Gemini 8 & Agena 8 docking, Hacker, op. cit. , pp. 309-312

The target launch vehicle lifted from pad 14 at 10 o'clock in the morning. Its trajectory was at first low and to the right (south) of the intended flight path. The sustainer engine rammed the target back on track. In a little more than five minutes, the Atlas had done its job. Now it was Agena's turn. After a short coast, its secondary propulsion system burst into life. The crucial test for the Agena came with the firing of its main engine, and the engineers crossed their fingers and held their breaths. But it worked. The engine ignited and carried the target into a 298-kilometer circular orbit.[46] Planners had wondered if the Agena could so position itself that astronauts could catch it. The answer was yes!

With one up and one to go, attention turned to pad 19. Fourteen minutes before the Atlas-Agena lifted, Armstrong and Scott slid through the spacecraft hatches into their couches. As the flight-preparation crew helped harness Scott to his parachute, they found one of its catches full of glue. Backup command pilot Conrad and McDonnell pad leader Guenter Wendt began digging it out. Just a little thing like that, Scott thought, "might have cost us a launch," but he could not help smiling as he watched Conrad sweat over the job. The catch came unglued and Gordon, the backup pilot, tried the fitting a few times to prove to Scott that it was working. Learning of the Agena's nearly perfect orbit, Armstrong said, "Beautiful, we will take that one."[47]

Given the Agena's orbital parameters, the Gemini launch vehicle should lift off at 10:40:59 a.m. The powerful engines of Titan II throbbed into life exactly on time, and Armstrong and Scott felt the hold-down bolts shear for breakaway. GLV-8 started off a little low, as had Atlas, but soon straightened to boost the 3788-kilogram (8351-pound) spacecraft into an elliptical orbit 160 by 272 kilometers.[48]

After the first hurdle had been vaulted, the next challenge was catching the target. Procedures were much the same as those for *Gemini VI-A*, although this time there was no friendly target to point its attached transponder toward the spacecraft's radar. Armstrong and Scott began the chase 1963 kilometers behind the Agena.

Thirty-four minutes into the flight, the Sun set and, in the engulfing darkness, the crew could see brilliant fires streaming from their spacecraft's thrusters. As the radiator in the adapter expelled water, the thrusters fired to compensate for a sideward turn. The Carnarvon, Australia, tracking station told them the radiator was not much of a problem and passed to them the Flight Director's "go" for a day's flight.[49]

Over the Pacific, the two astronauts had some time to sightsee. Molokai, Maui, and Hawaii hove clearly into view. Armstrong tried to see Kauai and Oahu, but cloud banks obscured them. Minutes later, Scott said to his partner, "We're going over Baja California now. Can you see it?" But Armstrong had his eyes on the Los Angeles ship basin in the other direction, and his response was, "Oh, look at all those ships!" Armstrong then spotted the Rogers Dry Lake bed. He looked for, but was not certain he found, Edwards Air Force Base, where he had spent seven years piloting experimental airplanes. Over Texas, both men wanted to see if they could spot their homes, but work preempted this scenic interlude. At the low point of their first circuit of Earth, Armstrong aligned the inertial platform for a height adjustment maneuver. At 1:34 hours elapsed time, he touched off a five-second burst of the thrusters for a small retrograde change in velocity, to lower the apogee slightly. Armstrong noticed a problem in cutting off residual thrust. This resulted in varying computer readings and made it difficult to tell the exact deceleration obtained.[50]

On their mission, Schirra and Stafford had been so preoccupied that they had not taken time to eat, which left them hungry, as well as tired, when they caught up to Borman and Lovell. Scott and Armstrong knew they would be very busy all three days of their mission, so each grabbed a package of food and started preparing a meal, which seemed to take longer than they thought it would. When they had to stop and align the platform for a maneuver to raise the perigee, they placed the food packages against the spacecraft ceiling. Weightlessness was handy.[51]

Nearing second apogee (2:18:25 hours), Armstrong fired the thrusters to add 15 meters per second to their speed. Again, tail-off residuals made it hard to get a computer reading.[52] After this maneuver, Armstrong and Scott pulled their food from the ceiling. Although Armstrong's chicken and gravy casserole had been mixed with water for half an hour, it was still dry in spots and not much like home cooking. But he finished it and washed it down with fruit juice to keep from dehydrating. Then he tried a package of brownies, which were stuck together and crumbly. They were hard to eat without scattering weightless scraps all over the cabin.[53]

The next maneuver was designed to push the spacecraft into the target's orbital plane. Armstrong yawed *Gemini VIII's* nose 90 degrees south of the flight path. Over the Pacific Ocean, 25 minutes before completing the second revolution (2:45:50 hours), the command pilot punched the aft thrusters to produce a horizontal velocity change of 8 meters per second. He waited for the ground controllers to tell him if any adjustment was needed. Hearing nothing, he assumed his thrusting had been correct. Over the Guaymas, Mexico, tracking station, Lovell, the Houston CapCom, suddenly cut in on the remote site line to order him to add 0.6 meter per second to his speed. With only a minute to get ready, there was little time to turn the spacecraft and no time to align the platform. "It was . . . a pretty quick loose burn . . . without much preparation," Scott said.[54]

Armstrong and Scott then began the rendezvous radar test. They did not expect to get radar contact as quickly as Schirra and Stafford had, but the Westinghouse development team had promised target acquistion at 343 kilometers. The radar locked on solidly at 332 kilometers, which was good enough.[55]

Over the Tananarive tracking station, 3:48:10 hours after launch, Armstrong nosed the spacecraft down 20 degrees and applied the aft thrusters for an in-plane (with the target) velocity change of 18 meters per second. This gave them a nearly circular orbit close to 28 kilometers below that of the target. The spacecraft was now in position to start the terminal phase of rendezvous.[56]

The crew sighted a shining object 140 kilometers ahead, which must be the Agena. After closing to a range of 102 kilometers, all doubts were erased—the target gleamed in the sunlight. Scott switched the computer from the catchup to the rendezvous mode and watched the distance dwindle on the slide, automatically. Just before sunset, the Agena suddenly disappeared, but at twilight its acquisition lights blinked into view.[57]

When the Agena was at the proper angle (10 degrees) above them, Armstrong aligned the inertial platform for the translation maneuver. Then he pitched *Gemini VIII's* nose up 31.3 degrees and canted the vehicle 16.8 degrees to the left. At 5:14:56 hours, ground elapsed time, the command pilot fired his aft thrusters, later making two small corrections. High over the *Coastal Sentry* Quebec tracking ship, stationed near Antigua Island, at 5:43:09 hours, he braked the spacecraft. Since he could see the Agena, Armstrong judged his braking action by eye as Scott called out radar range and range rate. At a distance of 46 meters, relative velocity between the two vehicles had been canceled. The second rendezvous in the Gemini program had been achieved.[58]

For 36 minutes after rendezvous, Armstrong's delicate maneuvering kept his spacecraft on station with the target vehicle. As the command pilot drove, Scott inspected the Agena—checking antennas, docking lights, and the like. Finding it hard to see all of the target's instrument panel displays near the docking cone, he used the telescopic sight of a hand-held sextant. But a really good look would have to wait until they were docked, when these instruments would become a second dashboard. Meanwhile, Armstrong studied the general appearance of the Agena. It seemed stable, and he nudged the spacecraft to within a meter (about three feet) of the target. Then, at 6:32:42, Keith K. Kundel, CapCom on the *Rose Knot* Victor, radioed, "Go ahead and dock."[59]

Armstrong eased *Gemini VIII* toward the target at a barely perceptible rate of 8 centimeters (3 inches) per second. "About two feet [60 centimeters] out," he told the *Rose Knot* Victor. In a matter of seconds, Armstrong gleefully reported, "Flight, we are docked! It's . . .really a smoothie—no noticeable oscillations at all." For a moment, the flight controllers in Houston could not realize that they had really done it. Then pandemonium broke loose, with back slaps, hand shakes, cheers, and tremendous grins.[60]

[46] Gemini 8 mission commentary transcript, 16 March 1966, tape 20, pp. 2-3, tape 21, p. 1; "Gemini VIII Mission Report," pp. 6-3, -4; "Atlas SLV-3, Space Launch Vehicle Flight Evaluation Report, SLV-3 5302," General Dynamics GDC/BKF66-012 and Supplemental Report No. 7 to "Gemini VIII Mission Report," 17 June 1966, p. 10; "Gemini Agena Target Vehicle 5003, Systems Test Evaluation (45-Day Report)," LMSC-A817204 and Supplemental Report No. 6 to "Gemini VIII Mission Report," 5 May 1966, p. 2-12.

[47] "Gemini VIII Technical Debriefing," 21 March 1966, pp. 1-2; Scott interview; Gemini 8 mission commentary, tape 23, p. 1.

[48] Gemini 8 mission commentary, tape 30, p. 1, tape 31, p. 1, tape 34, p. 2; "Gemini VIII Debriefing," pp. 5, 6; "Gemini VIII Mission Report," pp. 2-1, 6-4, -5; "Launch Vehicle No. 8 Flight Evaluation," Martin Co. Engineering Report No. 13227-8 and Supplemental Report No. 2 to "Gemini VIII Mission Report," April 1966, pp. vii, II-1, -2.

[49] "Gemini VIII Mission Report," p. 4-2; "Gemini VIII Debriefing," p. 13; Gemini 8 mission commentary, tape 37, p. 4; "Gemini VIII Voice Communications (Air-to-Ground, Ground-to-Air and On-Board Transcription)," McDonnell Control No. C-115471, n.d., pp. 8-10.

[50] "Gemini VIII Debriefing," pp. 18-20; "Gemini VIII Mission Report," pp. 4-2, 7-2; "Gemini VIII Voice," pp. 15-18.

[51] "Gemini VIII Debriefing," pp. 21, 22; "Gemini VIII Voice," p. 25.

[52] "Gemini VIII Debriefing," pp. 22-23; "Gemini VIII Mission Report," pp. 4-2, 7-2.

[53] "Gemini VIII Debriefing," pp. 23-25; "Gemini VIII Mission Report," p. 7-25.

[54] "Gemini VIII Debriefing," pp. 27-29; "Gemini VIII Mission Report," pp. 4-2, 7-3; Gemini 8 mission commentary, tape 44, pp. 4-6; "Gemini VIII Voice," pp. 34-35.

[55] "Gemini VIII Debriefing," pp. 29-30; "Gemini VIII Voice," pp. 39-40; Ben Vester et al., interview, Baltimore, 25 May 1966.

[56] "Gemini VIII Debriefing," p. 30; "Gemini VIII Mission Report," pp. 4-2, -3, 7-3, -4; "Gemini VIII Voice," p. 40.

[57] "Gemini VIII Debriefing," pp. 34, 35, 36, 37-38; "Gemini VIII Mission Report," pp. 4-3, 7-3, -4, -8, -19; "Gemini VIII Voice," pp. 43, 44, 45, 47.

[58] "Gemini VIII Debriefing," pp. 36-40, 41, 42, 43-47; "Gemini VIII Mission Report," pp. 4-3, 7-4, -19; "Gemini VIII Voice," pp. 55-60.

[59] "Gemini VIII Mission Report," pp. 4-3, 7-4, -19; "Gemini VIII Debriefing," pp. 47-49; "Gemini VIII Voice," pp. 60, 61, 64, 65, 67, 68, 70; "Air-Ground Playback Briefing," 17 March 1966, tape 6A, p. 1.

[60] "Gemini VIII Voice," pp. 70, 71; Gemini 8 mission commentary, tape 58, p. 1.

Planning for Gemini-9,
Hacker, op. cit., pp. 327-8

The second major issue on the Gemini IX mission—when to rendezvous with the target vehicle—was not so hotly pursued. Planners for *Gemini VI,* considering possible sources of trouble, had concluded that rendezvous should take place no sooner than the fourth orbit. This was a well researched procedure, which Walter Schirra and Stafford had demonstrated in high style. But some engineers in the Apollo Spacecraft Program Office wanted to tamper with success. Rendezvous in the first, or at least by the third, spacecraft revolution would more closely approximate lunar orbit rendezvous.[19] In September 1965, mission planners began working on a tentative M=3 rendezvous (in the third spacecraft orbit) for Gemini IX and X. For the rest of the year, they worked on this new rendezvous scheme.[20]

NASA, Air Force, and industry representatives met in Houston on 20 January 1966 to review the results of these labors. After the spacecraft had separated from the launch vehicle, the first maneuver—"IVAR" for the unwieldly "insertion velocity adjust routine"—would reduce orbital insertion errors. The crew would use the inertial guidance system to raise or lower spacecraft trajectory immediately. At the apogee of the first circuit, the crew would perform a "phase adjust," to establish the proper phase relation between the spacecraft and the Agena. One and a half orbits later came another change, this time a triple play, to correct phase, height, and out-of-plane errors. The final maneuver was to circularize the flight path two and a quarter revolutions after insertion. This would place the spacecraft about 28 kilometers below the target and ready to start firings to catch it. The remaining maneuvers were similar to those required for a fourth-orbit rendezvous.[21]

No one doubted that this sequence would work but some saw no reason for an M=3 at all. Two camps formed. One group insisted that it closely approximated lunar orbit rendezvous; the other maintained that the kinship was so slight that it was not worth doing. The second group also contended that ground tracking and ground computer capabilities for this approach were not as good as they were for rendezvous in the fourth revolution. Schneider believed that the third-circuit concept would be useful to Apollo operations. Mueller agreed with him, and that settled the issue.[22]

The third Gemini IX debate, radar versus optical tracking, grew from a type of rendezvous clearly applicable to Apollo. This matter first came up when several engineers, looking for ways to keep the spacecraft from getting too heavy, wanted to pull the radar out of both Apollo vehicles. The command module lost its radar in February 1965 when the ASPO Configuration Control Board ruled that the astronaut aboard the mother ship could use an optical sight to help rendezvous with the radar-and-flashing-light equipped lunar module. Later that year, with weight reduction becoming even more pressing, the lunar module's radar was the candidate for removal. This meant that during lunar operations—whether on takeoff from the Moon or at any time the two vehicles were apart—rendezvous of the two ships would depend entirely on astronaut eyes, optical sights, flashing lights, and computers. This was too much for the men who had to fly the machines; they did not entirely trust their eyes or the suggested equipment. They wanted the help of electronic radar signals on one vehicle bouncing back from the transponder of the other. At least, they said, the radar should remain on the lunar module.[23]

Stafford and Cernan did agree to include a test on Gemini IX to compare optics and radar by performing a rendezvous from above the target vehicle. In this exercise, the Agena would be over the Sahara Desert, which would simulate the lunar surface, and the crew would try to fly down to it, using both radar and optics.[24]

[19] Vearl N. Huff, interview, Washington, 24 Jan. 1967.

[20] Memo, Mathews to dist., "Mission Planning," GV-66198, 25 Sept. 1965; memo, Mathews to dist., "Mission Planning for Gemini IV through XII," GV-66208, 1 Oct. 1965; Huff interview; memo, Mathews to dist., "Mission Planning for Gemini IX, X, XI, XII," GV-66289, 2 Dec. 1965.

[21] "Abstract of Meeting on Trajectories and Orbits, January 20, 1966," 31 Jan. 1966; "Gemini Rendezvous Summary," MSC Internal Note No. 67-FM-128 (TRW Systems Group No. 05952-H281-R0-00), 1 Nov. 1967, pp. 2-2, B-2 through -5, C-2; W. Bernard Evans and Marvin R. Czarnik, "Summary of Rendezvous Operations," in *Gemini Summary Conference*, NASA SP-138 (Washington, 1967), pp. 10-11; P. W. Malik and G.A. Souris, *Project Gemini: A Technical Summary*, NASA CR-1106 (Langley, Va., 1968), p. 274; memo, Carl R. Huss to MSC Historical Office, Attn: Grimwood, "Comments on draft chapter of Gemini narrative history . . . ," 70-FM-H-29, 3 June 1970; memo, Robert E. Prahl to dist., "Gemini IX Insertion Velocity Adjust Routine (IVAR) Study," 66-FM32-56, 26 April 1966; memo, Ben F. McCreary to Chief, Mission Planning and Analysis Div., "Gemini IX booster recontact study for overspeed insertions requiring IVAR corrections," 66-FM34-25, 20 April 1966; memo, Mathews to dist., "Gemini IX M=3 differential altitude," GV-66434, 23 May 1966; memo, Mathews to Asst. Dirs., Flight Ops. and Flight Crew Ops., "Gemini IX Mission Activities Priorities," GV-66415, 3 May 1966; letter, Mathews to NASA Hq., Attn: Schneider, "Gemini IX Mission Activities Priorities," GV-66416, 3 May 1966.

[22] Note, Schneider to Mueller, 4 Feb. 1966, annotated, "OK if no impact on F.O. [flight operations]. G."

[23] A. L. Brady, "Configuration Control Board No. 4 Minutes, February 3, 1965"; memo, Jackson B. Craven to Chief, Apollo Flight Systems Br., "CSM Rendezvous Radar and LEM Weight Study," 9 Feb. 1965; memo, R. Wayne Young to Chief, Guidance and Navigation (G&N) Contract Engineering Br., "G&N Configuration Control Panel Meeting No. 5," 12 Feb. 1965; memo, Owen E. Maynard to Chief, Instrumentation and Electronic Systems Div. (IESD), "Requirement for VHF ranging capability between CSM and LEM," PS6/65M182, 15 Feb. 1965; memo, Maynard to Chief, IESD, "Maximum acceptable ambiguity for CSM-LEM VHF ranging system," PS6/65M201, 25 Feb. 1965; Cline W. Frasier, "LEM Rendezvous Radar vs. Optical Tracker Study," 16 March 1965; André J. Meyer, Jr., notes on GPO staff meeting, 11 Jan. 1966, p. 1; memo, Robert C. Duncan to Chief, IESD, "Request for support: Evaluation board for LORS [lunar optical rendezvous system]—RR [rendezvous radar] 'Olympics,' " EG4-66-80, 25 Jan. 1966, with enclosure, memo, Wayne Young to Grumman, Attn: Robert S. Mullaney, "Contract NAS 9-1100, Rendezvous Radar Testing," EG4-3-66-70, 25 Jan. 1966; memo, Donald K. Slayton to Chief, Guidance and Control Div., "LORS—RR 'Olympics,'" 1 Feb. 1966; MSC News Release No. 66-38, 2 June 1966; Apollo Spacecraft Program Quarterly Status Report No. 16, for period ending 30 June 1966, p. 53; Quarterly Activity Report for Office of the Assoc. Adm., Manned Space Flight, for period ending 31 July 1966 p. 55.

[24] Stafford, interview, Houston, 3 April 1967; NASA News Release No. 66-97, "Project: Gemini 9," press kit, 4 May 1966, pp. 13-14; "Gemini IX-A Mission Report," p. 2-2; "Gemini Program/Mission Directive," NASA Program Gemini working paper No. 5039, 19 Nov. 1965, Appendix A, "Gemini Missions," p. A-9-2.

More planning for Gemini-9, Hacker, op. cit., pp. 329

Working up the flight plan, with its heavy emphasis on rendezvous and extravehicular activity, began in 1965 and lasted until Gemini IX was launched. By January 1966, three types of rendezvous had been included: third spacecraft orbit, from above the target vehicle, and a very high altitude maneuver to reach an imaginary (or phantom) target. The phantom rendezvous (which depended on the Agena's propulsion system) was soon canceled by the planners, both because they still did not completely trust the target vehicle's engines and because they did not want to expose the crew to too much radiation.[26]

Gemini IX soon picked up a third rendezvous, anyway, one that *Gemini VIII* missed doing—re-rendezvous from an equiperiod orbit. The spacecraft thrusters were used for an upward velocity change to separate it from the target. If the firing were precise and all conditions were right, the spacecraft and Agena would automatically rendezvous at the end of an orbit, because the more elliptical spacecraft orbital path would intersect the circular orbit of the target at the proper point. Theoretically, the closing maneuvers should involve only braking the spacecraft to reachieve stationkeeping (alias re-rendezvous) with the target.

Stafford was beginning to worry about doing three rendezvous; his spacecraft was the last to have the smaller tanks—150 kilograms as opposed to (on Spacecraft 10) 208 kilograms of maneuvering fuel. But the equiperiod rendezvous was designed as a fuel-cheap way to evaluate maneuvers and lighting conditions for a dual rendezvous with a passive target scheduled for Gemini X. And Mathews decided that the lunar module abort rendezvous could remain in the flight plan for Gemini IX, but it would have a lower priority and would be contingent on fuel and time.[27]

So rendezvous was the first major objective on Gemini IX, and preparing for the different types produced its share of headaches. But the second most important activity, extravehicular work with the AMU, was a bigger source of trouble.[28]

[26] "Gemini Program/Mission Directive," Appendix A, Sec. A-9; Ted A. Guillory, Charles L. Stough, and Lt. Charles F. Davis, Jr., "Gemini IX Flight Plan," Final, 18 April 1966; Kenneth A. Young, telephone interview, 19 March 1970; memo, Mathews to dist., "Mission Planning for Agena," GV-66245, 21 Oct. 1965; Meyer notes, 11 Jan. 1966; "Trajectories and Orbits Meeting, January 20, 1965"; memo, Mathews to Asst. Dirs., Flight Ops. and Flight Crew Ops., "Gemini IX Mission Plan and Flight Plan," GV-66380, 24 March 1966.

[27] Evans and Czarnik, "Summary of Rendezvous Operations," pp. 12-14; Malik and Souris, *Gemini Technical Summary*, pp. 288-90; "Gemini IX-A Mission Report," p. 4-17; TWX, Mathews to NASA Hq., Attn: Day, GV-12393, 24 March 1966; TWX, Mathews to McDonnell, Attn: Walter F. Burke, "Contract NAS 9-170, Spacecraft Consumables Loading for Gemini IX," GV-12410, 22 April 1966; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Spacecraft Consumables Loading for Gemini X," GV-12453, 21 June 1966.

Results of Gemini-9, Hacker, op. cit., pp. 332-4

Stafford and Cernan met with no untoward incidents on 3 June. The flight began precisely at 8:39:50 a.m. Stafford watched the instruments more closely than had his predecessors, since he had this new IVAR (insertion error correction) to handle in starting the rendezvous sequence. Six minutes after launch, CapCom Neil Armstrong said, "You are go for IVAR." Seconds later, the command pilot fired the spacecraft thrusters in the chase toward the target vehicle 1060 kilometers ahead.[45]

By the time Stafford and Cernan arrived over the Canary Islands—only 17 minutes after launch—the computers had ground out the figures. Armstrong gave the crew the data for the phase adjustment near the first apogee. At 49 minutes into the flight, the thrusters added 22.7 meters per second to spacecraft speed to raise its perigee from 160 to 232 kilometers. "I felt that one, Tom!" Cernan exclaimed.[46]

During the hour before the triple play—to correct phase, height, and out-of-plane errors—the crew checked systems, went through stowage lists, took off gloves and helmets, and got cameras ready for the rendezvous. To circularize the flight path, at 2:24 hours elapsed flight time Stafford pitched the nose of the spacecraft down 40 degrees and turned it three degrees to the left of its flight path. Fifty-one seconds later, he fired the aft thrusters to add 16.2 meters per second to the vehicle's speed. The orbit now measured 274 by 276 kilometers—22 kilometers below and 201 kilometers behind the target vehicle and closing with it at 38 meters per second.[47]

Over Tananarive, 12 minutes before Stafford had fired the thrusters, the crew got some flickers of a radar contact with their target. A range reading of 240 kilometers between the vehicles showed on the scale. George Towner and the other Westinghouse radar builders were relieved; they had worried about acquisition of a target that would wig, wag, and wobble. The Agena was a stabilized vehicle; the ATDA was not, and its radar reflectivity changed with its continually changing attitude. Within 222 kilometers, however, electronic lockon was relatively good.[48] 120 NM

At 3:20 hours, the crew caught sight of their goal 93 kilometers away. For some time, it flitted in and out of view on an optical sight. At 56 kilometers, it became quite clear and remained visible from then on. As he drew nearer, Stafford reported seeing flashing acquisition lights. Thinking for a moment that the shroud had jettisoned after all, he said, "All right. We're in business." Surely they could not have seen the running lights so clearly if the shroud were still attached. While making minor corrections, he was glad that he could see the little "shiners" so well, because moonlight, streaming through his window, almost blinded him. The Moon soon became an asset, however, as its rays reflected off the ATDA.[49]

Stafford began slowing his spacecraft at 4:06 hours. During the closure period, he peered out the window, trying to see if the shroud was there or not. Then he exclaimed, "Look at that moose!" As the distance dwindled, he knew that he had been indulging in wishful thinking—"The shroud is half open on that thing!" Seconds later, Cernan remarked, "You could almost knock it off!" When the final braking was completed, the two vehicles were only 30 meters apart and in position for stationkeeping. But it did not seem likely that the spacecraft nose could slip into the mouth of the "moose" and dock.[50]

The crew described the shroud in detail and wondered out loud what could be done to salvage the situation. ~~One of Stafford's re-~~

three good lessons were learned from this mistake: (1) simulate processes completely, (2) keep experienced people on the job, and (3) follow written procedures exactly.[53]

Gemini IX-A now began its equiperiod rendezvous. Five hours after launch, Stafford nosed the spacecraft down 90 degrees and fired the forward thrusters for 35 seconds to increase his speed by 6 meters per second. The crew quickly found that the target was disappearing below them. Later, in the darkness, they plotted their position with a sextant and checked the result against a preplanned chart solution. Mission planning had been right; all that was necessary to complete the rendezvous was to slow the spacecraft down. At 6:15 hours, Stafford began a series of four maneuvers to bring the spacecraft back to stationkeeping alongside the target. The second of the three rendezvous exercises was easy.[54]

Less than an hour after *Gemini IX-A* returned to its target (6:36 hours elapsed time), the crew got ready to leave again, for the third planned rendezvous.[55] At 7:15 hours, Stafford fired the aft thrusters to decrease the spacecraft speed by 1.1 meters per second and widen the distance between the two satellites.

Stafford and Cernan could now relax a little. It had been an exhausting day. Still wanting to snap the alligator's jaws off, they chatted with ground controllers about the shroud. Then they checked spacecraft systems, ate, and tried to sleep. Cabin noises and lights made sleeping difficult, however, and they only dozed for 40 minutes or so at a time; their scheduled eight hours of slumber were fitful, at best.[56]

The next day—4 June—Spacecraft 9 led its target by 111 kilometers. That retrograde maneuver (against the direction of the flight path) had lowered the orbit of the spacecraft (it now measured 289 by 296 kilometers) and the target traveled a nearly constant 298 kilometers above the planet. Thus the spacecraft, being nearer Earth, illustrated the paradox of slowing down to go faster, relative to the surface of the world, than the object flying overhead. The stage was set for Stafford and Cernan to do a rendezvous from above; but they first had to accelerate the spacecraft in the direction of the flight path so it would leap to a higher altitude than the target. Automatically, then, the lower flying target would reduce the spacecraft's 110-kilometer lead. To rendezvous, the crew only had to cancel out altitude and velocity vectors that had placed their vehicle above and ahead of its objective.[57]

A phase adjustment at 18:23 hours was followed a little more than 30 minutes later by a height adjustment. Another burst from the thrusters put the spacecraft into an orbit measuring 307 by 309 kilometers. The slant range to the target, which had stretched to 155 kilometers, began to shorten. Within 15 minutes, Stafford reported that the vehicles were only 100 kilometers apart. Forty minutes later, Cernan called out a 37-kilometer mark. At 21:02, the distance was 28.6 kilometers. Stafford pointed the nose of his spacecraft down 19 degrees and yawed it to the left 180 degrees, aiming at the other vehicle, which was still below and behind him.[58]

Over the Atlantic Ocean, then the Sahara Desert, on past the African continent, Stafford and Cernan had trouble spotting the target, but the electronic eye of the radar did not. When they were 37 kilometers away, they had seen the vehicle reflected brightly in the moonlight and, later, in the sunlight. As the Sun rose, however, they lost sight of it completely. The range had closed to less than six kilometers before Stafford saw what looked to him "like a pencil dot on a sheet of paper." Without the radar, he said, they would "have blown that rendezvous." But at 21 hours and 42 minutes after launch, *IX-A* and the target were again side by side. Three types of rendezvous had been completed in less than 24 hours.[59]

At the end of the third rendezvous, the Carnarvon, Australia, flight controller told Cernan that Flight Director Charlesworth wanted the crew to start getting ready for EVA. Stafford had begun to worry about the amount of fuel that would be consumed if he continued stationkeeping with the target. Unless the flight controllers thought Cernan might actually do something about the shroud, the command pilot wanted to get out of the vicinity of the ATDA before the pilot got out of the spacecraft. The crew was also pretty tired. As they approached Houston, Armstrong told Stafford to postpone EVA until the third day and to leave the ATDA. Stafford accelerated the spacecraft by one meter per second and moved away forever from the angry alligator.[60]

To the public, the frustrations of *Gemini IX-A*—the formidable shroud and the fogged faceplate—overshadowed its accomplishments. Flying formation with and examining an unstable body had been a useful experience. Of even more significance were the advanced rendezvous maneuvers, proving that the flight controllers and crews could handle sophisticated rendezvous techniques that might be applicable to Apollo. Had *Gemini IX-A* been *VIII*, the results might have been viewed differently—as just part of the learning process. But docking, a primary objective, had not been achieved; and extravehicular activity had not succeeded in evaluating the maneuvering unit.

(OTSOT pp 332-4)

[45] [Ertel], *Gemini IX-A*; "Gemini IX-A Voice Communications (Air-to-Ground, Ground-to-Air, and On-Board Transcription," McDonnell Control No. C-115803, n.d., pp. 8-10; "Gemini IX A Technical Debriefing," 11 June 1966, pp. 9-11; "Gemini IX-A Mission Report," pp. 4-14, -15; TWX, Mathews to SSD, Attn: Hull, and McDonnell, Attn: Burke, "Gemini IX ATDA Ephemeris Data and GLV Insertion Parameters," GV-12437, 23 May 1966.

[46] "Gemini IX-A Voice," pp. 13, 15, 16; "Gemini IX-A Mission Report," p. 4-15; "Gemini IX A Debriefing," p. 15.

[47] "Gemini IX A Debriefing," pp. 16, 17; "Gemini IX-A Mission Report," pp. 4-15, -16; "Gemini IX-A Voice," pp. 20, 21, 25, 26, 32.

[48] "Gemini IX-A Voice," pp. 28, 29, 30, 32, 33; George Towner, interview, Baltimore, 25 May 1966; "Gemini IX-A Mission Report," p. 7-2.

[49] "Gemini IX-A Mission Report," pp. 7-2, -3; "Gemini IX-A Voice," pp. 37-51; "Gemini IX A Debriefing," pp. 30, 31, 34-37.

[50] "Gemini IX-A Mission Report," p. 4-16; "Gemini IX-A Voice," pp. 55, 56, 57.

[51] "Gemini IX-A Voice," pp. 58-64; Stafford and Cernan interviews.

[52] Schneider, interview, Washington, 23 Jan. 1967; Cernan and Stafford interviews; "Gemini IX-A Voice," pp. 65, 66, 112.

[53] "Gemini IX-A Mission Report," pp. 5-161 through -164; TWX, Mathews to SSD, Attn: Hudson, GV-12356, 10 Feb. 1966; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Augmented Target Docking Adapter," GV-12359, 17 Feb. 1966; memo, Purser to Gilruth and Low, 7 June 1966; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Gemini, Definition of Augmented Target Docking Adapter/Shroud Problems Relative to Gemini IX-A Mission," GP-7579, 9 June 1966; letter, Burke to MSC, Attn: Mathews, "Contract NAS 9-170, Project Gemini, Definition of ATDA Shroud Separation Problem during GT-IX-A," 306-09-244, 20 June 1966; letter, Edward C. Welsh to Mueller, 21 June 1966; letter, Mueller to Welsh, 7 July 1966; memo, Mathews to Chief, Gemini Spacecraft Procurement Sec., "Investigative testing of Augmented Target Docking Adapter shroud release mechanism," GP-62268, 13 July 1966; Scott H. Simpkinson, interview, Houston, 18 Jan. 1967; H. H. Luetjen, interview, Cape Kennedy, Fla., 25 May 1967; memo, Simpkinson to Grimwood, "Orbital Operations Perfected," 14 May 1970, with annotated pages of comment draft attached; Simpkinson, telephone interview, 29 March 1971.

[54] Memo, Bobby K. Culpepper to dist., "Trajectory information for the Gemini IX/ATDA mission," 66-FM6-43, 24 May 1966; memo, Mathews to NASA Hq., Attn; Schneider, "Gemini IX-A Mission Activities Priorities," GV-66437, 26 May 1966; "Gemini IX-A Mission Report," pp. 4-16, -17, 6-12, 7-3, -4, -25, -26; "Gemini IX A Debriefing," pp. 43-56; "Gemini IX-A Voice," pp. 67, 71, 72, 73, 76, 84.

[55] "Gemini IX-A Mission Report," p. 4-16; Paul C. Kramer, Edwin E. Aldrin, and William E. Hayes, "Onboard Operations for Rendezvous," in *Gemini Summary Conference*, pp. 37-38.

[56] "Gemini IX-A Voice," pp. 85, 86, 89, 92, 94-96; "Gemini IX A Debriefing," pp. 57, 61, 62, 63, 64.

[57] [Ertel], *Gemini IX-A*.

[58] "Gemini IX-A Mission Report," pp. 4-18, -19, -32, -33, 6-13, -15, 7-4, -5; "Gemini IX-A Voice," pp. 108, 110, 114, 119, 120, 124, 127-28.

[59] "Gemini IX-A Mission Report," pp. 7-5,

Planning for Gemini-10, Hacker, op. cit. , pp. 342-3

Gemini X, like *VIII* and *IX*, was a complex flight with multiple objectives. Among these was a dual rendezvous involving two Agenas—one launched for the mission, the other a passive target left over from *Gemini VIII*. Using the target's main engine to propel the docked Agena/spacecraft combination to high altitudes had been hotly debated on two previous missions. When the Atlas dropped into the Atlantic Ocean on 17 May 1966, the time for discussion was past. Since neither *Gemini VIII* nor *IX-A* had provided the hoped-for experience of firing the Agena's main engine while it was docked to a spacecraft, a decision had to be made promptly. There were only three flights left in the program. Nor would there be any preliminary, low-level practice first. The next day, Mathews told his staff that Gemini X would dock with Agena 10 and together they would climb to Agena 8.[75]

On 24 January 1966, John Young and Michael Collins were named to fly Gemini X.* When Young first heard about the dual rendezvous plan, he thought, "they must be out of their minds." The astronaut had two worries. Could he slow down the linked vehicles and stop them in time to keep from crashing into the second Agena? *VIII*'s Agena, having run out of electrical power, was dead, with no radar transponder or other apparatus to help in the search. Could he even find the old Agena, using only optical equipment? Young recalled, "We hadn't worked on any of these procedures. The problem with an optical rendezvous is that you can't tell how far away you are from the target. With the kind of velocities we were talking about, you couldn't really tell at certain ranges whether you were opening or closing."[76]

Young also remarked, "We didn't have an EVA program," but that soon changed. Collins would do experiments, retrieve packages from both the spacecraft and the passive target, test a zip gun, and visit an unstabilized vehicle. The backpack was dropped for missions X and XI and replaced by a 15-meter umbilical to supply oxygen and electrical support.[77]

Deciding what to do was only the beginning; how to do it was the bigger challenge. The second part of the double rendezvous (with the passive Agena) was particularly tricky. Agena 8, like all Earth-orbital vehicles, had been precessing above and below the equator on its orbital path. With no help from the dead target possible, the Gemini X Agena and spacecraft would have to be launched at very precise times. Suppose circumstances delayed the launches? It had happened before—more often than not! The mission planners would have to come up with a new set of numbers in a hurry. With events so closely relat-

*Lovell and Aldrin were selected as backup command pilot and pilot, respectively. On 21 March 1966, after the deaths of See and Bassett, they were moved into the backup positions for Gemini IX-A. Bean and Clifton Williams then became the alternate crew for Gemini X.

ed, delay or failure at any point threatened all aims of the flight.

While shaping the Gemini X mission for the dual rendezvous, the planners decided to give the crew some helpful experience in onboard navigation, using optical equipment, charts, and the spacecraft computer. The crew would join its first target in the fourth orbit. Mission sequence was the next consideration. When should the dual rendezvous take place—the second day or the third day? Mission planners eventually decided that the second day should be devoted to experiments, the third to chasing the passive target. This, in itself, appeared to create a conflict of aims; although Agena 10 was needed to carry the spacecraft to the second target, many of the planned experiments could not be performed while the vehicles were docked.

About 50 people kicked this problem around at a trajectories and orbits meeting on 28 April 1966. Obviously, the launch dates would have to be jockeyed to get the best phase relationship between the spacecraft and target for both the dual rendezvous and the experiments.[78]

Even assuming that both launches went as planned, shaping the second rendezvous was an exacting task. The North American Air Defense (NORAD) Command, at Colorado Springs, had kept track of Agena 8's whereabouts ever since it ran out of electrical power. To begin the rendezvous, the docked Gemini X/Agena 10 combination should first go into a large elliptical orbit, 298 kilometers at perigee and 752 kilometers at apogee. After six revolutions to judge phase relationships, Agena 10 would then maneuver down to an approximately 398-kilometer circular orbit near Agena 8's space lane, as reported by NORAD.

The high altitude aspect of the flight raised its usual qualms. Although the Gemini Program Office no longer resisted the use of the big Agena engine while the vehicles were docked, McDonnell did not like the idea of the vehicles passing through so many high orbits, which might affect a safe emergency reentry if the retrorockets did not perform as needed. There was also the South Atlantic radiation zone to be considered. In a trajectories and orbits meeting at the end of June 1966, the maximum acceptable altitude for the dual rendezvous was set at 298 by 1065 kilometers, based on radiation constraints and actual radiation levels measured in 1964. But the decision to use Agena for docked maneuvers had already been made, and any misgivings had to be laid aside. After careful study, the planners concluded that an emergency reentry from an elliptical orbit with a perigee of 298 kilometers could be made even if only three out of the four retrorockets fired. Finally, they plotted the spacecraft's orbital track with great care, to avoid the heavy radiation patches.[79]

With the memory of past flights still fresh—when no one had been sure what target, if any, would be waiting—they made alternate and contingency plans for Gemini X. If the target vehicle for this flight did not reach orbit, the mission would be renamed X-A, and the spacecraft would be launched into a 162- by 385-kilometer orbit to rendezvous with the Agena 8 on the 16th revolution. The alternate plans also covered experiments, extravehicular activity, and systems tests.[80]

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PROJECT GEMINI
TASK MSC/TRW G-11

ORBITAL AND RENDEZVOUS REPORT FOR GEMINI 10
REPORT IX

Prepared by
Mission Design Department
TRW Systems

13 JUNE 1966 [redacted]

Prepared for
MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
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TRW SYSTEMS

4. NOMINAL PLAN

4.1 SUMMARY OF NOMINAL PLAN

The Gemini 10 mission is characterized by the following major events:

a) Lift-off of the Gemini-Atlas-Agena 10 target vehicle at 3:30:30 PM, EST.

b) Lift-off of the Gemini 10 launch vehicle at 5:11:09 PM, EST.

c) Initial rendezvous with the Agena 10 near the fourth spacecraft apogee.

d) Standup EVA during the 15th spacecraft revolution.

e) Dual rendezvous with the Agena 8 passive target vehicle during the 30th spacecraft revolution.

f) Umbilical EVA during portions of 30th and 31st spacecraft revolutions.

g) Retrofire during the 43rd spacecraft revolution to splash down in a west Atlantic recovery area thereby ending the 3 day mission.

Briefly, the maneuvers required of the spacecraft and spacecraft/ Agena 10 docked configuration to accomplish initial and dual rendezvous and perform retrofire orbital adjustment are as follows:

a) A spacecraft height adjustment maneuver (N_H) at first perigee.

b) A spacecraft phase adjustment (N_{C1}) near second apogee.

c) Spacecraft coelliptical maneuver (N_{SR}) near the third apogee point.

d) Terminal phase initiation (TPI) by the spacecraft about three minutes before entering darkness near the end of the third spacecraft revolution.

e) Terminal phase finalization (TPF) which results in a velocity match completing initial rendezvous near the fourth spacecraft apogee.

f) A docked Hohmann transfer maneuver (HOH ′) at the 5th spacecraft perigee to raise apogee to 220 nautical miles. This is the first maneuver to effect dual rendezvous.

g) A docked phase adjustment maneuver (N_{C1}') at the 6th spacecraft apogee which raises perigee to approximately 190 nautical miles.

h) A docked plane change (N_{PC}') maneuver (if required) at the first common node after the 13th spacecraft apogee.

i) A docked height adjustment (N_{H1}') at the 14th spacecraft perigee to lower apogee to about 208 nautical miles.

j) A docked co-elliptical maneuver (N_{SR1}') at the 15th spacecraft apogee to nearly circularize the orbit at 208 nautical miles.

k) Terminal phase initiation (TPI′) by the spacecraft during the 30th revolution to intercept the passive Agena 8 target.

l) Terminal phase finalization (TPF′) about 20 minutes after TPI′ to effect a velocity match and rendezvous with the passive target (spacecraft now in approximately a 215 nautical mile circular orbit).

m) Final height adjustment maneuver by the spacecraft to lower perigee to 143 nautical miles (apogee at 215 nautical miles), in the 20th revolution, in preparation for retrofire.

A schematic diagram of the complete mission can be found on page A-59, Gemini 10 Mission Profile.

4.2 DETAILED DISCUSSION OF MISSION PLAN

4.2.1 Passive Agena Target Orbit

In determining the characteristics of the Agena 8 passive target orbit at the time of Agena 10 insertion those elements which could be propagated over several months time with acceptable accuracy have been predicted (i.e., semi-major axis, eccentricity, inclination, longitude of ascending node) while the other elements which primarily determine initial target phasing (i.e., argument of perigee, mean anomaly) have been assumed for the purpose of developing a representative mission plan.

The prediction of the Agena 8 orbit at the time of Agena 10 insertion was based on digital ephemeris generation routines calibrated with NORAD radar tracking data received from MSC. The in-orbit angular position of the passive target was assumed such that phasing at the time of Agena 10 insertion required the maximum of two first mission day maneuvers by the docked configuration to accomplish dual rendezvous.

The orbital elements of the Agena 8 passive target vehicle at the time of Agena 10 insertion with which the dual rendezvous plan was developed are as follows:

Time of elements	t = 20:39:31 hr:min:sec, GMT
Semi-major axis	a = 22246183.5 feet
Eccentricity	e = 0.0014997875
Inclination	i = 28.86819243 degrees
Argument of perigee	ω_p = 176.7434349 degrees
Inertial ascending node*	ΩA = 150.7829933 degrees
Mean anomaly	M = 2.069301992 degrees
Inertial velocity	V = 25192.49 feet per second
Inertial flight-path angle	γ = 0.003108 degrees
Inertial heading angle	Ψ = 118.863046 degrees
Geocentric latitude	φ_c = 0.570138 degrees
Geodetic latitude	φ_d = 0.573980 degrees
Earth fixed longitude	λ = 19.021186 degrees
Radius	R = 22212839.5 feet
Local altitude above the oblate earth	h = 1287108.0 feet

* - [X-axis referenced through Greenwich meridian at midnight (00:00:00 GMT) prior to launch.]

4.2.2 Gemini-Atlas-Agena Target Vehicle (GAATV) Launch

The GAATV will be launched from Cape Kennedy Launch Complex 14 at 20:30:30 GMT (3:30:30 p.m. EST). This afternoon launch has been selected to take advantage of the opening of the GAATV launch window with respect to the passive Agena 8 target and thereby provide the longest period of dual rendezvous in-plane launch opportunity (about 16 days for 3:30 p.m. to 7:30 a.m. Cape launch time limits for the Agena 10). The GAATV will be launched along an 84.4-degree azimuth east of north and about 9.1 minutes later inserts the GATV into a near-circular 161-nautical mile orbit having an inclination of 28.87 degrees. The precise orbital elements of GATV insertion are shown in Table 4 on page A-6. At this time the Agena 8 target leads the GATV by approximately 80 degrees.

4.2.3 Gemini-Titan Launch

At 22:11:09 GMT (5:11:09 p.m. EST) the Gemini-Titan will be launched from Complex 19 at Cape Kennedy. The Gemini launch vehicle (GLV) launch azimuth is biased from the parallel value of 96.6 degrees to about 98.7 degrees east of north so that a small amount of GLV yaw steering will place the spacecraft in the Agena 10 target plane at the time of initial rendezvous TPF and eliminate the necessity of a plane change. More detailed information may be obtained from the spacecraft launch window plot on page A-65.

Twenty seconds after SECO, at an inertial velocity of 25730 feet per second, the spacecraft will separate from the second stage of the Titan booster by firing the two aft thrusters of the orbital attitude maneuvering system (OAMS). At this time the spacecraft will trail the Agena 10 target vehicle by about 1010 nautical miles (the spacecraft trails the passive Agena 8 at this time by about 5135 nautical miles or 80.5 degrees) and will have acquired an inertial velocity of 25740 feet per second which will result in an elliptical orbit having perigee and apogee of 87 nautical miles and 146 nautical miles, respectively. The Incremental Velocity Adjustment Routine (IVAR) will be used to correct in-plane velocity errors within 5 to 50 feet per second.

Table 4 of the appendix may be consulted for the spacecraft orbital elements at insertion.

4.2.4 Midcourse Initial Rendezvous Maneuvers

Table I on page A-1 lists all of the maneuvers required of the spacecraft and docked spacecraft/Agena 10 configuration for the entire mission.

4.2.4.1 Height Adjustment (N_H)

At 1:35:01 g.e.t. when the spacecraft is at first perigee a small height adjustment maneuver ($N_H = 1.5$) is applied tangentially in a posigrade direction to correct for the effects of orbital decay due to atmospheric drag. This maneuver requires a velocity increment of 0.6 feet per second from the spacecraft. The Agena 10 target leads the spacecraft at this time by about 590 nautical miles which corresponds to a phase angle of 9.4 degrees and the spacecraft catch-up rate is 6.7 degree/orbit.

The precise orbital elements after this maneuver and all subsequent maneuvers may be obtained from Table 4. of the appendix on page A-6. It is also noted that this height adjustment maneuver may be performed at the second spacecraft perigee ($N_H = 2.5$) at the discretion of the Flight Dynamics Officer.

4.2.4.2 Phase Adjustment (N_{C1})

Near the second spacecraft apogee at a ground elapsed time of 2:18:49 the spacecraft performs a phase adjustment maneuver with a posigrade, horizontal velocity increment of 54.7 feet per second ($N_{C1} = 2.0$). The resultant orbit has a perigee and apogee of 116.9 nautical miles and 146.1 nautical miles, respectively which decreases the catch-up rate to 4.4 degrees/orbit thus providing the correct phasing at the third spacecraft apogee (1.7 degrees). The spacecraft trails the GATV at the completion of the phase maneuver by about 385 nautical miles.

4.2.4.3 Coelliptical Maneuver (N_{SR})

At 3:48:09 g.e.t. near the third spacecraft apogee a co-elliptical maneuver will be performed which aligns the line-of-apsides of the spacecraft orbit with that of the Agena 10 orbit whicle producing the desired 15 nautical mile height difference at both apogee and perigee. This maneuver is executed with a slight pitch-up attitude (4.4 degrees) using the spacecraft aft thrusters. The total velocity increment required is 51.2 ft per second of which 51.0 feet per second is applied horizontally in a posigrade direction and 4.0 feet per second is applied vertically upward. The spacecraft trails the Agena 10 target at this time by about 110 nautical miles or 1.7 degrees and is catching up at a rate of 2.3 degrees/orbit and should have on-board radar lock-on.

4.2.5 Terminal Phase Initial Rendezvous Maneuvers

About four minutes after initiating the co-elliptical maneuver the crew will switch the computer to the rendezvous mode and begin terminal phase systems checkout and procedures. Reference 2, "Gemini 10 Flight Plan", should be consulted for detailed crew activities during this period. The crew will be able to monitor the catchup parameters for about 44 minutes prior to initiating the intercept transfer. The catch-up parameters are shown on pages A-71 and A-72.

4.2.5.1 Terminal Phase Initiation (TPI)

The first maneuver of the terminal phase which places the spacecraft on an intercept trajectory is executed at 4:36:18 g.e.t. or 3 minutes before entering darkness near the end of the third spacecraft revolution. The spacecraft is pitched up to 28.0 degrees along the line-of-sight to the target and applies a total of 33.0 feet per second with the aft thrusters to complete the maneuver (ΔV_x = 29.3 feet per second, ΔV_y = -15.4 feet per second, ΔV_z = 0.2 feet per second, platform coordinates). The range to the Agena 10 target at this time is approximately 33 nautical miles.

4.2.5.2 Intermediate Corrections

During the terminal phase the target will nominally travel through a central angle of 130 degrees from terminal phase initiation to terminal phase finalization. Two intermediate corrections are scheduled if required at 12 and 24 minutes after TPI at central angles of 81.8 and 33.6 degrees from the target, respectively.

4.2.5.3 Terminal Phase Finalization (TPF)

The theoretical velocity-matching maneuver to complete rendezvous will require about 44.9 feet per second total velocity, excluding additional requirements due to the final approach being controlled by semi-optical techniques. This maneuver is executed at 5:08:59 g. e. t. when the spacecraft is 7 minutes from daylight.

The propellant budget for the terminal phase maneuvers as well as the other spacecraft maneuvers is shown in Table II (page A-2) of the appendix.

4. 2. 6 Activities Following Initial Rendezvous

After the velocity-matching maneuver the crew will station keep with the Agena until the first docking which should be completed as the spacecraft passes over Hawaii at approximately 6:00:00 g. e. t. The docking will be followed by the required experiments and tests, which are described in Reference 3, preceding the first dual rendezvous maneuver which will be performed approximately two-thirds through the 5th revolution.

4. 2. 7 Dual Rendezvous Midcourse Maneuvers

4. 2. 7. 1 Docked Hohmann Transfer Maneuver (HOH′)

At 7:32:12 g. e. t., in the 5th spacecraft revolution, on the first mission day the crew will initiate the first of the dual rendezvous midcourse maneuvers using the Agena propulsion (PPS) system in the docked configuration. This burn is applied horizontally and posigrade and requires a velocity increment of 102. 6 feet per second. Upon completion of this maneuver the apogee altitude will have been raised to 220 nautical miles and the perigee will remain at 161 nautical miles. It is currently planned to let this first dual rendezvous maneuver also serve as the first docked calibration burn in order to evaluate generally the execution accuracy of the Agena primary propulsion system.

4. 2. 7. 2 Docked Phase Adjustment (N_{C1}')

Approximately one-half revolution after the HOH′, at 8:18:24 g. e. t., a second first mission day docked maneuver will be performed to adjust the catch-up rate of the spacecraft/Agena 10 with respect to the passive Agena 8 target. The resulting rate after the 51. 9 feet per second PPS, horizontal, posigrade burn is 1.5-degree/orbit with the passive Agena 8 leading by 30.4 degrees.

It is noted here that the philosophy inherent in establishing the two first mission day maneuvers (HOH′ and N_{C1}′) is that the docked configuration will not be placed in an orbit having an apogee altitude greater than 220 nautical miles. There is currently under consideration a mission ground rule which would allow the crew to transfer into very high apogee altitude orbits (possibly as high as 400 nautical miles, but with perigee remaining around 161 nautical miles to provide acceptable retrofire conditions). If this rule is accepted it would very probably negate the requirement to do two first mission day maneuvers in order to obtain correct phasing for the initial conditions that have been assumed in this representative mission plan. Figures 6 and 7 of the appendix illustrate the required first mission day maneuvers as a function of initial Agena 8/ Agena 10 phasing for the 220 nautical mile apogee limit and 400 nautical mile apogee limit philosophies, respectively.

4.2.7.3 Docked Plane Change (N_{PC}′)

Beginning at 9 hours into the spacecraft flight the crew will take an 8 hour rest period which ends about 17:00:00 g.e.t. At 19:11:48 g.e.t. there is a docked plane change maneuver scheduled. This maneuver is nominally of zero magnitude but a PPS burn (docked configuration yawed out-of-plane) could be required in the real-time situation due to unintentional lift-off delays or intentional lift-off delays to adjust initial phasing and/or dispersions. Figure 5 on page A-66is a launch window diagram for the GAATV 10, with respect to the passive Agena 8 target, which shows the velocity penalty that is incurred for plane changes resulting from launch time variations of the Atlas.

4.2.7.4 Docked Height Adjustment (N_{H1}′)

At the 14th spacecraft perigee (N = 14.5, 21:21:56 g.e.t.) after a number of undockings, dockings and experiments the crew will perform a SPS burn in the docked mode to lower apogee to approximately 207 nautical miles, the resultant perigee remaining at 190 nautical miles. This maneuver will require a velocity increment of 19.4 feet per second applied in a retrograde, horizontal direction. At this time the Agena 8 passive target leads the docked configuration by about 18.1 degrees (approximately 1145 nautical miles) and the catch-up rate is 2.3-degree/orbit.

4.2.7.5 Docked Coelliptical Maneuver (N_{SR1}')

The last of the docked configuration burns to accomplish dual rendezvous will be performed at 22:07:40 g.e.t. at the 15th spacecraft apogee. This maneuver will align the line-of-apsides of the spacecraft orbit with that of the passive Agena 8 orbit and produce the desired height differential (7 nautical miles) at both apogee and perigee. The maneuver will be executed with the docked vehicle aligned very nearly along the local horizontal (ΔV_x = 29.4 feet per second, ΔV_y = 1.1 feet per second, ΔV_z = 0.0 feet per second) using the Agena SPS to apply a total of 27.5 feet per second in a posigrade direction. The remaining 2.0 feet per second of the required 29.5 feet per second for this maneuver will be applied by the spacecraft to simultaneously effect final separation from the Agena 10. The spacecraft will also apply the necessary radial velocity to effect the coellipticity.

The spacecraft is now closing on the passive Agena 8 at a rate of 1.0 degree/orbit and lags the target by approximately 1080 nautical miles (16.9 degrees).

4.2.8 Dual Rendezvous Corrective Midcourse Maneuvers

Unlike any previous Gemini rendezvous exercise the dual rendezvous of this mission has a large time lapse between the initial co-elliptical maneuver and the initiation of terminal phase (approximately 25 hours or 16 1/2 revolutions). This sequence may be attributed to the two following considerations: The first is a marginal spacecraft fuel budget which makes it desirable to perform the initial co-elliptical maneuver with the Agena propulsion system while still in a docked configuration and secondly a desire to provide a maximum of undocked mission time to facilitate the accomplishment of a majority of the experimental objectives (a large number of the scheduled experiments simply cannot be successfully conducted while in a docked mode).

In order to minimize dispersions in position, velocity and time of arrival at terminal phase initiation the following nominally zero corrective midcourse maneuvers are scheduled to be performed by the spacecraft throughout the period from the initial coelliptical maneuver to TPI′:

Maneuver	Purpose	Time of Maneuver (g. e. t.)	Counter Line No.
N_{C2}'	Phase Adjustment	28:45:00	N = 19.0
N_{H2}'	Height Adjustment	40:15:00	N = 26.5
N_{C3}'	Phase Adjustment	41:00:00	N = 27.0
N_{CC}'	Corrective Combination	45:00:00	N = 30.25
N_{SR2}'	Corrective Co-elliptical	45:30:00	N = 30.5

These maneuvers are scheduled to take advantage of favorable orbit determination update data via the tracking network and to avoid interference with the stand-up EVA (approximately 22:47:00 to 23:50:00 g. e. t.) and the second crew rest period (approximately 31:00:00 to 39:00:00 g. e. t.).

4.2.9 Dual Rendezvous Terminal Phase Maneuvers

The following ground rules and constraints were used in establishing the terminal phase trajectory for dual rendezvous:

a) Spacecraft onboard radar not available for rendezvous with a passive target (Agena 8).

b) The passive target must be visually acquired in order to execute the terminal phase transfer.

c) The passive target will have no acquisition lights (lower intensity running lights may be activated however); therefore, continuous visual tracking requires continuous sunlight illumination.

d) The angle between the line-of-sight to the sun and the line-of-sight to the passive target must be sufficiently large to illuminate the side of the target toward the spacecraft and shield the spacecraft's windows from direct sunlight.

e) The sun should be nearly overhead at terminal phase initiation.

f) The passive target travel angle during terminal phase should be relatively short (ωt = 80 degrees).

g) At terminal phase initiation the spacecraft orbital altitude should be approximately 7 nautical miles below that of the passive target.

h) The rendezvous (velocity match) should occur 5 to 10 minutes prior to sunset on the spacecraft.

4.2.9.1 Terminal Phase Initiation (TPI′)

At 47:07:22 g.e.t. in the 29th spacecraft revolution the crew will apply a velocity increment of 25.1 feet per second with the spacecraft pitched up to 36.2 degrees (V_x = 20.3 feet per second, V_y = -14.8 feet per second, V_z = 0.0 feet per second). This maneuver is executed 28 minutes prior to darkness and places the spacecraft on an intercept trajectory with the passive Agena 8. The resultant orbit after TPI′ has a 208.4 nautical mile perigee and 220.0 nautical mile apogee. At this time the Agena 8 target is leading the spacecraft by 0.2 degrees or about 13 nautical miles. The catch-up rate during the terminal phase as a result of TPI′ will be about 0.2 degree/orbit (.0022 degree/minute).

4.2.9.2 Terminal Phase Finalization (TPF′)

The velocity matching maneuver to complete dual rendezvous will be applied at 47:27:17 g.e.t. in the 30th spacecraft revolution. The spacecraft will be pitched up to 84.8 degrees and the forward thrusters will be used to apply the necessary braking velocity of 42.4 feet per second (V_x = 3.8 feet per second, V_y = 42.2 feet per second, V_z = 0.1 feet per second). The spacecraft will be 7 minutes from darkness at this time and will begin station-keeping with the target in its 214.5 nautical mile perigee, 215.2 nautical mile apogee orbit.

It is anticipated that the optimum propellant requirements (Table II, page A-2) for the terminal phase maneuvers (TPI′ and TPF′) will be exceeded due to the reliance of the crew on optical closing techniques.

4.2.10 Activities Following Dual Rendezvous

Immediately following the velocity match maneuver the crew will continue preparation for the umbilical EVA which will begin about 47:50:00 g.e.t. and end about 48:40:00 g.e.t.

4.2.11 Final Spacecraft Maneuver to Achieve Retrofire Orbit (HOH)

At 51:08:10 g.e.t. in the 32nd spacecraft revolution a final maneuver will be performed to lower perigee to approximately 143 nautical miles (apogee remaining at 215 nautical miles). This will be a retrograde maneuver executed horizontally and will require 125 feet per second from the forward spacecraft thrusters. The purpose of this final maneuver is to place the spacecraft into an acceptable elliptical orbit from retrofire considerations. Lowering of perigee and the resulting 143 nautical mile by 215 nautical mile orbit was selected in lieu of transferring into a 161 nautical mile circular orbit (nominal Gemini design retrofire orbit) in order to conserve spacecraft propellant.

4.2.12 Nominal End-of-Mission Retrofire

The Gemini 10 three day mission will be nominally terminated by retrofire in the 43rd spacecraft revolution at 69:44:05 g.e.t. Splashdown will occur in the 44-1 area of the West Atlantic (28.25°N/75°W) at approximately 70:17:00 g.e.t.

4.2.13 Gemini-Agena-Target Vehicle (GATV) Activities Following Spacecraft Recovery

Following splashdown of the spacecraft at about 71:55:00 g.e.t. a series of Agena 10 maneuvers will be initiated to further evaluate the maneuvering capability of the Agena and to position it in a high orbit for possible use as a passive target on a future Gemini mission. This maneuver sequence will probably consist of four PPS test burns plus a phantom rendezvous exercise. The exact post-splashdown Agena 10 sequence will be defined at a later date.

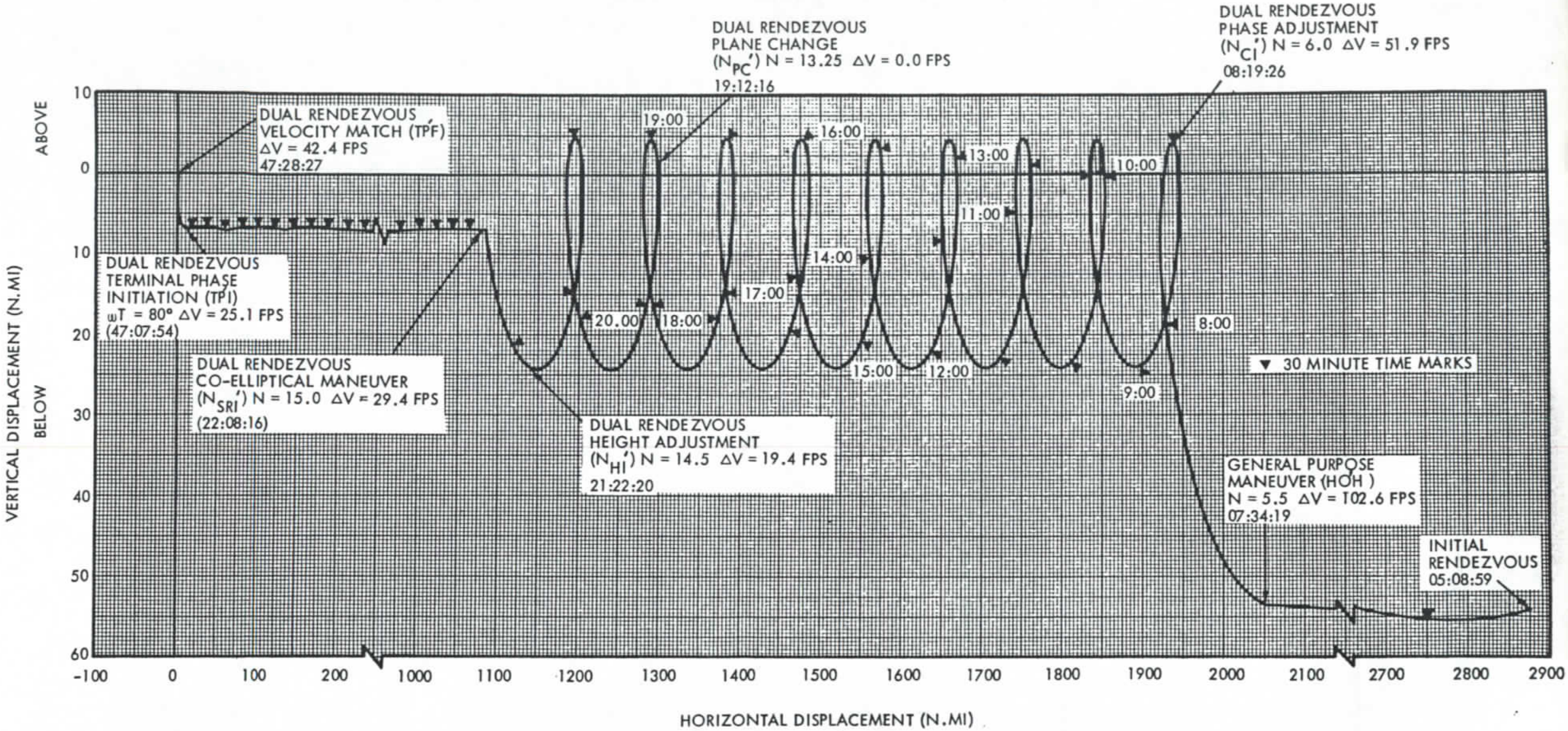

Figure 13. Relative Trajectory of Spacecraft From Initial Rendezvous Through Dual Rendezvous in Passive Target (Agena 8) Curvilinear Coordinate System

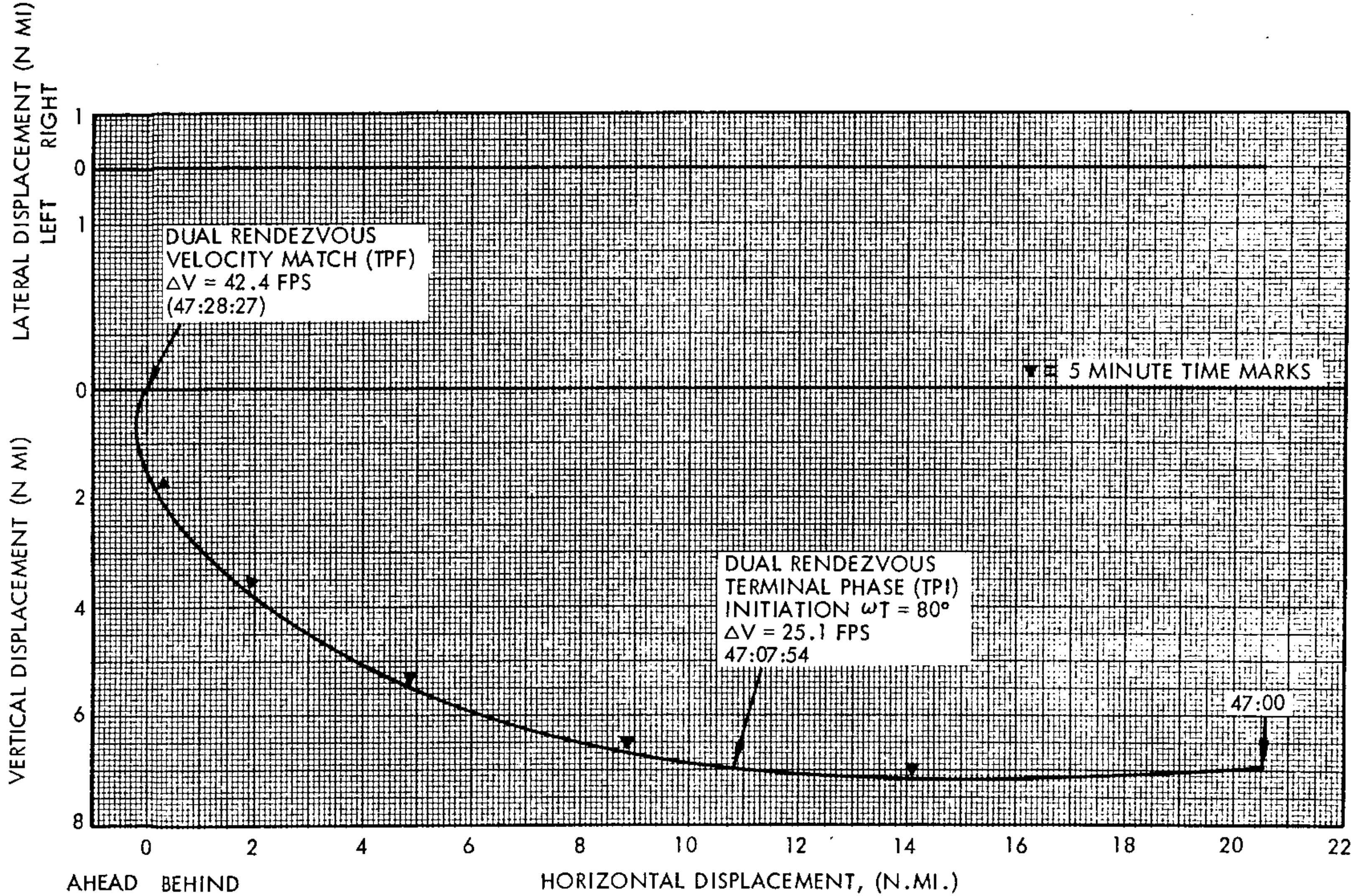

Figure 14. Relative Trajectory of Spacecraft from TPI' to Dual Rendezvous in Passive Target (Agena 8) Curvilinear Coordinate System

Results of Gemini-10, Hacker, <u>op. cit.</u>, pp. 344-351

After the premission review, the traditional meal, and the ritualistic suiting up, Young and Collins left the crew quarters on 18 July 1966 for pad 19—to begin the most complex manned flight so far. They had been awakened at noon for a 5:20 p.m. takeoff, when a 35-second window offered the best chance for rendezvous with the two Agenas. The Atlas lifted its payload toward space at 3:39 p.m., just two seconds late.* One hundred minutes later, the Gemini launch vehicle boosted the spacecraft skyward exactly on time. Except for a slight shaking and a buzzing in their ears, Young and Collins had a nice ride to start chasing their first target.[81]

At entry into orbit, *Gemini X* trailed its Agena by 1800 kilometers. Flight Director Lunney told the crew they were all set for a fourth-orbit rendezvous. Collins unstowed a Kollsman sextant to sight on selected stars for an attempt at optical navigation. Young pointed the spacecraft while his crewmate tried to find the horizon. Collins realized that he was using the wrong reference when he saw stars below the line. He had been mistaking the airglow, a band of radiant light from the upper atmosphere, for the horizon. Even after he corrected this, Collins could not get the lens of the sextant to work properly, as the optical image of the stars did not agree with what he had been taught. He laid the Kollsman aside and tried an Ilon instrument, but that was little help as the Ilon had a severely limited field of view.[82]

Young and Collins checked their figures with Lunney, who had been watching their activities carefully through telemetry. When the trio found that the numbers did not agree with those of the ground computers, Gordon Cooper, the Houston CapCom, passed the word that the crew would have to use the ground computations. Young then fired the thrusters to adjust their orbit to 265 by 272 kilometers. When he aligned the platform for the terminal phase, the command pilot did not realize that the spacecraft was turned slightly. As he thrusted toward the target, Young needed two large midcourse corrections. The spacecraft path toward the Agena was not lined up properly. So he had to stop thrusting briefly and take off on a new tack. The final translational maneuvers to reach the Agena cost nearly 181 kilograms of fuel, or three times more than any earlier mission.[83] Five hours and 52 minutes after launch, Young reported a rigid dock.[84]

Because too much fuel had been used, Lunney decided to omit docking practice—backing away and returning to the target's cone. Young and Collins wondered if the second rendezvous might also be canceled, but, some six and a half hours into the mission, the ground controllers started giving the crew the data they would need for the burn. Then, an hour later, the CapCom at Hawaii cleared them to try for second rendezvous.

The Agena main engine roared into life exactly on time. For 80 seconds, the target vehicle thrust the spacecraft upward, adding 129 meters per second to their speed. The crew, at the moment flying backward, had little to say about their reactions to a negative one-g force (a shove to the front of the body—"eyeballs out"—rather than a push on their backsides—"eyeballs in"—as during launch). They were thrown forward from the seats against the body straps. Young later described the first ride on a space switch engine:

> At first, the sensation I got was that there was a pop [in front of our eyes], then there was a big explosion and a clang. We were thrown forward in the seats. We had our shoulder harnesses fastened. Fire and sparks started coming out of the back end of that rascal. The light was something fierce, and the acceleration was pretty good. The vehicle yawed off—I don't remember whether it was to the right or to the left—but it was the kind of response that the Lockheed people had predicted we would get.... The shutdown on the PPS [primary propulsion system] was just unbelievable. It was a quick jolt ... and the tailoff ... I never saw anything like that before, sparks and fire and smoke and lights.[85]

Gemini X reached an orbit that measured 763 kilometers at the top and 294 kilometers at the bottom. The Agena had pushed the spacecraft more than 463 kilometers above its initial apogee. Young and Collins now viewed Earth from a higher elevation than any human beings ever had. Instead of gazing at the planet in wonderment, however, they confined their attention to their own little, artificial world. They watched spacecraft systems and kept an eye on the radiation dosage readings (which were within tolerable limits). During his technical debriefing, Young only reported, "We took some pictures at apogee.... I don't know where it was, but it shows the curvature of the earth.... We took some pictures coming down hill. I think it was the Red Sea area." Thus, in rating one impression over the other—record high altitude versus Agena ignition—Young and Collins were more affected by the firing of the switch engine than they were by the unique vantage point they had reached. This lack of awe at their record height was caused, at least in part, by the fact that the switch engine blocked much of the downward view.[86]

Nine hours into the flight, the pilots bedded down, sleeping fitfully. Both were still wondering if the second rendezvous would be done. Besides, neither was "really bone-tired," Collins said. Charlesworth's shift in Mission Control was busy that night, reviewing alternate plans for adapting the mission to fulfill its objectives.

When Young and Collins opened for business after 18 hours of flight, their spirits lifted as the CapCom at Carnarvon gave them the numbers for the next target vehicle firing. With the Agena/spacecraft combination faced about so the main engine would fire directly into the flight path, Young made a 78-second burn to reduce the velocity by 105 meters per second and lower the apogee to 382 kilometers. The pilots were again pressed forward in their seats, but this time they were impressed more by the firepower of the Agena than by its fireworks. "It may be only 1 g, but it's the biggest 1 g we ever saw! That thing really lights into you," Young commented.[87]

Like rendezvous maneuvers in the past, the next Agena burn (and the final one with the main engine) aimed at circularizing the orbit. At 22:37 hours, the target drove the spacecraft along the flight path to add 25 meters per second to the speed. This brought the low point of the orbit up to 377.6 kilometers—only 17 kilometers below Agena 8.[88]

(section deleted here on experiments)

Young and Collins awakened to a "morning" of increased activity. In addition to normal systems check, the ground network also reminded them of the experiments expected this day—the S-26 ion wake measurement, to study the ion and electron structure of the spacecraft's wake (after it undocked from the Agena), S-5 synoptic terrain, and S-6 synoptic weather photography. The pilots also had to work in two maneuvers to help them catch up with Agena 8.

Their Agena switch engine had accomplished its task, and more. After being hooked to it for 39 hours, however, they were getting a little tired of looking at it. Young said that watching the Agena out his window was

> just like backing down the railroad [track] in a diesel engine looking at a big boxcar in front of you.... The big drawback of having the Agena up there is that you can't see the outside world. The view out of the window with the Agena on there is just practically zilch.[92]

On freeing themselves from their Agena, the crewmen began preparing for Collins' exit from the spacecraft. Young now needed to make the final maneuvers to get the spacecraft close enough to the Agena 8 for Collins to reach it. Collins connected the 15-meter umbilical to his suit and then fastened it out of the way until time to use it.

"45:38. First sighting of Gemini VIII," Young said. "At this minute it's blurry." After the distance between the two vehicles had been calculated, the Houston CapCom (on the remote line through the Canton station) informed Young, "Your range, Gemini X, is 95 [nautical] miles [176 kilometers]." The crew then learned that what they had been looking at was their own Agena just 5.5 kilometers away. Houston offered consolation, "95 miles is a pretty long range," and Young answered, "You have to have real good eyesight for that." They didn't see the *Gemini VIII* Agena until it was 30 to 37 kilometers from them, looking to Young like "a dim star-like dot until the sun rose above the spacecraft nose." NORAD's constant care had paid off. They found Agena 8 just where it was supposed to be.[93]

At 47:26 hours Young started the final closure, with Collins computing the figures for two midcourse corrections. The crew found the old Agena pretty stable, and Young moved in to stationkeep about 3 meters above it. In less than 30 minutes, he told the Houston CapCom that they were going down for a closer look at the micrometeorite collection package. Back in Mission Control Center, fuel usage during stationkeeping was being very closely watched. When it proved to be reasonable, *Gemini* X received a go for the next extravehicular exercise. "Glad you said that," Young answered, "because Mike's going outside right now."[94]

Collins emerged from the spacecraft at dawn. Like Cernan on *Gemini IX-A*, he found that all tasks took longer than he expected. But he picked off the package from the spacecraft exterior. Next, he moved to the adapter to attach his zip gun to the nitrogen fuel supply. Back in the cockpit area once again, he held on while Young moved the spacecraft to within two meters of the Agena.

Collins pushed off from the spacecraft, floated freely in space, and grasped the outer lip of the docking cone on the target. As he clutched at the experiment package, he wished for handholds—or more hands. Cernan had warned him that it would be hard, and it was. He soon lost his grip on the smooth lip and drifted away from the package and from the Agena. He had to decide quickly whether to pull on the umbilical, coiling about like a snake, or to use the hand-held gun. Being about 5 meters away from the spacecraft, Collins chose the gun. It worked, and he propelled himself first to the spacecraft and then back to the Agena, using a series of squirts to get to the package. This time he clung to wire bundles and struts behind the adapter cone and grasped the S-10 experiment. Collins was supposed to attach a replacement device in its place, but he abandoned this idea, fearing he would lose the one he had picked up. Using the umbilical, he pulled himself hand over hand back to the cockpit and gave the S-10 package to Young.

So far, the umbilical had been snubbed so it would extend only 6 meters. The pilot now unsnapped the buckle that released the remaining 9 meters, intending to evaluate the gun. But the gun play stopped before it started. The Hawaii CapCom told Young, "We don't want you to use any more fuel [for stationkeeping]." Young replied, "Well, then, he'd better get back in." To Collins he said, "Come on back in the house."[95]

Getting back into the spacecraft was surprisingly difficult. Collins had gotten himself tangled in the umbilical. Since the pressurized suit made it difficult to see or feel just where the line had wrapped itself about him, he had to wait while Young helped unwind him and got him back into the seat. But fuel remained the big question. Houston called them, "just ... to confirm that you're not using any fuel." Young replied, "We've got everything shut off."

Gemini IX-A and *X* had successfully grappled with some of the specific needs of the Apollo program, acquiring operational experience while fostering healthy debates between the two programs on procedures and equipment. Perhaps the greatest benefit to Apollo was the demonstration and practice of several types of rendezvous. Each provided a storehouse of information. In addition, the orbit-shaping maneuvers to the higher altitudes established that the trapped-radiation hazards could be avoided on trips into deep space. Then, too, the very fact that one spaceborne vehicle could meet another, latch onto it, and use it as a kind of space tug offered many possibilities for such space flight concepts as shuttles, space stations, and space laboratories.

[75] "Gemini Program/Mission Directive," Appendix A, Sec. 10; Meyer notes, 18 May 1966, p. 1.

[76] Jack Amerine, "Young, Collins Named Crew of Gemini-10," *Houston Chronicle*, 25 Jan. 1966; Jim Maloney, "Young and Collins Gemini 10 Crew," *The Houston Post*, 25 Jan. 1966; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Gemini, Astronaut Fit Check," GP-7513, 5 April 1966; "Gemini and Apollo Crews Selected;" John W. Young, interview, Houston, 8 May 1967.

[77] John Young interview; Meyer, notes on GPO staff meeting, 1 Feb. 1966, p. 2; "Gemini Program/Mission Directive," Change No. 2, 15 Feb. 1966, p. D-10; memo, Mathews to Asst. Dir., Flight Crew Ops., Attn: Chief, Flight Crew Support Div., "Fifty-foot umbilical for Spacecraft 10," GS-64116-A, 25 Feb. 1966; memo, James V. Correale to GPO, "Gemini extra-vehicular life support system," 17 Sept. 1963; "General Requirements for an Engineering Study and Preliminary Design of a One-Man Propulsion Device for the Gemini Program," Exhibit A, "Statement of Work," 19 Sept. 1963; memo, Richard S. Johnston to Mgr., GPO, "Gemini Extravehicular Life Support System Development," 25 March 1964; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Gemini Configuration Control Board Meeting Number 94, 3-12-66," GV-12376, 14 March 1966; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Gemini—Action Items of NASA/McDonnell Management Meeting, 3-23-66," GP-7510, 1 April 1966; Burns et al., "Gemini Extravehicular Activities," pp. 3-12, -13; Bell et al., "Life Support Systems for Extravehicular Activity," pp. 4-88, -89; Johnson, Schultz, and Huber, "Maneuvering Equipment," p. 6-4.

[78] Mathews memo, GV-66208, 1 Oct. 1965; "Abstract of Meeting on Trajectories and Orbits, February 16, 1966," 3 March 1966; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Gemini, Meeting on Gemini X Onboard Rendezvous Procedures," GS-10104, 22 March 1966; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Gemini, Onboard Procedures for Gemini X Primary Rendezvous," GS-10107, 7 April 1966; memo, Mathews to Asst. Dir., Flight Ops., "Gemini X Mission Plan," GV-66389, 7 April 1966; "Abstract of Meeting on Trajectories and Orbits, April 28, 1966," 31 May 1966; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Gemini Configuration Control Board Meeting Number 102, May 9, 1966," 10 May 1966; Meyer notes, 14 June 1966.

[79] "Trajectories and Orbits Meeting, February 16, 1966"; "Trajectories and Orbits Meeting, April 28, 1966"; Howard W. Tindall, Jr., telephone interview, 5 Nov. 1969; TWX, Networks Ops. to W. H. Wood, "GT-8 Agena," 25 March 1966; Mathews memo, GV-66447, 26 May 1966; memo, Mathews to Asst. Dirs., Flight Ops. and Flight Crew Ops., "Gemini X Mission Changes and Priorities," GV-66454, 10 June 1966; Elvin B. Pippert, Jr., J. V. Rivers, and Tommy W. Holloway, "Gemini X Flight Plan," Final, 22 June 1966; TWX, Mathews to SSD, Attn: Gardner and Hull, "Revisions to the Gemini Program Mission Directive for Gemini X," GV-12456, 27 June 1966; memo, Mathews to NASA Hq., Attn: Schneider, "Gemini X Mission Changes and Priorities," GV-66458, 27 June 1966; "Abstract of Meeting on Trajectories and Orbits, June 29 and July 8, 1966," 14 July 1966; Larry D. Davis, telephone interview, 12 Nov. 1969.

[80] Elms, "Interim Report," pp. 5-6; "Abstract of Meeting on Gemini IX Agena Real Time Mission Evaluation Support, April 27, 1966," 6 May 1966; letter, Mathews to NASA Hq., Attn: Schneider, "Contingency Missions for Gemini X, XI, and XII," GV-66461, 23 June 1966; TWX, Mathews to SSD, Attn: Hull, and McDonnell, Attn: Burke, "Pertinent Gemini X Information," GV-12455, 24 June 1966; letter, Schneider to Kraft, 7 July 1966; TWX, Mathews to SSD, Attn: Hull, and McDonnell, Attn: Burke, "Gemini X Alternate Mission," GV-12461, 8 July 1966; Gemini 10 News Center Release No. 10, "Alternate Gemini 10 Plans," 16 July 1966.

[81] NASA News Release No. 66-155, "Gemini 10 Launch Set for July 18," 17 June 1966; TWX, Mathews to SSD, Attn: Hull and Lt. Col. Fountain M. Hutchison, "Flight Safety Review for Gemini Launch Vehicle 10," GP-7613, 12 July 1966; TWX, Mathews to SSD, Attn: Gardner, "Gemini X Atlas-Agena Target Vehicle System Flight Safety Review," GP-7614, 12 July 1966; Gemini 10 News Center Release No. 12, "Status Report," 17 July 1966; [Ivan D. Ertel], *Gemini X: Multiple Rendezvous, EVA Mission*, MSC Fact Sheet No. 291-G (Houston, September 1966); Gemini 10 mission commentary transcript, 18-21 July 1966, tape 3, p. 1, tape 4, p. 1, tape 5, p. 1; "Gemini Program Mission Report, Gemini X," MSC-G-R-66-7, August 1966, pp. 1-1, 4-1; TWX, Kleinknecht to NASA Hq., Attn: Webb, and MSC, Attn: Gilruth, "Launch Summary Report, Gemini X Mission," GT-11215, 19 July 1966; "Gemini X Technical Debriefing," 26 July 1966, pp. 1-12; Michael Collins, interview, Houston, 17 March 1967; Frank Thistle, *Rocketdyne: The First 25 Years . . . .* (Van Nuys, Calif., 1970).

[82] "Gemini X Debriefing," pp. 12-19; "Gemini X Mission Report," pp. 5-14, -15, 7-2, -23, -24; "Gemini X Voice Communications (Air-to-Ground, Air-to-Air and On-Board Transcription)," McDonnell Control No. C-115883, n.d., pp. 10-20, passim; William H. Allen, ed., *Dictionary of Technical Terms for Aerospace Use*, 1st ed., NASA SP-7 (Washington, 1965), p. 9.

[83] "Gemini X Voice," pp. 57, 61-67, 69, 71, 72, 73, 76; "Gemini X Debriefing," pp. 28, 29, 32-41; John Young and Collins interviews; memo, Mathews to Asst. Dir., Flight Ops., "Ground support required for the Gemini X onboard M=4 rendezvous," GS-64121, 19 April 1966; Elms, "Second Interim Report, Gemini Mission Review Board, August 18, 1966," n.d., p. 1; memo, Mathews to Chief, Gemini Spacecraft Procurement Sec., "Contract NAS 9-6408, additional postflight analysis on Gemini X mission," GP-62332, 3 Aug. 1966; Meyer, notes on GPO staff meeting, 18 Aug. 1966, p. 2.

[84] "Gemini X Voice," p. 78; "Gemini X Mission Report," p. 1-2.

[85] "Gemini X Mission Report," pp. 1-2, 4-8, -25, 5-151; "Gemini X Voice," pp. 85, 89, 90, 91, 92; "Gemini X Debriefing," pp. 47, 50; Gemini 10 News Center Release No. 3, "Gemini 10 Flight Controllers," 13 July 1966.

[86] James M. Grimwood and Barton C. Hacker, *Project Gemini Technology and Operations: A Chronology*, NASA SP-4002 (Washington, 1969), pp. 266-67; "Gemini X Voice," pp. 93-99; "Gemini X Debriefing," p. 51; "Gemini X Mission Report," pp. 4-8, -21, -26.

[87] "Gemini X Technical Debriefing," pp. 52-53; "Gemini X Voice," pp. 99-107; "Gemini X Mission Report," pp. 4-8, -25.

[88] "Gemini X Voice," pp. 112, 113; "Gemini X Debriefing," pp. 59, 60; "Gemini X Mission Report," pp. 4-8, -21, -26.

[92] "Gemini X Voice," pp. 183-90, 192, 194, 196-97; "Gemini X Mission Report," pp. 4-8, -21, -26, 6-17, -18, 7-27; "Gemini X Debriefing," pp. 75, 76; Kleinknecht TWX, GT-11217, 20 July 1966, pp. 13-14; "Abstract of Meeting on Gemini Experiment S-26, Ion Wake Measurement, Gemini X and XI, September 13, 1965," 23 Sept. 1965; TWX, Electro-Optical Systems, Inc., to MSC, Attn: James W. Campbell, No. 15, 1 Aug. 1966; David B. Medved, "Experiment S026 (S-26), Ion-Wake Measurement," in "Gemini X Experiments Interim Report," pp. 105-14; Paul D. Lowman, Jr., and Herbert A. Tiedemann, "Experiment S005 (S-5), Synoptic Terrain Photography," ibid., pp. 63-72; Kenneth M. Nagler, "Experiment S006 (S-6), Synoptic Weather Photography," ibid., pp. 73-79.

[93] "Gemini X Mission Report," pp. 1-3, 7-27; "Gemini X Voice," pp. 202, 208-11, 218, 219; "Gemini X Debriefing," pp. 79-81; memo, Mathews to dist., "Mission Planning," GV-66170, 2 Sept. 1965; TWX, Mathews to SSD, Attn: Gardner, "Stability of Non-Powered Agena," GV-12186, 6 Sept. 1965; "Abstract of Meeting on Atlas/Agena Coordination, April 21, 1966," 10 May 1966; Gemini 10 News Center Release No. 13, "NORAD role in Gemini 10," 17 July 1966.

[94] "Gemini X Mission Report," p. 4-9; "Gemini X Voice," pp. 219-34, 236-38; Gemini 10 mission commentary, tape 165, p. 1, tape 167, p. 1, tape 169, p. 3.

[95] "Gemini X Mission Report," pp. 7-32, -33, 8-59, -60; "Gemini X Debriefing," pp. 95-107; Kleinknecht TWX, GT-11216, 19 July 1966, p. 13; "Gemini X Voice," pp. 170, 238-50; Mathews TWX, GV-12376, 14 March 1966; memo, Mathews to Chief, Engineering Div., Attn: Head, Test Systems Sec., "Government-furnished aeronautical equipment 50-foot umbilical support to McDonnell Aircraft Corporation for Gemini X," GP-62088, 22 March 1966; "Abstract of Meeting on Experiment S-10 (Agena Micrometeorite Collector), August 9, 1965," 18 Aug. 1965; TWX, Gilruth to NASA Hq., Attn: Mueller, "T-017 Meteoroid Impact," 8 July 1966; Curtis L. Hemenway, "Experiment S010 (S-10), Agena Micrometeorite Collection," in "Gemini X Experiments Interim Report," pp. 81-95; Burns et al., "Gemini Extravehicular Activities," pp. 3-12, -13; Collins, John Young, and Johnson interviews.

Michael Collins, <u>LIFTOFF</u>, Grove Press, New York, 1988

on accurate measurements but on tight timing as well, and I find myself slipping farther and farther behind as I fill charts and graphs with hastily scribbled numbers. I compare the maneuvers I have calculated that will cause us to overtake our Agena with the ground's solution. The results are quite different and we are forced to use the ground data, much to the chagrin of Magellan, as John has taken to calling me.

Within 4 hours we have made three maneuvers, or "burns," and are 15 miles below our Agena and closing nicely. From now on we are on our own and the ground can no longer help us. At a range of 40 miles when the Agena is 30° above us, we thrust toward it, to establish an intersecting trajectory. Up until this point we have seen it only as a flashing light, but now we can begin to make out its cylindrical shape.

John is flying and I am alternating between peering out the window and reading numbers from our computer. At a mile out, we are closing at 25 mph, which is about right. But then things start to go wrong. We have gotten off to one side somehow and our closing rate has dribbled off to zero. We have to thrust toward the Agena again and now we are swinging around it in a tightening arc. We have done this before in the simulator and we don't like it a bit. "Whoa, whoa, whoa, you bum!" John yells. We call this curlicue maneuver a whifferdill, and it's the biggest fuel waster in the book. When John finally pulls up next to the Agena we have only 36% of our fuel remaining instead of the 60% we expected at this point. It's a gloomy cockpit.

Our spirits are restored somewhat by the docking. John guides our snout easily and gracefully into the Agena's docking collar, latches snap into place, and a motor in the Agena pulls us tightly together until we are "rigidized," in NASA language.

The next thing I know 7 hours have passed and there is a voice in my ear. It's Houston, calling us to get started on Day Three. While we are eating breakfast they outline a test to determine if our eye irritation has been caused by our carbon dioxide absorbent, lithium hydroxide, somehow escaping from its container. During my next EVA I will be operating on a separate oxygen supply fed through a 50-foot umbilical, so I am less concerned about myself than John, who will be hooked up to the same oxygen hoses as yesterday.

I obviously need to see without impediment in order to go over to the Agena and retrieve an experiment package from it. But so must John also be able to see clearly, to fly the Gemini up next to the Agena and keep it there, in precise position while I am scrambling around outside. He will also be essential as a pair of eyes guarding my rear and letting me know if my trailing umbilical cord is in danger of wrapping around the Agena, or getting snagged on it. We pass the lithium hydroxide test with flying colors and that is a relief.

Next we make two small orbit adjustments using our Agena's power and then we separate from it. The Agena is an old friend by now and we hate to see it go, but we also enjoy being free—for the past 40 hours our view has been impeded by the Agena stuck on our nose, and we have gone around the world craning our necks like someone in a caboose trying to see around the locomotive up front.

We are only 8 miles below the Gemini 8 Agena and closing at a slower, more cautious rate than we used to catch our own Agena, in deference to the fact that we have no radar to assist us. We see it for the first time, a tiny speck at which John points our nose. While he tracks it precisely I measure the rate at which our nose's angle above the horizon is increasing. By comparing these actual angles with a chart full of theoretical ones, I am able to calculate when we should depart this orbit and transfer to an intersecting trajectory.

Getting there without wasting fuel is only half the problem; the other half is getting there on time—before sundown, because with no radar to tell us range and range rate, we will surely slide by it in the darkness. This entire scheme has been calculated months before, to make the best use of our 55-minute "day," but it's a tight schedule nonetheless, one that calls for us to reach the Agena just 5 minutes before sundown.

Things look good as we close in. The Agena grows from a dot to a cylinder and with my sextant I can now measure the angle it subtends. By comparing its growth with my clock, I give John estimates of our range and closing speed, but beyond that I can only shout words of encouragement and antiwhifferdill sentiments. John brakes to a halt, smoothly this time, and now we are riding serenely next to the Agena, with our fuel gage reading 15%. Not bad!

GT-X dual rendezvous, including whifferdill & passive target (mission report), MSC-G-R-66-7, Aug 1966 (tech lib microfiche T76-11995)

The notorious "whifferdill" threw the Gemini out of plane and twice around the target. It very nearly caused a propellant redlines breakout call, which would have been the only US orbital rendezvous failure once we thought we knew how to do it.

Study Guide: Note the fairly off-handed way the crew and MCC applied "Kentucky windage" to the various burn solutions they were getting.

Points to Ponder: Identify symptoms of a bad terminal phase trajectory and imagine how they might have given warnings to the crew.

Footnotes to History:

[redacted]

T 76-11995 C.1

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC-G-R-66-7

GEMINI PROGRAM MISSION REPORT

GEMINI X

(U)

CLASSIFICATION CHANGED TO
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BY AUTHORITY OF
EO 11652, GT, 1172
DATE APR 29 1976

GROUP 4
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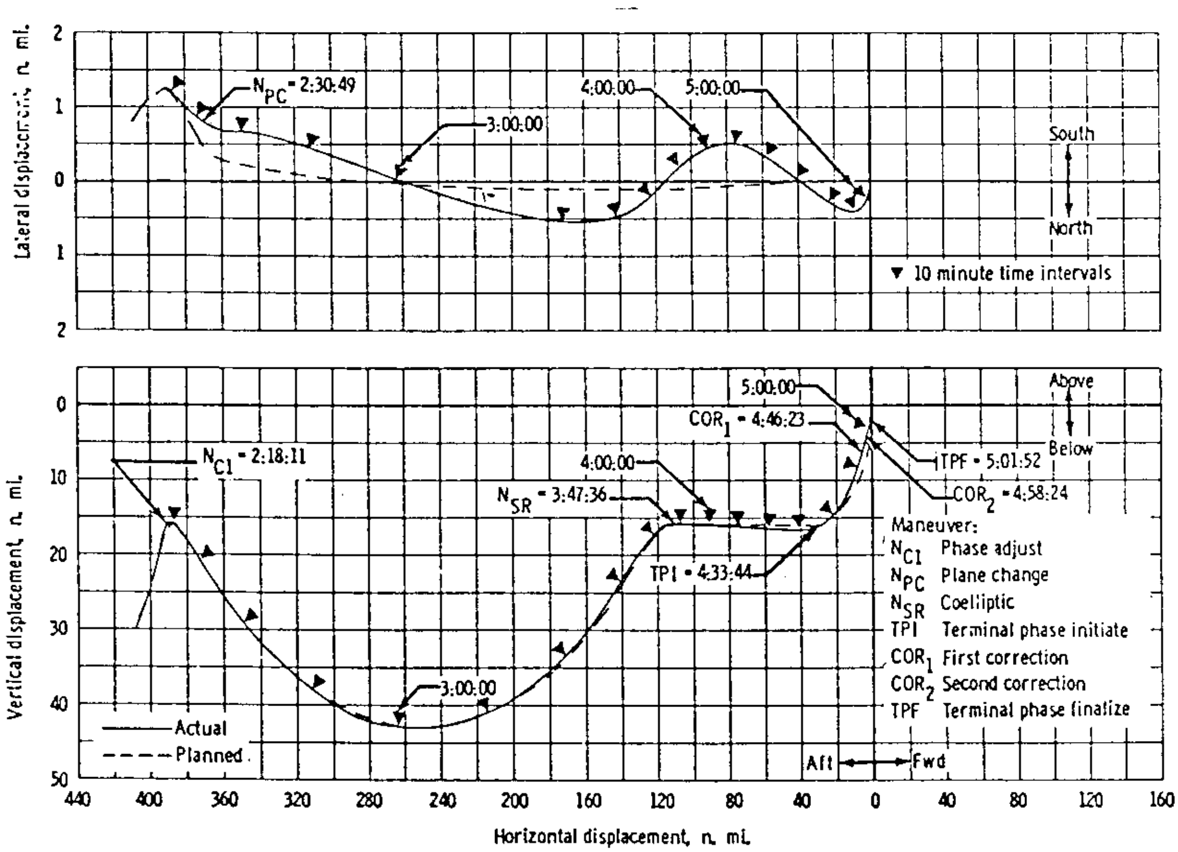
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

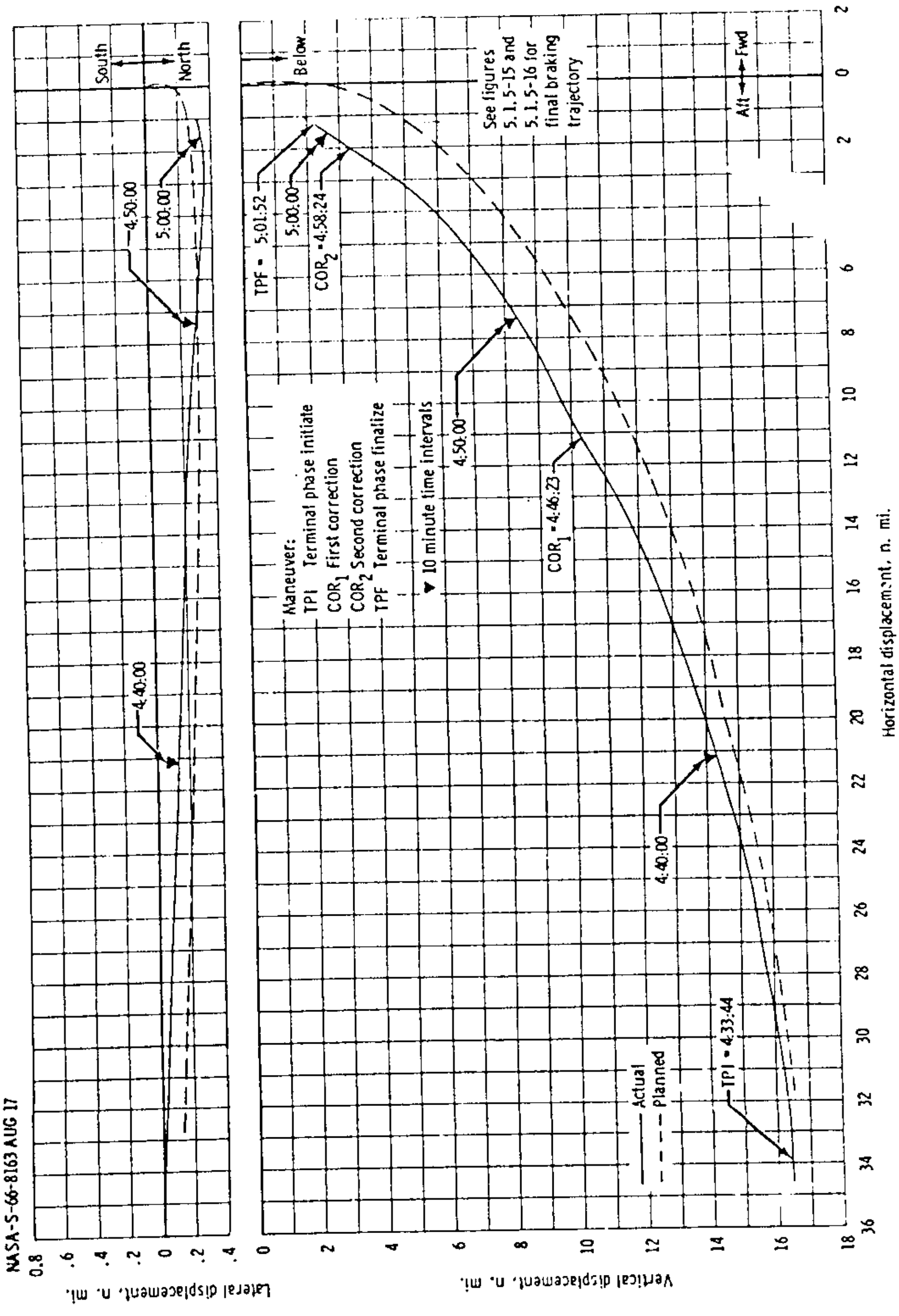
AUGUST 1966

[redacted]



(c) Relative trajectory profile measured from Gemini X GATV to Spacecraft 10 in curvilinear coordinate system.

Figure 4-5. - Continued.



(d) Relative trajectory profile of first rendezvous from TPI to TPF as measured from Gemini X GATV to Spacecraft 10 in curvilinear coordinate system.

Figure 4-5. - Concluded.

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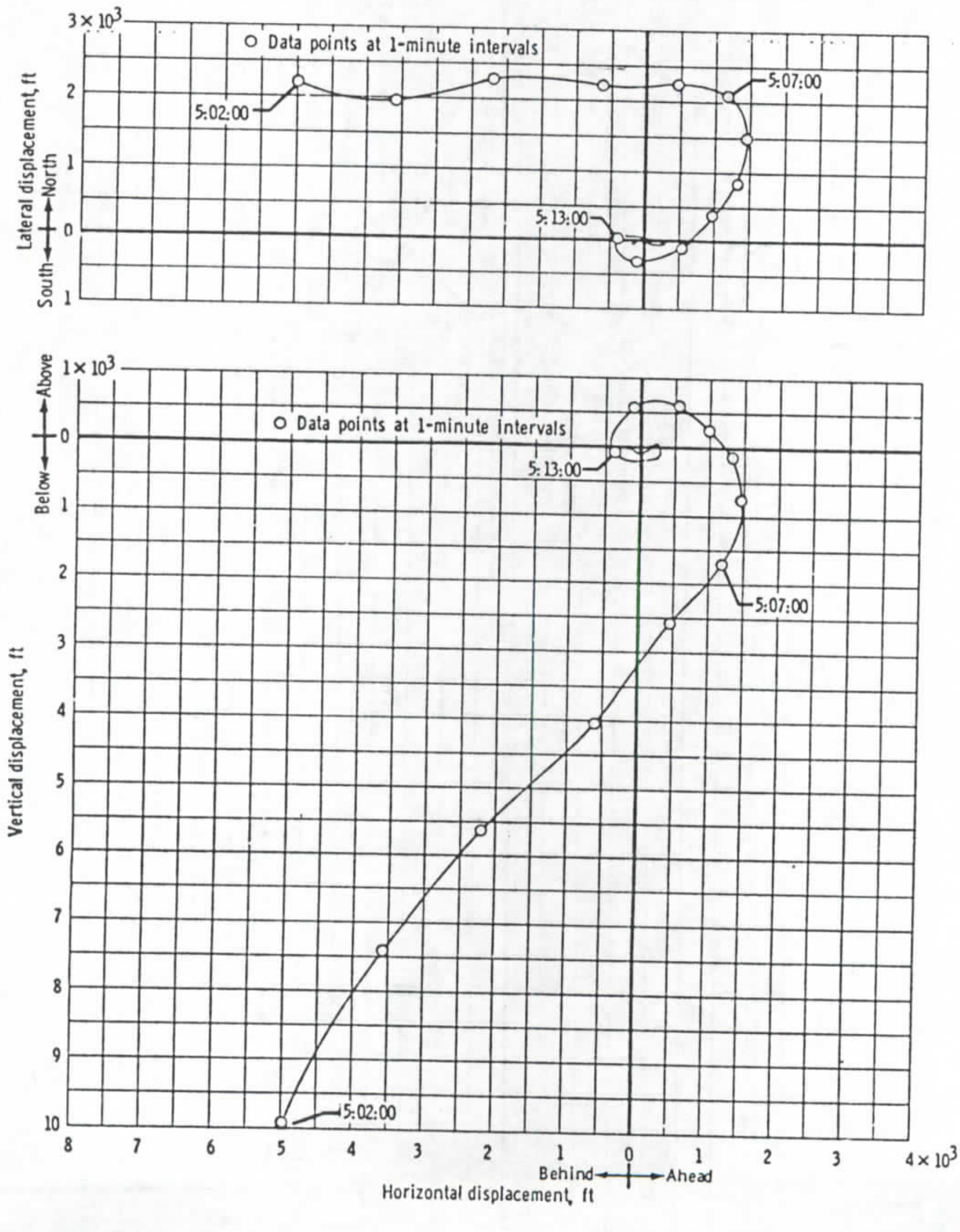

Figure 5.1.5-15. - First rendezvous final approach.

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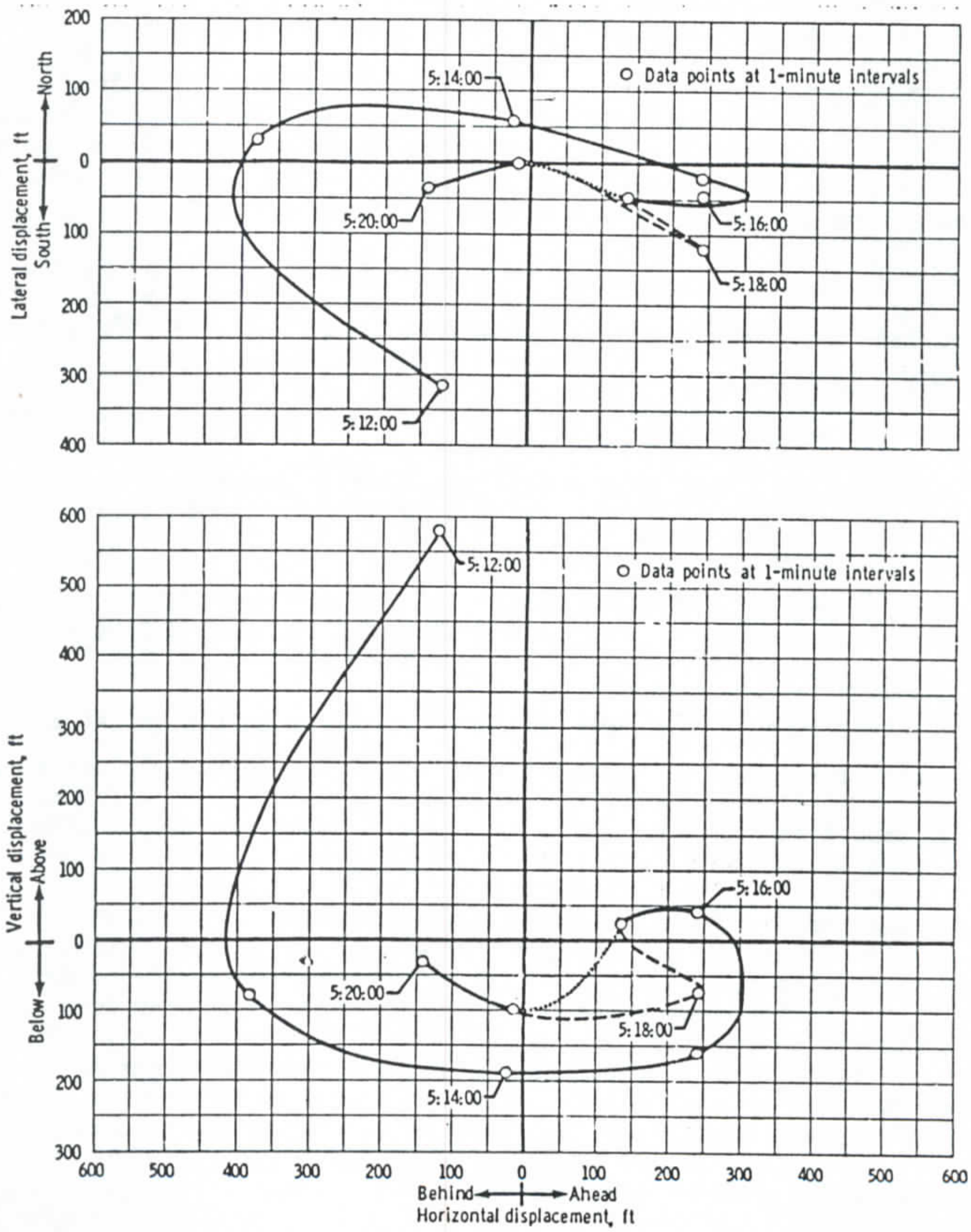

Figure 5.1.5-16. - First rendezvous final approacl. (expanded scale).

Z, relative to the next prediction. They continued to add time and, as a result, actually predicted to the second nodal crossing.

7.1.1.2.4 Orbit-determination-vector translation solutions: After entering the erroneous data obtained during the orbit determination phase on the charts, it was apparent that the solutions were out of tolerance, and the orbit determination effort was suspended. Further elaboration on piloting techniques are discussed in section 7.1.2.

7.1.1.3 First rendezvous.- The first rendezvous was made using the M=4 mission plan which includes two phasing maneuvers, a coelliptic maneuver $\left(N_{SR}\right)$, and terminal phase maneuvers. This section includes only the maneuvers after N_{SR}. The N_{SR} maneuver and all maneuvers prior to that were performed in accordance with ground-computed parameters.

7.1.1.3.1 Terminal phase preparations: Radar lock-on was achieved 41 minutes prior to N_{SR} at a range of 234 nautical miles, and the computer was switched to the rendezvous mode at N_{SR} + 4 minutes. After switching to the rendezvous mode, the computer constants were verified, and ωt (total angle of orbital travel to rendezvous) and other constants were entered.

Platform alignment was initiated at N_{SR} + 10 minutes 40 seconds at an elevation angle of eight degrees, about one degree earlier than planned. The eight data points of angle and ΔR taken during the alignment showed Δh at that time to be near 15 nautical miles. Alignment was terminated about one minute later than planned.

The range and angle data points subsequent to the platform alignment showed that Δh had changed abruptly to 17 nautical miles, indicating a possible guidance system error. The remainder of the data taken prior to the terminal phase initiate maneuver (TPI) confirmed that Δh was staying near 17 nautical miles. Most of the data available to the crew indicated that the rendezvous at this point was very near nominal. Therefore, after applying a correction to the nominal TPI solution of 33 ft/sec forward of +2 ft/sec forward for each mile below the nominal Δh of 15 nautical miles, the crew interpreted this information as requiring 37 ft/sec forward at TPI.

About 14 minutes before sunset, visual contact was made at a range of 48 nautical miles and a pitch angle of 20 degrees. The angle between the sun and the line of sight was approximately 120 degrees. The crew reported that agreement between the radar and the reticle boresight was within half a degree in yaw and virtually on center in pitch.

7.1.1.3.2 Terminal-phase rendezvous maneuvers: Table 7.1.1-I shows the terminal phase maneuvers that were calculated by the ground computer, by the onboard computer, and by the crew with backup charts, and the table also shows the terminal phase maneuvers that were actually applied.

TPI occurred at 4:33:44 ground elapsed time (g.e.t.), about seven minutes before darkness. Because of the general agreement of the onboard computer solution with the backup solution, the fore/aft and up/down components of the onboard computer solution were applied at TPI. The crew believed that the out-of-plane component of the closed-loop solution was in error, as it disagreed with FDAI trends during the coelliptic phase and with the ground solution. Therefore, this component was rejected.

The forward component of the onboard computer TPI solution was confirmed to have been too large by both the first and second backup midcourse solutions and by the first midcourse correction calculated by the onboard computer (ωt = 82 degrees); therefore, the aft component of the onboard computer solution was applied in full for the first midcourse correction. The downward component of the onboard computer solution was weighted by the backup solution because the performance of the guidance system up to that point appeared to the crew to be somewhat erratic. The first correction out-of-plane component from the computer was more representative of the crew's estimate of the approach trajectory than the out-of-plane component at TPI and was small enough to be neglected.

The third backup midcourse correction indicated insufficient down ΔV from the first correction. This was confirmed by both the fourth backup solution and the second onboard computer solution (ωt = 34 degrees). The computer solution was chosen, and, by observing the in-plane target drift after the maneuver, it was determined that the correction was adequate in this axis. The computer out-of-plane solution was applied, but the crew reported it did not significantly reduce the relative motion in that axis. Therefore, it was necessary to apply considerable ΔV to null the out-of-plane drift shortly after the second correction. This resulted in an approach from the side, and a high propellant expenditure was experienced at that time. Rendezvous was reported as being completed at dawn. After the second midcourse correction, the crew reported an unintentional forward velocity input that may have been associated with an interference problem between the translation controller and a pocket on the leg of the command pilot's suit (see section 7.1.2).

7.1.1.4 Second rendezvous.- The coelliptic phase of the second rendezvous began with N_{SR} at 46:09:28 g.e.t. This maneuver fixed Δh at 7.2 nautical miles. Platform alignment was initiated at sunrise which occurred at 47 hours 4 minutes g.e.t. The Gemini VIII GATV was reported visible during the platform alignment at 47 hours 7 minutes, when the sun was below the nose of the spacecraft. As the sun came above the nose of the spacecraft, visibility was lost until after the platform alignment was completed and a 180-degree roll maneuver had been executed. Visibility was reacquired at a sun angle of approximately 28 degrees above the line-of-sight at which time the elevation angle to the target was about 26 degrees.

The TPI maneuver occurred at 47:27:20 g.e.t. at an elevation angle of 32.8 degrees, allowing 33 minutes before sunset to complete the rendezvous. The forward component computed onboard agreed with the ground solution and was applied by thrusting 30 seconds forward because the computer was not started prior to the maneuver. Table 7.1.1-II is a summary of the solutions for the TPI maneuver and the midcourse corrections.

After TPI, the crew reported that visibility improved enough for very accurate tracking. The first and second midcourse corrections were 4 ft/sec up and 1 ft/sec down, respectively, and both were applied. After the second midcourse correction was performed, the in-plane inertial line-of-sight rate was very low and required little correction. A ΔV of 5 ft/sec was applied in nulling the out-of-plane drift. A range estimate with the sextant confirmed that the time at two nautical miles was near nominal, and braking was initiated at a range of 1.5 nautical miles. Difficulty was experienced in optically establishing the proper closing rates required at ranges less than 1000 feet. A considerable amount of time was spent in closing from 1000 to 20 feet. However, station-keeping was initiated with three minutes remaining before darkness.

7.1.1.5 Extravehicular activity.- Two extravehicular operations were performed. The first was a standup EVA, and the second was an umbilical EVA after rendezvous with the passive Gemini VIII GATV.

7.1.1.5.1 Standup EVA: Preparations for the standup EVA were accomplished as practiced. The EVA started at 23:24:00 g.e.t. (sunset) after the spacecraft was depressurized and the hatch was opened without difficulty. The extravehicular pilot performed Experiment S013 (Ultraviolet Astronomical Camera) during the night pass and began Experiment M410 (Color Patch Photography) after sunrise. The crew reported that eye irritation hampered vision to the extent that they could not see to make the required camera f-stop adjustment to complete Experiment M410; consequently, they terminated the EVA six minutes early at 24:13:00 g.e.t. When the EVA was terminated early, the color plate for Experiment M410

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7.1.2.5 Rendezvous.-

7.1.2.5.1 First rendezvous (M=4): Maneuvers conducted prior to the first rendezvous were composed of the IVAR apogee-adjust maneuver and ground-commanded maneuvers for the phase adjust, the plane change, and the coelliptic maneuvers. Performance of these maneuvers was nominal. No problems were encountered in reducing maneuver residuals to an acceptable level. The final phase of the primary rendezvous started with the platform alignment that was accomplished after the coelliptic maneuver. This alignment was continued as the pitch angle changed from 8 to 12 degrees. At a range of 58 nautical miles from the GATV, the radar attitude indicators indicated a 2-1/2 mile out-of-plane error. The assumption was made, based on the ground backup solution, that the platform alignment was faulty. Data taken after the platform alignment showed the total ΔV, with the computer in the rendezvous mode, to be reducing in an orderly and expected manner until about three data points (300 seconds) prior to terminal phase initiate (TPI). Then the total ΔV stopped decreasing at the expected rate. At the point when the computer solution was accepted, the total ΔV was 93 ft/sec. The polar plot (fig. 7.1.2-1) showed the spacecraft to be two miles low. Computation of ΔΔR, the semi-independent calculation based on radar range, showed that the spacecraft was more than one mile low, and the ground also reported that the spacecraft was one mile low.

The terminal phase solutions and the maneuvers applied are shown in table 7.1.1-I. At terminal phase initiate, the closed-loop solution, with the exception of the out-of-plane component, was applied. Correction of the out-of-plane error was to be made with the closed-loop solution during the first midcourse maneuver. The first midcourse correction applied was 15 ft/sec aft and 14 ft/sec down. All the closed-loop down thrust was not applied because of a probable error in the up/down ΔV. The possibility of an error was first noticed during preparations for the coelliptic maneuver, when repeated attempts to enter 6 ft/sec in address 26 resulted in 12 ft/sec in address 26. The range rate, after the application of the second midcourse correction, was excessive. The solutions for the second midcourse correction were as shown in the table, and the down-and-right closed-loop (25 ft/sec down and 5 ft/sec right) was applied. Upon completion of the application of the down-and-right correction, it was noted that a ΔV reading of 22 ft/sec appeared in the aft IVI window. Of this ΔV, 15 ft/sec was due to the down-and-right correction, but it is possible that the other 7 ft/sec resulted from an inadvertent forward-thruster firing caused by a new pressure suit configuration with a full left-thigh pocket and by a cramped leg position. Immediately after application of the second midcourse correction, an additional 13 ft/sec was braked because the range rate was still excessive. Braking was commenced and right-thrust corrections were immediately made to null target drift. When the target was sighted against the star background, there was a large out-of-plane-to-the-right motion of the target across the stars. Continual right thrusting and additional braking corrections were made. The out-of-plane drift proceeded so swiftly that even lagging braking did not null the out-of-plane line-of-sight rate. (Note: Lagging braking consists of moving the spacecraft attitude off the line-of-sight to the target in a direction to take advantage of vertical and/or lateral components of the resultant vector to null line-of-sight errors.) A decision was then made to continue with the same procedure and complete the rendezvous, knowing that a high propellant expenditure would be required. Completion of this rendezvous on time was mandatory in order to continue the flight plan and attempt the dual rendezvous with the Gemini VIII GATV.

The spacecraft passed out-of-plane 700 to 900 feet to the south and above the GATV. The final approach was made from the south, above, and behind the target. From this quadrant, 4 or 5 ft/sec had to be added twice to complete the rendezvous. In the command pilot's mind, there was one significant mistake made in the primary rendezvous, in that excessive energy was applied during the terminal phase initiate maneuver. It is his opinion that if the ΔΔR semi-independent onboard solution or the ground solution had been applied, the problems resulting from the large midcourse corrections would never have occurred. The probable bad platform alignment caused the closed-loop solution and the onboard backup solution at TPI to be almost unacceptable. However, there was no information available to the crew to determine that these maneuvers were less correct than either the ΔΔR solution or the ground backup TPI solution. Clearly, a method of rendezvous which reduces the effect of variations between the several TPI vector solutions is highly desirable. The total rendezvous energy requirement and the significance of variations between TPI solutions would be minimized by a considerable reduction in the normal coelliptic altitude differential. The optical rendezvous discussed in section 7.1.2.5.2 has shown that the lighting constraints on initiation of the terminal phase intercept can be significantly decreased by using smaller differential coelliptic altitudes. Low-energy braking can be readily accomplished in darkness as was demonstrated on the Gemini IX-A mission. It cannot be overemphasized that the maximum probability of a rendezvous with low fuel consumption is best established by the correct terminal phase initiate maneuver.

7.1.2.5.2 Second rendezvous: On the third day of the mission, a platform alignment was started as sunrise occurred on the Gemini VIII GATV, the second target vehicle for the dual rendezvous. During this alignment, it was possible to see the target for the first time as a dim star-like dot until the sun rose above the spacecraft nose. Platform alignment was completed approximately 11 minutes after target sunrise. The spacecraft was then inverted and was pitched up to the expected pitch sighting angle of about 20 degrees; however, because of earthshine streaming into the window (and sunshine when the nose was rolled slightly in either direction), the target could not be seen. From 15 minutes to 18 minutes after sunrise, the target was seen intermittently as a point light source at an estimated range of 20 to 16 miles. Thereafter the target was seen continuously.

The terminal phase initiate maneuver was applied 22 minutes and 40 seconds after spacecraft sunrise, with ΔV's of 25 ft/sec forward and 1 ft/sec up. The ground backup initiation time for the TPI maneuver was 23 minutes and 17 seconds after sunrise on the spacecraft, and the associated ΔV's were 24.9 ft/sec forward, 1.1 ft/sec up, and 3.3 ft/sec left. Target tracking was accomplished by continuously scanning between the Gemini VIII GATV and the spacecraft Flight Director Attitude Indicator (FDAI) to establish zero roll and to null spacecraft rates. The change in light intensity from the bright outside illumination to the relatively dim attitude indicator in the cockpit was fatiguing to the eyes, making the tracking task extremely difficult. Accurate tracking was required for the pilot to compute the midcourse corrections—4 ft/sec down (first midcourse) and 1 ft/sec up (second midcourse). After the second midcourse correction, a 3 ft/sec left thrust was applied and the inertial needles were selected. The inertial needles were perfectly nulled (indicating zero inertial line-of-sight rates) from completion of the second midcourse correction until the spacecraft was well inside the ground-supplied arrival time for a 2-mile range (16 minutes and 16 seconds after the initiation of the transfer maneuver). At an estimated range of 1 1/2 miles, the closing velocity was arbitrarily reduced by 20 ft/sec. Left thrust of 3 to 5 ft/sec was also added. Inside an estimated range of one mile, the closing velocity was arbitrarily reduced by an additional 10 ft/sec. It then appeared to both crewmen that closure was slowed considerably. Therefore, the closing velocity was increased by 5 ft/sec. The spacecraft passed close to the GATV while braking velocity was being applied. Braking with the forward-firing thrusters was continued. The target was kept in sight and braking was converted to the vertical and lateral thrusters. Braking was completed using the aft thrusters. Closure was made to within 100 feet of the target approximately 30 minutes and 30 seconds after the transfer maneuver was initiated.

Both the inability of the crew to establish satisfactory range and range rates by using the onboard sextant and the difficulty encountered in tracking by continuously looking outside and inside the cockpit should not be minimized. It was estimated that the sextant readings provided useful ranges to the crew when the spacecraft was within a range of one mile. At that time, however, it was too late to perform the braking schedule with a reasonable propellant consumption. The second rendezvous required that station keeping with the Gemini VIII GATV be achieved before sunset. Therefore, in order to assure the completion of rendezvous, the range rate was purposely maintained relatively high. With this high range rate, the transfer from inertial line-of-sight nulling to station keeping at the last possible moment required the use of additional propellant to avoid over-controlling in the close vicinity of the GATV.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEMINI X
TECHNICAL DEBRIEFING

July 26, 1966

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

[redacted]

That's what I did anyway.

Collins: Okay the third correction was, of course, backup solution only 7 aft, and 10 down, and we applied none of that. The fourth correction was 1 forward, 25 down, and as this is a closed-loop solution, and 5 right, and my backup was 3 aft, and 14 down. And we applied 0 fore-aft, 25 down, and 5 right.

Young: And this didn't leave us set up very good. Another thing that happened on that particular burn which I certainly don't understand was that the 25 down ended up coupling into 24 aft.

Collins: Yes. When we finished making the 25 down burn we had 24 aft.

Young: I don't understand that either.

Collins: I don't understand that. You didn't burn out the 24 aft, did you?

Young: Yes, I started braking shortly thereafter, but - that was a bad - the only thing I can think of that might have caused some of it, (and I hope the dickens it certainly wasn't, but we'd have to look at the traces to see whether the thrusters were firing or not) was the fact that I was cramped up in the seat, and I couldn't spread out my knees; I had a pocket on my pants that might have been forcing my hand up when I was putting in forward thrust and down thrust at the same time. That is the only thing I can think of. I had that big fat pocket and I might have been doing that. If that was, we are really in a bad way, I don't think so, but it could be. If it was it really would have fixed our wagon. It almost did. Okay, at that time I asked for inertial needles.

Collins That is right after the last closed-loop solution, we put in 99, 90002, and the needles took. I put those inertial needles in a total of three times.

Young I was going to give the system a good checkout. And here is my last error in judgment; I put in the inertial needles and I was checking them against the radar needles and out the window, a motion of the target and I decided that I would leave the cotton-picking range rate up high, to take a look at the braking schedule on the dual. I decided this before lift-off, but it was an error in judgment, I think. I know there was target motion against the stars, the moment I looked at it, so the last maneuver hadn't set me up well at all, to hit the thing.

FCSD REP Out of plane mostly, was it?

Young Yes, it was mostly out of plane. And I had an out-of-plane Whifferdill going on me. I started thrusting out of plane the moment that I looked up and saw the target and kept right on thrusting and we did a great huge Whifferdill. What I should have done was brake that scn-of-a-gun on down, and not worried about the dual Rendezvous. I think it is an error to try to do more than one thing at a time; you've got to worry about one Rednezvous at a time. I think I made at least three errors in judgment on that Rendezvous. The first one was inability to distinguish between a correct closed-loop solution and a poor one. And the correct one was probably 37 feet a second forward, and no left-right, and no up-down. The second one was not applying all the first correction due to the fact that I suspected the up-down windows from that crazy thing that we got out on the N_{SR} up-down. The third one was not braking that thing down, because I decided to look at the dual braking schedule. And with all that out of plane, I just couldn't hack it.

Collins I don't believe it would have helped you to brake early.

Young Yes, it would. I could have gotten on the inside of it instead of coming back on it.

Collins I think there is something screwy with this out of plane. Look at this thing. The first closed-loop solution says 16 left, and you applied zero left, and then the first correction and the second correction are both to the right, closed-loop. That didn't make any sense. Does it?

Young No.

Collins See you applied zero left....

Young Yes, we applied the last right correction, but that didn't stop the out of plane.

Collins All right the, how could the closed-loop ask for 16 left, and you give it nothing, and the have its first and second correction be 1 right and 5 right? I don't understand that part.

Young That is where you are on the nose all right, but I don't think 16 left would have got it. Because if we had put in 16 left we really would have had a right out of plane. It was going like this, and even if it had been coming back like this and going like that, there is no way it could do a whole node from 35 miles on in.

Collins That is right. You can only do a small fraction of a node.

Young That is right, the first solution was just flat wrong, and I knew that because the target was on this side of the ball. Assuming the ball was right, the target was continuously on the right side of the ball, the whole way. And if I had applied the first one left, we would really have had the lick. So, I didn't do that. I only applied half that first up-down because of that funny at N_{SR}, where we got twice as much up-down as the thing really put in there.

REP Did you say there was a 37 in there some where, where was that?

Collins No, he guessed that is what it should have been based on how low we were.

Young Yes, sure, that is what we should have applied. Two miles low and we got 41. If we had applied that 37 I bet we would have sailed in there like gangbusters. I guess you learn by experience, but that's sure a hard rock. And then not to brake it down, that was just dumb because I really had an out of plane going for me by the time I looked out the window. I did the last burn which was a pretty long burn, 25 down, so I was looking in the cockpit for a long time. It pretty well faded the up-down correction.

Collins We went by on the left, didn't we?

Young The Whifferdill was an out-of-plane Whifferdill at about 800 feet out, and then we came on back in and got it, at the cost of a lot of gas. The closed-loop was not correcting right for the out of plane. And where we got all the out of plane from I don't know either. We really had some motion here. I was thinking maybe when I took out this aft I didn't apply it properly. Another thing that happened there that I don't understand was the second closed-loop correction, which was 25 down; when I got through thrusting that 25 down, I had 24 aft.

Collins In the window, I don't understand that either.

Young Then I took that out, and so there I was in the cockpit another long time, and by the time I looked out of the darn cockpit the cotton-picking target is going out to the right like a bat out of hell. The only thing I can think of that might cause that is that I had unstrapped before to stow everything, and I had a pocket on my suit I might have been pushing down on it so that the position of that thing in floating up might have put us on

[redacted]

forward thrust or something, but I don't think so. I really don't. If so, it was really a screw-up. Anyway, then we finally got in there and rendezvoused with it and it was right at dawn when we finally got up close enough to see what the heck was going on.

Collins: Yes, all this was in the dark, too.

Young: Yes, well, we were getting there a little early. I had a heck of a time getting stopped on that son-of-a-gun, but it didn't take a lot of gas to do it once we got in there. And I think that accounts for the fuel expenditure.

Collins: Well, I think maybe it does too, except I am not at all convinced there is not a fuel quantity error in this sytem just because of what happened very late in the flight.

Young: It wasn't much of one because the rate pressure was down so low it couldn't be very much.

Collins: Yes, but we had at least 50 feet per second Delta V after they computed we ran out. We used 50 feet per second after they computed we ran out and we still had some left when we separated. So that is a sizeable amount of gas.

Young: I don't know if we used that much.

Collins: Well, they will have to see. Well, we used 25 feet per second in that 100 foot per second retrograde burn, more than they calculated we were going to use. Remember they said we were going to run out of the main tank at 75 feet per second.

[redacted]

Young We stayed in PLATFORM for two orbits and that PLATFORM was just going like gangbusters the whole time.

Collins That is right and we separated with a reg pressure of 670 or 700 or something like that. I am not sure what it was.

Young And it was still there when we...

Collins That is right, the last time we saw the adapter we had around 700 pounds of source pressure.

Young Doing those kind of corrections you are not going to get in there cheap, and doing that kind of Whifferdill is going to cost you. There is no doubt about it because I had to thrust to do it, and they are just errors in judgment. I didn't understand the closed-loop solution, that is for sure.

Collins I don't think the closed-loop solution was right, do you?

Young Not for the out-of-plane, it wasn't, which was the problem right there. It sure wasn't.

Collins Well, even for forward.

Young It wasn't right for the forward either, but - In retrospect, what I should have done is null it against the stars and the heck with all the braking schedules. Just go ahead and get on in there. I probably would have saved a hundred pounds. But I really had to check those inertial needles because nobody had ever checked them before as near as I could tell. I didn't have any confidence that they were going to work right and knew dang well the needles wouldn't do it.

I was using the inertial needles instead of the stars. They were working, I just wasn't applying enough thrust. I applied all I had. I just wasn't getting there. I wish I would have applied a 37 forwa d. That was a big mistake right there. Four lousy feet a second could have saved the whole ball game I am sure. It would have cost some gas because we were low, probably 120 to 130 pounds. I was so confident that I could do this on inertial needles and demonstrate this dual braking schedule.

Collins To continue, the Agena lights worked normally. The Agena commands all worked normally. (As soon as we got in the dark I could see the Agena.)

Young I compared the position of the Agena with the position of the boresight on the target and in pitch, the radar needles were perfect with the optical sight and in yaw, when the radar needles were centered, the Agena was one-half degree to the right. I think that is outstanding.

Collins I started taking pictures of the Agena with the Hasselblad and with the 16mm as we were coming in. We should have some good Agena pictures.

Young We alined the platform BEF.

Collins Yes, BEF, I think.

Young It was a BEF platform alinement and just a piece of cake flying that rascal. In fact, formation flying is just like in an

[redacted]

airplane. It doesn't take any gas and it doesn't take any work either. Up to this time we had been out to the side of it BEF and hadn't taken a look at the Status Display Panel. So, but that time it was time to go in and dock and we took a look at the Status Display Panel. Something I would like to say about this whole time was that a couple of times, that son- of-a-gun got in the sunlight and I couldn't see it. Just lost it.

Collins When was this?

Young When we were flying formation on the Agena.

Collins First time, huh.

Young Yes, when that sun came up.

Collins Oh, yes, I remember. I could see it one time and you couldn't, and I was telling you where it was.

Young Yes. I wasn't very far away from it, maybe 10 feet or so.

Collins It was over on my side.

Young Although we weren't closing on it at any great rate it was just uncomfortable. Man, the sun really bounces off that son-of-a-gun, you know. It really gets to you. The Status Display Panel, we did that, and then went on in and docked.

Collins Went on in and docked; it was a nice docking.

Young That son-of-a-gun just went --(slurping sound). I don't know how they will transmit that, but it really grabs a hold of you and just pulls you right in there. Looked like it knew what

[redacted]

Planning Gemini-11,
Hacker, op. cit.,
pp. 353, 354, 355

Some significant goals had been set for the last two flights. For example, the Apollo Spacecraft Program Office successfully pushed for a rendezvous in the first spacecraft revolution, which would simulate lunar orbit rendezvous. There was also interest in linking an Agena to a spacecraft by a tether and then spinning the combination to produce something like artificial gravity. One short-lived proposal, a rendezvous between Gemini XII and an Apollo spacecraft, was squelched after review by both program offices. Another idea, a flyby or rendezvous of a Gemini spacecraft with an Orbiting Astronomical Laboratory, also came to nothing. And, finally, on the last mission the Air Force still hoped to fly the Astronaut Maneuvering Unit (AMU), a task that Eugene Cernan had been forced to abandon on *Gemini IX-A*[3]

On 21 March 1966, Charles Conrad and Richard Gordon were named as command pilot and pilot for Gemini XI. Neil Armstrong and William A. Anders were picked as alternates. James Lovell and Edwin Aldrin were announced as the Gemini XII crew on 17 June, with Gordon Cooper and Cernan as backups. Of the eight men, only Anders had not previously been assigned to Gemini.

Another unique objective for XI, direct (first orbit) rendezvous, had been suggested before Gemini flights began. Proposed by Richard R. Carley of GPO, the idea had been put aside when interest had focused on a concentric, fourth-orbit plan. Carley's proposal revived when the Apollo office insisted on a closer simulation of lunar orbit rendezvous. With some signs of reluctance, GPO asked McDonnell to study the maneuver. The first meeting to phrase plans and ground rules for the study revealed some foot-dragging; its results included a curious stipulation: "There should be no artificial restrictions in the plan to make the mission simulate Apollo operations or to simulate lunar rendezvous conditions."[7] That position was soon reversed as Apollo interests prevailed. The first change in the flight plan to include direct rendezvous made any launch delay a reason for shifting the mission to "a modified M = 3 [rendezvous in the third orbit] plan," but the following version "recycled [the launch] to the next direct rendezvous launch opportunity."[8]

The Gemini Mission Review Board reviewed all these new activities in depth, especially the first-orbit rendezvous, which might be a heavy fuel user.[14] Young and Collins had expended so much fuel in the *Gemini X* rendezvous that the board was dubious about trying a first-orbit linkup, largely computed onboard, with an Agena target. But Flight Director Glynn Lunney assured the group that Mission Control could give the crew backup data on orbital insertion and on the accuracy of their first maneuver; the network would have plenty of information to help them begin the terminal phase of rendezvous. The board concluded that if the rendezvous used only half the fuel supply, about 187 kilograms, there would be ample for the rest of the mission. Some skeptics remained; William Schneider, Deputy Director for Mission Operations, bet board chairman James Elms a dollar that it could not be done that economically.[15]

[3] Memo, Mathews to dist., "Establishment of a Committee for Apollo/Gemini Mission Planning Coordination," GV-02466, 18 Jan. 1965; memo, Mathews to dist., "Mission Planning Gemini XI and XII (Onboard Direct Rendezvous)," GV-66300, 27 Dec. 1965, with enclosure, "Ground Rules for McDonnell Aircraft Company [*sic*] Onboard Direct Rendezvous Study," Ref. ECP 659, n.d.; memo, Mathews to dist., "Mission Planning Gemini VIII through XII (Tethered Vehicle Studies)," GV-66296, 16 Dec. 1965; Meyer, notes on GPO staff meeting, 25 Jan. 1966, p. 1; "Abstract of Meetings on Trajectories and Orbits, June 29 and July 8, 1966," 14 July 1966; Lee, "Minutes of Senior Staff Meeting, April 15, 1966," p. 3; memo, Mathews to dist., "Gemini XII," GV-66284, 2 Dec. 1965; Meyer, notes on GPO staff meeting, 11 Jan. 1966, p. 1; memo, John A. Edwards to Assoc. Adm., Manned Space Flight, "OAO-A1/Gemini XII," 2 Sept. 1966; letter, Maj. Gen. Ben I. Funk to Robert R. Gilruth, 12 July 1966.

[7] Memo, Christopher C. Kraft, Jr., to dist., "Second meeting of Mission Planning Coordination Group," 22 Oct. 1963; Raymond L. Zavasky, recorder, "Minutes of Senior Staff Meeting, June 12, 1964," p. 3; TWX, Mathews to SSD, Attn: Col. Richard C. Dineen, "Direct Ascent Rendezvous Guidance for Gemini," GP-51690, 12 Feb. 1965; memo, Mathews to dist., "Mission Planning for Gemini IX, X, XI, XII," GV-66289, 2 Dec. 1965; Mathews memo, GV-66300, 27 Dec. 1965; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Gemini, Development of Gemini Computer Math Flows," GS-10090, 5 Jan. 1966; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Gemini, Initial Conditioning for First Apogee Rendezvous Analyses," GS-10095, 2 Feb. 1966; TWX, Mathews to SSD, Attn: Dineen, "Mission Planning Information," GV-12386, 16 March 1966; "Abstract of Meeting on Trajectories and Orbits, April 19, 1966," 6 May 1966; Wyendell B. Evans, telephone interview, 20 Aug. 1973.

[8] Mathews memos, GV-66289, 2 Dec. 1965, and GV-66300, 27 Dec. 1965; Meyer notes, 25 Jan. 1966, p. 1; "Gemini Program/Mission Directive," p. A-11-1, Change 1, 1 Jan. 1966, and Change 2, 15 Feb. 1966.

[14] James C. Elms, telephone interview, 29 Oct. 1969.

[15] Elms, "Second Interim Report—Gemini Mission Review Board, August 18, 1966;" Elms interview.

Gemini-11 results, Hacker, <u>op. cit.</u>, pp. 358-9, 368-9

On 12 September 1966, Conrad and Gordon arrived at the pad and stepped into their seats exactly on time. Guenter Wendt, McDonnell pad leader, signaled his men to close the hatches, but they soon had to reopen Conrad's. He suspected that some oxygen was leaking from his side of the cabin. He was right. When the hatch had been fixed, the countdown went on. At 8:05 a.m., the Atlas roared into action. Gemini XI had its target.[23]

If ever two pilots waited anxiously for the starter's gun to crack, Conrad and Gordon did. For the first orbit catchup, the time to come out of the chute was unbelievably short. It was the shortest launch window in the Gemini program. *Gemini X,* for example, had 35 seconds in which to launch, Gemini XII would have 30 seconds. Mathews had informed McDonnell and SSD that Gemini XI's launch window was only long enough for an "on-time launch." The postlaunch mission report, however, gave two seconds as the length of the window for a first-orbit rendezvous. Rocketeers of the forties, fifties, and early sixties would have been aghast at the idea of having to launch within two ticks of the clock.[24]

Conrad chanted the count: " . . . 3, the bolts blew, and we got lift-off." This was at 9:42:26.5, just half a second into the two-second period. The Titan booster shoved *Gemini XI* toward a first-orbit rendezvous with near-perfect accuracy. At six minutes, the flight control circuit carried the glad tidings, "Gemini XI, you're GO for M equals 1." This welcome word came at booster separation, when debris could be seen out the window. Gordon had warned himself not to look, but temptation got the better of him for a brief instant.[25]

Immediately upon insertion, Conrad and Gordon performed an insertion-velocity-adjust-routine (IVAR) maneuver, to correct the flight path up or down, right or left, and add to or decrease speed as needed. During IVAR, any decrease in spacecraft speed (retrograde firing) is done with great care because of the danger of recontact with the launch vehicle. The rules, therefore, say that the pilots must have the booster in sight before they begin to cut their speed at this point. Their computer showed the crew they had made very precise insertion corrections that would help them catch a target 430 kilometers away.[26]

The first onboard calculations had succeeded; now it was time to try again. There would be no help from the ground stations, as *Gemini XI* was out of telemetry and communications range. At the appointed moment, Conrad made an out-of-plane maneuver of one meter per second. He then pitched the spacecraft nose 32 degrees up from his horizontal flight plane. Now came the test to see if their first figures had been right. They turned on the rendezvous radar—the electronic lockon signal registered immediately. Happily, the crew switched the onboard computer to the rendezvous mode and began preparing for the final part of the catchup. When they could talk to the ground again, Gordon said, "Be advised we're [within] . . . 50 [nautical] miles [93 kilometers]."[27]

Young, the Houston CapCom, then cut in over the remote line through Tananarive to give the crew some numbers for the remainder of the chase. Conrad and Gordon checked these calculations against their own and found the differences so minor they could have used either set to do the job. They decided to stick with their own solutions. Just as the spacecraft neared the high point of the orbit, Conrad fired the thrusters to produce multidirectional changes—forward, down, and to the right—to travel the remaining 39 kilometers to the target. Suddenly the Agena, whose blinking lights they had been watching in the darkness, flashed into the sunlight over the Pacific and almost blinded them. They scrambled for sunglasses, then Conrad jockeyed the spacecraft to within 15 meters of the target's docking cone. Over the coast of California, only 85 minutes after launch, rendezvous in the first orbit was achieved.[28]

A gleeful crew called out, "Mr. Kraft—would [you] believe M equals 1?" He would. Moreover, they still had 56 percent of their maneuvering fuel. This transmission made a believer out of Mission Director Schneider. He fished in his pants pocket, pulled out a one-dollar bill, and scribbled a notation for Elms: "Sep[aration] 85#, Plane Change 5#, TPI 145#, Midcourse 20#, Braking 150#, [total], 405#. I never lost a better dollar. Bill Schneider."[29]

After appropriate congratulations, Young told Conrad and Gordon to go ahead and dock. Seconds later, Conrad reported matter-of-factly, "We are docked." The *Gemini XI* crew now had an opportunity to do something else that NASA had wanted for a long time—docking and undocking practice. Each man pulled out and drove back once in daylight and once in darkness. It was easy—much easier, Conrad said, than in the translation and docking trainer on the ground. For the first time, also, a copilot was given the chance to dock with a target vehicle.[30]

Even while docking and backing away from the Agena, the crew was meeting another flight objective. Attached to the Agena target docking adapter was S-26, an experiment that studied the ion-wake structure during docking practice. Two other experiments were started at that time—S-9, nuclear emulsion, and a modified form of S-29, libration regions photography. The crew turned on the emulsion package shortly after the hookup with the target, and a telemetry check disclosed that it was working. Gordon later retrieved it from behind the command pilot's hatch. S-29, a study of dim light phenomena, could not be carried out as planned because of the three-day mission delay. The Milky Way now obscured the intended target. Instead, the crew photographed the gegenschein and two comets.

After the last docking, the crew used the main Agena engine in a test run before going to high altitude. Facing 90 degrees away from the flight path, Conrad fired the main engine, adding a velocity of 33 meters per second to pull over into a new orbital lane. This really impressed them. Gordon remarked to Young (who had flown the Agena/spacecraft combination in *Gemini X*), "I agree with you, John, riding that PPS [primary propulsion system] is the biggest thrill we've had all day."[31]

(deleted sections on EVA & tether operations)

The flight controllers had asked the crew about the remaining fuel on several occasions; they were using less fuel than had been expected. And now there was a chance for some realtime planning on the credit side of the ledger. In the past, realtime planning had been in response to such problems as degraded fuel cells, "angry alligators," or whirling spacecraft. An exercise that had been in a contingency plan, if something had gone wrong, was now fitted into the mission because almost everything had gone right.

After the two vehicles separated, Conrad had intended to decrease the spacecraft speed so *Gemini XI*, in a lower orbit, would pull ahead, leaving the Agena behind. Instead, the flight controllers told him to get ready for what was called a "coincident-orbit" (later renamed "stable-orbit") rendezvous. The spacecraft would follow the Agena by 28 kilometers and in its exact orbital path. If the plan succeeded, the crew would, in essence, be stationkeeping at very long range and with the use of very little fuel.[41]

Because of the change in plan, the separation maneuver would be different. Instead of a retrograde firing, so the Agena would trail above and behind them, Conrad and Gordon added speed and height to the spacecraft's orbit so the target passed beneath and in front of their vehicle. When the crew saw the Agena below them, moving swiftly across the South American terrain, they understood why Thomas Stafford and Cernan had trouble keeping their target in sight during the rendezvous-from-above exercise on *Gemini IX-A*.

Next they fired the thrusters to place the spacecraft in the same (coincident) orbit as the Agena and trailing it. Three-quarters of a turn around the world, Conrad decreased his forward speed and, as expected, the spacecraft dropped into the Agena's lane 30 kilometers behind the target and with no relative velocity between the vehicles.[42]

While doing their long-distance formation flying, Conrad and Gordon began to work on night image intensification (D-15), which thev thoroughly enjoyed. This was a test to see if their night vision could be enhanced by equipment that scanned objects on the ground and relayed what it saw to a monitor inside the spacecraft. While Conrad aimed the spacecraft at desired targets—lights of towns and cities, cloud formations, lightning flashes, horizon and stars, airglow, coastlines, and peninsulas—Gordon watched the displays. Each pilot described what he was seeing to the spacecraft tape recorder. Conrad was handicapped by his dirty window. And the glow from the television monitor prevented him from becoming fully dark adapted. Still, the two revolutions (or about three hours) of just riding, watching, and taking pictures were very pleasant. Perhaps the most exciting sight was the lights of Calcutta, India. Outlined on the monitor was a shape almost identical to an official map of the city.

On one occasion during the experiment, the crew noticed the lights of the Agena and asked the ground how far from the target they were. The flight controller on the *Rose Knot* Victor replied that they were still 30 kilometers behind and closing very slowly. They could expect it to be about 26 kilometers away when they woke the next morning. But, when the crew broke their sleep period, in revolution 41, the target was 46 kilometers ahead. This, however, presented no problems for the re-rendezvous.[43]

The second rendezvous in *Gemini XI*, like the first, took only one orbit. At 65:27 hours of flight time, Conrad tilted the spacecraft nose 53 degrees above level flight and fired the forward thrusters. This slowed the spacecraft speed and moved it closer to Earth. Now the spacecraft was in a lower orbit than the Agena and ready for the catch-up maneuver. While they waited for the final approach, the crew did the S-30 dim light photography/orthicon experiment, taking pictures of the gegenschein and zodiacal light, and completed D-15. They also turned off the switch to raise the temperature of the S-4 radiation experiment and then turned it back on. At 67:33 hours, S-4 was turned off for the last time.

An hour after the catchup maneuver began, with his ship almost level and aimed directly ahead, Conrad gave the aft thrusters a burst to raise the spacecraft orbit. Now the Agena floated just above them, its tether pointing straight up. At 66:64 hours elapsed time, Conrad began to brake his spacecraft; six minutes later, he reported that he was on station and steady with the Agena. Gordon noticed that the tether on the target had started waving slowly and surmised that this was caused by the exhaust from *Gemini XI's* thrusters. Twelve minutes later, the crew broke away from the Agena for the last time. Conrad later said, "We made the 3 foot [1 meter] per second retrograde burn and left the best friend we ever had." Gordon added, "We were sorry to see that Agena go. It was very kind to us."[44]

Conrad suggested that Flight Director Lunney might send up a tanker—the crew would be happy to refuel, remain in orbit, and do some more work. But, while this air-to-ground joking was going on, the crew was getting ready to land.[45]

[23] "Gemini XI Technical Debriefing," 19 Sept. 1966, pp. 1-2; Gemini 11 mission commentary, 12 Sept. 1966, tape 3, p. 1, tape 23, p. 1; [Ertel], *Gemini XI*; Guenter F. Wendt, interview, Titusville, Fla., 23 May 1967; G. Merritt Preston, interview, Cape Kennedy, 24 May 1967.

[24] "Gemini XI Mission Report," p. 4-1; [Ertel], *Gemini XI*; Gemini II mission commentary, tape 37, p. 1; TWX, Mathews to SSD, Attn: Col. Robert R. Hull, and McDonnell, Attn: Burke, "Gemini X and X-A planning information," GV-12473, 12 July 1966; TWX, Mathews to SSD, Attn: Hull, and McDonnell, Attn: Burke, "Gemini XI Launch Windows," GV-12487, 3 Aug. 1966; TWX, Mathews to SSD, Attn: Hull, and McDonnell, Attn: Burke, "Gemini XII Launch Windows," GV-12517, 6 Oct. 1966.

[25] "Gemini XI Debriefing," pp. 3, 6, 8, 9; [Ertel], *Gemini XI*; "Gemini XI Voice Communications (Air-to-Ground, Ground-to-Air and On-Board Transcription)," McDonnell Control No. C-11598, n.d., pp. 2, 4, 5, 6.

[26] "Gemini XI Mission Report," pp. 4-13, 5-8, -9; Paul C. Kramer, Edwin E. Aldrin, and William E. Hayes, "Onboard Operations for Rendezvous," in Gemini Summary Conference, NASA SP-138 (Washington, 1967), pp. 27-28.

[27] "Gemini XI Mission Report," pp. 4-13, -24, 5-12, 7-18; "Gemini XI Debriefing," p. 12; "Gemini XI Voice," p. 13.

[28] "Gemini XI Mission Report," pp. 4-13, -14, -24, 5-12, -13, 7-18, -19, -20; "Gemini XI Debriefing," pp. 14, 20, 21; "Gemini XI Voice," pp. 14, 17, 18-23.

[29] "Gemini XI Voice," p. 24; Elms interview; TWX, Mathews to McDonnell, Attn: Burke, "Contract NAS 9-170, Spacecraft Consumable Loadings for Gemini XI," GV-12494, 12 Aug. 1966.

[30] "Gemini XI Debriefing," pp. 207-209; "Gemini XI Voice," pp. 29, 36, 37; "Gemini XI Mission Report," pp. 4-1, 7-20.

[31] "Gemini XI Debriefing," pp. 24-25, 26, 27-28, 184, 185; "Gemini XI Voice," pp. 29, 31-34, 40, 42, 45, 46; "Abstract of Meeting on Gemini Experiment S-26, Ion Wake Measurement, Gemini X and XI, September 13, 1965," 23 Sept. 1965; David B. Medved and Ballard E. Troy, Jr., "Experiment S026, Ion-Wake Measurement," in "Gemini XI Experiments Report," pp. 119-20; F. W. O'Dell et al., "Experiment S009, Nuclear Emulsion," ibid., p. 85.

[41] Gemini 11 press kit, p. 14; "Gemini XI Mission Report," p. 6-12, 7-28; "Change of Shift Briefing," 14 Sept. 1966, tape 7A, pp. 1, 2; Kramer, Aldrin, and Hayes, "Onboard Operations for Rendezvous," p. 39.

[42] "Gemini XI Mission Report," pp. 1-3, 4-15, -26, 5-29, 6-12, -13, 7-28, -29; "Gemini XI Debriefing," pp. 60, 61; "Gemini XI Voice," pp. 241, 243-44, 245, 250-51; Carl R. Huss, Kenneth A. Young, and James D. Alexander, telephone interviews, 15 May 1970.

[43] "Gemini XI Mission Report," pp. 4-15, 8-13 through -16; "Gemini XI Voice," pp. 263, 266-85, 288-303; "Gemini XI Debriefing," pp. 64-68; Thomas J. Shopple, George F. Eck, and Albert R. Prince, "Experiment D015, Night Image Intensification," in "Gemini XI Experiments Report," pp. 17, 21-23, 28, 30, 31-34.

[44] Kramer, Aldrin, and Hayes, "Onboard Operations for Rendezvous," p. 39; "Gemini XI Mission Report," pp. 1-3, 4-15, -16, -27, 6-14, -15, 7-29, -30, 8-4 through -6, -13, -25, -65; "Gemini XI Voice," pp. 308, 321-24; "Gemini XI Debriefing," pp. 69-74.

[45] "Gemini XI Voice," pp. 315, 321.

Gemini-12 results,
Hacker, op. cit., pp. 375-6

Things now went smoothly and, a little more than an hour after launch, Aldrin reported, "Be advised we have a solid lock-on . . . 235.52 [nautical] miles [436.18 kilometers]." From Houston, Conrad replied, "It looks like the radar meets the specs." When the spacecraft moved into a circular orbit below and behind its target, the radar showed the Agena to be 120 kilometers away. But this was the last figure the crew could trust; reception got so poor that the onboard computer refused to accept the radar's intermittent readings.

The radar failure meant that *Gemini XII* would have to rely on the backup charts it carried to complete the rendezvous. Aldrin, a member of the team that had planned and worked out chart procedures, now had a chance to see if his doctoral studies at MIT and the simulator training in St. Louis with McDonnell and MSC engineers really were practical in space.[64] The pilot, who was sometimes called "Dr. Rendezvous," had already pulled out and used the T-2 manual navigation sighting sextant to take a look at the target. When the radar went on the blink, this piece of experimental gear became operationally important.

In the automatic rendezvous mode, the radar would have fed range and range rates to the computer. Lovell would then have flown the spacecraft by the resulting numbers. This time the computer would be left in the catchup mode, and either Aldrin or Mission Control—or both—had to figure range and range rates to see if the computer was correct. For this backup method, Aldrin used the sextant to measure the angle between the local horizontal of the spacecraft and that of the Agena, ahead of and above them. He checked this information with his rendezvous chart and cranked the necessary corrections into the computer. Lovell flew the spacecraft with these numbers to rendezvous with the target, arriving there after 3 hours and 45 minutes of flight. They had used only 127 kilograms of fuel. Lovell called the *Coastal Sentry* Quebec at 4:13 hours elapsed time, saying, "We are docked." But *Gemini XII* was the fourth flight to make that announcement, and the shipboard flight controller merely replied, "Roger."[65]

For the second time, a Gemini crew was able to practice docking and undocking. They unlatched the vehicles and Lovell tried the task during the night. But the spacecraft was misaligned; the target's docking cone did not unlatch. Instead, it locked bumpers, catching on one of the three latches. Much like an automobile driver mired in the mud, Lovell fired the aft and forward thrusters, trying to rock the spacecraft free. Both vehicles were shaken, but he broke loose without damage to either. A few minutes later, Aldrin docked without difficulty.[66]

The next item on the agenda was the firing of the Agena to go to a higher altitude, but that part of the flight plan had to be changed. Eight minutes after the Agena was launched, its main engine suffered a momentary six percent decay in thrust chamber pressure and a corresponding drop in turbine speed. So, while Lovell and Aldrin chased and caught the Agena, then practiced docking, Mission Director Schneider and Flight Director Lunney had to decide whether the main engine should be fired. They soon decided that prudence was the better course—it should not.

[64] "Gemini XII Mission Report," pp. 1-2, 4-1, -15, 5-20, 6-6 through -8, 7-1; "Gemini XII Voice," pp. 26, 30; "Gemini XII Debriefing," pp. 23, 28-31; Edwin E. Aldrin, Jr., "Line of Sight Guidance Techniques for Men in Orbital Rendezvous" (Ph.D. dissertation, Massachusetts Institute of Technology, 1964); Dean F. Grimm, interview, Houston, 13 April 1968.

[65] "Gemini XII Debriefing," pp. 21, 27, 31, 32, 34, 37, 49; "Gemini XII Mission Report," pp. 1-2, 4-17, 6-8, 7-25, -26; "Gemini XII Voice," pp. 33-44; "Interim Report, Manned Space Flight Experiments, Gemini XII Mission, November 11-15, 1966," MSC-TA-R-67-3, August 1967, p. 149; Gemini 12 mission commentary transcript, 11 Nov. 1966, tape 56, p. 3.

[66] "Gemini XII Mission Report," pp. 4-1, 5-1, -15, 7-2, -26; "Gemini XII Debriefing," pp. 53, 54-55, 57, 61; "Gemini XII Voice," pp. 67, 75.

Gemini-12 narrative

MEN FROM EARTH, Buzz Aldrin,

Bantam Books, New York, 1989, pp. 153

Jim and I had no chance to relish the silent luxury of orbital flight. We began our long prerendezvous litany, each of us studying the flapping pages of his flight plan like a priest in some solemn ritual. The main computer keyboard of the Gemini cabin instrument panel was on the right side where I sat. Chanting our readouts of speed and altitude, I tapped the data into the computer's memory.

We had rehearsed the procedures for orbital rendezvous hundreds of times, but the real maneuver was still hectic. After stuffing my helmet into a nylon sack between my knees, I jammed my pressure gloves between my right thigh and the edge of the ejection seat. A moment later, as I flipped switches on my instrument panel, I was startled by a gloved hand snaking around behind my head. Of course, it was just my empty glove, which had floated free.

The next hour was extremely busy, working toward the rendezvous with the Agena about 300 miles ahead. With my helmet off, I did manage to look out at the tropical night sky as we passed over Africa on our way toward the Indian Ocean. Orbital sunrise was coming up on Australia. Spears of dawn cut the twilight. One hour after launch, we glided into full day, two-thirds of the way around the planet from the Cape.

Twenty-five minutes later, we made our first attempt at radar contact with the Agena. I have to admit we were both amazed when the computer readout immediately clicked with the desired digits.

"Houston," I called, "be advised, we have a solid lock-on... two hundred thirty-five point fifty nautical miles."

"It looks like the radar meets the specs," Pete Conrad called from Mission Control.

"It sure does," Jim agreed, staring at his instruments.

But our early success was short-lived. As we circularized our orbit to pull behind and below the Agena over North America, the radar malfunctioned. Jim announced this "radar dropout," and it looked like we were heading toward another embarrassing Gemini failure. Now I had to earn my pay. The fallback for this situation was for the crew to consult intricate rendezvous charts—which I had helped develop—

interpret the radar data using the "Mark One Cranium Computer" (the human brain), and then verify all this with the spacecraft computer. It was a demanding task, but it was the only way we could salvage the rendezvous mission. We also had to fly the rendezvous without wasting all our thruster fuel. This was about the best test yet of the Lunar Orbit Rendezvous concept: if astronauts in *Earth* orbit couldn't pull off a contingency rendezvous such as this, LOR was just too risky for Apollo crews.

Jim flew the spacecraft while I verified the radar information and slaved over the charts. I could barely read the data because it was so densely printed. I lost track of time, but I could tell darkness from daylight as we drifted around the Earth, slowly advancing on the Agena. Finally, four hours after liftoff, we pulled up to the long black-and-white cylinder. Jim didn't wait around for permission to dock. He coordinated his two hand controllers and eased the nose of our spacecraft straight into the Agena's docking throat.

"Houston," Jim called, "we are docked."

Below us, the capcom on the tracking ship *Coastal Sentry Quebec* merely replied, "Roger."

I checked the propellant-quantity gauges. We had used less than 280 pounds of fuel, one of the program's most economical and successful rendezvous and dockings.

We practiced docking and undocking several times. The latches hung up once, but Jim shook us loose with no damage (though the grinding noise was a little disturbing). My attempts at docking went easier than they had in the simulators. However, when we began preparations to fire the Agena engine to raise our orbit, Houston told us they had a problem. The Agena had suffered a thrust "decay" after launch, and flight director Glynn Lunney didn't feel right about letting us fire the target vehicle's engine. (It could explode, ruining our day.) So we were stuck here in our original orbital plane for the duration of the mission.

Summary of Rendezvous Operations,
W.B. Evans and M.R. Czarnik, 1967,
"Gemini Program Summary Conference"

2. SUMMARY OF RENDEZVOUS OPERATIONS

By W. Bernard Evans, *Office of Vehicles and Missions, Gemini Program Office, NASA Manned Spacecraft Center;* and Marvin R. Czarnik, *Dynamics Group Engineer, McDonnell Aircraft Corp.*

Introduction

One of the major objectives of the Gemini Program was to develop and to demonstrate techniques for the rendezvous and docking of space vehicles. This objective is of vital importance since rendezvous and docking is mandatory for success in many future manned space-flight programs. For example, lunar orbital rendezvous has been selected as the primary mode for the Apollo lunar-landing mission which requires one rendezvous and two dockings. Other programs requiring rendezvous are planetary missions, manned space stations, and unmanned satellite inspection and repair missions.

During the Gemini Program, the following types of rendezvous techniques were evaluated: fourth orbit ($M = 4$), third orbit ($M = 3$), first orbit ($M = 1$), optical rendezvous, rendezvous from above, stable orbit rendezvous, and optical dual rendezvous. These techniques were used successfully in the completion of 10 rendezvous operations (table 2–I). A major factor in achieving success during these operations can be attributed to the implementation of an extensive analysis, simulation, and training program leading first to the Gemini VI–A rendezvous mission, and subsequently to more complex missions. During the Gemini III mission, the spacecraft propulsion system and the guidance and control system were evaluated. On the Gemini IV mission, a plan was developed and an attempt was made to station keep and rendezvous with the spent second stage of the launch vehicle. During Gemini V, a phantom rendezvous and a spacecraft radar-to-ground transponder tracking test were performed. The phantom rendezvous involved a series of maneuvers based upon ground tracking and computations, and precisely duplicated the maneuver sequence and procedures planned for the midcourse phase of the Gemini VI–A mission.

TABLE 2–I.—*Mission Summary*

Gemini mission	Type of rendezvous
VI–A	Fourth orbit ($M = 4$)
VIII	Fourth orbit ($M = 4$)
IX–A	Third orbit ($M = 3$)
	Optical re-rendezvous
	Re-rendezvous from above
X	Fourth orbit ($M = 4$)
	Optical dual
XI	First orbit ($M = 1$)
	Stable orbit
XII	Third orbit ($M = 3$)

Sufficient data were obtained from the spacecraft radar tracking test during the Gemini V mission to adequately flight-qualify the radar for the Gemini VI–A flight. Even though the rendezvous operations planned for the first three manned Gemini flights were not all successful, they were extremely valuable to the program since they provided flight experience and indicated areas requiring further analysis, simulation, and training.

On December 15, 1965, the Gemini VI–A crew, using the Gemini VII spacecraft as the target vehicle, completed the first space rendezvous operation. Although this mission did not include a docking, it was successful and after lift-off proceeded almost precisely as planned. On the following mission, the Gemini VIII crew successfully performed the first rendezvous and docking with a Gemini Agena Target Vehicle. Subsequent, more complex, rendezvous operations were successfully performed during the Gemini IX–A, X, XI, and XII missions. These successes have provided confidence in the ability to accomplish such operations. However, rendezvous must still be recognized as a highly precise operation that is rather unforgiving of errors which occur during the final approach, details of which will be discussed in this paper.

Review of Rendezvous Operations Development

An explanation of rendezvous can be greatly simplified by a description of the relative-motion concept. Figure 2–1 shows a coordinate system centered on the target vehicle in a circular orbit with the *X*– and *Y*–axes in the target orbital plane. The *Y*–axis rotates with the target vehicle and is positive radially upward; the *X*–axis is curvilinear and positive opposite the direction of motion. The out-of-plane parameter is the *Z*–axis, which completes the right-hand coordinate system. The motion of the spacecraft with respect to this reference is illustrated in figure 2–2.

Figure 2–2(*a*) shows the spacecraft in a lower circular orbit. It should be noted that

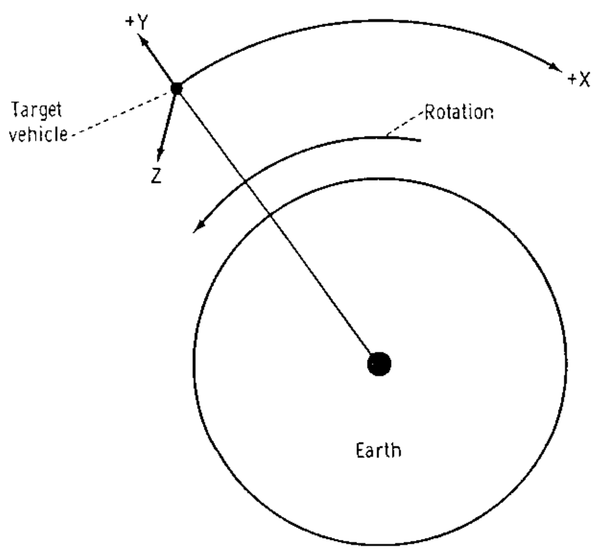

FIGURE 2–1.—Target-centered coordinate system.

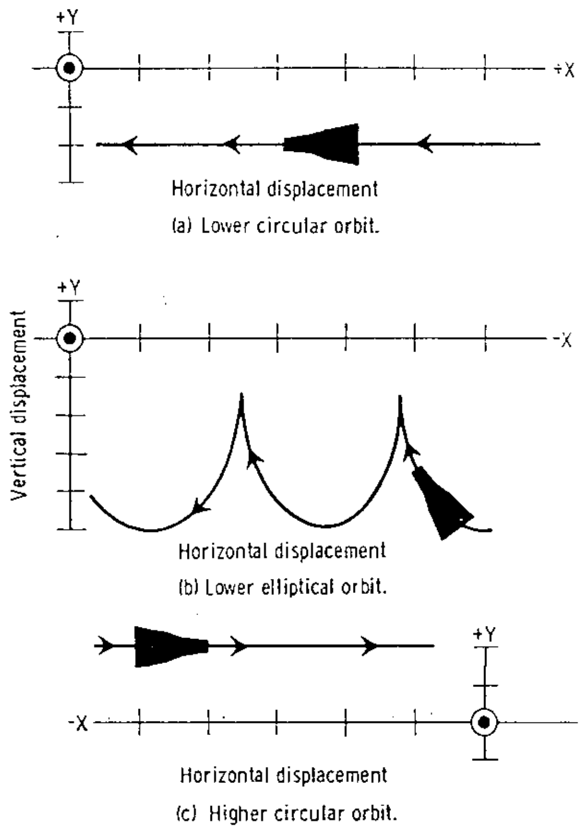

FIGURE 2–2.—Motion relative to a target-centered coordinate system.

the radial displacement *Y* is constant while the trailing displacement *X* decreases with time, since the spacecraft in the lower orbit has a higher angular rate. Figure 2–2(*b*) shows a lower elliptical orbit. As can be expected, this orbit has a catchup rate; however, the radial displacement also changes with the low points representing perigees, and the high points, apogees. Figure 2–2(*c*) illustrates a spacecraft in a circular orbit higher than the target orbit. The radial distance is constant, as in the case of the lower circular orbit; however, in this case the trailing displacement changes since the target now has the higher angular rate. The following paragraphs use this coordinate system in describing the Gemini rendezvous operations.

The development of the operational rendezvous missions required extensive analyses as previously described in reference 1. For

Gemini VI, many concepts were evaluated and three were selected as candidates for the Gemini VI mission. The first was the tangential concept which included the tangential approach of the spacecraft to the target vehicle following four orbits of ground-controlled midcourse maneuvers. The second concept had a similar catchup sequence, except that the final midcourse maneuver established a coelliptical approach trajectory, and the spacecraft closed-loop guidance system was then used to establish a collision course. A third concept featured rendezvous at first spacecraft apogee. Following a tangential approach of the spacecraft to the target, the spacecraft would be inserted on a collision course with the target, and the spacecraft closed-loop system would be used to correct insertion dispersions.

After the three concepts had been selected, analyses were performed to determine the concept best suited for the Gemini VI mission. In June 1964, prior to the flight of Gemini II, the coelliptical rendezvous concept was selected for the Gemini VI mission.

Description of Initial Rendezvous Operations

Gemini VI–A, VIII, and X

Figures 2–3 and 2–4 present typical relative trajectory plots of the fourth-orbit rendezvous conducted on Gemini VI–A, VIII, and X. On each mission, the spacecraft was inserted into an orbit essentially coplanar with the target vehicle. The first orbit was left free of rendezvous maneuvers to allow the crew sufficient time to verify satisfactory spacecraft operation. A number of midcourse corrections were performed before completing the rendezvous during the fourth spacecraft orbit near the end of the fourth darkness period. At the first spacecraft perigee, an apogee height-adjust maneuver N_H was performed to correct for in-plane insertion dispersions. At the second apogee, a phase-adjust maneuver N_C, was performed to raise the perigee, thus providing the catchup rate required for proper phasing of the terminal-phase initiation near the fourth darkness entry. An out-of-plane correction

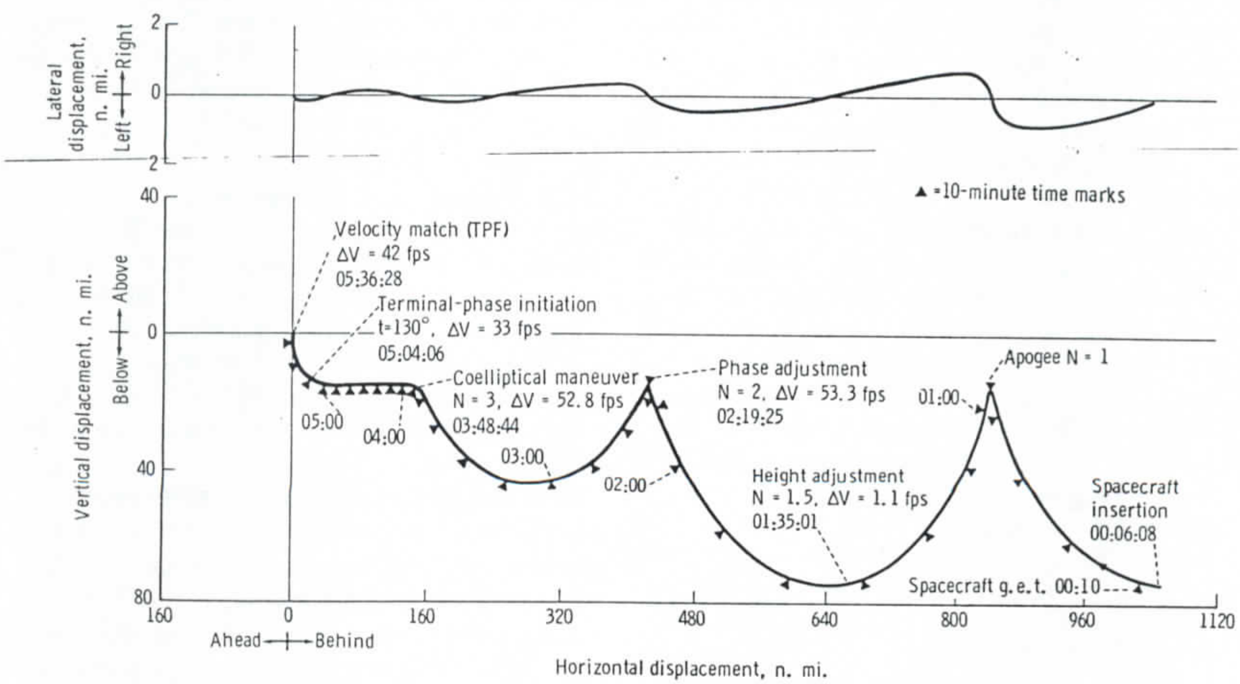

FIGURE 2–3.—Typical relative trajectory of spacecraft from insertion to rendezvous in target-vehicle curvilinear coordinate system. Gemini VI–A, VIII, and X missions.

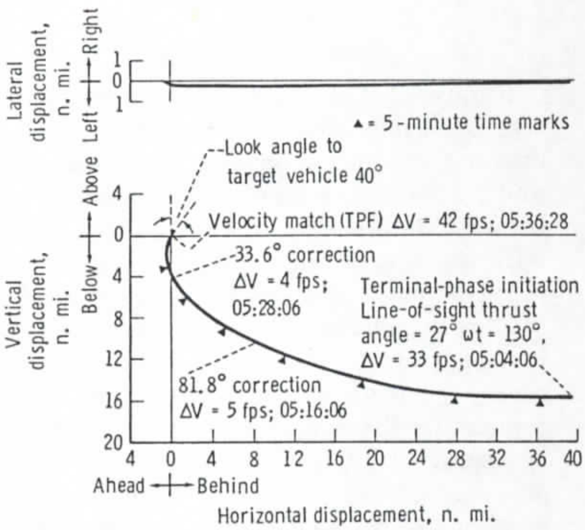

FIGURE 2–4.—Typical relative trajectory of spacecraft from terminal-phase initiation to rendezvous in target-vehicle curvilinear coordinate system. Gemini VI–A, VIII, and X missions.

P_C was applied at the nodal crossing after the second apogee to correct out-of-plane insertion dispersions. At the third spacecraft apogee, a coelliptical maneuver N_{SR} was performed to produce a constant altitude differential of 15 nautical miles. The onboard system then provided solutions for the terminal-phase-initiation (TPI) maneuver, which would occur when the line-of-sight elevation angle reached the nominal value of 27°. Two vernier corrections followed at 12-minute intervals. Finally, braking (terminal-phase finalization (TPF)) and line-of-sight rate control were effected by a manual operation based upon radar and visual data.

The transfer trajectory was selected to satisfy several of the mission requirements in the area of onboard procedures. First, in order to provide a backup reference direction for the terminal-phase-initiation maneuver in case of a guidance-system failure, the maneuver had to be performed along the line of sight to the target. The second requirement was a low terminal line-of-sight angular rate and a low closing rate. Finally, the terminal-phase-initiation point had to be below and behind the target vehicle; and the final approach, from below and ahead of the target vehicle, in order to optimize the lighting. These factors were evaluated, and a 130° transfer was selected.

The selection of the nominal coelliptical differential altitude of 15 nautical miles was based upon a tradeoff between two considerations. First, the range to the target at the terminal-phase-initiation point had to be small enough to assure visual acquisition. Second, a large differential altitude was required to minimize the effect of insertion dispersions and catchup maneuver errors on the location of the terminal-phase-initiation point. For example, a differential altitude of 15 nautical miles resulted in a 3-sigma dispersion of ±8 minutes in the timing of the terminal-phase-initiation maneuver. Early error analysis indicated a ±15-minute variation in terminal-phase-initiation timing for a differential altitude of 7 nautical miles. Flight experience demonstrated that the launch-vehicle and spacecraft guidance systems accuracies, crew procedures, and ground-tracking accuracy were better than had been expected; as a result, the altitude differential was reduced to 5 and 7 nautical miles in the later rendezvous operations.

Gemini IX–A and XII

A second primary rendezvous technique was utilized on Gemini IX–A and XII (figs. 2–5 and 2–6). This technique resulted in rendezvous in the third spacecraft orbit near the end of the third spacecraft darkness period. A phase-adjust maneuver N_{C_1} was performed at first spacecraft apogee to provide the correct phasing at the second apogee. Approximately three-fourths of an orbit later, the first of a set of two maneuvers was performed: a combination phasing, height-adjust, and out-of-plane correction. The first maneuver N_{CC}, combined with the following coelliptical maneuver, provided a fixed rendezvous time with minimum propellant usage. The out-of-plane portion of the first maneuver established a node at the following coelliptical maneuver point. The coelliptical maneuver N_{SR} eliminated the out-of-plane

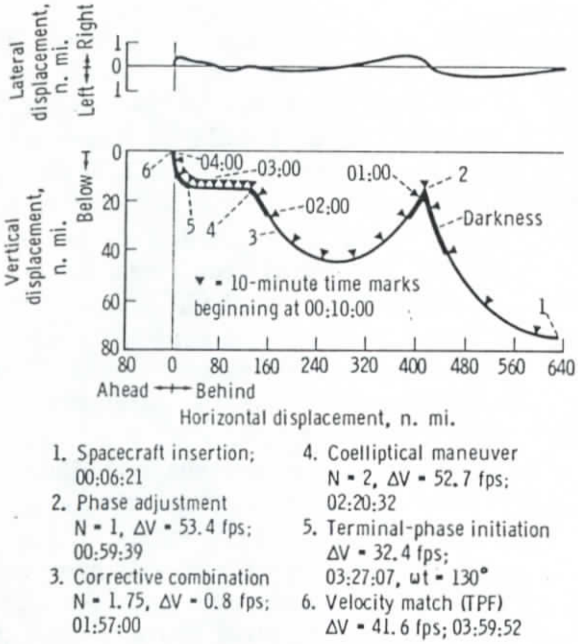

FIGURE 2-5.—Typical relative trajectory. Gemini IX-A and XII missions.

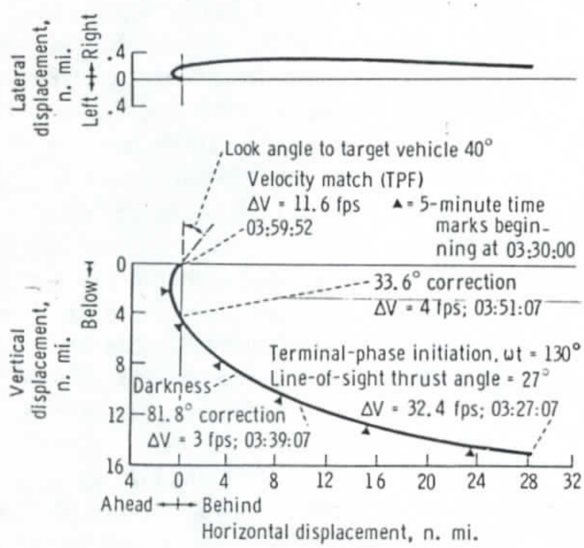

FIGURE 2-6.—Typical relative trajectory, terminal phase. Gemini IX-A and XII missions.

Gemini XI

The third primary rendezvous conducted during the program was the first-orbit technique used for Gemini XI (figs. 2-7 and 2-8). The limited time available to conduct the first-orbit rendezvous prohibited the multicorrection catchup phase and coelliptical approach used on other missions. Instead, a correction was made at spacecraft insertion to remove out-of-plane motion and to adjust motion and established coelliptical orbits with an altitude differential that varied within certain limits. The terminal phase of this technique was the same as the fourth-orbit technique, except that procedural changes were necessary to accommodate the variable altitude differential.

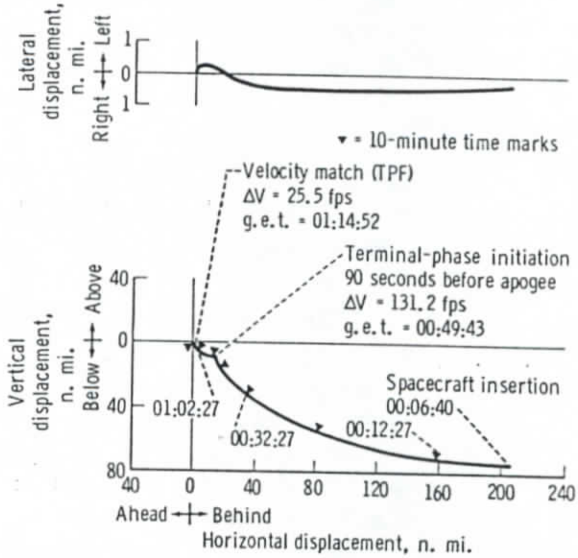

FIGURE 2-7.—Relative trajectory. Gemini XI mission.

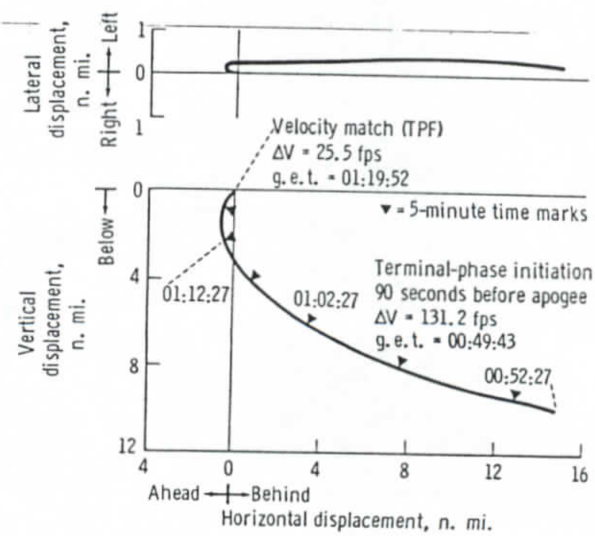

FIGURE 2-8.—Relative trajectory, terminal phase. Gemini XI mission.

apogee height and phasing. This correction was based upon onboard navigation information obtained from the spacecraft guidance system. At 90° after insertion, a second out-of-plane correction, also based upon onboard information, was performed. Terminal-phase initiation occurred just prior to first spacecraft apogee with the spacecraft 10 nautical miles below and 15 nautical miles behind the target vehicle. A 120° transfer was used with two vernier corrections at 12-minute intervals after the terminal-phase initiation. After a manual braking and line-of-sight phase, rendezvous was completed within the first orbit.

Description of Re-Rendezvous and Dual Rendezvous Operations

The first of three re-rendezvous techniques was an optical rendezvous from an equiperiod orbit and was conducted on the Gemini IX–A mission (fig. 2–9). The purpose of this rendezvous was to evaluate the optical rendezvous procedures, and particularly the terminal-phase lighting, required for the dual rendezvous scheduled for Gemini X. An upward radial velocity change was used to separate the spacecraft from the target vehicle into an equiperiod orbit. Approximately one-half orbit after separation, a correction

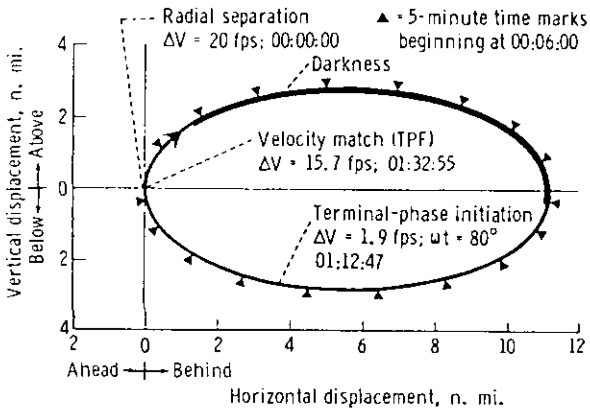

FIGURE 2–9.—Relative trajectory of spacecraft for (equiperiod) re-rendezvous in target vehicle curvilinear coordinate system. Gemini IX–A mission.

was applied based upon the time the line of sight to the target vehicle crossed the local horizontal. The time and the magnitude of the terminal-phase-initiation maneuver were determined from visual angle observations, and an 80° transfer was initiated when the Sun was nearly overhead. Two vernier corrections also based upon visual angle measurements were applied, and rendezvous occurred just prior to sunset. It was a requirement that the spacecraft be in a stationkeeping mode prior to entering darkness with a passive target.

A second re-rendezvous technique (figs. 2–10 and 2–11) was developed to evaluate a terminal-phase condition with an Earth background. Two midcourse maneuvers were used to insert the spacecraft into a coelliptical orbit 7.5 nautical miles above the target vehicle. Except for a reversal in approach direction, the terminal phase was identical to that employed on the earlier coelliptical approach from below. Experience gained during this rendezvous indicates that the probability of success would be very low in case of a radar guidance system failure because of the extremely poor target visibility.

During the Gemini XI mission, a third re-rendezvous exercise was performed. This rendezvous was ground controlled except that the terminal braking and line-of-sight control phases were performed by the crew using visual observations (no radar). After the initial separation maneuver, the spacecraft was in a nearly circular orbit at the same altitude as the target vehicle, but with a trailing displacement of approximately 25 nautical miles. Since the relative motion of the vehicles in this configuration was approximately zero, the rendezvous was referred to as a stable-orbit rendezvous (fig. 2–12). A ground-computed maneuver was performed which placed the spacecraft on a trajectory to intercept the target vehicle in 292° of target orbital travel. With 34° of orbital travel remaining, a second and final ground-computed maneuver was applied. The rendezvous was then completed by the flight crew using visual cues. The terminal-phase portion of

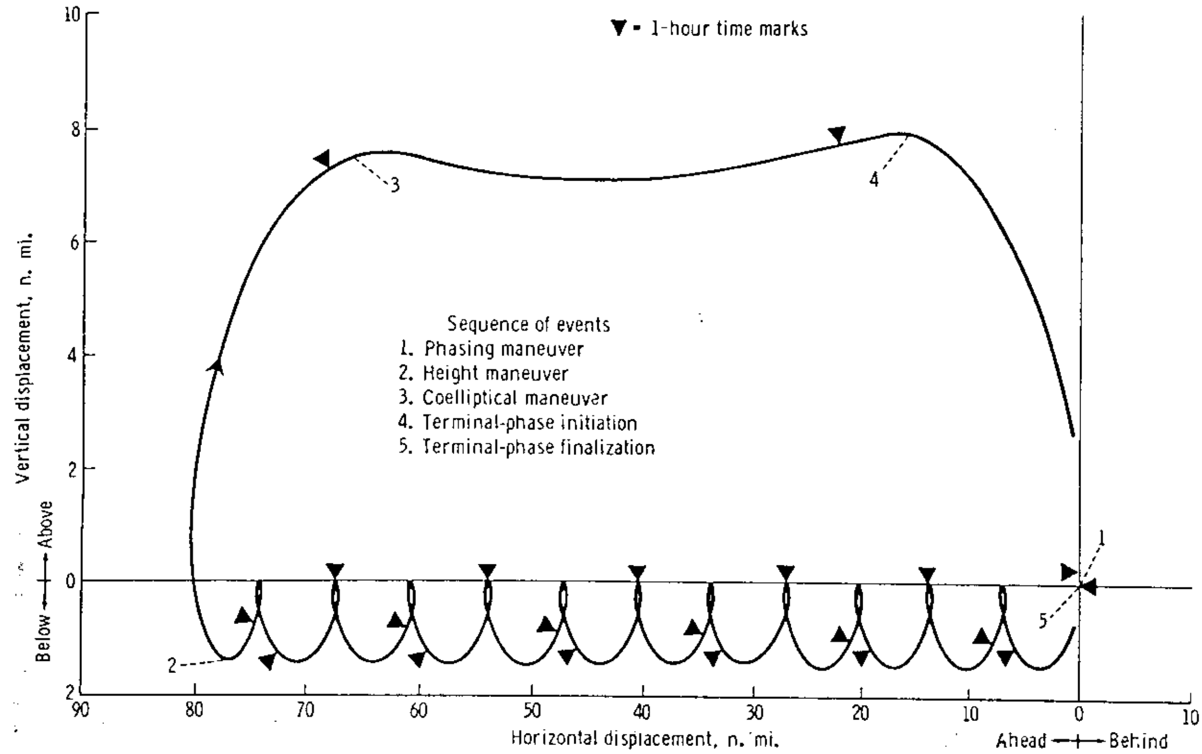

FIGURE 2-10.—Relative trajectory profile for re-rendezvous from above. Gemini IX-A mission.

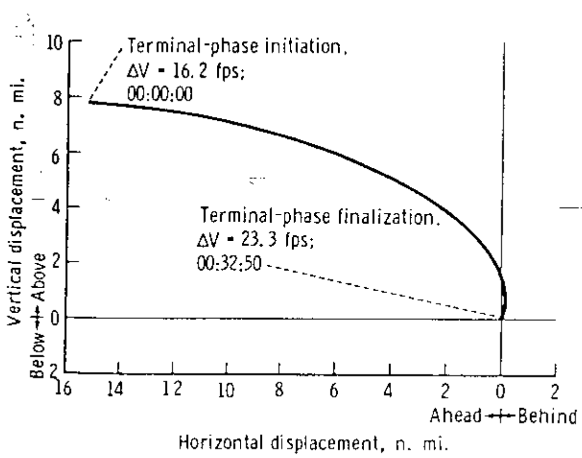

FIGURE 2-11.—Relative trajectory re-rendezvous from above. Gemini IX-A mission.

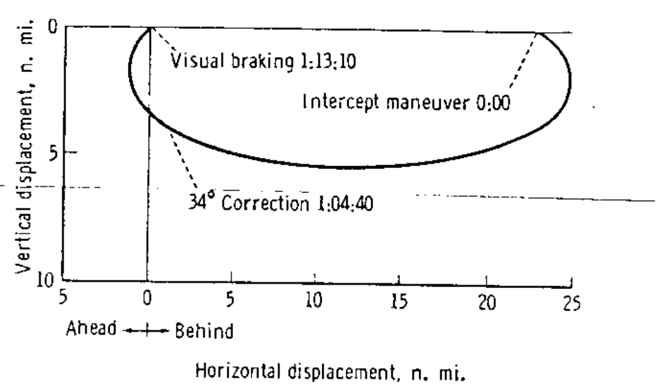

FIGURE 2-12.—Gemini XI stable orbit re-rendezvous.

this rendezvous had the same characteristics as the tangential concept previously described. Theoretically, the propellant required is small when compared with the coelliptical approach; however, with minor dispersions at the intercept maneuver point, the lighting conditions, approach angles, and propellant consumption for the braking phase can vary widely. The reason is that, for most cases, the spacecraft will end up approaching the target from above, resulting in poor target visibility. This type of rendezvous generated considerable interest in its application to certain rendezvous operations, particularly where a highly precise ground-tracking system is used to provide the terminal-phase maneuvers. The commitment to conduct such a rendezvous reflected the confidence that was established during Gemini in the capabilities of the ground-tracking, computation, and control facilities.

In addition to the primary and re-rendezvous missions, a dual rendezvous was performed by the Gemini X crew. The target vehicle launched during the Gemini VIII mission was left in orbit and was the passive target for the dual operation. One problem encountered during the development of the Gemini X mission was obtaining precise state vectors for the passive target vehicle, and making accurate predictions far enough in advance to find acceptable launch windows. Because of the inaccuracies in drag prediction, it was necessary for launch date, lift-off time, and catchup sequence to be flexible. The catchup sequence included a series of maneuvers by the docked Gemini X spacecraft and Gemini X target vehicle for gross catchup, and another series of maneuvers by the undocked spacecraft for fine catchup. The capability for large changes in altitude during the gross catchup sequence allowed an acceptable wide variation in the initial-phase angle. The terminal approach was coelliptical with an altitude differential of 7 nautical miles; the terminal-phase guidance employed was the same as for the optical rendezvous conducted on Gemini IX–A.

Rendezvous Considerations and Flight Results

In developing the rendezvous missions, many factors were considered, primarily launch procedures, system requirements, and crew procedures.

Launch Procedures

Development of the launch procedures required extensive analyses to define methods of controlling out-of-plane displacement, establishing launch-window length, and developing a countdown method.

Selecting a target orbit inclination slightly above the latitude of the launch site makes the out-of-plane displacement relatively small for a long period of time (fig. 2–13). By varying the launch azimuth so that the spacecraft would be inserted parallel to the target-vehicle orbital plane, the out-of-plane displacement of the launch site at the time of launch becomes the maximum out-of-plane displacement between the two orbit planes. The out-of-plane displacement could also be minimized by using the variable launch-azimuth technique with guidance in yaw during second-stage powered flight. This is accomplished by biasing the launch azimuth of the spacecraft so that the launch azimuth is at an optimum angle directed toward the target-vehicle orbital plane (fig. 2–14). As a result, the out-of-plane distance would be reduced prior to the initiation of closed-loop guidance during the second-stage flight. This technique would effectively use the launch-vehicle performance capability to control the out-of-plane displacement. Sufficient performance capability existed in the Gemini Launch Vehicle to control the out-of-plane displacement to within ±0.55° (table 2–II). The maximum allowable wedge angle of ±0.55° was not needed on any of the rendezvous missions. By selecting an inclination of

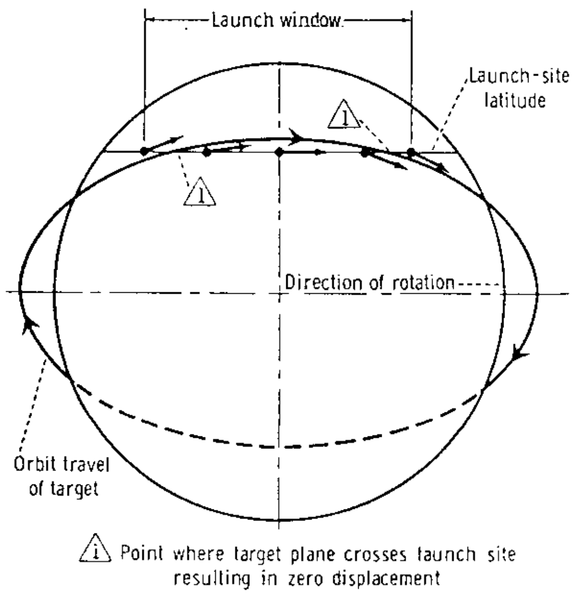

FIGURE 2–13.—Variable azimuth launch technique.

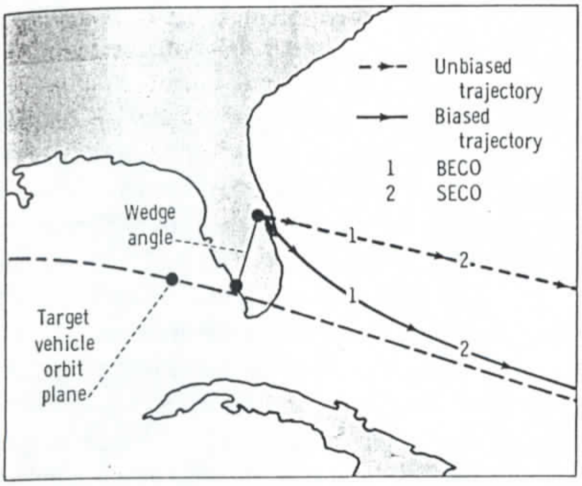

FIGURE 2-14.—Typical Gemini rendezvous launch. Biased launch azimuth and Stage II yaw steering.

TABLE 2-II—*Yaw Steering Summary*

Gemini mission	Targeted out-of-plane displacement, deg
VI-A	0.20
VIII	−.21
IX-A	−.50
X	−.077
XI	−.131
XII	−.16

28.87°, 0.53° above the launch-site latitude, and by using a variable launch-azimuth technique, the out-of-plane displacement could be controlled to within 0.53° for 135 minutes.

During the early planning phases of the Gemini Program, a relatively large launch window (table 2-III) was considered mandatory; however, later experience indicated that reliable countdown procedures could be developed, and it is now the general opinion that large launch windows are not required. Since Gemini V, the launches have either been essentially on time, or the launch has been scrubbed. By suitable planning, minor launch delays can be easily absorbed in the count, and if major problems occur, large launch-window lengths are not particularly helpful. An on-time launch capability provides a tremendous potential in planning operational rendezvous missions and indicates

TABLE 2-III.—*Gemini Launch Performance*

Mission	Launch attempts	Launch date	Launch-time deviation
I	1	Apr. 8, 1964	On time
II	2	Jan. 19, 1965	−4 min
III	1	Mar. 23, 1965	−24 min
IV	1	June 3, 1965	−16 min
V	2	Aug. 21, 1965	On time
VI	1	(a)	—
VI-A	2	Dec. 15, 1965	On time
VII	1	Dec. 4, 1965	On time
VIII	2	Mar. 16, 1966	On time
IX	1	(b)	—
IX-A	2	June 3, 1966	On time
X	1	July 18, 1966	On time
XI	3	Sept. 12, 1966	On time
XII	3	Nov. 11, 1966	On time

[a] Target-vehicle failure.
[b] Target launch-vehicle failure.

that rendezvous operations, booster performance permitting, are operationally feasible at any orbital inclination.

Initial analyses of countdown methods indicated that the highest probability of mission success could be achieved by simultaneously counting down both vehicles. Even though simultaneous countdowns have been used extensively in Gemini, nothing in the results clearly indicates that this is a necessity.

Systems Requirements

A primary consideration in the development of the rendezvous operations was the area of systems requirements. The requirements for the systems design were based upon design-reference missions. As the designs became established, however, the operational missions were developed to exploit the systems capabilities, and, of course, the missions were ultimately limited by the systems capabilities. For example, a desired objective during the Gemini XII mission planning was to complete a rendezvous during the second orbit ($M=2$). Accomplishing this objective within acceptable dispersions would have required a trajectory correction based on radar range at a point outside the spacecraft radar-range capability. As a result, the second-apogee rendezvous plan was eliminated.

Crew Procedures

Further requirements were imposed to achieve workable crew procedures. The major requirements in this area were the following:

(1) Sufficient time for the crew to complete the necessary activities

(2) Approach trajectories which are reasonably insensitive to insertion dispersion and to errors in midcourse maneuvers

(3) Lighting conditions which are compatible with backup procedures

(4) Low terminal-approach velocities and line-of-sight angular rates

(5) Backup procedures for guidance-systems failures

The requirement to allow sufficient time for crew procedures had an effect on several of the Gemini missions. For example, the first orbits of the Gemini VI–A and VIII missions were free of rendezvous maneuvers, allowing the crew sufficient time to verify the satisfactory operation of all spacecraft systems. The Gemini X primary rendezvous was changed from a third-orbit to a fourth-orbit rendezvous to allow the crew sufficient time to conduct the heavy procedural workload required by the star-horizon onboard orbit determination.

The second procedural requirement, approach trajectories which are reasonably insensitive to insertion dispersion and errors in midcourse maneuvers, was also important in the development of the fourth-orbit rendezvous. An objective was to develop a mission which could effect a near-nominal terminal-approach trajectory notwithstanding insertion dispersions, spacecraft equipment degradation, or ground tracking and computation errors. This objective established the need for the development of backup terminal-phase procedures in the event of a guidance-component failure.

The need for lighting conditions (fig. 2–15) compatible with backup procedures affected all the rendezvous missions. The desired lighting situation for an active target was that the crew (1) see the target by reflected sunlight prior to and at terminal-phase initiation, (2) see the target acquisition lights against a star background during the terminal transfer, and (3) see the target by reflected sunlight for docking after exit from darkness. This lighting situation enabled the crew to maintain target visibility throughout the terminal-rendezvous operations, and established the capability for making inertial line-of-sight angle measurements in the event of a guidance platform failure. The lighting requirement was a factor in selecting the location of the terminal-phase-initiation point, the central angle of the transfer, and the terminal-approach angle. The desirable lighting conditions for rendezvous with an active target were different than for rendezvous with a passive target (fig. 2–16). Since a passive target would not

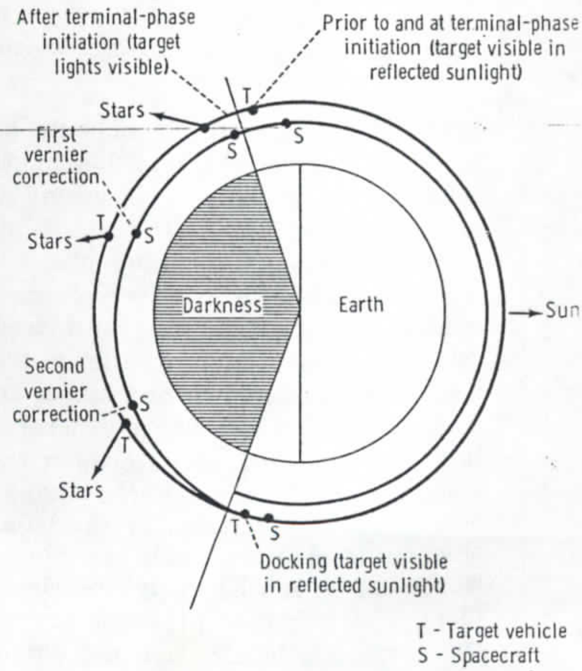

FIGURE 2–15.—Desired lighting situation for primary rendezvous.

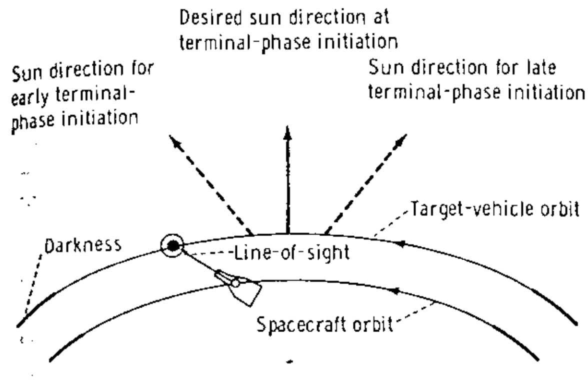

FIGURE 2-16.—Desired lighting situation for passive rendezvous.

be visible in darkness, the terminal-phase portion of the Gemini X dual optical rendezvous was conducted entirely in daylight. The desired terminal-phase initiation occurred near the midpoint of the daylight period. Earlier initiations would have placed the sunline too near the line of sight to the target, thereby obscuring target visibility. Later initiations would not have allowed adequate time in daylight for completing the rendezvous. Gemini experience has shown that lighting is not a major constraint for an active rendezvous provided the spacecraft guidance system does not fail during the terminal approach; but lighting is a major constraint for an optical rendezvous.

The fourth requirement was that the terminal trajectory allow a low terminal-approach velocity and low line-of-sight angular rate. The requirement was important in selecting the trajectory parameters for the coelliptical and the first-orbit rendezvous plans. The 130° transfer utilized on several of the missions was chosen primarily because of the low line-of-sight angular rate near intercept. The biased apogee approach was selected for Gemini XI because the direct tangential approach would have resulted in a high closing velocity.

Throughout the Gemini Program, there was a question of the level of effort to be applied to the development of backup procedures to accommodate guidance-system failures. During the Gemini XI first-orbit rendezvous mission, a problem with the radar system developed just prior to the final terminal-phase midcourse correction. Even though a backup solution for this maneuver was computed and applied, rendezvous could have been accomplished without the correction, since the correction required in this particular instance was small (2 ft/sec). However, on Gemini XII, a failure of a primary guidance-system component required the use of the backup procedures. The radar system failed prior to the terminal-phase-initiation maneuver on this mission, and backup procedures were employed throughout the terminal phase to complete the rendezvous.

The terminal phase of a rendezvous operation involves precision maneuvers and careful control of closing and line-of-sight rates. Table 2–IV compares fuel expenditures encountered during terminal-phase operations with the theoretical minimum. A considerable variation exists between the ratio of actual-to-minimum propellant for various types of terminal-phase conditions, and also for different flights using the same or similar terminal-phase conditions. This variation reflects the critical nature of the task, in that fairly small velocity vector errors can cascade to high propellant consumption or failure to complete the rendezvous. The braking operation is particularly critical. Braking too soon will increase line-of-sight control requirements, and require more time to control the spacecraft during the closing sequence.

An additional comparison of rendezvous performance is shown in table 2–V where the actual terminal-phase vernier corrections are compared with the preflight minimal predicted. This comparison provides an especially good measure of guidance-system performance, since the maneuvers were nominally very small and became large only with degradation of guidance-system performance or with control difficulties.

A number of terminal-phase rendezvous operations were satisfactorily completed during the Gemini Program by using optical

TABLE 2–IV.—*Rendezvous Propellant Usage*

Gemini mission	Type of rendezvous	Conditions at start of terminal phase	Propellant usage, lb		
			Actual	Minimum	Ratio
VI–A	$M = 4$	Coelliptic: $\Delta h = 15$ n. mi. $\Delta X = 25$ n. mi.	130	81	1.6[illegible]
VIII	$M = 4$	Coelliptic: $\Delta h = 15$ n. mi. $\Delta X = 25$ n. mi.	160	79	2.0[illegible]
IX–A	$M = 3$	Coelliptic: $\Delta h = 12$ n. mi. $\Delta X = 22$ n. mi.	113	68	1.6[illegible]
IX–A	Optical	$\Delta h = 2.5$ n. mi. $\Delta X = 3.5$ n. mi.	61	20	3.0[illegible]
IX–A	From above	$\Delta h = -7.5$ n. mi. $\Delta X = -10$ n. mi.	137	39	3.5[illegible]
X	$M = 4$	Coelliptic: $\Delta h = 15$ n. mi. $\Delta X = 30$ n. mi.	360	84	4.2[illegible]
X	Optical dual	Coelliptic: $\Delta h = 7$ n. mi. $\Delta X = 12$ n. mi.	180	73	2.46
XI	$M = 1$	Spacecraft at apogee of 87/151 orbit: $\Delta h = 10$ n. mi. $\Delta X = 15$ n. mi.	290	191	1.52
XI	Stable orbit	$\Delta h = 0$ n. mi. $\Delta X = 25$ n. mi.	87	31	2.81
XII	$M = 3$	Coelliptic: $\Delta h = 10$ n. mi. $\Delta X = 20$ n. mi.	112	55	2.04

TABLE 2–V.—*Vernier Correction Solutions for Primary Rendezvous*

Gemini mission	Actual correction, ft/sec		Nominal correction, ft/sec	
	First	Second	First	Second
VI–A	11	7	1	2
VIII	15	9	1	0
IX–A	1	3	2	5
X	20	23	2	3
XI	6	2	0	2
XII	2	5	2	5

techniques alone (no closed-loop radar-computer operation). Optical rendezvous requires careful control of lighting conditions, and a stabilized reference such as an inertial platform is highly desirable. During simulations, rendezvous have been effected without platform information; however, the probability of success is relatively low.

Concluding Remarks

The rendezvous operations conducted on Gemini have demonstrated that rendezvous is operationally feasible with an active or a passive target. It has also been demonstrated that the operation can be performed using only onboard guidance information after lift-off; using only ground-supplied information; or by using a combination of onboard and ground-supplied information.

Reference

1. ANON.: Gemini Midprogram Conference, Including Experiment Results. NASA SP-121, 1966.

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An Assessment of Rendezvous Accomplishments

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As the Gemini Program closes, it is fitting to review the accomplishments that have been made in one of the major objectives of the program—space rendezvous. Just two years ago, rendezvous was in the research stage, with speculation or uncertainty, even controversy, prevailing on its difficulty. Now real in-flight experience has been achieved, with the finding on the whole that rendezvous is not a particularly difficult operation. Certain problems have been singled out, however, and some of these will be brought out in the ensuing discussion.

In making this review, we would like to center discussion around an earlier report on rendezvous, Reference 1, and on the table given at the end of this article. Reference 1 has been chosen because it gave a review of rendenzvous concepts while they were still in the research stage. The report presented research findings and indicated problems and possible operational aspects and procedures of rendezvous as envisioned at that time; it thus gave an outlook, and served as a prognosticator of rendezvous operations. It was felt worthwhile to see how good the outlook and procedures set down in the report have proved in the light of actual flight experience. The table serves to help focus on the various rendezvous operations made in the Gemini flights; entries are not as complete as they might be, particularly near the bottom of the listing, because of the lack of published information at this time.

It is stated as a reminder at this point that the Gemini Program had other main objectives beside rendezvous and docking. Other objectives included (a) subjecting two men and equipment to long duration flights, (b) investigating extravehicular activity, and ability to perform various tasks while in space, (c) perfecting methods of re-entry and landing at pre-selected landing areas, and (d) gaining additional information concerning the effects of weightlessness, and physiological reactions of crew members during long duration missions, and other medical data required in preparation for the lunar missions of the Apollo Program. This discussion, however, is restricted mainly to the rendezvous and docking objectives.

The following is a listing of the possible uses of rendezvous that was given in reference 1.

Assembly of orbital units
Perform space missions with smaller launch vehicles
Personnel transfer
Rescue
Retrieval
Proper placements of special purpose satellites
(24-hour orbiter, communications satellites)
Inspection
Interception

Let us review these items with respect to accomplishments.

Assembly: The link-up of Gemini VIII with its Agena target on March 16, 1966, was the first complete rendezvous and docking operation and represents the first time vehicles have ever been "assembled" in space. Connections in this case were made automatically through use of self-latching mechanisms. The securing together of parts, as by use of bolts and nuts, has not been demonstrated, but certain of the extravehicular activities (EVA) by Collins in the Gemini X flight in which he recovered a micrometeorite detection box from Agena VIII, and the EVA by Aldrin in Agena XII involving various plug and bolt exercises, may be considered similar to the operation of manually attaching or securing a part. Some of the earlier EVA indicated that it was more difficult to perform a task than anticipated, or that it took longer, mainly because of encumberances of the umbilical cord or of specific parts of the spacesuits such as the gloves. Thus, improvements in suit design and feel through the fingers, and perhaps improved work scheduling, are needed if assembly is also to include small parts' attachment.

Space missions: The fact that rendezvous allows space missions to be performed with smaller launch vehicles is straightforward; this reason is one of the fundamental reasons why Lunar Orbit Rendezvous (LOR) was chosen for the Apollo mission. The basic idea of LOR was brought out in Reference 1; References 2 and 3 discuss the scheme in greater detail.

Transfer and rescue: Operations to date have not included personnel transfer and rescue. The EVA by White, Cernan, Collins, and Aldrin, were, however, not too far removed from transfer operation, since depressurization, hatch opening, and physical transfer from one environment to another were involved. In fact, personnel transfer through use of air locks would seem to be easy in comparison to some of the EVA exercises tried. Shuttle transfer, as with a space station operation, still remains to be done, however.

Retrieval: As was mentioned earlier, retrieval—at least of small packages—has been demonstrated (the retrieval of the micrometeorite detection box by Collins from Agena VIII).

Placement: The placement of special purpose satellites at specific points in space has been demonstrated now several times. Reference is made here to the several communication satellites, such as Syncom, that have been orbited.

Inspection: Inspection was very vividly demonstrated by Stafford and Cernan in their Gemini IX-A flight. They flew in close to and encircled the Augmented Target Docking Adapter (ATDA), the standby replacement for the Agena target vehicle, visually inspected it from numerous vantage positions, and took pictures, thus confirming the suspected trouble that the shroud had not left the vehicle. Stafford's words indicated the detail of the inspection possible: "We have a weird looking machine here ....both the clam shells of the nose cone are still on but they are open wide. The front release has let go and the back explosive bolts attached to the ATDA have both fired....the jaws are like an alligator's jaw that's open at about 25 to 30 degrees and both the piston springs look like they are fully extended.... It looks like an angry alligator out here rotating around."

Interception: The item interception in the list was intended to refer to a hard type rendezvous wherein one vehicle forceably intercepts another space vehicle (analogous to the Sidewinder missile concept). This type rendezvous has not been demonstrated.

Thus, it is seen that almost all the uses originally envisioned for rendezvous have been demonstrated by the Gemini flights.

We want now to examine rendezvous accomplishments from a more technical point of view. To do this, we give first a brief description of the Gemini rendezvous equipment and then discuss various rendezvous developments, essentially along the line used in Reference 1.

Gemini Rendezvous Equipment

Control of the Gemini spacecraft was accomplished by means of an orbital attitude and maneuver system (OAMS) as depicted in Figure 1. The system was bipropellant, and had a total ΔV capability of about 700 fps for Gemini VI through IX, and up to about 900 fps for X, XI, and XII. These figures included allowance for any attitude hold useage that might be involved. Three manual modes of operation were available for attitude control about the three axes: (1) a direct on-off mode in which the thrusters simply turn on when the stick is deflected; (2) a rate command mode in which angular rate is proportional to stick deflection; and (3) a pulse mode in which the deflection of the stick out of detent gives one pulse. Translation control was by direct mode only. Both platform and horizon-scanner modes were also available to the system. Separate control systems were provided for re-entry attitude

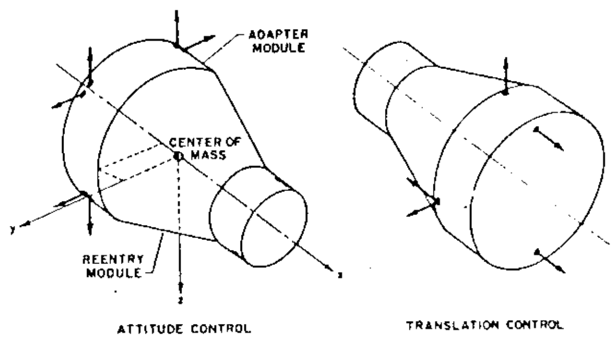

Fig. 1. Orbital attitude and maneuver system of the Gemini Space Craft

and retrograde maneuvers. Other rendezvous equipment on the Gemini included radar, a rendezvous computer, a docking light, an "8-ball" or artificial horizon instrument for alignment, a sextant, a windshield reticule for bore-sighting, and a nose docking cone. Digital readout from the radar-computer link provided maneuver information to the pilots, such as time of application and amount of fore-aft, right-left, or up-down thrusting they were to make with the vehicle bore-sighted on the target. Angle information was furnished from the platform. An optical scheme involving on-board charts with step-by-step procedures also was developed for use in terminal phase operations, to provide a check and a back-up or alternative scheme to the radar system. The Agena had a radar transponder, a docking cone receptacle with lights, and an instrument panel for assessing the state of the vehicle. A cold gas system was used for Agena stabilization.

Launch Windows and Ascent

Because rendezvous involves precise timing, a concern existed earlier in rendezvous considerations as to whether pad hold times would cause serious interference with the ability to execute rendezvous (in the general case, the launch window is only a few minutes). A scheme was therefore developed to increase the launch window up to several hours. As outlined in Reference 1, the scheme involved two basic ideas: (1) the use of a target orbit plane with an inclination only about 1° greater than the latitude of the launch site; and (2) the use of a chasing or parking orbit. The use of such an inclination would place the launch site in the vicinity of the target plane for several hours, with the thought that the launch for rendezvous could be made anytime during the interval without excessive fuel penalty being caused. The chasing orbit idea was to allow for the adjustment of orbital phase; that is, it would allow the orbit angular positions of the two vehicles to be brought together.

An interesting finding of the Gemini Flight Program is that these large launch windows were not needed. It was found that if trouble occurred on the launch pad it could either be remedied in a few minutes, or it was such that a day or days of delay might be involved. Thus, large launch windows associated with launch vehicle and spacecraft readiness were not required. Another type of constraint was introduced, however.

This constraint was the requirement introduced to execute the terminal phase and docking maneuvers during darkness—at least for the first few flights. This condition dictated to some extent when the launch of Gemini was to be made. The target plane inclination chosen in the flights was a value about one-half degree greater than the launch latitude of 28.34°. This choice still gave a launch window of about two hours, which gave adequate flexibility to achieve a rendezvous during darkness, and yet kept out-of-plane corrections to a minimum; that is, the major portion of any out-of-plane corrections could be made through use of a dog-leg type of trajectory during thrusting portions of Gemini Launch Vehicle (GLV) flight, without serious fuel penalty.

Orbit Choices

For accomplishing catch-up in angular position, Reference 1 outlined two concepts, one called a parking orbit in which the interceptor was in an inner orbit essentially co-circular or co-elliptic with the target orbit, the other an elliptic chasing orbit in which the apogee of the interceptor orbit was tangent to the targent orbit. In either case, the interceptor can close in on the target angular position with each revolution because of the smaller period associated with the inner orbit. Originally in the Gemini Program, the plan was to use the second of these two procedures. Later, from research work and experience gained in additional simulator studies of terminal phase and docking operations, it was decided to change the plan to one which effectively represented a combination of the two concepts. The plan finally adopted and used in the Gemini flights was to use an elliptic chasing orbit with an apogee about 15 miles lower than the target orbit altitude; the target orbit was to be essentially circular. Terminal phase initiation (TPI) was thus purposely designed to take place when the Gemini was slightly below and behind Agena; this would allow the terminal phase to be performed looking away from the Earth.

Figure 2 illustrates orbit altitude variations as envisioned in earlier planning and as finally adopted in a representative Gemini flight, in this case Gemini VIII. The figure indicates the time of initiation of some of the more significant maneuvers, and also serves as a means for defining some of the terminology used in describing the flight profile. As an example, the Gemini VIII flight profile shown is referred to as an $m = 4$ rendezvous, where m is defined essentially as the number of apogee passages before TPI.

To help interpret Figure 2 and as a means for quickly estimating some of the relative orbital parameters that pertain to rendezvous cases in general, the following good approximations obtained from the laws of orbital mechanics are offered for those who might like to make their own quick estimations. See also Figure 3. For the difference in orbital period,

$$\Delta T = T_1 - T_2 = 3/4 \frac{\varepsilon_a + \varepsilon_p}{r_1} T_1.$$

For the change in circumferential range position each revolution,

$$\Delta R = 4.72 (\varepsilon_a + \varepsilon_p).$$

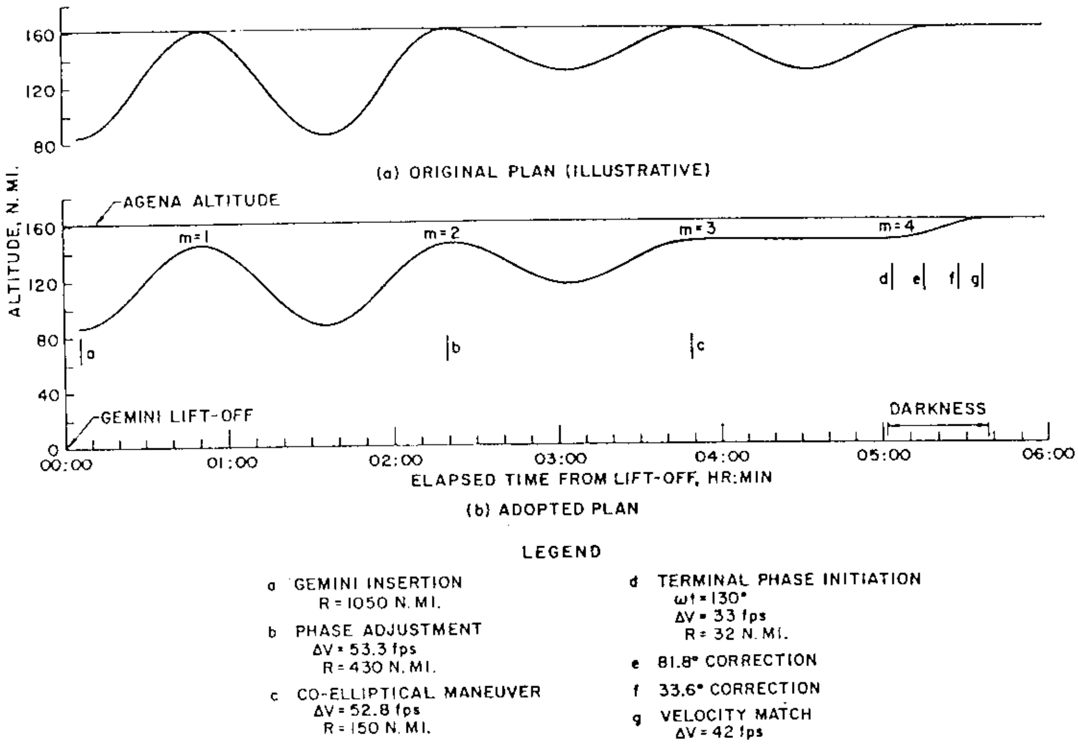

Fig. 2. Orbit plan for Gemini 8 (R equals range between Gemini and Agena).

TABLE 1 GEMINI FLIGHTS AND RENDEZVOUS ACCOMPLISHMENTS

Flight	*Dates*	*Crew*	*n*	*Objectives*	*Experiments*	*Remarks*
GT-1	April 8, 1964	Unmanned	64	Check dynamic loads; demonstrate structural compatibility of spacecraft and launch vehicle	—	—
2	Jan. 19, 1965	Unmanned	Sub-orbital	Flight qualify total spacecraft as integrated system	—	—
3	March 23, 1965	Grissom-Young	3	Manned qualification of spacecraft; precise orbit changes	3	Orbit change, 100–139 to 98–105; out-of-plane change; OAMS fired to slow down as in re-entry—gave perigee of 52
4	June 3–7, 1965	McDivitt-White	62	Spacecraft performance for 4 days; prolonged exposure; EVA; station-keeping and rendezvous with 2nd stage, out-of-plane maneuvers; OAMS as backup to retrograde system	11	White 20 mins. outside; rendezvous cancelled; computer re-entry cancelled; ballistic-type re-entry—computer out
5	Aug. 21–29, 1965	Cooper-Conrad	120	Demonstrate performance for 8 days; evaluate rendezvous and navigation system used Radar Evaluation Pod; prolonged exposure	17	Rendezvous with "phantom" Agena; 124.2–193.2 s. m. orbit sought, 124.0–192.6 obtained; L band radar link with Cape; first use of fuel cell and rendezvous equipment; simulated some TPI tasks; landing short due to error in retrograde timing
7	Dec. 4–18, 1965	Borman-Lovell	206	Long duration flight; medical and exposure effects; target for 6	20	Station keeping exercises with 2nd stage; orbit circularized to 186 s. m.; removed suits
6	Dec. 15–16, 1965	Schirra-Stafford	16	Closed-loop rendezvous with 7	—	$m = 4$ rendezvous of 6 with 7 to within 1 foot—the 1st "manned" rendezvous in space; station keeping about 7; quick pad turn around; 1st manually controlled re-entry to predetermined point
8	Mar. 16, 1966	Armstrong-Scott	7	Rendezvous and docking; EVA	4	$m = 4$; tumbling encountered after docking; multiple Agena restart; Agena later sent to 221 circular parking orbit involving 10 maneuvers; 1st docking; 2nd rendezvous of 2 spacecraft; 1st rendezvous of manned with unmanned; 1st successful Agena target; 1st (emergency) retrieval in secondary area; 1st countdown of 2 vehicles; Scott EVA not made
9-A	June 3–6, 1966	Stafford-Cernan	50	Major rendezvous investigation flight; EVA for Cernan	3	Agena lost; ATDA used instead—shrouds did not separate, precluded docking; 3 rendezvous, 1st was $m = 3$, one was 1st pure optical, two in daylight; 2 hrs. 5 mins. of EVA; AMU presented difficulty
10	July 18–21, 1966	Young-Collins	44	Rendezvous and docking with with Agena 10; rendezvous with Agena 8; two EVA's	14	35 sec. launch window for $m = 4$ rendezvous with 10 and later on-board rendezvous with A-8; excessive fuel usage in 1st; maneuvering and Agena [illegible] object; space [illegible] and troubles

TABLE I (Continued)

Flight	Dates	Crew	n	Objectives	Experiments	Remarks
11	Sept. 12–15, 1966	Conrad-Gordon	44	m = 1 rendezvous and docking		1st rendezvous and docking during 1st orbit, all on-board; 4 dockings; 1st automatically controlled re-entry
12	Nov. 11–15, 1966	Lovell-Aldrin	59	Rendezvous and docking; EVA; tethering		m = 3 rendezvous; backup optical and chart scheme used due to radar failure; 2 dockings; tethering experiment led to gravity gradient capture; automatically controlled re-entry

n = No. of revolutions

For the relative velocities at apogee,

$$\Delta V_a = V_1 - V_a = \left(\frac{\varepsilon_p}{4r_1} - \frac{3\varepsilon_a}{4r_1}\right) V_1.$$

Illustrative numbers as obtained from these equations for conditions approximating the first apogee passage shown in Figure 2 are

$$h_1 = 185 \text{ sm}, \quad r_1 = 4145 \text{ sm},$$
$$h_a = 168 \quad, \quad r_a = 4128 \quad, \quad \varepsilon_a = 17$$
$$h_p = 100 \quad, \quad r_p = 4060 \quad, \quad \varepsilon_p = 85$$
$$\Delta T = 0.01845\ T_1$$
$$= 0.0184 \times 90.5 = 1.66 \text{ min.}$$
$$\Delta R = 482 \text{ sm}$$
$$\Delta V_a = 52 \text{ fps.}$$

In addition, the following equation illustrates the sensitivity of altitude change to velocity change; specifically the change in apogee height due to a velocity increase ΔV_p at perigee is given by

$$\Delta r_a = \frac{2\, r_a (r_a + r_p)}{r_p} \frac{\Delta V_p}{V_p}.$$

For the orbital values listed in the preceding illustration, this equation indicates that a $\Delta V_p = 1$ fps at perigee produces an apogee increment of 0.66 statute miles ($V_p = 25{,}370$). In the flights, it was found that orbital altitude or height adjust maneuvers could be made quite readily. In fact, velocity changes to within 0.1 fps were found possible.

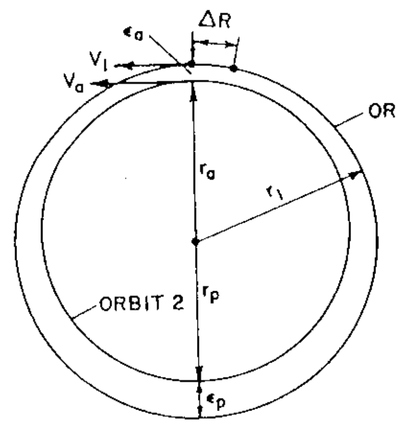

Fig. 3. Orbital parameter definitions

Terminal Phase

As pointed out in Reference 1, a very substantial research effort went into investigating the terminal phase of rendezvous. Both analytical and simulator studies were made, including piloted and automatic control. Two broad categories of schemes evolved. One was labeled the "orbital mechanics" approach in which a coasting-type trajectory is followed with thrust correction being made at intermediate points to control the flight path. The other was called the "proportional navigation" type, wherein a flight path is followed such as to keep the angular rate of the line of sight essentially zero (inertially fixed). Interestingly, in the Gemini program a combination of the two schemes was selected. For the first part of the terminal phase, the orbital mechanics scheme was used. The terminal phase initiation (TPI) point, or first terminal phase burn, was chosen so as to give a terminal phase lasting over about 130° of orbital travel. Two other correction burns were then made, one at about 80° of travel remaining, the other at about 30° to go. The on-board computer indicated, at intervals of about 800 seconds, the magnitude and direction of the corrective thrusts necessary. After the burn at 30°, guidance was made in accordance with the proportional navigation scheme, using a visual line of sight with star background.

During the final portion of the terminal phase, braking maneuvers as given by a preplanned schedule were applied. Range was given by the on-board radar; range rate for use in the braking maneuvers was found simply by crude time differentiation of the range signal—incremental range divided by incremental time. Braking started at about 2-1/2 miles out with a reduction to about 40 fps from 50 fps. By 3000 ft away, the relative velocity had been brought down to 5–10 fps. In an optical approach, the sextant was used to guide the braking maneuvers. The sextant was also available for angle information in event of platform failure. (See also discussion in Reference 4.)

The nominal rendezvous plan adopted was essentially the following: The Agena target vehicle was to be placed in a near circular orbit of altitude near 185 statute miles with its axis perpendicular to the orbital plane. This attitude was selected to improve its visibility, especially in daylight, because of the large reflective surface presented, and because at night the running lights it carried could be seen better. The approach, as mentioned, was to be from behind and below, with the Gemini axis bore-sighted onto the Agena. During the final stage, the Gemini was to come up in front of the Agena orbital path and simultaneously execute a 180° yaw maneuver so that the resulting situation would be essentially the Gemini flying "backwards" in front of the Agena. To dock, the Gemini would move from this position in a side-wise motion, essentially facing and pivoting about a vertical axis through the Agena, until alignment was made with the Agena axis. Final docking motion thus meant movement perpendicular to the orbital plane. Figure 4 is given as an indication of the magnitudes of some of the motion parameters that were involved in a nominal terminal phase plan.

In general, the terminal phase maneuvers were found to be quite easy for the rendezvous operations made with a closed-loop type of control, with the approach from behind and below, and involving the use of radar and visual line of sight. Darkness and the use of the flashing light on the Agena target were of considerable help. Other rendezvous with lesser instrumentations and with different approaches were also tried to assess difficulty. For example, with Gemini IX-A, after the first rendezvous in darkness—which actually was a rendezvous simulating the rendezvous that is being considered in the LOR plan—a second rendezvous was made using on-board optical devices only, and in daylight operations. Questions being studied were whether a target could be seen in bright sunlight and whether rendezvous could be completed without backup lighting. The rendezvous was defined as achieving a position 2-1/2 miles above, 11 miles behind, and with equal orbital period as the Agena target. It was successfully accomplished, but Stafford's comment on visibility is interesting. On this flight the shroud failed to come off the ATDA; docking was thereby precluded, but the optical rendezvous was helped considerably because of the brilliant reflection pattern the large shroud gave in the sunlight—in his words, a "blessing to see."

Following this, another close-in rendezvous was attempted in the daylight by an approach from above and behind, as might be necessary in the lunar-orbit rendezvous mission in event of an aborted descent. In this attempt, the Agena target became lost frequently in the Earth's background, and without the radar, the target may have been lost completely. The wisdom of choosing a basic rendezvous approach from behind and below, as additional research and ground-based simulators had shown, and the value of a radar link, were thus demonstrated.

In the Gemini X flight, still another type of rendezvous was made after rendezvous and docking with the Agena X target vehicle. The Agena rockets were used to make orbit maneuvers and to boost the Gemini-Agena combination into a higher orbit so as to make a rendezvous with the spent Agena VIII vehicle which had been boosted to a higher circular parking orbit (221 s. mi.) following the Gemini VIII flight. The plan to make both of these rendezvous involved an initial launch window of only 35 seconds. Three additional complications were involved in the Agena VIII rendezvous: (1) the rendezvous was made with an uncooperative target since the radar transponder was no longer working; (2) it, therefore, had to be done optically only; and (3) it was done in daylight. In this instance, a phasing orbit having apogee larger and a perigee smaller than the target orbit was used. Rendezvous was very successful, and, in fact, it was on this rendezvous that the retrieval of the micrometeorite detection box from Agena VIII was made. Figure 5 depicts the relative trajectory followed during the terminal phase; the figure is representative of terminal phase motion as used

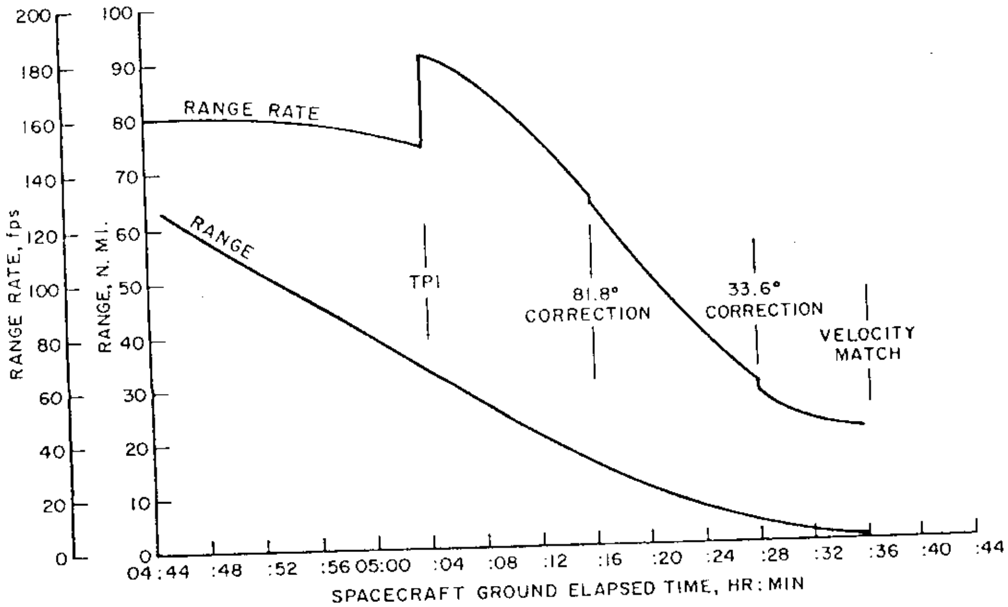

Fig. 4. Planned range and range rate during last sixty n.m. of catch up for Gemini 8.

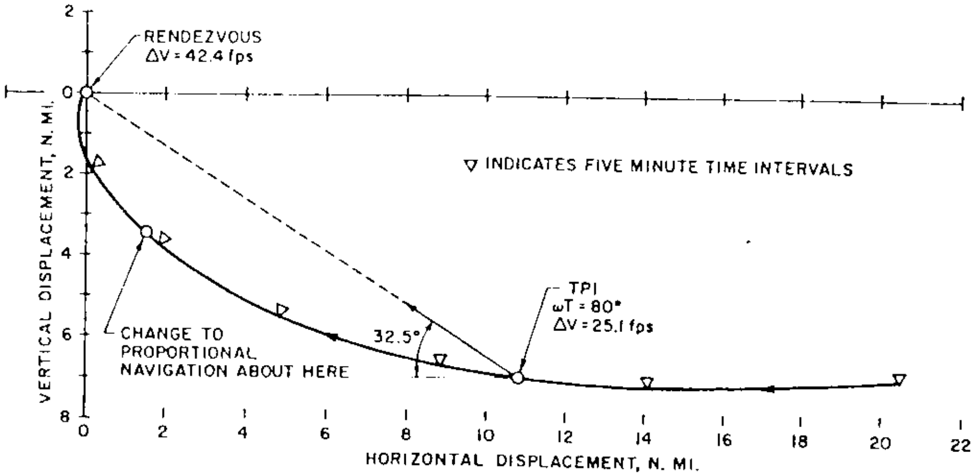

Fig. 5. Terminal phase path of Gemini 10 relative to Agena 8 (coordinates rotating about earth and centered in Agena).

in other flights. A TPI with 80° travel remaining is noted in this case, however, in contrast to the 130° value nominally chosen.

The rendezvous mission of Gemini XI was distinguished because of several reasons. Simultaneous countdowns of both the target and the Gemini vehicles were proved, and the rendezvous was the first to be made with on-board equipment alone during first orbit ($m = 1$). A plane change maneuver at the first nodal crossing was also involved. A second rendezvous involving a standoff point about 15 miles behind and at the same altitude was also made; this was made with input from ground control because of the failure of the radar transponder. To point out more specifically the role of ground control and the on-board computation in deciding on the rendezvous maneuvers, the following summary is given:

For flight 6, ground control gave the insertion correction, and the corrections to apply at first perigee, second apogee, and third apogee circularization; from then on, the pilots were on their own. This was essentially true also for flights 8, 9, and 10. For flight 11, $m = 1$ rendezvous, ground control gave insertion data only; all the remaining maneuvers, including out of plane corrections, were made by on-board computation. In flight 12, the radar link failed, and rendezvous was made by the on-board optical back-up procedure.

Flight 12 also included a tethering experiment involving a cable connection between the Gemini and Agena vehicles. Malfunction of two thrusters caused difficulty in the experiment, but evidence at the moment is that successful gravity gradient capture was realized in the tethered and taut cable state.

From the point of view of mathematics, most of the computer logic and motion analysis was made in accordance with the first-order terminal phase laws that are given in Reference 1, with modification to include a curvilinear coordinate rather than an axis tangent to the flight path, thus giving some slight improvement in accuracy. Since trajectory control during rendezvous operations proved to work out essentially as planned, it would seem that the first-order laws are quite adequate, at least for terminal phase distances of magnitude as encountered in the Gemini flights. In instances where excessive fuel was reported to have been consumed during some of the earlier station-keeping exercises, the trouble appears to have been mainly that control was not made in an efficient manner, or that initial conditions that developed made the problem more severe than it was supposed to be. (In some instances, inadvertent opening of thrusters for prolonged periods of time was also involved.)

Docking and Station-Keeping

The Gemini flight experience indicated the docking and station-keeping operations to be relatively easy. A large part of this outcome is attributed to the excellent training that was made possible through the various ground-based docking simulators, in particular the simulator at the Langley Research Center and the one at the Manned Spacecraft Center.

For docking, the Gemini had a docking floodlight; and alignment control was assisted by means of the "8-ball" or artificial horizon instrument. The Agena docking cone also had lights, including, in particular, a circular fluorescent tube around the edge of the docking cone. The Agena also had an instrument panel mounted near the cone so that the pilots could monitor the readiness of the Agena vehicle before docking. The Agena nose cone had a V-cut out which, through means of a radial rod on the Gemini, aligned the two vehicles precisely in roll during the final few inches of movement of the Gemini nose cone. As the nose cone bottomed, three automatic latches secured the two vehicles together.

Flight plans called for a nominal closing-docking velocity of about 1 fps to insure latching. In the first docking exercise, Armstrong brought the crafts together at a velocity of 3/4 fps—in his words "a real smoothie." Almost all docking and station-keeping activities in subsequent flights indicated equal ease in performance. It appears that motion for close-in station-keeping distance is governed adequately by the simple laws of a gravity-free field, since no particular difficulty due to orbital mechanics appeared to complicate the maneuvers. The flight experience indicated that station-keeping could be performed well as long as the distance was about 200 feet or less, since distance judgment in this interval was found to be fairly good.

Research Studies

A considerable amount of research effort went into the rendezvous problem prior to Gemini, and, as mentioned earlier in this review, helped to set the stage for the actual procedures used in flight. Some of the research continued during the Gemini program to tackle specific problems, and some is still underway with respect to rendezvous as it will be used in the Apollo project. Reference 5 gives information gained from simulator studies on visual aspects of docking. The report showed that lack of visual cues can lead to terminal errors as might be expected, and that with adequate visual information, pilots can complete successful docking consistently under both day- and night-lighting conditions.

Reference 6 gives results of a study of remote controlled docking with television, and shows that this form of control is quite feasible. In Reference 7, simplified guidance schemes are investigated, and a simple thrusting logic scheme is developed for setting up and maintaining a station-keeping operation from a set of arbitrary initial conditions. Reference 8 represents an interesting analytical study of "second-order" orbit equations in application to determining the orbit of an object vehicle from observations made in another spacecraft in a known circular orbit. Results are accurate and show considerable improvement over first-order theory for the case of relatively long trajectories with large separation of the vehicles. Studies of this type should be valuable in application to the Lunar-Orbit-Rendezvous problem.

Concluding Remarks

Previous research study and Gemini flight experience have provided us with much insight and experience on the problem of rendezvous in space. The flight experience has turned out unexpectedly broad. Rendezvous has been made with cooperative targets using a closed-loop radar link, with uncooperative or "dead" targets, in night- and daylight-lighting conditions, and with on-board optical schemes. In some flights, several rendezvous have been made, including a boost to a much higher altitude by means of the attached target vehicle. Rendezvous operations have even included the successful undocking from another vehicle following unplanned and wild gyrations of the combined vehicles that arose due to a thruster which opened. In general, the feeling is that most rendezvous operations are not particularly difficult.

Mention should also be made of the quick pad turnaround time as involved in the Gemini VII and VI flights. This may be an important aspect of some future space flights as with a space laboratory. Simultaneous countdown of two vehicles was also demonstrated in the Gemini XI flight. Another part of the Gemini flights that was not touched upon in this review specifically, but which is very much a part of over-all rendezvous operations, is the landing and recovery problem. Gemini demonstrated that various kinds of re-entry and landing schemes may be used. Both pilot and automatic control of re-entry and landing, with accuracy to within a few miles of the target point, and an "emergency" type landing in a secondary area, all were proved.

The program brought out the fact that successful accomplishment of various space mission objectives depends, of course, on the reliability of the hardware. Some of the difficulty encountered with hardware items included stuck thrusters, a failed transponder, a non-separated shroud, fuel-cell troubles, and improper suit operation. Thus, the importance of hardware development, of reliability, and the use of redundant systems is brought out. In this connection, it is noted that flexibility of operation is a significant factor in space operations. The fact that mission redirection or changes could be made successfully when difficulty or hardware failures were encountered, or when emergency arose, is, in itself, a remarkable achievement.

In concluding this review, we mention that the Gemini program also shows that certain rendezvous problems still need further attention. Without elaboration, some of these problems are the following: Terminal phase approaches besides that of from below and behind are in need of further development. Optical schemes could stand improvement, and consideration should be given to the use of optical filters for discerning target vehicles having a camouflaging background. The so-called simplified on-board guidance and trajectory schemes need streamlining to improve their ease of application. Thus, a somewhat universal and easily understood guidance scheme for handling the general rendezvous problem should be sought. And, finally, rendezvous operations around the moon, especially for abort-type maneuvers, for application to the Apollo mission should be examined for possible improvements.

Acknowledgement

I wish to express thanks to my friends at Langley Research Center and at the Manned Spacecraft Center who helped in supplying much of the information contained herein—including from the latter, Messrs. B. Evans, D. Carley, P. Kramer, E. Lineberry, and in particular, C. Mathews, Gemini Program Manager. Their cordial and generous help is much appreciated.

References

1 John C. Houbolt, "Problems and potentialities of space rendezvous," *Astronautica Acta* 8, 406–429, (1961); AMR 15 (1962), Rev. 7384.

2 John C. Houbolt, "Lunar-orbit rendezvous and manned lunar landing," *Astronautics* 26–35, Apr. 1962.

Cobb, "Visual aspects of a full-size pilot-controlled simulation of the Gemini-Agena docking," NASA TN D-2632, (1965); AMR 18, (1965), Rev. 3903.

6 E. R. Long, Jr., J. E. Pennington, and P. L. Deal, ... with television," NASA

3 John C. Houbolt, "Lunar rendezvous," *International Science and Technology* 62–70, Feb. 1963.

4 Proceedings of the Gemini Mid-Program Conference, Feb. 23–25, 1966, Houston, Texas.

5 J. E. Pennington, H. G. Hatch, E. R. Long, and J. B.

7 G. C. Moen and J. R. William, "A simplified guidance technique for station keeping," AIAA Guidance and Control Specialist Conference, Seattle, Washington, Aug. 1966.

8 R. S. Dunning, "Determination of orbit of a spacecraft with respect to an object in a known circular orbit," NASA ... (1966), AMR 18, (1966), Rev. 7435.