilot then applies thrust to drive the displays to zero. Upon the completion of thrusting, the first midcourse correction is complete, and the identical cycle is repeated for the second midcourse correction which occurs at 33.6° central angle travel to go to rendezvous. This maneuver corresponds to a time of 23 minutes 40 seconds after the midpoint of the transfer maneuver.

When the second correction has been completed, the computer is switched from the rendezvous mode to the catchup mode. This allows radar data to the computer to be updated every one-eighth second. From this point in the trajectory, the target motion with respect to the stars should be essentially zero; therefore, the command pilot is required to note any motion of the target vehicle with respect to the celestial

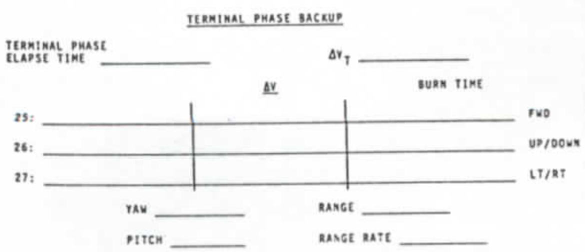


FIGURE 29–3.—Terminal phase backup monitor sheet.

background and null the motion. The pilot, meanwhile, is continuously monitoring pitch angle, range, and range rate to determine trajectory characteristics and is assisting the command pilot by giving him position reports and providing backup information. Braking thrust at the termination of rendezvous is applied as a function of range. The nominal range for initiation of braking is 3000 feet, and at 1500 feet the range rate is reduced to 4 feet per second.

Backup Procedures

Columns 2, 3, and 4 on figures 29–2 through 29–4 present the sequence of the backup rendezvous procedures in the event of radar, computer, or platform failure. It should be noted that the procedures and the arrangement of the procedures were specifically tailored to insure that an orderly transfer could be made in the event of system failure. Four midcourse corrections are used in the backup procedures, while only two are used in closed-loop guidance. The increased number was required to detect a trajectory error as early as possible and to make the appropriate corrections. The second and fourth backup measurements provide a check of the first and second closed-loop maneuvers. An optical sight with a collimated reticle was one of the essential pieces of hardware to implement the backup procedures. This sight was used to track the target and measure inertial angular rates.

Radar Failure

A radar failure eliminates range and range rate from the analog meter and the computer. In this event, the initiation cue is based upon line-of-sight elevation angle. The spacecraft is controlled to a specified pitch attitude of 27.4° using the flight director indicators, and the target vehicle is visually observed. Visual observation is a mandatory requirement unless thrusting is initiated on ground-calculated time. When the target passes through the center of the reticle, thrusting is initiated. Once again the nominal change in velocity is applied along the line of sight, and a correction normal to the line of sight is based upon the measured change in the elevation angle as read from the computer. The intermediate corrections rely upon this capability to read elevation angle from the computer to enable the pilot to calculate corrections normal to the line of sight. Since ranging information is not available, a small braking maneuver is selected by time, and the final braking thrust is not applied until the command pilot can visually detect size growth of the target vehicle.

Computer Failure

A computer failure precludes the use of accurate elevation or pitch angle as an initiation cue. The reference then used to provide this cue is the attitude indicator ball. Loss of the computer also prevents use of the velocity displays. The transfer thrusting application is therefore based on the nominal change in velocity along the line of sight and a calculated change normal to the line of sight. The calculation is based on the change from nominal of the inertial elevation angle. The first two intermediate corrections are based only upon the variation of the inertial elevation angle from nominal, using the optical reticle as the measuring device and the celestial background as the inertial reference. The last two corrections include range-rate data from the analog meter. The pilot uses the stopwatch feature of his wristwatch to measure the time of thrust in each axis which corresponds to the required change in velocity.

Platform Failure

In the event of a platform failure, the initiation cue is ranged obtained from the computer. The initial transfer and the four intermediate corrections are based upon deviations in the change of range and inertial elevation angle from the nominal. The change in inertial elevation angle is measured by using the optical reticle. The reticle pattern and markings were designed to insure the required accuracy for this measurement. The procedures for the trajectory from the end of the fourth backup midcourse maneuver to termination of rendezvous are the same as previously discussed under closed-loop rendezvous procedure.

Flight Charts

The flight charts are an extension of the Gemini V charts and were tailored for the Gemini VI–A mission. The Gemini V charts were developed specifically for the planned exercise with the rendezvous evaluation pod. The Gemini VI–A charts have been refined considerably from Gemini V charts due to experience gained from simulations and crew training. Figure 29–3 is the form used for recording the ground-computed termination phase initiation. Figure 29–4 is the form used for recording data necessary to monitor the trajectory and for the determination of the proper point for transfer. Figure 29–5 is used to determine the initial thrusting required for transfer as a check on the closed-loop solution and as a backup in case of a system failure. Figure 29–6 is used to calculate intermediate corrections in the backup procedures and to check the closed-loop solution for the two midcourse maneuvers. All measurements and thrust applications are made orthogonally with respect to an axis system oriented along the spacecraft axes. The spacecraft X-axis is alined with the line of sight to the target. Figure 29–7 is the monitor sheet used for closed-loop guidance. Figure 29–8 is a curve used to determine separation from the target vehicle using only range from the computer.

Figure 29–9 is a polar plot of the nominal Gemini VI–A trajectory from the circularization maneuver to termination of rendezvous. Nominal range, range rates, elevation angles, and ground elapsed times are provided at various points along the trajectory.

Discussion of the Gemini VI–A Rendezvous

The closed-loop guidance technique was used satisfactorily during the Gemini VI–A rendezvous mission. The radar range data that were read from the computer were highly accurate throughout the entire maneuver and provided the crew with the necessary information to monitor the trajectory, shown in figure 29–10(a). Radar range-rate data from the analog meter showed close correlation to computed data with less than 3-feet-per-second difference, and was limited in accuracy only by the meter markings and readability. Angle data after the circularization maneuvers were slightly erratic in value (fig. 29–10(b)). The pilot noted that the closed-loop guidance solutions appeared to give values near the nominal and was concerned primarily with the way this anomaly would affect the selection of the correct angle to push the START COMP button during the transfer maneuver.

(a)

GT-6 RENDEZVOUS FLIGHT CHARTS
NOMINAL AND ACTUAL CONDITIONS – CIRCULARIZATION TO TERMINAL INITIATION

AFTER SWITCHING COMP TO RENDEZVOUS MODE, PERFORM THE FOLLOWING:

VERIFY r_T: 54 73082
T: 53 53776
$1/\dot{A}_T$: 24 12690
$RL\dot{O}$: 92 00000

INPUT ωT: 83 13000
Δ: 93 04820

RDR DATA POINTS	TIME FROM NSR INITIATE MIN:SEC	θ NOM DEG	θ ACTUAL ADD 59 DEG	R NOM N.M.	R ACTUAL ADD 69 N.M.	ΔR ACTUAL N.M.	ΔR NOM N.M.		ΔV_I NOM FPS	ΔV_I ACTUAL ADD 71 FPS	ΔV_T NOM FPS
1	4:00	5.4		136.09			2.60				
2	5:40	5.5		133.49			2.60				
3	7:20	5.7		130.89			2.60				
4	9:00	5.8		128.29			2.60				
5	10:40	6.0		125.69			2.60				
6	12:20	6.2		123.09			2.60				
7	14:00	6.3		120.49			2.60				
8	15:40	6.5		117.89			2.60		230.0		518
9	17:20	6.7		115.29			2.60		222.1		502
10	19:00	6.9		112.69			2.60		214.2		486
11	20:40	7.1		110.09			2.60		206.3		470
12	22:20	7.3		107.49			2.60		198.4		454
13	24:00	7.5		104.89			2.60		190.5		438
14	25:40	7.7		102.30			2.60		182.6		422
15	27:20	7.9		99.71			2.59		184.7		406
16	29:00	8.2		97.12			2.59		176.9		390
17	30:40	8.5		94.53			2.59		169.1		374
18	32:20	8.8		91.94			2.59		161.3		358
19	34:00	9.1		89.35			2.59		153.5		342
20	35:40	9.4		86.76			2.59		145.7		327

(*a*) Between 4 minutes and 35 minutes 40 seconds from coelliptical maneuver (NSR).
FIGURE 29-4.—Transfer maneuver monitor sheet.

The backup solution calculated from the flight data charts indicates that an angle bias existed. The fact that range and range rate prior to transfer were exactly nominal led to a belief that elevation angle and elevation angle rate also should have been nominal. This difference may have been partly due to a platform alinement. The cause of the remainder of the difference has not been determined. This effect caused the crew to transfer one data point later than the nominal point, and also indicated that the two spacecraft were less than the nominal 15-nautical-mile vertical separation. This in turn led to an erroneous change in velocity solution to be calculated along the line of sight for the backup procedure.

The ground-calculated backup solution showed close agreement with the closed-loop data. In subsequent missions, however, ground solutions will not be available for some rendezvous transfers; hence, the requirement will continue to exist to provide the crew with an independent onboard method of calculating transfer velocities.

The target-center polar plot was used to provide backup verification. The data are correct for direction and generalized for magnitude of the thrust vector. The five values that were available to the crew for the transfer solution are shown in table 29–I.

It was noted by the pilot, immediately after the final backup calculation, that the 23-foot-per-second solution along the line of sight

(LOS) was in error, as the data from points prior to this gave 32 feet per second. As noted in table 29–I, the polar plot and the change in range-change ($\Delta\Delta R$) solutions indicate that 32 feet per second should be applied along the line of sight. The ground-calculated solution was additional verification of this number. Had the computer failed to arrive at a solution or given an erroneous value, sufficient information existed onboard from the polar plot and $\Delta\Delta R$ method to correctly determine that the transfer change in velocity was in fact 32 feet per second along the line of sight. This was the change in velocity that the crew would have applied in case of a failure mode. This problem highlights the fact that the crew must have ample onboard methods to correctly interpret and execute the transfer maneuver.

(b)

RDR DATA POINTS	TIME FROM NSR INITIATE MIN:SEC	θ NOM DEG	θ ACTUAL ADD 59 DEG	R NOM N.M.	R ACTUAL ADD 69 N.M.	ΔR ACTUAL N.M.	ΔR NOM N.M.		ΔV_T NOM FPS	ΔV_T ACTUAL ADD 71 FPS	ΔV_T NOM FPS
21	37:20	9.7		84.18			2.58		137.9		311
22	39:00	10.0		81.60			2.58		130.2		296
23	40:40	10.4		79.02			2.58		122.5		281
24	42:20	10.8		76.44			2.58		114.8		265
25	44:00	11.2		73.87			2.57		107.1		249
26	45:40	11.7		71.30			2.57		99.5		234
27	47:20	12.2		68.73			2.57		92.0		219
28	49:00	12.7		66.17			2.56		84.5		204
29	50:40	13.3		63.61			2.56		77.1		189
30	52:20	13.9		61.06			2.55		69.9		174
31	54:00	14.5		58.52			2.54		62.8		159
32	55:40	15.3		55.98			2.54		56.1		145
33	57:20	16.1		53.45			2.53		49.7		131
34	59:00	16.9		50.93			2.52		43.9		118
35	00:40	17.9		48.43			2.50		38.9		106
36	02:20	19.0		45.93			2.50		35.0		95
37	04:00	A 20.1		43.45			2.48		32.6		86
38	05:40	B 21.4		40.99			2.46		32.0		80
39	07:20	C 22.9		38.55			2.44		33.3		75

(*b*) Between 37 minutes 20 seconds and 1 hour 7 minutes 20 seconds from coelliptical maneuver (NSR).
FIGURE 29–4.—Concluded.

TABLE 29–I.—*Transfer Solution Values*

Thrust	Closed-loop	Backup charts	Ground	Polar plot	$\Delta\Delta R$
Along line of sight	31 ft/sec forward	23 ft/sec forward	32 ft/sec forward	32 ft/sec forward	32 ft/sec forward
Normal line of sight	4 ft/sec up	2 ft/sec up	2 ft/sec up	0 ft/sec	0 ft/sec
Lateral line of sight	1 ft/sec right	----------	2 ft/sec left	----------	

GT-6 RENDEZVOUS FLIGHT CHARTS
INITIAL THRUST CALCULATION

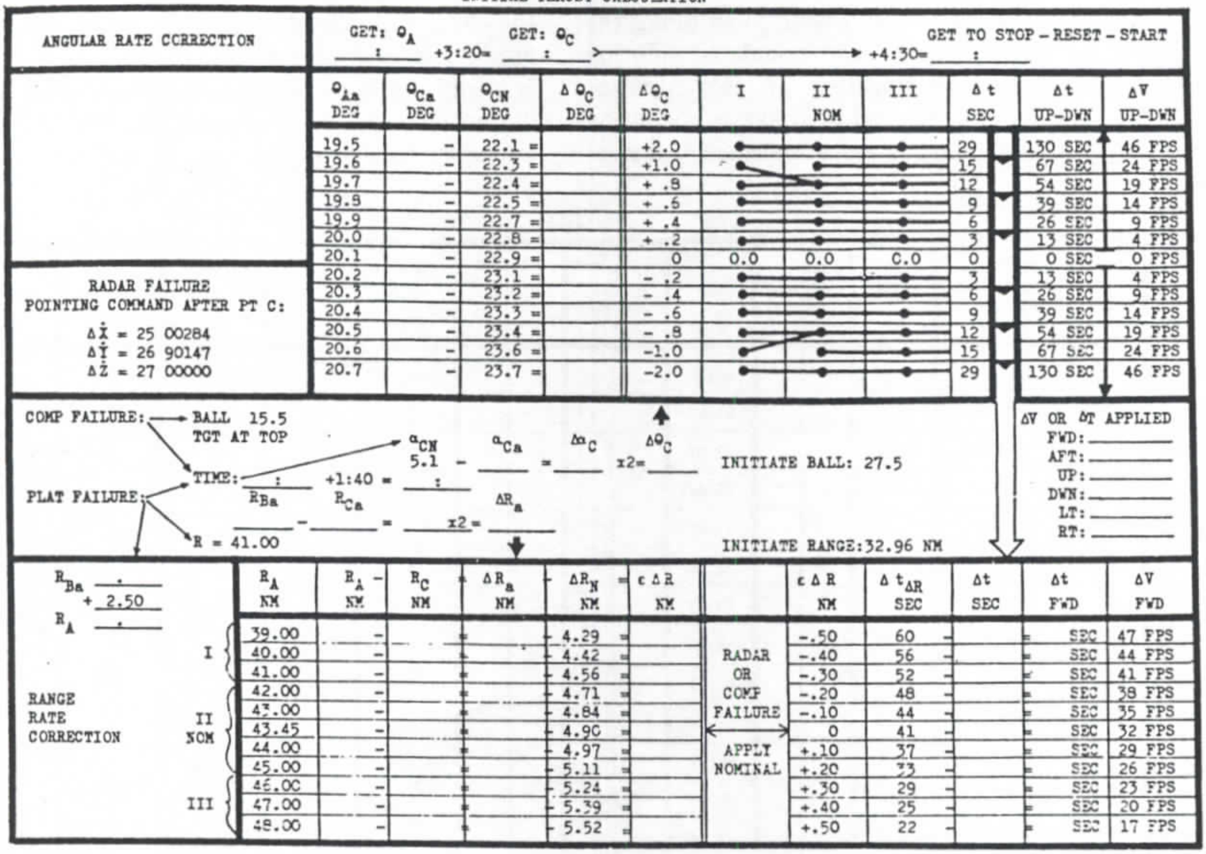


FIGURE 29–5.—Initial thrust calculation sheet.

A significant problem developed when the Gemini VII spacecraft went into darkness. The Gemini VI–A crew was not able to acquire it visually until a range of 25.7 nautical miles, when the spacecraft's docking light became faintly visible. The observed light was not sufficient to provide tracking for the first two backup midcourse corrections. The flashing acquisition lights were not seen until 14.5 nautical miles because the apparent intensity of the docking light was much greater. The crew had previously been briefed that the acquisition light should be visible for tracking at a range of 30 nautical miles.

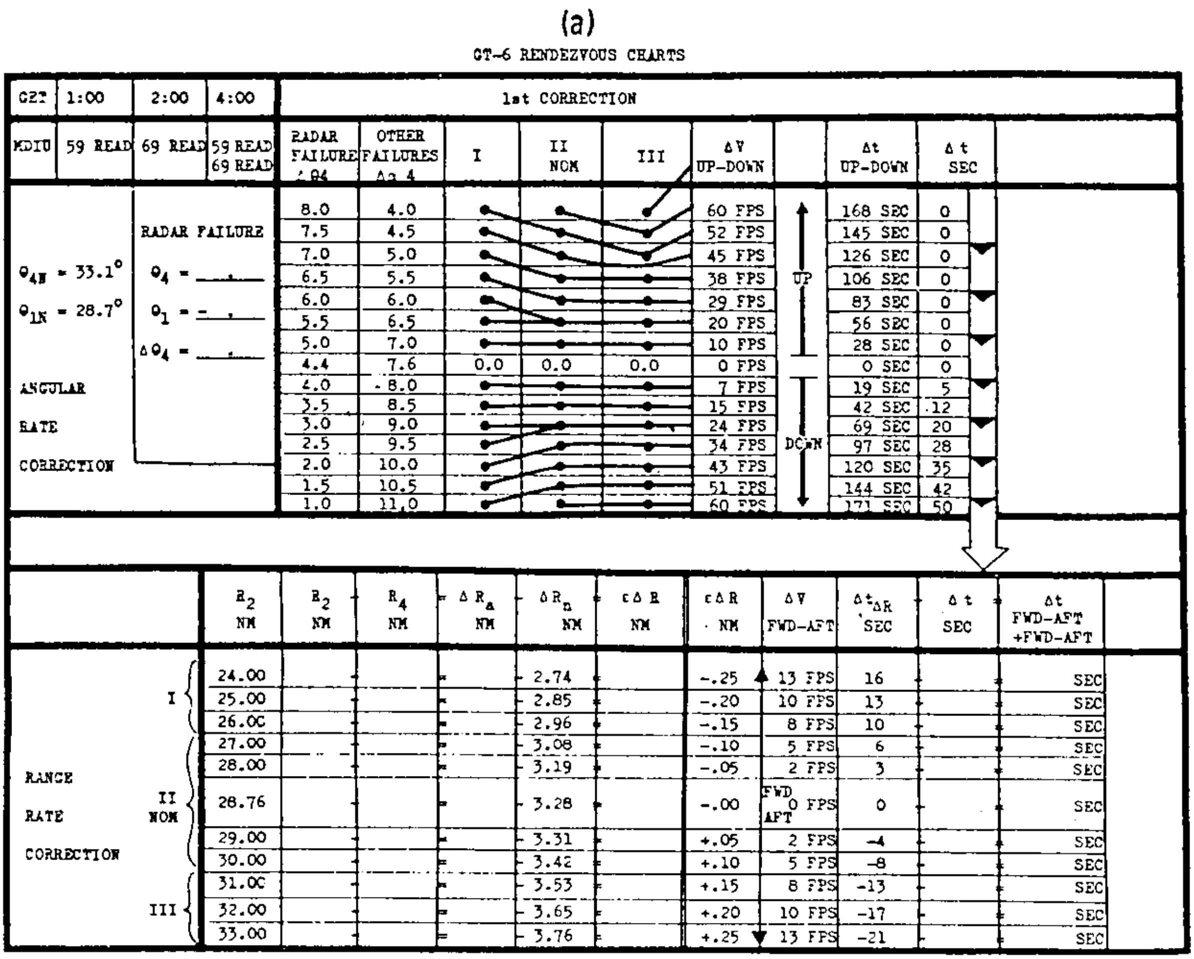
The platform alinement performed during the period from 5 to 10 minutes after transfer precluded any backup solution to the first midcourse maneuver. The backup solution for the second midcourse maneuver was calculated and requested 6 feet per second up, versus 3 feet per second up, and 4 feet per second forward for the closed loop (table 29–II). The backup solution would have been adequate to provide an intercept with the Gemini VII spacecraft.

After the second midcourse correction, the computer was switched into the catchup mode and the pilot recorded pitch angle and range data at 1-minute time intervals. The command pilot nulled the inertial angular rate by thrusting toward the target vehicle whenever it exhibited motion with reference to the stars.

The target vehicle became illuminated in sunlight at approximately 0.74 nautical mile. Braking was initiated at 3000 feet and completed at 1500 feet, at which time the range rate had been reduced to 7 feet per second. The end of the rendezvous occurred and station keeping was initiated when the Gemini VI–A spacecraft was directly below the Gemini VII spacecraft at a distance of 120 feet.

TABLE 29-II.—*Midcourse Maneuver Values*

Thrust	Closed-loop	Backup charts	Polar plot
(a) First midcourse maneuver			
Along line of sight	7 ft/sec forward	Not available due to computer program	5 ft/sec forward
Normal line of sight	7 ft/sec up	Not available due to platform alinement	5 ft/sec up
Lateral line of sight	5 ft/sec left	Not calculated	Not calculated
(b) Second midcourse maneuver			
Along line of sight	4 ft/sec forward	Not available due to computer program	5 ft/sec forward
Normal line of sight	3 ft/sec up	6 ft/sec up	5 ft/sec up
Lateral line of sight	6 ft/sec right	Not calculated	Not calculated



(*a*) First correction maneuver.

FIGURE 29-6.—Intermediate correction calculation sheets.

(b)

GT–6 RENDEZVOUS FLIGHT CHARTS

GET 7:00 8:00 10:00		2nd CORRECTION								
MDIU 59 READ 69 READ 59 READ 69 READ		RADAR FAILURE $\Delta\theta_{10}$	OTHER FAILURES $\Delta\theta_{10}$	I	II NOM	III	ΔV UP–DOWN		Δt UP–DOWN	Δt SEC
		9.5	2.5				42 FPS		118 SEC	0
	RADAR FAILURE	9.0	3.0				36 FPS		101 SEC	0
		8.5	3.5				30 FPS		85 SEC	0
$\theta_{10K} = 44.1°$	θ_{10}: ___.___	8.0	4.0				24 FPS	UP	69 SEC	0
		7.5	4.5				18 FPS		51 SEC	0
$\theta_{7N} = 38.1°$	θ_7 :–___.___	7.0	5.0				12 FPS		32 SEC	0
		6.5	5.5				6 FPS		16 SEC	0
ANGULAR	$\Delta\theta_{10}$: ___.___	6.0	6.0	0.0	0.0	0.0	0 FPS		0 SEC	0
		5.5	6.5				6 FPS		16 SEC	5
RATE		5.0	7.0				12 FPS		32 SEC	9
		4.5	7.5				18 FPS		51 SEC	15
CORRECTION		4.0	8.0				24 FPS	DOWN	69 SEC	20
		3.5	8.5				30 FPS		85 SEC	25
		3.0	9.0				36 FPS		101 SEC	29
		2.5	9.5				42 FPS		118 SEC	34

		R_8 NM	R_8 NM –	R_{10} NM =	ΔR_a NM –	ΔR_n NM =	$\epsilon\Delta R$ NM	$\epsilon\Delta R$ NM	ΔV FWD–AFT	$\Delta t_{\Delta R}$ SEC +	Δt SEC =	Δt FWD–AFT +FWD –AFT
	I	17.00				2.43		–.25	13 FPS	16		SEC
	I	17.50				2.50		–.20	10 FPS	13		SEC
	I	18.00				2.57		–.15	8 FPS	10		SEC
RANGE	II NOM	18.50				2.65		–.10	5 FPS	6		SEC
RATE	II NOM	19.00				2.72		–.05	2 FPS	3		SEC
CORRECTION	II NOM	19.37				2.77		.00	FWD 0 FPS AFT	0		SEC
	II NOM	20.00				2.86		+.05	2 FPS	–4		SEC
	II NOM	20.50				2.93		+.10	5 FPS	–8		SEC
	III	21.00				3.00		+.15	8 FPS	–13		SEC
	III	21.50				3.08		+.20	10 FPS	–17		SEC
	III	22.00				3.15		+.25	13 FPS	–21		SEC

(*b*) Second correction maneuver.
FIGURE 29–6.—Continued.

Status of Gemini Rendezvous Procedures and Charts

Numerous modifications to the Gemini VI–A procedures and flight data charts have been made for the Gemini VIII mission. In addition, possible changes are contemplated for subsequent missions. A format change in the charts was indicated by usage of the Gemini V and VI–A charts. The charts used for the backup transfer, as well as the four intermediate correction charts, have been changed to a nomograph presentation. This allows the user to interpolate directly without calculation, as in the case of the present charts. In addition, this presentation provides a far greater expansion of the data and limits than was possible with the tabular format. This was not critical with the present charts and mission requirements, but future applications may require a much greater flexibility; thus it was deemed advisable to change from this standpoint.

The calculations required have been changed to make them additive only, rather than additive or subtractive. The concept of the intermediate correction charts for monitoring and backup has also been changed. Previously, the charts were designed using a reference trajectory with a perfect intercept of the target. When an error in the trajectory was noted, the present charts tried to force the trajectory back to nominal; consequently, the rendezvous trajectory was shifted, and rendezvous was obtained earlier or later, depending on the error. This approach is sufficient to complete rendezvous but does not constrain the target's total central angle travel to 130°; therefore, the time to rendezvous becomes a variable. The new charts provide that the backup procedures present the same calculated corrections as the closed-loop guidance, and further insure that the same total central angle travel is obtained.

Changes to the computer program and readout capability have decreased crew workload and have increased ability to obtain key parameters at the required times. These items are instantaneous range, range rate, and pitch angle. Range and pitch angle were formerly available only at specified intervals and defined times in the programing sequence. Range rate had to be calculated from range points. Monitoring of the closed-loop guidance previously has been restricted to only certain time intervals, due to inability to obtain these parameters. The crew will now have access to these values over a greatly extended time period. This change greatly enhances monitoring of the closed-loop guidance and provides far greater latitude in developing procedures which are more consistent with operational constraints. This point should not be overlooked in the design of future space applications.

The flight director attitude displays were marked in a manner whereby the reading accuracy could be read to only ±2° in most areas and to ±5° when the spacecraft was within ±30° of 90° pitch. The displays are presently being re-marked to 1° increments and will provide reading accuracy to within ±0.5° at all pitch angles. This new marking will provide accurate angle measurements for the transfer maneuver and for midcourse corrections in case of computer failure.

Concluding Remarks

The closed-loop rendezvous guidance system performed satisfactorily. The radar range in-

(c)

GT–6 RENDEZVOUS FLIGHT CHARTS

GET	13:00	14:00	16:00	3rd CORRECTION
MDIU	59 READ	69 READ	59 READ 69 READ	

		RADAR FAILURE $\Delta\theta_{16}$	OTHER FAILURES $\Delta\alpha_{16}$	I	II NOM	III	ΔV UP-DOWN		Δt UP-DOWN	Δt SEC
		12.0	0				28 FPS		80 SEC	0
	RADAR FAILURE	11.5	.5				24 FPS		68 SEC	0
		11.0	1.0				20 FPS		56 SEC	0
$\theta_{16N} = 59.4°$	θ_{16} = ____	10.5	1.5				16 FPS	UP	44 SEC	0
		10.0	2.0				12 FPS		33 SEC	0
$\theta_{13N} = 51.0°$	θ_{13} = ____	9.5	2.5				8 FPS		22 SEC	0
		9.0	3.0				4 FPS		11 SEC	0
	$\Delta\theta_{16}$ = ____	8.4	3.6	0.0	0.0	0.0	0 FPS		0 SEC	0
ANGULAR		8.0	4.0				3 FPS		8 SEC	2
		7.5	4.5				6 FPS		16 SEC	5
RATE		7.0	5.0				9 FPS		25 SEC	7
		6.5	5.5				12 FPS	DOWN	34 SEC	10
CORRECTION		6.0	6.0				16 FPS		44 SEC	13
		5.5	6.5				20 FPS		55 SEC	16
		5.0	7.0				24 FPS		69 SEC	20

		R_{14} NM	R_{24} NM	R_{16} NM	ΔR_a NM	ΔR_n NM	εΔR NM	εΔR NM	ΔV FWD-AFT	$\Delta t_{\Delta R}$ SEC	Δt SEC	Δt FWD-AFT +FWD -AFT	$\dot{R}$ ANALOG 16:00
		9.00				1.58		-.25	13 FPS	16		SEC	85
	I	9.50				1.66		-.20	10 FPS	13		SEC	88
		10.00				1.75		-.15	8 FPS	10		SEC	90
		10.50				1.84		-.10	5 FPS	6		SEC	93
RANGE		11.00				1.93		-.05	2 FPS	3		SEC	96
RATE	II NOM	11.76				2.06		.00	FWD 0 FPS AFT	0		SEC	98
CORRECTION		12.00				2.10		+.05	2 FPS	-4		SEC	100
		12.50				2.19		+.10	5 FPS	-8		SEC	103
	III	13.00				2.28		+.15	8 FPS	-13		SEC	106
		13.50				2.36		+.20	10 FPS	-17		SEC	108
		14.00				2.45		+.25	13 FPS	-21		SEC	111

(c) Third correction maneuver.
FIGURE 29–6.—Continued.

(d)

GT-6 RENDEZVOUS FLIGHT CHARTS

GET	19:00	20:00	22:00	4th CORRECTION
MDIU	59 READ	69 READ	59 READ 69 READ	

ANGULAR RATE CORRECTION

$\theta_{22N} = 80.7^\circ$

$\theta_{19N} = 69.2^\circ$

RADAR FAILURE

θ_{22}: ____.____

θ_{19}:–____.____

$\Delta\theta_{22}$:____.____

RADAR FAILURE $\Delta\theta 22$	OTHER FAILURES $\Delta\alpha 22$	I	II NOM	III	ΔV UP-DOWN		Δt UP-DOWN	Δt SEC
18.5	–6.5				30 FPS	UP	84 SEC	0
17.5	–5.5				25 FPS	UP	72 SEC	0
16.5	–4.5				20 FPS	UP	56 SEC	0
15.5	–3.5				15 FPS	UP	42 SEC	0
14.5	–2.5				10 FPS	UP	30 SEC	0
13.5	–1.5				6 FPS	UP	18 SEC	0
12.5	– .5				3 FPS	UP	9 SEC	0
11.5	+ .5	0.0	0.0	0.0	0 FPS		0 SEC	0
10.5	+1.5				3 FPS	DOWN	9 SEC	3
9.5	+2.5				6 FPS	DOWN	18 SEC	5
8.5	+3.5				10 FPS	DOWN	30 SEC	9
7.5	+4.5				15 FPS	DOWN	42 SEC	12
6.5	+5.5				20 FPS	DOWN	56 SEC	16
5.5	+6.5				25 FPS	DOWN	72 SEC	21
4.5	+7.5				30 FPS	DOWN	84 SEC	25

		R_{20} NM	R_{20} NM –	R_{22} NM =	ΔR_a NM +	ΔR_n NM =	$\varepsilon\Delta R$ NM	$\varepsilon\Delta R$ NM	ΔV FWD-AFT	$\Delta t_{\Delta R}$ SEC –	Δt SEC =	Δt FWD-AFT +FWD –AFT	$\dot{R}$ ANALOG 22:00
RANGE RATE CORRECTION	I	4.00				0.86		–.25	13 FPS	16		SEC	51
	I	4.50				0.97		–.20	10 FPS	13		SEC	54
	I	5.00				1.08		–.15	8 FPS	10		SEC	56
	II NOM	5.50				1.18		–.10	5 FPS	6		SEC	59
	II NOM	6.00				1.29		–.05	2 FPS	3		SEC	62
	II NOM	6.32				1.36		.00	FWD 0 FPS AFT	0		SEC	64
	II NOM	7.00				1.51		+.05	2 FPS	–4		SEC	66
	II NOM	7.50				1.61		+.10	5 FPS	–8		SEC	69
	III	8.00				1.72		+.15	8 FPS	–13		SEC	72
	III	8.50				1.83		+.20	10 FPS	–17		SEC	74
	III	9.00				1.94		+.25	13 FPS	–21		SEC	77

(*d*) Fourth correction maneuver.
FIGURE 29–6.—Concluded.

formation obtained through the computer was very accurate and provided good data to monitor the closed-loop solution. The angle data obtained were slightly erratic and had a possible bias prior to the transfer maneuver. The angle data alone would provide a poor basis on which to base a rendezvous maneuver.

The backup charts and the polar plot gave the crew good information on the rendezvous trajectory and provided a means to complete the rendezvous maneuver in case system failures were encountered.

A continuously updated local-horizontal reference on the platform is highly desirable. The flight director attitude indicator that is referenced to local horizontal provides the flight crew an excellent reference for both the closed-loop and the backup guidance systems.

The optical sight is a mandatory piece of equipment for backup guidance techniques.

The acquisition lights used on Gemini VII were unsatisfactory and precluded optical tracking for transfer and the first two backup midcourse corrections. The lights should provide adequate means of tracking the target at the initiation of the transfer maneuver.

Orientation of the rendezvous phase was optimally located to present the most favorable lighting conditions for target acquisition and tracking, and use of the star background for measurements and braking. These considerations are a requirement for future missions.

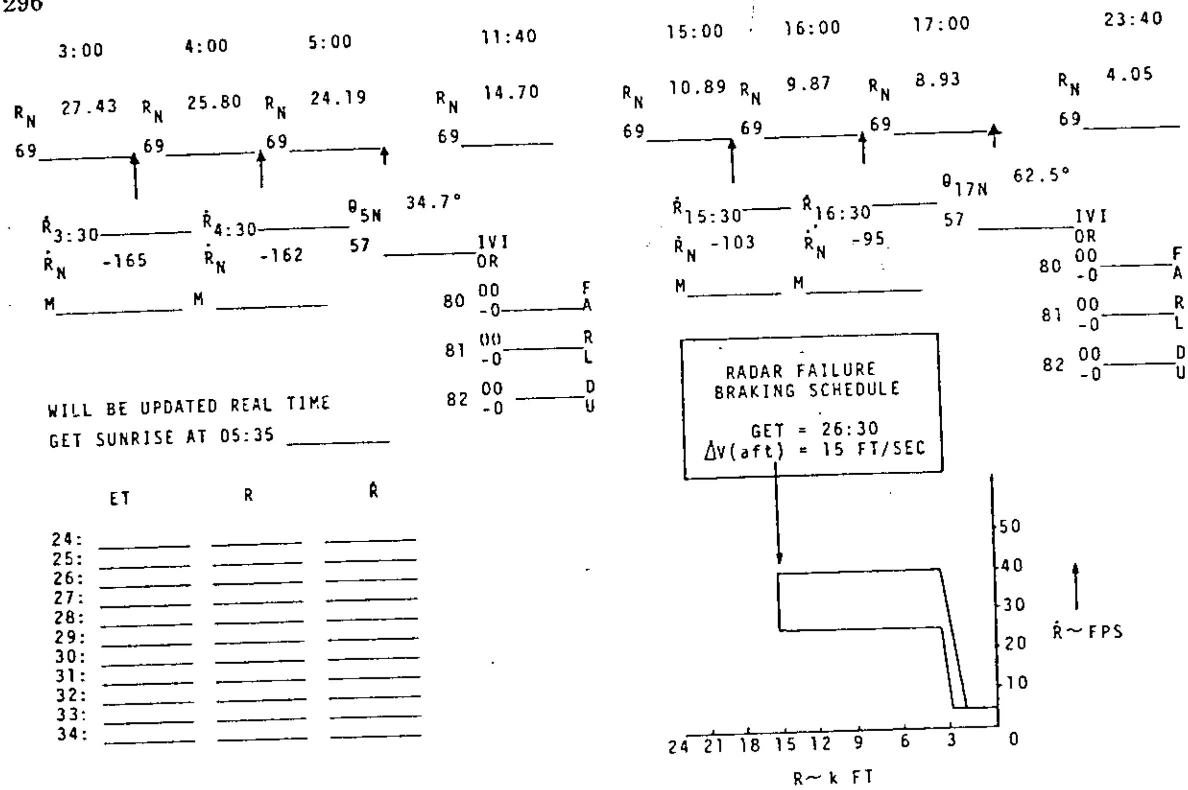


FIGURE 29-7.—Closed-loop intermediate correction monitor sheet.

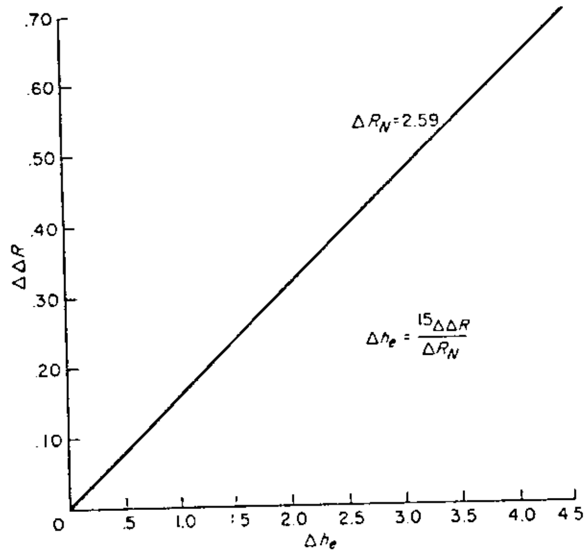


FIGURE 29-8.—Separation determination sheet.

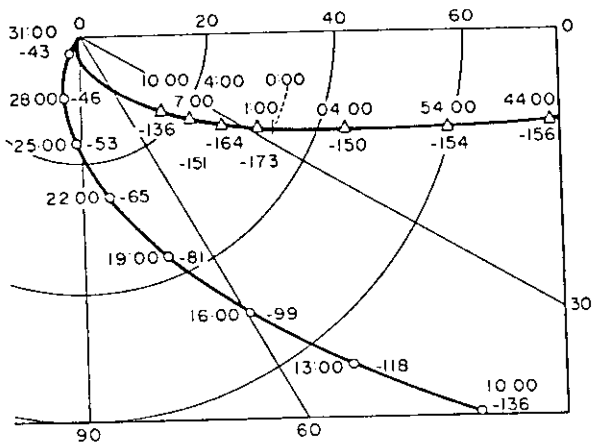
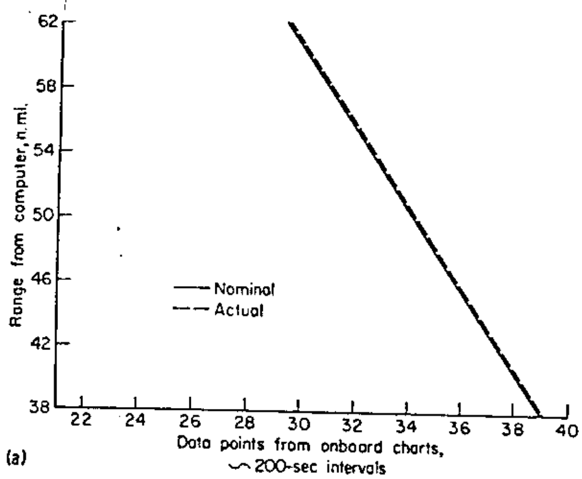
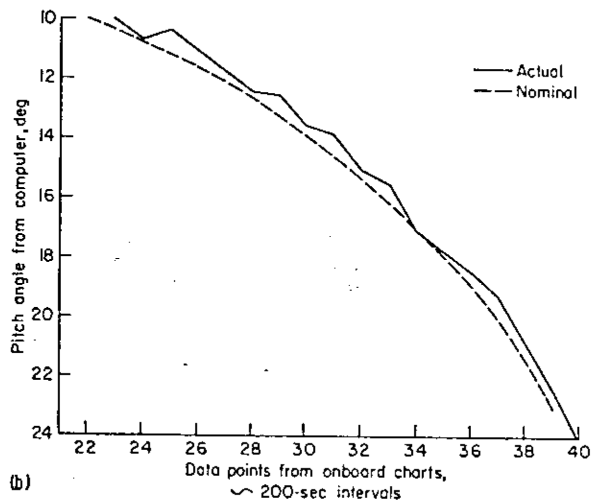


FIGURE 29-9.—Polar plot of nominal Gemini VI-A trajectory.



(*a*) Range versus time output.
FIGURE 29-10.—Gemini VI–A onboard data.



(*b*) Angle versus time computer output.
FIGURE 29-10.—Concluded.

Results of Gemini VI rendezvous, Hacker, <u>op. cit.</u> , pp. 286-8

At 8:37 a.m. *Gemini VI-A* rose from its pad. As if forcing it to move by will power alone, Schirra urged, "for the third time, go." A moment of wonder followed, as the launch vehicle seemed to shimmy. This shaking may have been only an impression; because of their recent experience, both pilots were highly attuned to movement and sound. At engine cutoff, Stafford checked the computer and got a reading of 7830 meters per second. This told them they were on their way. Borman and Lovell in *Gemini VII,* passing near the Cape Kennedy area, saw nothing except clouds; but they soon learned from the Canary Islands communicator that the orbital parameters of *VI-A* were 161 by 259 kilometers. A few minutes later, as they flew over Tananarive, Malagasy Republic, they saw *VI-A's* contrail and got a brief glimpse of the visitors' spacecraft. They put on their suits and waited for company to arrive.[67]

The rendezvous profile—dubbed "M equals 4" by the mission planners for convenience (the "M" had no special meaning)—scheduled the catchup to *VII* during the fourth revolution of *VI-A*. Schirra and Stafford faced six hours of maneuvering to reach Borman and Lovell.[68]

At insertion, the chase vehicle trailed its target by 1992 kilometers. The *VI-A* crew aligned the inertial platform to position their spacecraft for a height adjustment. Over New Orleans, after 94 minutes in space, Schirra ignited the thrusters to speed up by 4 meters per second. The perigee remained the same, but the acceleration kicked the apogee up to 272 kilometers. *Gemini VI-A,* being nearer to Earth and so moving faster, now lagged only 1175 kilometers behind *Gemini VII.*[69]

Near Carnarvon, at 2 hours 18 minutes ground elapsed time, Schirra began a phase adjustment. This had a twofold purpose: to reduce the distance to the target and to raise the chase vehicle's perigee to 224 kilometers. He pressed the button to add 19 meters per second to his velocity. Over the Pacific less than half an hour later, Schirra turned his spacecraft 90 degrees to the right (southward) and ignited the thrusters to push *Gemini VI-A* into the same plane as *Gemini VII.* Now the distance between the two vehicles had narrowed to 483 kilometers.[70]

Three hours 15 minutes into the mission, Elliot See told Schirra that radar contact should soon be possible with *Gemini VII*. The *VI-A* crew got a flickering radar signal, then a solid lock-on at 434 kilometers range. Over Carnarvon, at 3 hours 47 minutes, the aft thrusters fired for 54 seconds to add 13 meters per second to *Gemini VI*'s speed. The result was almost a circle, measuring 270 by 274 kilometers. In slant range distance, the two spacecraft were now 319 kilometers apart and closing slowly.[71]

Schirra and Stafford placed *Gemini VI-A* in the computer (or automatic) rendezvous mode at 3 hours 51 minutes into the flight. While the lower orbiting vehicle gained slowly on its target, Schirra dimmed the lights on his side of the spacecraft to improve outside visibility. At 5 hours 4 minutes, he exclaimed, "My gosh, there is a real bright star out there. That must be Sirius." The "star" was *Gemini VII*, reflecting the Sun's rays from 100 kilometers away.

Gradual catchup of the target vehicle lasted until 5 hours 16 minutes; Schirra prepared to make the last rendezvous maneuvers. The two ships were now close enough to allow Spacecraft 6 to thrust directly toward Spacecraft 7. He fired the thrusters and closed on *Gemini VII* at a rate of better than three kilometers every minute and a half.[72] Schirra and Stafford briefly lost sight of *Gemini VII* when it passed into darkness but soon picked up the target's running lights.[73]

Schirra made two midcourse corrections spaced 12 minutes apart (at 5 hours 32 minutes and 5 hours 44 minutes). Six minutes later, at a range of 900 meters from his target, Schirra began braking his spacecraft by firing the forward thrusters. Soon he had no difficulty seeing *Gemini VII*. Fittingly, in the terminal stage of rendezvous, the *VI-A* astronauts saw the stars Castor and Pollux in the Gemini (Twin) constellation aligned with their sister ship. Then Spacecraft 7 flashed into the sunlight—almost too bright to look at. From a distance of 200 meters, it resembled a carbon arc light. Following the braking and translation maneuver, *VI-A* coasted until the two vehicles were 40 meters apart, with no relative motion between them. The world's first manned space rendezvous was now a fact. In Mission Control, the cheering throng of flight controllers waved small American flags, while Kraft, Gilruth, and others of the jubilant crowd lit cigars and beamed upon this best of all possible worlds. At 2:33 p.m., 15 December 1965, *Gemini VI-A* had rendezvoused with *Gemini VII*.[74]

When Russian *Vostok III* flew within five kilometers of *Vostok IV* on 12 August 1962, some people believed, with the help of *Pravda* news dispatches, that rendezvous had been accomplished. The two spacecraft, however, were in different orbital planes; nor could they maneuver to stop relative motion between them. In simple terms, it was good shooting from the pad, but the result was the same as if two bullets had passed in the middle of a battlefield. Schirra knew what a real rendezvous in orbit was:

> Somebody said. . . when you come to within three miles [five kilometers], you've rendezvoused. If anybody thinks they've pulled a rendezvous off at three miles, have fun! This is when we started doing our work. I don't think rendezvous is over until you are stopped—completely stopped—with no relative motion between the two vehicles, at a range of approximately 120 feet [40 meters]. That's rendezvous! From there on, it's stationkeeping. That's when you can go back and play the game of driving a car or driving an airplane or pushing a skateboard—it's about that simple.[75]

Borman and Lovell had been fascinated by the fireworks of *VI-A's* thrusters during braking and startled by the 12-meter tongue of flame. As Schirra and Stafford neared, there was a second surprise. Borman said, "You've got a lot of stuff all around the back end of you." Minutes later, during stationkeeping, Schirra told Borman, "So do you." Cords and stringers three to five meters long streamed and flapped behind both spacecraft.[76]

Rendezvous maneuvers had cost *VI-A* only 51 kilograms (113 pounds) of fuel. Schirra still had 62 percent left in his tanks. It had been easy, he said, and there was plenty of fuel for stationkeeping, flyarounds, formation flying, and parking the spacecraft in specific relative positions. Borman and Lovell were not so wealthy; Flight Control told them to stop maneuvers when the *VII* tanks dropped to an 11 percent supply.

For more than three Earth revolutions, the two spacecraft stayed at ranges of from 0.30 meters to 90 meters. *VI-A* approached *VII* to examine the stringers on one occasion. On another, they flew nose to nose. Schirra and Stafford swapped the controls back and forth because the Sun streamed so brightly through first one window and then the other. When it was time for Borman and Lovell to perform an experiment, Schirra and Stafford moved out 12 meters and parked. For some 20 minutes, in one instance, neither bothered to touch the steering handle, as the spacecraft remained stable in relation to its sister ship. On the first night pass, the two spacecraft faced each other at distances ranging from 6 to 18 meters. Schirra had worried about visibility during darkness, but it turned out to be excellent—docking light, handheld penlight, and even *VII's* cabin lights were clearly visible to him.

Using what Schirra called his eyeball ranging system, the *VI-A* crew did an in-plane flyaround of *VII*, roving out to 90 meters. Believing this was too far away to be called stationkeeping, Schirra hurriedly brought *VI-A* within 30 meters. The astronauts were highly impressed with their ability to control the spacecraft. Velocity inputs as low as 0.03 meter (0.10 foot) per second provided very precise maneuvering. Because of this fine control, he and Stafford concluded that nuzzling into and docking with a target vehicle would be no problem.

[67] "Gemini VI-A Mission Report," p. 1-1, -2; Evert Clark, "At Last, Gemini 6 Day Is Perfect As Even Sun Comes Out in Time," *The New York Times*, 16 Dec. 1965; "Gemini VI Debriefing," pp. 13, 18; "Gemini VII Voice," III, pp. 751, 752, 755; "Gemini VII Debriefing," p. 145; "Gemini 7/6 Flight Controllers," [p. 15]; "Gemini VI-A Post Launch Report No. 1," p. lb.

[68] Grimm, Stafford, and Schirra, "Gemini VI Rendezvous," pp. 1-2; "Gemini VI-A Mission Report," p. 1-2.

[69] [Ivan D. Ertel], *Gemini VII/Gemini VI: Long Duration/Rendezvous*, MSC Fact Sheet No. 291-D (Houston, Jan. 1966), p. 9; "Gemini VI-A Mission Report, pp. 4-15, -16, -18; "Gemini VI-A Post Launch Report No. 1," p. lb; *Astronautics and Aeronautics, 1965: Chronology on Science, Technology, and Policy*, NASA SP-4006 (Washington, 1966), p. 551.

[70] "Gemini VI-A Mission Report," pp. 4-16, -18, 7-17; TWX, Kleinknecht to NASA Hq., Attn: Webb, and MSC, Attn: Gilruth, "Special Rendezvous Report—Gemini Mission VII/VI," 15 Dec. 1965; Grimm, Stafford, and Schirra, "Gemini VI Rendezvous," pp. 1-2; *Astronautics and Aeronautics, 1965*, p. 551.

[71] "Gemini VI-A Mission Report," pp. 1-2, 4-12, -16, -19; "Gemini VI-A Post Launch Report No. 1," p. 1c; Kleinknecht, "Special Rendezvous Report."

[72] "Gemini VI-A Mission Report," pp. 4-12, -19, 7-2, -20; Grimm, Stafford, and Schirra, "Gemini VI Rendezvous," p. 2; memo, Tindall to dist., "Rendezvous odds and ends," 65-FM1-212, 30 Dec. 1965; "Gemini VI Debriefing," pp. 27, 37-38.

[73] Thomas P. Stafford, Walter M. Schirra, and Dean F. Grimm, "Rendezvous of Gemini VII and Gemini VI-A," in *Gemini Midprogram Conference*, p. 291; "Gemini VI-A Mission Report," p. 7-21; "Gemini VII Voice," III, p. 766; Grimm, Stafford, and Schirra, "Gemini VI Rendezvous," p. 14.

[74] Kleinknecht, "Special Rendezvous Report"; Grimm, Stafford, and Schirra, "Gemini VI Rendezvous," p. 11; Stafford, Schirra, and Grimm, "Rendezvous of Gemini VII and Gemini VI-A," p. 291; "Gemini VI-A Mission Report," pp. 7-23, -24; Hodge interview; Tindall memo, 30 Dec. 1965; "Gemini VII Voice," III, p. 769; "Jubilation," caption of photo in MSC *Space News Roundup*, 23 Dec. 1965.

[75] U.S. Congress, House, Committee on Science and Astronautics, *Astronautical and Aeronautical Events of 1962: Report*, 88th Cong., 1st sess., 12 June 1963, pp. 146-47, 148; Robert Korengold, "2 Reds Go on Orbiting As Observers Report Signs of Rendezvous," *The Washington Post*, 14 Aug. 1962; David Miller, "Split-Second Precision Put 2 Vostoks Close Together," *New York Herald Tribune*, 14 Aug. 1962; Korengold, "Both Reds Pass Million Miles Travel in Orbit," *The Washington Post*, 14 Aug. 1962; TWX, Rhett Turnipseed to NASA, Houston, "Text of an Interview by an Izvestia Correspondent with the Soviet Cosmonaut Pavel Romanovich Popovich [21 Dec. 1965]," 29 Dec. 1965; "Gemini 7/6 Astronaut Post Flight Press Conference," 30 Dec. 1965, tape 8, p. 2; James M. Grimwood and Ivan D. Ertel, "Project Gemini," *Southwestern Historical Quarterly*, 81, no. 3 (January 1968), p. 407; [Ertel], *Gemini VII/Gemini VI*, p. 16.

[76] "Gemini VII Debriefing," pp. 137-38; "Gemini VI Debriefing," pp. 59-60; "Gemini VII Voice," III, pp. 767-68, 771.