3. GROUND CONTROL AND MONITORING OF RENDEZVOUS

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Summary

This paper discusses the ground control and monitoring function performed in support of the Gemini rendezvous missions. Included are discussions of the support philosophy adopted for Gemini; the resulting influence upon mission design; and comparisons between predicted and actual flight results.

Introduction

The concepts adopted for the ground support of Gemini were in keeping with the basic mission-design criterion of maximizing the probability of achieving rendezvous. A flexible ground system was developed to permit the flight-control team to react to anomalous situations routinely, while still preserving standardized conditions for the terminal-phase rendezvous. Since the possibility existed for a multitude of anomalous situations, a real-time mission-planning capability was implemented in the Mission Control Center—Houston. This capability consisted of computer-driven displays which permitted the flight controllers to assess current conditions, and to select a maneuver sequence compatible with mission constraints. In effect, the role of the flight controllers was to provide a series of midcourse maneuvers which achieved a particular relative separation and velocity between the spacecraft and the target vehicle. Following the final midcourse maneuver, the role changed more to monitoring the onboard-computed intercept maneuver and the final terminal-phase operations. The following discussion will compare, from a ground-support standpoint, the primary rendezvous missions as well as the re-rendezvous operations which may be conducted during a flight.

Gemini Rendezvous Missions

The ground support of a rendezvous mission was planned so that all information that the flight crew would nominally request, plus additional backup information, would be available at an optimum time in the flight plan. Once the basic mission plan was developed, a large number of final details had to be refined in simulations of the mission with the actual flight-crew personnel. The primary maneuver updates from the Mission Control Center—Houston had to be scheduled at a time that would afford maximum radar tracking history in the mission computers at the Manned Spacecraft Center, Houston. The Gemini rendezvous missions were separated into two distinct mission phases, the midcourse maneuver and the terminal rendezvous. For the midcourse phase, the flight-control team was the primary source for the maneuver computations. The purpose of these maneuvers was to effect a rendezvous between the spacecraft and a point in space that would result in the desired spacecraft displacement and velocity with respect to the target vehicle. To accomplish this, preestablished maneuver points were selected so that the propellant requirements for this mission phase were minimized, and sufficient network tracking was available for maneuver updates. Of course, the first rendezvous mission, Gemini VI–A, had the most uncertain conditions. Consequently, for this mission, a

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plan was selected which afforded rendezvous in the fourth spacecraft revolution with the following salient features:

(1) The Gemini Launch Vehicle was targeted to provide the desired altitude differential between the target and spacecraft orbits at spacecraft apogee. Also, a dogleg launch trajectory was flown in order to insert the spacecraft into the plane of the target orbit.

(2) The first spacecraft orbit was free of rendezvous activity so the crew could make the necessary systems checks, and the ground controllers could determine the precise spacecraft orbit.

(3) Preestablished maneuver points were selected to account for expected dispersions in lift-off time and spacecraft insertion conditions.

(4) The site chosen to update a maneuver had acquisition so that adequate time remained for the crew to orient the spacecraft to the maneuver attitude.

The midcourse maneuver sequence can be seen in figure 3–1. Tracking during the first revolution indicated that the altitude differential at spacecraft apogee exceeded the acceptable tolerance; thus, the initial midcourse translation was a height adjustment performed at spacecraft perigee near the end of the first revolution. The second midcourse maneuver was a phase adjustment which occurred at the second spacecraft apogee. Out-of-plane errors were removed with a maneuver at the common node following the second apogee. Subsequent radar-tracking information indicated the need for an additional adjustment to the altitude differential at spacecraft apogee. This maneuver was performed at perigee near the end of the second revolution. The final midcourse translation was a coelliptic maneuver performed at the third apogee. The purpose of this maneuver was to place the spacecraft orbit at a constant altitude difference below the target-vehicle orbit. The same basic mission plan was also successfully used on Gemini VIII. For the Gemini IX–A mission, the midcourse-maneuver sequence had the additional requirement to more nearly duplicate the Apollo time line and midcourse phase planned for the lunar rendezvous operations. This led to rendezvous in the third spacecraft revolution with a somewhat different maneuver sequence (fig. 3–2). The phase-adjustment maneuver was performed at the first spacecraft apogee. Since the phasing maneuver was based upon a minimal amount of tracking, a second midcourse maneuver designed to achieve phasing, height, and plane requirements was scheduled in the second revolution. The location of this maneuver was

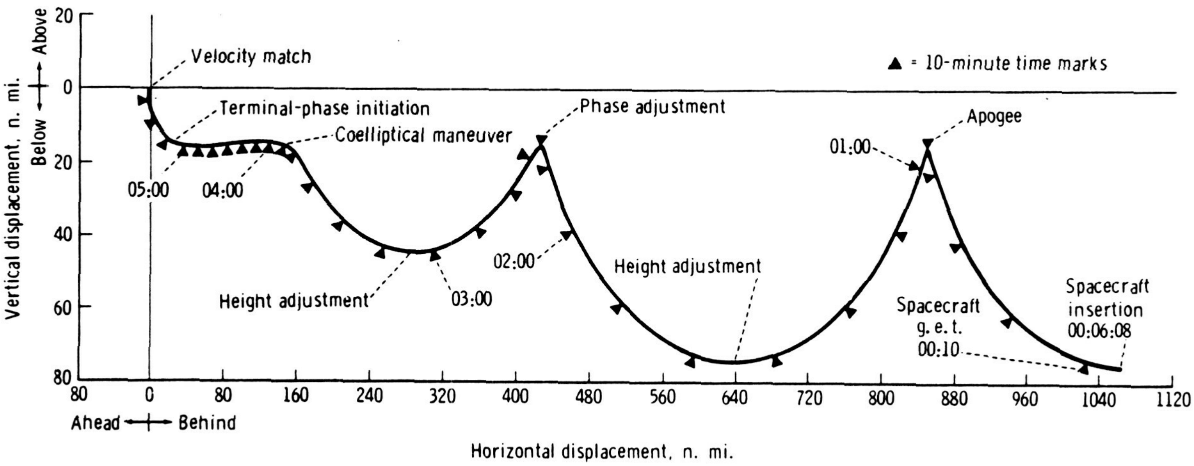

FIGURE 3–1.—Relative trajectory of spacecraft from insertion to three-revolution rendezvous in target-centered curvilinear coordinate system.

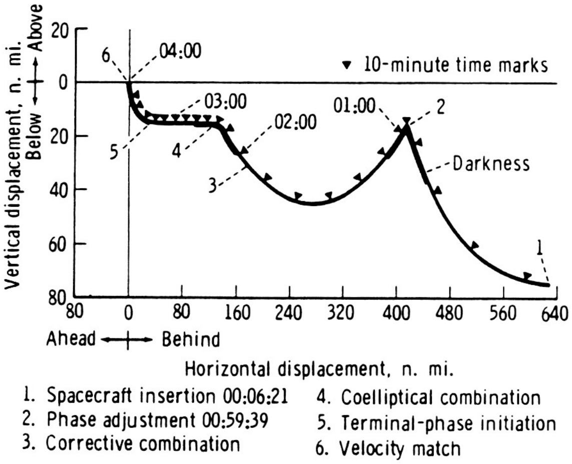

FIGURE 3–2.—Relative trajectory of spacecraft from insertion to two-revolution rendezvous in target-centered curvilinear coordinate system.

TABLE 3–I.—*Dual Rendezvous Planning*

Gemini VIII target-vehicle vector [a]	Gemini X target-vehicle launch time, Greenwich mean time, hr:min:sec	Required apogee, n. mi.
3/19/66	3:40:58	225
3/30/66	3:40:54	245
4/25/66	3:37:30	470
5/16/66	3:37:30	400
6/ 9/66	3:46:30	390
5/24/66	3:41:55	360
6/20/66	3:40:26	420
7/18/66	3:39:46	409

[a] Column shows dates when the passive Gemini VIII target vehicle was in proper position for lift-off of the Gemini X mission to accomplish dual rendezvous.

selected to afford a maximum amount of tracking over the continental U.S. stations. The final maneuver in this sequence provided a constant altitude differential between the two orbits, and also placed the Gemini spacecraft in the plane of the target vehicle.

The initial rendezvous maneuver sequence utilized on Gemini X was identical to that of Gemini VI–A. However, the ground controllers had the additional tasks of evaluating onboard maneuver calculations based upon star measurements and upon the Inertial Guidance System ascent vector; and of giving a go—no-go decision on these solutions based upon retaining acceptable terminal-phase conditions. The flight plan also included a rendezvous between the spacecraft and the passive target vehicle, which had been launched during the Gemini VIII mission and then placed in a higher parking orbit. This plan created an additional complexity, as compared with the earlier rendezvous missions, and necessitated an on-time launch for both the target vehicle and the spacecraft. Table 3–I shows the variation during the 4-month period preceding flight in lift-off time required of the Gemini X target vehicle, as well as the required apogee altitude for dual rendezvous phasing. After the crew completed the initial docking with the Gemini X target vehicle, they initiated midcourse maneuvers (fig. 3–3) to achieve desired conditions for the terminal phase of rendezvous with the passive Gemini VIII target vehicle. The Gemini X target-vehicle propulsion system was used to perform these maneuvers while the spacecraft and target vehicle were docked; the spacecraft propulsion system was used after undocking.

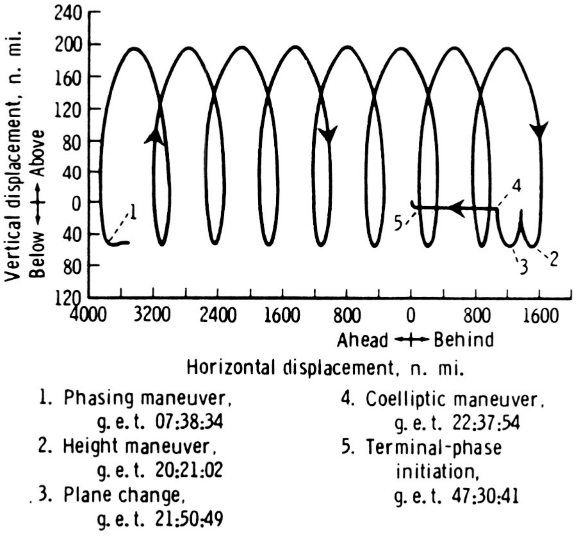

FIGURE 3–3.—Relative trajectory of Gemini X dual rendezvous in target-centered curvilinear coordinate system.

The ground support of the first-orbit rendezvous during the Gemini XI mission (fig. 3–4) was approached in a considerably different manner than during prior rendezvous missions. The only midcourse maneuver scheduled was a plane-change maneuver to account for insertion dispersions. The location of this maneuver was approximately a quarter of a spacecraft revolution after insertion. The major role of the flight controllers for this mission was to evalute the predicted relative conditions at the time of the terminal intercept maneuver, and to give a go—no-go decision for the first-orbit rendezvous. The basis for the go—no-go decision was dependent on the resultant propellant cost for the terminal-phase operations, and on the relative conditions which would preclude the use of onboard backup charts required in the event of degraded systems performance. In addition to providing a go—no-go decision, a contingency maneuver plan was computed in the event that the decision was no-go. This plan was based upon rendezvous in the third revolution.

For the Gemini XII initial rendezvous, the midcourse maneuver sequence was identical to that of the Gemini IX–A mission. The additional complexity involved for this mission included ground evaluation of the onboard-computed plane-change maneuver and the final maneuver to establish the constant altitude differential.

Following the final midcourse maneuver update, the ground provided a backup terminal-phase-initiate maneuver to serve as a comparison between the onboard closed-loop and backup solutions. In addition, supplemental information, such as the variation in altitude differential, was passed to the crew.

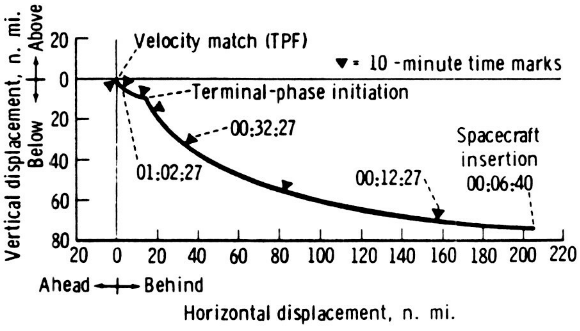

FIGURE 3–4.—Relative trajectory of Gemini XI from insertion to rendezvous in target-vehicle curvilinear coordinate system.

Re-Rendezvous Operations

Three re-rendezvous operations were included in the Gemini Program to increase the rendezvous experience. These exercises investigated such factors as variation in lighting and terminal-approach conditions. The equiperiod re-rendezvous of the Gemini IX–A mission was used to study proposed lighting conditions for the dual rendezvous of Gemini X. The second re-rendezvous of Gemini IX–A investigated a terminal approach from ahead and above the target vehicle in support of future Apollo rendezvous operations. The re-rendezvous of Gemini XI was a totally different technique from any previously flown. The spacecraft was given phasing maneuvers from the ground such that no relative phase rate existed between the two vehicles prior to the intercept maneuver. In this configuration, the spacecraft trailed the target vehicle by approximately 25 nautical miles in the same orbit (fig. 3–5). The vehicles remained in this configuration for approximately 12 hours, at which time a ground-computed intercept maneuver was applied, with the final terminal-phase control performed visually by the crew. This technique was flown to compare the propellant cost with that required for long-term, close-range station keeping.

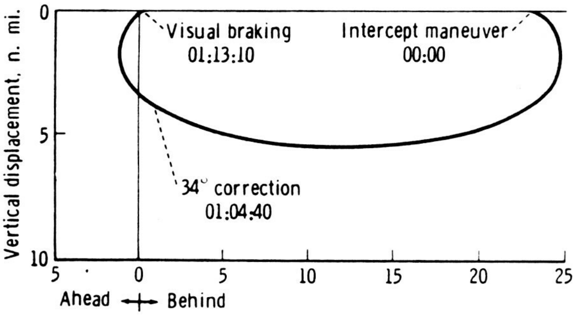

FIGURE 3–5.—Gemini XI stable orbit re-rendezvous.

Flight Results

The effectiveness of the ground-computed midcourse maneuvers can best be evaluated by the propellant required for midcourse maneuvers, and how accurately the conditions for terminal-phase initiation were met. As shown in table 3–II, the lighting conditions obtained were within desired limits; above-nominal midcourse propellant usage was largely due to dispersions in insertion conditions. The variation in altitude differential following the coelliptic maneuver was well within the limits for the use of onboard backup charts on all flights. The ground-computed terminal-phase solutions were consistently in very close agreement with both onboard solutions for all missions.

Gemini Agena Target Vehicle

Prior to spacecraft launch and subsequent rendezvous operations, the Gemini Agena Target Vehicle was monitored and evaluated to insure proper configuration for use as a passive target. Of prime concern, other than total electrical failure, was the verification of insertion into the proper orbit. Any significant error in insertion would require correction by a plane-change maneuver from the target-vehicle propulsion system.

Upon achieving a nominal insertion, complete checkout of vehicle performance and attitude conditioning was accomplished by the target-vehicle flight controllers. This normally consisted of correcting the memory system and configuring the target docking equipment for the rendezvous by real-time commands. The target vehicle was further commanded to an orientation of —90° from the flight path (docking adapter to the north) in order to present a larger target to the spacecraft radar system and to provide a larger target for visual acquisition in sunlight exposure.

From target-vehicle lift-off to spacecraft rendezvous, three major parameters were evaluated to assure a safe target. The propellant-tank differential pressure was of prime concern because a reversal pressure would cause the loss of the target vehicle. The battery temperature was continuously evaluated to predict a rate of change, since the target would be lost if the temperature became excessive. The Attitude Control System pressure was evaluated to assure a nonleak condition which would provide adequate control to preclude vehicle instability and associated unsuitability for docking.

Conclusion

Effective ground support and control has been demonstrated in the successful accomplishment of the rendezvous missions of the Gemini Program. Of key importance in this success was the flexible real-time planning capability which afforded the necessary response to a variety of mission situations.

TABLE 3–II.—*Rendezvous Midcourse Phase Summary*

Gemini mission	Velocity		Variation in terminal-phase initiation time, min [a]	Variation in altitude differential, n. mi.
	Nominal, ft/sec	Actual, ft/sec		
VI–A	117	159	2.1	1.1
VIII	117	150	9.7	1.2
IX–A	126	173	−1.2	.2
X	120	141	−2.2	.9
XI	30	44	.3	—
XII	135	167	5.0	1.3

[a] Positive values indicate late terminal-phase initiations.