GEMINI

- Introduction (J. Oberg)

- Gemini III rendezvous plans, Hacker, op. cit.
- Gemini IV prox ops with Titan-II (from mission report)
- Gemini IV results, Hacker, op. cit. , and Aldrin, Men From Earth

- "GT-5 Will Test Rendezvous System", Missiles & Rockets, June 28, 1965
- Gemini-V rendezvous plans, NASA Press Kit
- "GT-5 Proves U.S. Rendezvous Ability", Missiles & Rockets, Aug 30, 1965

- Gemini VI preparations, Hacker, op. cit. , and Aldrin, Men From Earth
- Gemini VI-A Rendezvous Mission Planning, E.C. Lineberry, "Gemini Mid-Program Conference"
- Rendezvous of Gemini VII and Gemini VI-A, T.P. Stafford et al., op. cit.
- Results of Gemini VI rendezvous, Hacker, op. cit.

- Gemini 8 docking, Hacker, op. cit.

- Planning for Gemini-9, Hacker, op. cit.
- Results of Gemini-9, Hacker, op. cit.

- Planning for Gemini-10, Hacker, op. cit.
- Detailed Gemini-10 rendezvous plan report (TRW)
- Results of Gemini-10, Hacker, op. cit.
- Excerpts from Michael Collins, LIFTOFF, on GT-10
- Gemini-X rendezvous whifferdill (from mission report)

- Planning Gemini-11, Hacker, op. cit.
- Gemini-11 results, Hacker, op. cit.

- Gemini-12 results, Hacker, op. cit.
- Gemini-12 narrative, Aldrin, Men from Earth

- Summary of Rendezvous Operations, W.B. Evans and M.R. Czarnik, "Gemini Program Summary Conference"
- "An Assessment of Rendezvous Accomplishments", John Houbolt, Applied Mechanics Reviews, January 1967.

- PROJECT GEMINI: A Technical Summary, sections on rendezvous (plus details on usage of onboard backup charts)
- "Onboard Operations for Rendezvous", Kramer, Aldrin, Hayes, GPSC.

GEMINI

Now it was time to conduct rendezvous in orbit, once the studies were complete and the best techniques chosen and learned.

The earliest technique for Gemini rendezvous, as proposed from engineers at McDonnell Douglas (which built the vehicle), involved launching into an orbit whose apogee was at the target orbit and whose perigee could then be adjusted to control closing rate (see attached chart). In Houston, engineers came up with the scheme to launch into a lower orbit for phasing, then make a transfer. In both cases, terminal phase transfers were 180°.

The former case optimized for ground control (burns could be made to occur for the convenience of ground tracking and communications), while the later leaned toward on-board control (burns could optimized for lighting during terminal phase). Although the latter case lost control of AOS coverage, its advantages were recognized. The classic aerospace dichotomy between ground-based versus on-board control appeared in these considerations, and the theme continues in the manned space program (as it does elsewhere) to the present time.

Technology. Cooperative radar; optical sensors. One key rendezvous scheme consideration was designing for systems failure. For example, Gemini had only one IMU and its backup "rate hold" mode had a drift rate too high for dependable rendezvous navigation (this drove the designers to seek to utilize other more dependable reference frames, such as star background or target-LOS).

An early proposal for Gemini-III to maneuver around a jettisoned pod were scrubbed, and the pod was carried by Gemini-V (however, power problems caused the cancellation of these maneuvers). Meanwhile, on Gemini-IV, a naive and poorly-prepared plan for stationkeeping with the Titan-II booster's second stage fell afoul of orbital mechanics when the pilot, relying on airplane instincts, attempted to overtake the booster from behind and above by thrusting towards it, thus actually building up his orbital energy and flying past into a higher orbit which rapidly pulled him away from the target . The behind/above region of the relative motion plot was later privately dubbed "the McDivitt Quadrant" by rendezvous planners; many years later, during a briefing for the Solar Max mission, MS "T.J." Hart expressed his sincere intention to succeed so that there never would be any such thing as a "Hart Quadrant". The mission report plus Hacker's narrative, plus Aldrin's pointed criticisms, show what happened and why, and how the embarrassment had a major positive role in demonstrating that orbital rendezvous had to be taken seriously by astronauts, it couldn't be done with existing instincts and reflexes.

Making the Gemini-VI rendezvous work is the subject of the next several readings. Hacker discusses pre-flight procedural development and training (Aldrin's major role is described), and Lineberry discusses flight profile selection criteria. Stafford's paper describes the actual mission (Hacker gives a more superficial overview, too).

The series of rendezvous and docking operations in 1966 is then discussed. Hacker describes the Gemin-8 docking with the Agena, then the complex planning for Gemini-9 and the way it actually turned out, then the same process for Gemini-10. A more detailed discussion of the rendezvous problems on Gemini-10 (the infamous "whifferdill") is presented based on an astronaut's memoirs and on post-flight studies (NASA and TRW). Similar discussions are provided for Gemini-11 and Gemini-12, on which by incredible fate Aldrin was co-pilot and had to actually utilize the back-up manual rendezvous charts he had been developing since his PhD days at MIT (they worked, as his personal narrative proudly and correctly tells).

Summaries of Gemini's accomplishments in rendezvous are provided both by operational engineers (Evans and Czarnik) and by Houbolt, by this time departed from NASA but still eager to put his pet theme into a proper perspective.

Gemini Rendezvous Summary

Gemini-4 Jun 03, 1965 McDivitt, White
Stationkeeping with Titan-II upper stage (failure)

Gemini-5 Aug 21, 1965 Cooper, Conrad
Rendezvous Evaluation Pod (REP) rendezvous, cancelled
"Phantom Rendezvous" maneuvers

Agena-6 Oct 25, 1965 unmanned
Target for Gemini-6, failed to orbit

Gemini-6 Dec 15, 1965 Schirra, Stafford
Rendezvous/flyaround with manned Gemini-7

Agena-8 Mar 16, 1966 unmanned
Gemini-8 Mar 16, 1966 Armstrong, Scott
Rendezvous/docking with Agena-8

Agena-9 May 17, 1966 failed to orbit
ATDA Jun 01, 1966 unmanned
Gemini-9A Jun 03, 1966 Stafford, Cernan
Rendezvous/flyaround with ATDA
Optical re-rendezvous
Rendezvous from above

Agena-10 Jul 18, 1966 unmanned
Gemini-10 Jul 18, 1966 Young, Collins
Rendezvous/docking with Agena-10
Rendezvous/stationkeeping with Agena-8

Agena-11 Sep 12, 1966 unmanned
Gemini-11 Sep 12, 1966 Conrad, Gordon
Rendezvous/docking with Agena-11
Stable-orbit rendezvous

Agena-12 Nov 11, 1966 unmanned
Gemini-12 Nov 11, 1966 Lovell, Aldrin
Rendezvous/docking with Agena-12

Gemini III rendezvous plans, Hacker, op. cit.

Such key questions as how long the mission was to be and how its specific objectives were to be met were much discussed. NASA Headquarters had tentatively approved the three-orbit flight suggested by the program office in April 1963. This seemed too short a mission, however, to use the rendezvous evaluation pod (REP), long planned to check out spacecraft radar and maneuvering systems. If the mission could not be lengthened, some other means must be found "to demonstrate and evaluate . . . the procedures necessary for the support of future . . . rendezvous missions." Equally unclear was how so short a flight could do much to prepare for future long-duration missions.[28]

MSC's Flight Operations Division did prepare a tentative mission plan in October 1963 that outlined possible use of the pod during the second orbit of a three-orbit mission. But the matter was settled when, on 4 January 1965, NASA Headquarters decided to strike the pod from Gemini 3.[29] The question of mission duration surfaced again late in the summer of 1964. Word leaked to the press that Grissom and Young, backed by the Astronaut Activities Office, were pressing for an open-ended mission; that is, leaving it up to the crew to decide how many orbits to try for after Spacecraft 3 was in space. GPO was averse to the idea, since the tracking network was then geographically limited and could only fully cover three orbits. Going beyond that on the first flight might be risky. NASA Headquarters again stepped in and squelched the idea. When a reporter asked Grissom what he thought about the decision, the answer was a curt, "We can do all the testing of the spacecraft we need in three trips."[30]

One of the first-order objectives for Gemini 3—one that had to be achieved for the mission to be judged a success and any threat to which was cause enough to hold or cancel the flight—was to "demonstrate and evaluate the capability to maneuver the spacecraft in orbit using the orbital attitude and maneuver system (OAMS)."

[28] Letter, Mathews to NASA Hq., Attn: Schneider, "Gemini Mission Assignments," GV-02183, 13 March 1964; Mathews, activity report, 28 April—4 May 1964, p. 1; memo, Walter C. Williams to Actg. Mgr., GPO, "Third Gemini Flight," 6 June 1963; "Abstract of . . . Coordination Meeting (Electrical), May 1, 1962," 2 May 1962; "Abstract of Meeting on Trajectories and Orbits, July 3, 1963," 9 July 1963; letter, Low to Elms, 19 July 1963.

[29] Memo, Christopher C. Kraft, Jr., to dist., "Proposed Mission Plan for GT-3," 25 Oct. 1963, with enclosure, "Proposed Mission Plan for the GT-3 Gemini Flight," 18 Oct. 1963; Meyer, notes on GPO staff meeting, 2 Jan. 1964; memo, Low to MSC, Attn: Mathews, "Configuration of Gemini Spacecrafts #2, 3, and 4," 4 Jan. 1964.

OTSOT
p.228

Gemini IV prox ops with Titan-II (from mission report)

Although it was realized that propagation of orbital motion, particularly relative motion, was an extremely difficult and "unearthly" pursuit, this point was not driven home until the GEMINI-IV mission's embarrassing fiasco of attempting stationkeeping with the booster. It failed because the pilot (with only one pre-flight rendezvous simulation) attempted to use jet fighter techniques to close with the target rather than proper orbital mechanics. As a result of this harmless humiliation, astronauts and operators at last focussed their attentions on carrying out the rendezvous process. The rest is history.

Study Guide: Note the unexpected "plume effects" of the Gemini OAMS on the target, at the initial separation.

Points to Ponder: On the first loop, derive a workable re-rendezvous plan, and imagine having to describe it to the crew in real time.

Footnotes to History: The behind/above region of the relative motion plot was later privately dubbed "the McDivitt Quadrant" by rendezvous planners; many years later, during a briefing for the Solar Max mission, MS "T.J." Hart expressed his sincere intention to succeed so that there never would be any such thing as a "Hart Quadrant".

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GEMINI PROGRAM MISSION REPORT

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GEMINI IV

(U)

Declassified by authority of
E.O. 11652
dtd 6/1/72
this date Sept 30, 1974 D.M. Smith

NASA

GROUP 4
DOWNGRADED
AT 3 YEAR INTERVALS;
DECLASSIFIED
AFTER 12 YEARS

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1965

JUNE 1965

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION ▫ MANNED SPACECRAFT CENTER

Gemini Program Mission Report, GEMINI-IV, pp 4-7 to 4-10

4.3.1.3 Station keeping. - Time histories of separation range, azimuth, and elevation during the first revolution between the spacecraft and the second stage of the launch vehicle are shown in figure 4-5. Relative motion between the spacecraft and stage II is shown in figure 4-6. These parameters were calculated by simulating each vehicle's trajectory, utilizing the corrected IGS insertion vector as shown in section 5.1.5.2.1. An initial spacecraft - launch-vehicle separation velocity of 6 to 7 ft/sec was established through simulations during postflight evaluation. A 4.1-ft/sec velocity increment was applied to the spacecraft using the aft-firing thrusters, and a 2 to 3 ft/sec velocity increment was applied to the launch vehicle which may have been a result of the shaped-charge firing or the effect of the OAMS aft-firing thrusters impinging on the launch vehicle or a combination of both. If uncompensated, this velocity difference would build up to give a separation of approximately 17 nautical miles at the end of the first revolution. The relative trajectory for this situation is shown in figure 4-7. The trajectory obtained from the simulation appears to be compatible with the following information available from the flight crew and from ground orbit determination.

(a) At Canary Island (22 min g.e.t.), the crew was almost directly above stage II.

(b) Stage II was never above the horizon (as viewed from the spacecraft).

(c) Prior to Carnarvon (52 min g.e.t.) the two vehicles came back together within a minimum range of 0.3 nautical mile.

(d) After darkness, stage II was well below and in front of the spacecraft.

(e) At the time of the last maneuver, stage II was well below and in front of the spacecraft.

(f) The final orbit obtained from the simulation agreed within 1.3 nautical miles of the actual orbit determined by ground tracking. A detailed list of all thrusts and attitudes is contained in table 4-IV, and a summary list of all maneuvers for each thruster is presented in table 4-V.

Two retrograde maneuvers were completed by 00:09:23 g.e.t. using the aft-firing thrusters and with the spacecraft in the BEF orientation (fig. 4-8). Prior to platform alinement, one additional small thrust was made with the aft-firing thrusters and a second with the up-firing thrusters. These four thrusts, totaling 5.1 ft/sec, were applied to reduce the separation rate and were greater than the separation velocity applied by the crew.

Figure 4-9 shows the principal velocity increments applied during the first 60 minutes of the station-keeping exercise. Also shown is the spacecraft attitude at the time of these thrusts.

During the station-keeping exercise, the critical nature of rate determination was demonstrated. After separation, following the four thrusts back toward the launch vehicle, a rate of 1.5 ft/sec away from the stage II existed, whereas, a rate toward it should have been established. The range was approximately 1800 feet at this time. Later, at the point of closest approach, an 8-ft/sec rate existed, normal to the line of sight, which should have been removed. The range at this time was also 1800 feet; however, both vehicles were in darkness. The ability of a flight crew member to determine rates of the target even in daylight is considerably impaired without a stable background or familiar objects in the foreground. At night, the ability to determine rates depends on the relative distance between two reference lights if they are both visible. If only one light is visible, the flight crew member's judgement depends on his ability to measure the intensity of the light, and, if this one light is flashing, the task becomes very difficult. Therefore, it appears necessary to follow a procedure which requires that perceptible rates be established. In addition, the data from this flight confirm that a limit of separation for maintaining a close-up station-keeping exercise should be established which provides that relative rates remain low, yet perceptible. At the same time, total fuel consumption must stay reasonable. Figure 4-7 shows that the maneuvers conducted after 32 minutes on this flight were less successful than those before that time in maintaining a close-up station with the second stage of the launch vehicle. The data also indicate that any attempt after that time to achieve a close-up station would have required a significant period of time and a number of thrust periods.

Referenced to the computer coordinate system, the IVI indicated total ΔV expenditure from the time of entering the catch-up mode to the close of the station-keeping exercise was:

$$\left|\Delta V_X\right| = 44 \text{ ft/sec} + +4 \text{ ft/sec} = 48 \text{ ft/sec}$$

$$\left|\Delta V_Y\right| = 75 \text{ ft/sec} + -9 \text{ ft/sec} = 66 \text{ ft/sec}$$

$$\left|\Delta V_Z\right| = 21 \text{ ft/sec} + +11 \text{ ft/sec} = 32 \text{ ft/sec}$$

The first term for each component is the sum of the magnitudes of the applied ΔV's along the respective axis. The second term is the accumulated ΔV over 4700 seconds due to accelerometer drift, resulting from a difference between input accelerometer bias terms and actual accelerometer bias.

Figure 4-7 illustrates the effectiveness of the thrusting history by showing the relative trajectory that would have resulted if thrusting had been terminated after several of the principal thrust periods. The range and range-rate time history for this period is shown in figure 4-10.

Review of these figures shows that the velocity increments applied through 00:09:21 g.e.t. succeeded in reducing the separation rate, but left a residual rate of 1.5 ft/sec away from the launch vehicle. As a result, the range from spacecraft to launch vehicle increased to 0.84 nautical mile and the range-rate increased to 6.5 ft/sec by 00:30:25 g.e.t. when corrective action was initiated. From 00:30:25 g.e.t. to 00:35:[illegible] g.e.t., thrusts were applied which cancelled the separation rate and produced a range rate of 2.[illegible] ft/sec towards the launch vehicle. The resulting orbit would have passed within 2700 feet of the launch vehicle if no further thrusts had been applied.

Further thrusting was applied at 00:44:30 g.e.t. and at 00:55:55 g.e.t., which resulted in reducing the closest approach distance to 1800 feet. At this point (00:52:00 g.e.t.) a relative velocity of 8 ft/sec normal to the line of sight existed. This velocity propagated into a separation distance of 1.6 nautical miles and a separation rate of 17 ft/sec by the time corrective action was initiated at 01:05:30 g.e.t. The corrective thrust applied was insufficient and the separation distance continued to increase throughout the remainder of the first revolution as shown by figure 4-6. The application of velocity changes was further complicated during this time (01:04:00 g.e.t. through the end of revolution 1) because of the apparent failure of an aft-firing thruster. It appears that if a procedure had been followed that required the crew (1) to initially establish a clearly perceptible closing rate with the target at all times and (2) to again establish a perceptible closing rate any time the range became larger than several stage II lengths, then the closeup station-keeping goal could perhaps have been achieved. If these procedures had been followed for the thrusts applied in the first 24 minutes after separation, it appears that closeup station keeping would have been achieved using less fuel than that actually expended in attempting the task. The values of rates needed to be perceptible are very sensitive to the lighting conditions and can cause high propellant consumption if these lighting conditions are inadequate. The lighting conditions also limit how close to the target station keeping can be maintained with safety.

Figure 4-9 shows the effect of applying a correction which establishes a closing rate such that the target is intercepted. This plot shows how one thrust correction could theoretically achieve closure; however, in a flight case a number of successive thrusts approaching the one shown would be required because of the sensitivity of the trajectory to small corrections. This trajectory would in this case have placed the spacecraft below and behind the target which is desirable to allow nulling of the translation rates against an inertial background and provide effective corrections during closure with the target.

7.1 FLIGHT CREW PERFORMANCE

7.1.1 Activities

The crew activities outlined in the flight plan were tailored to mission objectives which were ambitious during the early revolutions. In order to accomplish extravehicular activity (EVA) and rendezvous maneuvers in the vicinity of the launch vehicle, it was necessary to plan this activity early in the flight because of the predicted differential orbital decay rates of the two vehicles. It was decided to perform station keeping with the launch vehicle during the first two revolutions rather than separate during the first revolution and perform visual rendezvous maneuvers during the second revolution concurrent with spacecraft systems tests and the EVA preparation.

The separation and maneuver and subsequent rendezvous maneuver were planned after EVA on the third and fourth revolutions, respectively.

Crew performance is discussed in the following paragraphs and crew training summary is included at the end of this section.

7.1.1.1 Prelaunch.- Prelaunch preparations proceeded smoothly, and the crew was ready for ingress at the scheduled time of T-100 minutes. The erector problem and resultant launch delay had no noticeable effect on crew readiness. During this period, the crew performed all required countdown functions and was waiting for lift-off.

7.1.1.2 Launch and insertion.- The flight crew verified lift-off by calling out that the event timer was "counting." Powered-flight events occurred on schedule and were confirmed by the crew as required. The crew was well prepared for launch, and no unexpected events occurred during this phase of the mission.

7.1.1.3 Station-keeping maneuvers.- The crew members' account of the station-keeping maneuvers is contained in section 7.1.2 of this report, and a detailed evaluation of the exercise is included in section 4.3.1.3. Therefore, the chronology will not be repeated here. The command pilot did not achieve close-up station keeping with the second stage of the launch vehicle, initially as a result of insufficient translation thrust application to effect a zero relative velocity or a closing velocity immediately after separation. The difficulty in nulling relative velocity was increased as a result of the earth's being viewed as a background rather than the sky. Also, a 3 ft/sec retrograde velocity which was not predicted prior to the flight was imparted to the launch vehicle as a result of the separation maneuvers. The difficulty in estimating range rate of a tumbling vehicle was an additional factor in the difficulty encountered in achieving close-up station keeping. In addition, the crew was required to perform this complex task immediately after insertion before they became accustomed to the new environment, and they were also required to aline the platform which diverted their attention from the station-keeping tasks. All of these factors contributed to the failure of the close-up ~~of the~~ station-keeping exercise.

7.1.2.4.1 Station keeping: After separation and turnaround, the launch-vehicle second stage came into view at 200 to 500 feet behind the spacecraft and to the left of a line pointing back along the spacecraft track. The second stage was clearly visible against the dark sky, and the flashing lights were also clearly visible. The engine skirt was visible and appeared to be intact. The flight crew pointed the spacecraft at the second stage and thrusted for about 6 seconds. The crew did not have time to place the computer in catch-up mode before starting to thrust, but managed to place it there after about 2 or 3 seconds of thrust. The IVI's then counted up to 3 ft/sec. It appeared that the spacecraft and second stage were still separating; therefore, the crew thrusted for an additional 4 or 5 seconds. At that time, it appeared that the relative velocity was zero, or that the spacecraft was closing slightly. The spacecraft was then approximately 600 or 700 feet from the launch vehicle, and the crew started to aline the platform. Shortly after the crew began the alinement, the launch vehicle started to drop down below the spacecraft and finally went out of sight. The crew then thrusted down with the top thruster and waited about a minute more in the alining attitude. They then pitched down to sight the launch vehicle and found that it had dropped much further below than they had expected. It was difficult to see the launch vehicle against the earth background. The crew quickly returned to the alining attitude and placed the platform in orbit rate. The crew then retrothrusted for about 3 seconds and pitched the spacecraft down again to reacquire the launch vehicle, which was approximately 1000 feet below the spacecraft. At this point, two choices were available: One choice was to retrothrust to a different orbit and to attempt a rendezvous; the other was to force the spacecraft toward the launch vehicle by using the orbital attitude and maneuver system (OAMS) to overcome the relative velocities resulting from the now different orbits. Because of the time constraints of the flight plan, the brute force method was selected. The launch vehicle stayed below the spacecraft at a range of approximately 1200 feet as the spacecraft entered darkness. The launch vehicle disappeared in seconds as it entered darkness, and the flashing lights became visible. The crew continued to thrust both at the launch vehicle and in retrograde with most of the thrusting being at the launch vehicle. Just prior to Carnarvon, the crew had finally forced the spacecraft to an altitude approximately the same as the launch vehicle at a close range. Both flashing lights were intermittently visible throughout the maneuvers, and the distance between these lights gave some reference for judging range and range rate. The spacecraft was obviously getting close to the launch vehicle, and the crew fired a short burst to decrease the closing velocities. At about that time, the launch vehicle tumbling, which had reached a rate of 40 to 50 deg/sec, caused one of the lights to disappear. After that time, the crew was forced to judge range and range rate by the brightness of the single visible flashing light. This was extremely difficult to do, and the crew did not have a good estimate of range until the launch vehicle passed into sunlight. At that time, the launch vehicle was approximately 2 miles away, and its outline was visible below the spacecraft. During this daylight phase, the launch vehicle passed over a background of water, clouds, and land and was difficult to see at ranges greater than 1 mile. In thrusting toward it, the crew found that they could not close on it with a reasonable amount of fuel, and the range appeared to increase. The crew reported to the flight controllers that they could only close on the launch vehicle by a major expenditure of fuel; therefore, they recommended abandoning the station-keeping activity. Shortly thereafter, the crew was told to abandon the exercise. At that time, the launch vehicle was below and ahead of the spacecraft at a range of approximately 3 miles.

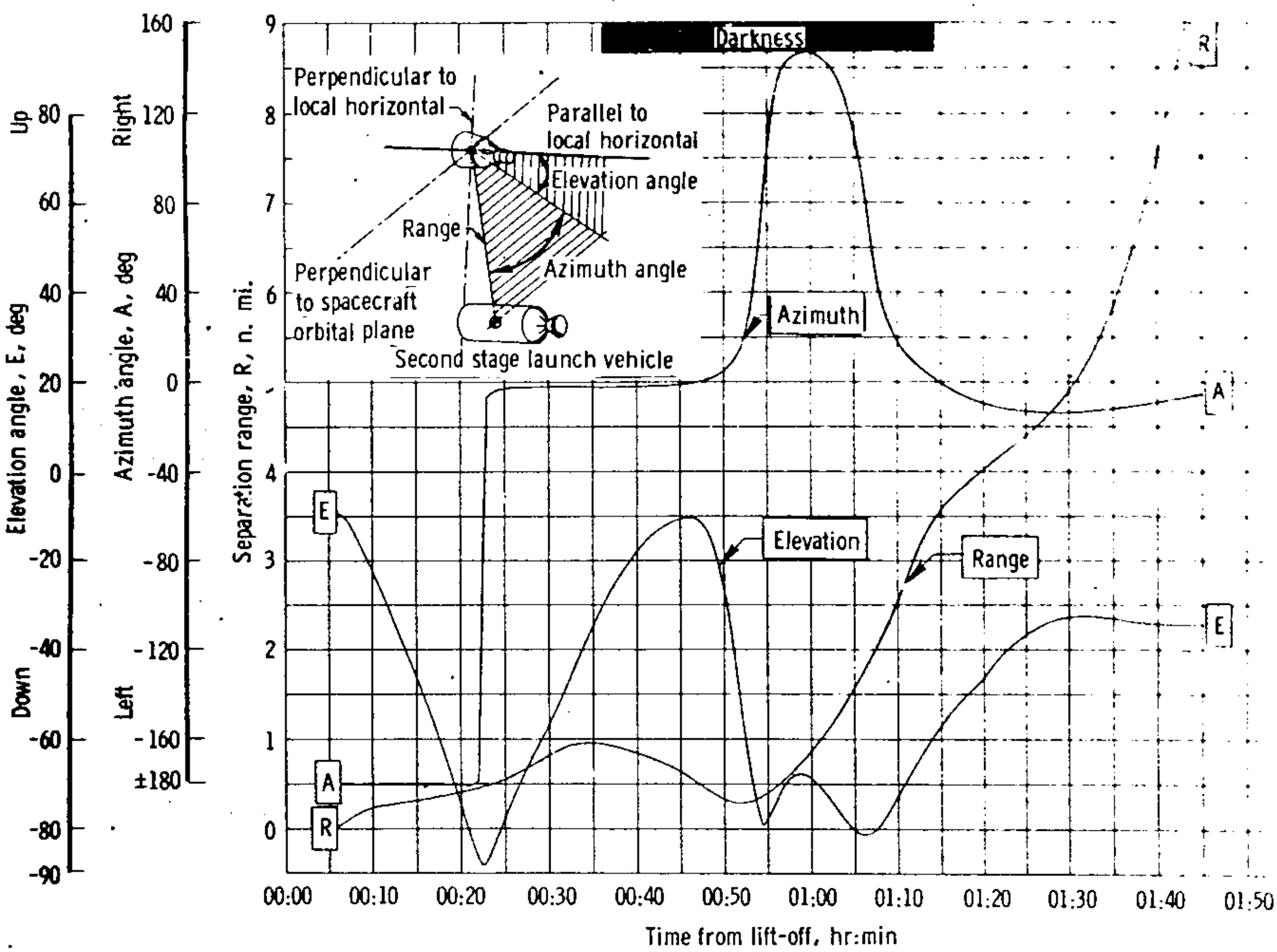

Figure 4-5. - Time history of separation range, azimuth, and elevation between the spacecraft and the second stage during the station keeping maneuvers.

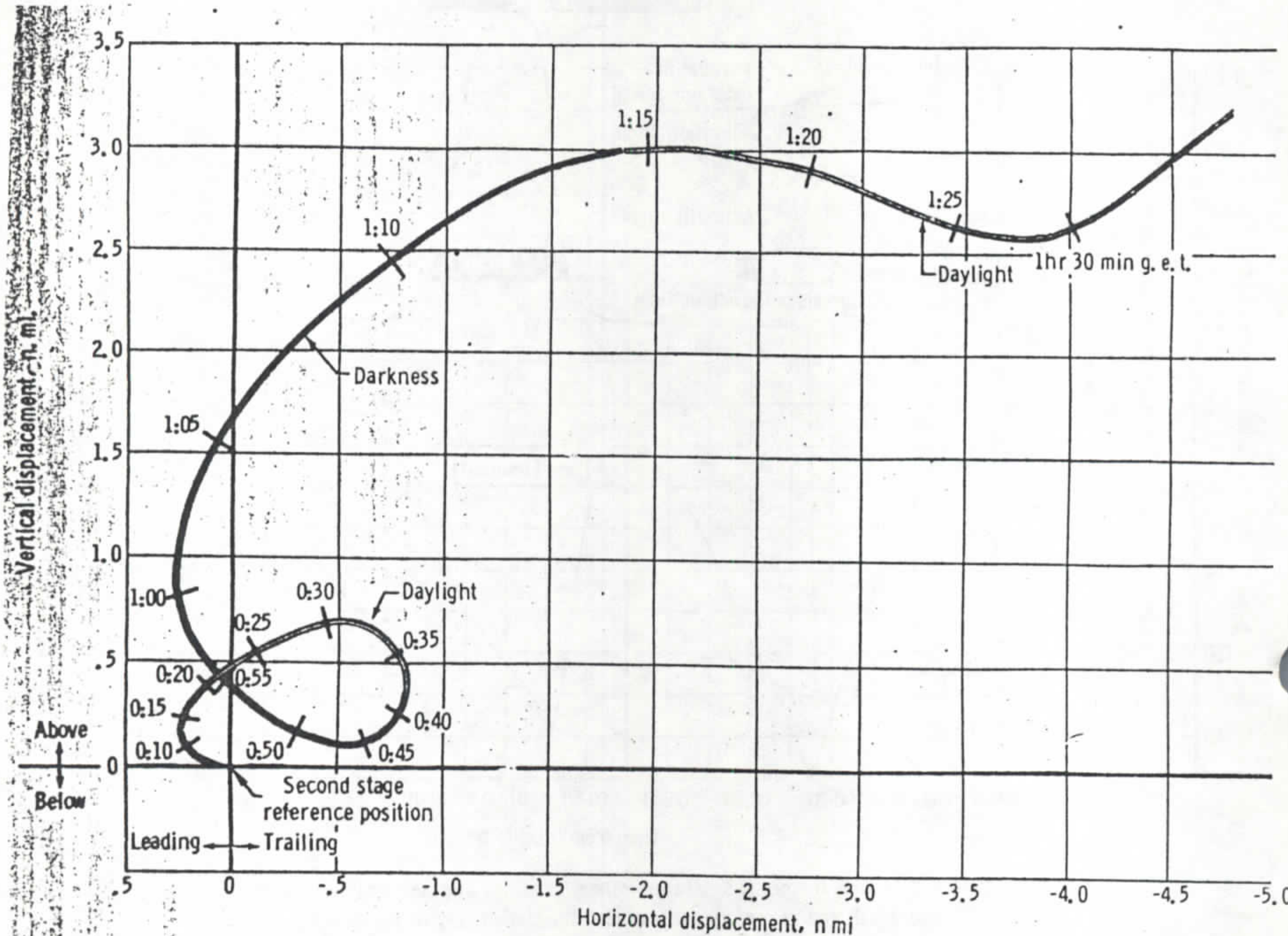

Figure 4-6. - Relative motion between the spacecraft and the second stage during station keeping maneuvers.

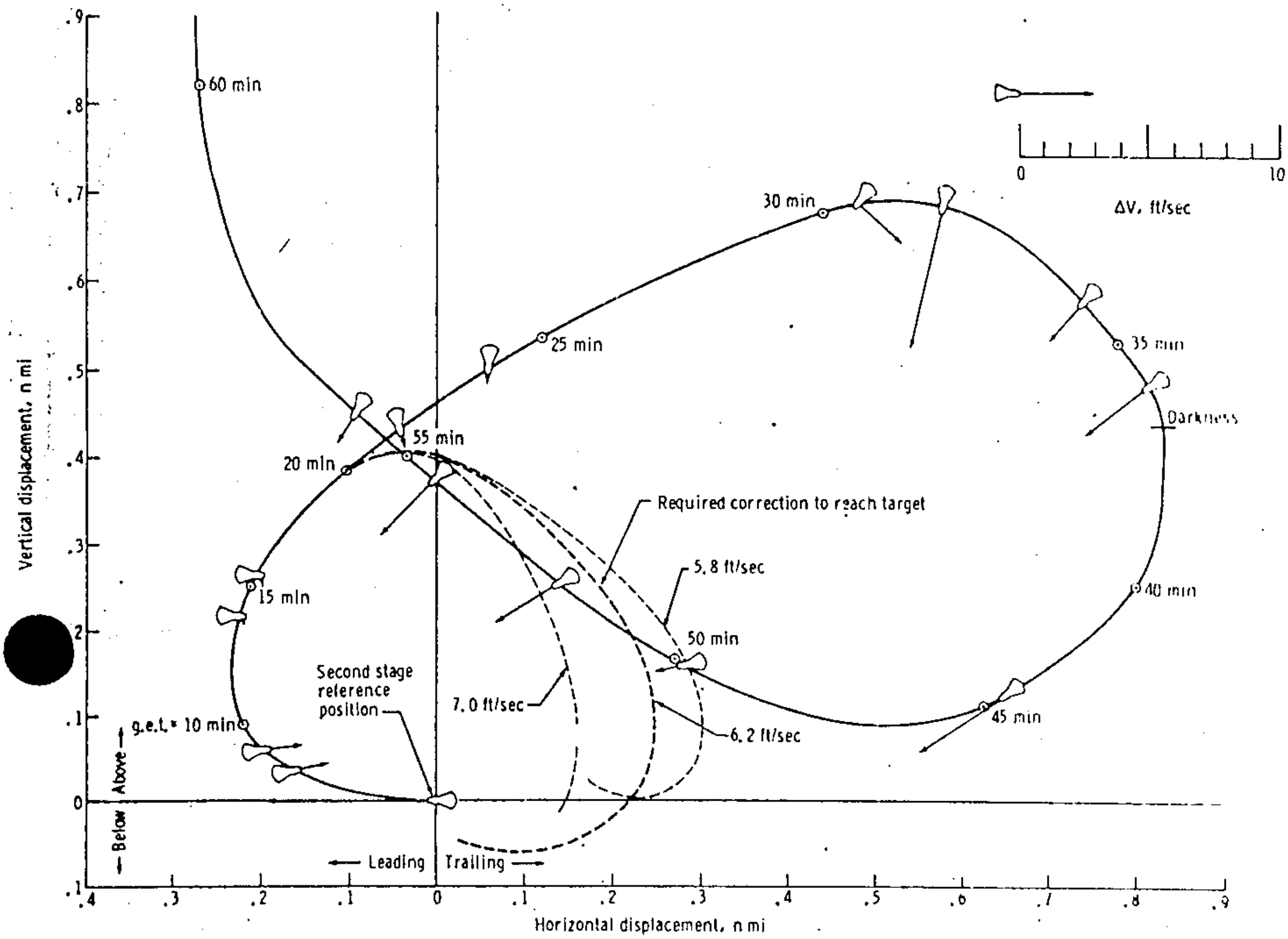

Figure 4-9. - Spacecraft-second stage relative position.

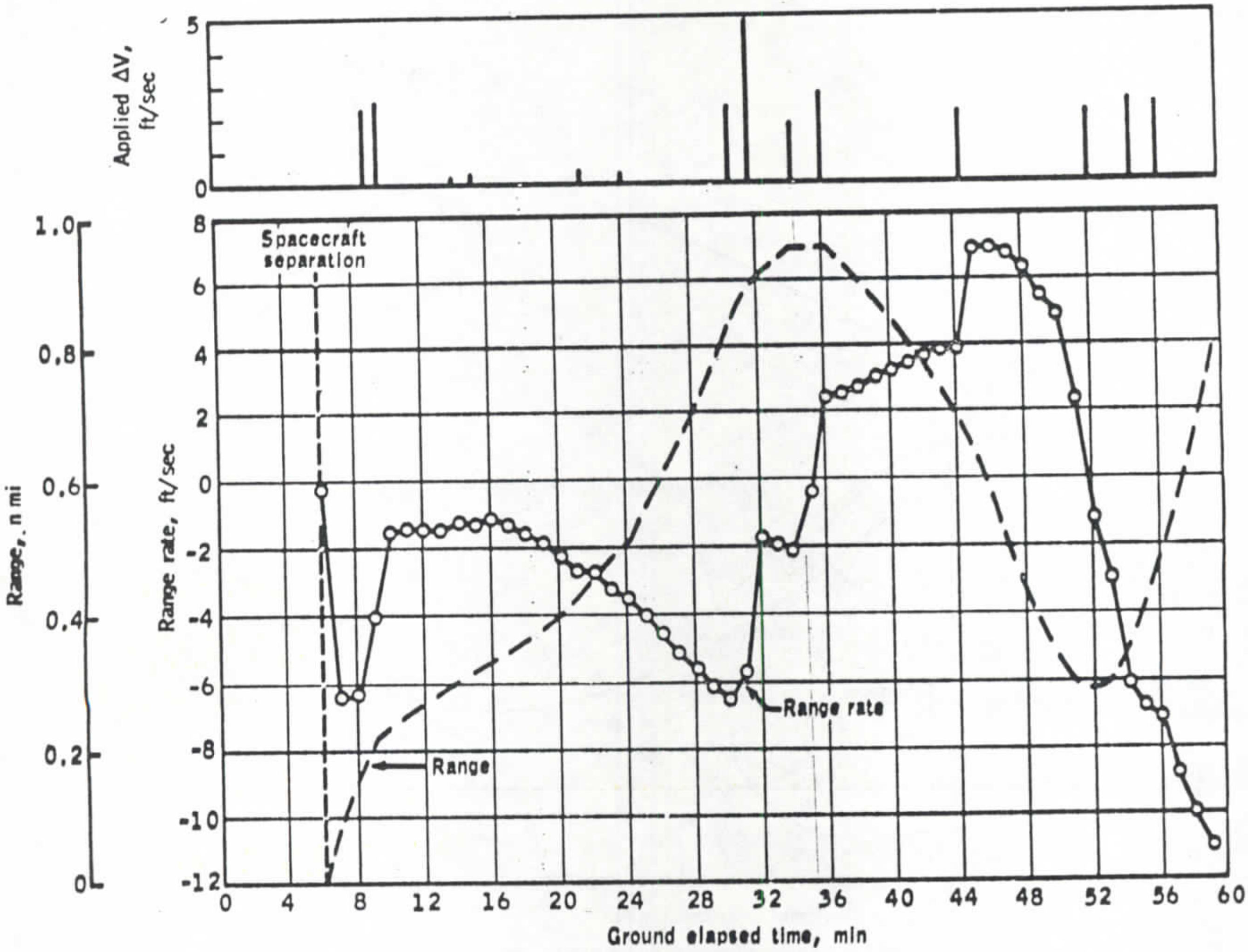

Figure 4-10. - Spacecraft - stage II range and range rate.

Gemini IV results, Hacker, op. cit. , and Aldrin, <u>Men From Earth</u>

In the spacecraft, McDivitt and White had no doubts about liftoff, as they felt their vehicle pick up speed. There was very little noise. The hush was broken only when the launch vehicle bounced like a pogo stick for a few seconds. Then everything smoothed into near silence again. Pyrotechnics shattered the illusion of quiet at stage 1 and, later, at stage 2 separation. The spacecraft entered an elliptical orbit of 163 kilometers at the low point (perigee) and 282 kilometers at the high point (apogee).[39]

As *Gemini IV* separated from its booster, McDivitt turned the spacecraft around to look for the trailing vehicle. White saw the rocket venting, with propellant streaming from its nozzle. How far was it, and where was it going? McDivitt estimated the distance as 120 meters; White guessed it was closer to 75 meters.

McDivitt braked the spacecraft, aimed it, and thrusted toward the target. After two bursts from his thrusters, the booster seemed to move away and downward. A few minutes later, McDivitt pitched the spacecraft nose down and the crew again saw the rocket, which seemed to be traveling on a different track. He thrusted toward it—no success—and stopped. McDivitt repeated this sequence several times with the same luck.[40]

As night approached McDivitt spotted the booster's flashing lights. He estimated that the distance to the target had stretched to perhaps 600 meters. He knew he had to catch the booster quickly if they were going to stationkeep and do extravehicular activity as planned. For a while, *Gemini IV* seemed to hold its own and even to close with the other vehicle. McDivitt thought they got to within 60 meters, but White estimated it at 200 to 300 meters. The target's running lights soon grew dim in the gray streaks of dawn and vanished with the sunrise. When the target hove into view about three to five kilometers away, McDivitt again tried to close the distance. Additional thrusting did not seem to bring it any closer. Well aware that he was a pioneer in orbital rendezvous and that choosing the right maneuvers might not be as easy as it seemed, McDivitt had previously asked Mission Director Kraft which was more important, rendezvous or EVA. The space walk, said Kraft. McDivitt knew he had to stop spending fuel chasing the elusive target by the "eyeball" method.

As GPO engineer André Meyer later remarked, "There is a good explanation [for] what went wrong with rendezvous." The crew, like everyone else at MSC, "just didn't understand or reason out the orbital mechanics involved. As a result, we all got a whole lot smarter and really perfected rendezvous maneuvers, which Apollo now uses." Catching a target in orbit is a game played in a different ball park than chasing something down on Earth's essentially two-dimensional surface. Speed and motion in orbit do not conform to Earth-based habit, except at very close ranges. To catch something on the ground, one simply moves as quickly as possible in a straight line to the place where the object will be at the right time. As *Gemini IV* showed, that will not work in orbit. Adding speed also raises altitude, moving the spacecraft into a higher orbit than its target. The paradoxical result is that the faster moving spacecraft has actually slowed relative to the target, since its orbital period, which is a direct function of its distance from the center of gravity, has also increased. As the *Gemini IV* crew observed, the target seemed to gradually pull in front of and away from the spacecraft. The proper technique is for the spacecraft to reduce its speed, dropping to a lower and thus shorter orbit, which will allow it to gain on the target. At the correct moment, a burst of speed lifts the spacecraft to the target's orbit close enough to the target to eliminate virtually all relative motion between them. Now on station, the paradoxical effects vanish, and the spacecraft can approach the target directly. *Gemini IV's* problem was compounded by its limited fuel supply; the Spacecraft 4 tanks were only half the size of later models, and the fuel had to be conserved for the fail-safe maneuvers. When McDivitt and White broke off their futile chase, they had exhausted nearly half their load of propellants.[41]

[39] "Preliminary Debriefing," Part I, pp. 17-18, 20-21, 23-25, 31; "Gemini IV Mission Report," p. 4-1.

[40] "Preliminary Debriefing," Part I, pp. 38, 50-57.

[41] Ibid., pp. 54-55, 58-69, 72; Gemini 4 mission commentary, tape 7, p. 1; Meyer, comments on draft chapter of Gemini narrative history, 28 Feb. 1969.

MEN FROM EARTH, Buzz Aldrin, Bantam Books

Liftoff came after a brief delay when the launch pad gantry stuck, but the ascent was flawless. Television coverage of the blast-off was broadcast to Europe via Early Bird satellite, another first for NASA (which the Soviets in their determination to be secretive could never do). There were some unpleasant longitudinal "pogo" booster oscillations, which were smoothed out, and *Gemini IV* was in orbit five minutes later. Unfortunately, McDivitt's awkward attempts at an "eyeball rendezvous" with the spent second stage were an utter failure. He tried to *fly* the spacecraft toward the slowly tumbling Titan booster shell, and naturally, he ran into the predictable paradoxes as the target alternately seemed to speed away and then drop behind. McDivitt had never grasped much rendezvous theory during his Houston training, and after the mission, one of the Gemini engineers, André Meyer, commented that McDivitt "just didn't understand or reason out the orbital mechanics involved."[16] I certainly knew what Andy was saying, having once hoped to interest a bunch of white-scarf astronauts in rendezvous techniques. Unfortunately McDivitt's abortive rendezvous wasted half their thruster propellant.

MEN FROM EARTH, Buzz Aldrin, Bantam Books, New York, 1989, pp. 70-1

I chose my thesis subject carefully. Hoping to work for either NASA or the Air Force after completing my doctorate, I wanted to make a positive contribution. Manned orbital rendezvous was a vital field, because any way you cut it, if we were going to assemble large interplanetary spacecraft, we'd have to master the techniques of space rendezvous—bringing two or more separately launched spacecraft together in orbit. With computers we could reduce the blizzard of spherical geometry and calculus equations down to automated rendezvous procedures. But I'd seen enough autopilots malfunction during my flying career to realize that the spacecraft NASA planned to use for Earth orbital and lunar spaceflight would need some kind of manual backup.

An astronaut "flying" a spacecraft just isn't the same as throwing a Super Sabre through a dogfight. There's no true up or down in space, nor is there lift in the traditional sense of the term. And orbital rendezvous is very complicated, but can appear deceptively simple. For example, an astronaut in a lower orbit—closer to Earth—might want to catch *up* with his partner in a higher orbit. The fighter pilot's instinct is to fire his engine and increase velocity. But speed and centrifugal energy are intertwined and this maneuver would loop the lower spacecraft above the target, placing him in a still higher orbit. He would also slow down, so that his partner would appear to drop below and speed away. They call this "orbital paradox," and it definitely can be puzzling. In short, the instincts an astronaut had that kept him alive flying jet fighters could easily betray him in space.

The problem becomes much more complex when the astronaut cannot see his rendezvous target or have radar contact with it. There is, however, one important link between standard aviation and manned spaceflight. Through the hand controller, the astronaut can operate the spacecraft reaction control system (RCS) thrusters, which act like the jet fighter's stick and rudder. When a pair of thrusters fires, the spacecraft pitches, rolls, or yaws. Firing a larger thruster propels the spacecraft in one direction—a process known as "translation," which is like opening the throttle of a jet plane. Relative to the direction the spacecraft is pointing, this can change velocity right or left, up or down, forward or aft.

My challenge was figuring out a way of putting these complex orbital mechanics into an exact sequence of maneuvers an astronaut could follow with the spacecraft's attitude and thrust hand controllers. Military flight instructors had done basically the same thing when they transformed theoretical aerodynamics into standard flight maneuvers using a plane's stick and throttle. By December 1962, my graduate work was almost complete and the Mercury program was in full swing. I sweated through my oral and written doctoral exams and emerged with only some finishing touches to put on my thesis. I dedicated it "To the men in the astronaut program, oh, that I were one of them." But I wasn't optimistic. NASA was still requiring that test pilot's diploma.

MEN FROM EARTH, Buzz Aldrin, Bantam Books, New York, 1989, pp.

Following NASA practice, the astronauts in my group were given specialty assignments outside our standard training courses. Some of the ex-test pilots concentrated on Gemini spacecraft hardware, such as the life-support and recovery systems or the retrorockets, while others focused on the Gemini's Titan launch booster. I worked on mission planning, specifically on orbital rendezvous flight plans. I finally felt my years at MIT had not been wasted. I was helping develop a concept of space rendezvous eventually known as the "concentric orbit flight plan," in which spacecraft number two (the chaser) would be premaneuvered into an inner matching orbit uniformly below and overtaking spacecraft number one (the target), and then initiate the intercept transfer, maintaining this collision course with small jet corrections to final closure and docking. I knew this approach was the best chance we had for a successful, practical rendezvous and docking for both Project Gemini and the Apollo LOR mission plan, because the concentric orbit concept would give the astronaut crew a second chance at completing the rendezvous if a computer or radar malfunctioned.

It wasn't easy translating these complex orbital mechanics into relatively simple flight plans for my colleagues. After a few months of trying to promote the intricate mechanics of the actual maneuvers at cocktail parties, I saw that most of these guys weren't really interested. Many were hard-core stick-and-rudder fighter jocks who had no appetite for astronautical theory. All they wanted to know was where to point the spacecraft and what thruster to fire to make it maneuver. They started calling me "Dr. Rendezvous"—some out of respect, others sarcastically—when I gave them a hard time for being so intellectually lazy.

The program managers, on the other hand, did appreciate my work in the rendezvous trenches. After I had spent two years in mission planning, Chris Kraft, the assistant director of MSC for flight operations, wrote a memo to Deke Slayton that focused on my contribution to Project Gemini's success and to the planned lunar orbital rendezvous for Apollo. "In the early stages of the development of the Gemini rendezvous mission plan," Kraft wrote, "Major Aldrin almost singlehandedly conceived and pressed through certain basic concepts which were incorporated in this operation, without which the probability of mission success would have unquestionably been considerably reduced." Kraft added that I was "... currently exerting a similar influence on the Apollo program in which the rendezvous exercise is not only a primary mission objective but rather a mandatory operation for the safe return of the flight crew from the moon."[1]

Those months in mission planning were among the most demanding and most rewarding of my life. I was enthralled with Gemini. There's no other way to describe my feelings for the program. Gemini was the realization of all the obscure astronautical theory I'd absorbed at MIT. Gemini was also the proving ground for Apollo.

Gemini VI preparations, Hacker, op. cit. , and Aldrin, Men From Earth

Rendezvous techniques remained largely in the realm of theory. When training for Gemini VI began in the spring of 1965, little had yet been done toward planning crew procedures for making the final maneuvers. Dean F. Grimm of MSC's Flight Crew Support Division joined forces with Astronaut Edwin Aldrin, who had studied the pilot's role in rendezvous for his doctoral dissertation at the Massachusetts Institute of Technology.

In 1963 and 1964, Aldrin worked hard at selling the project office and flight operations on a concentric rendezvous. The target would be launched in a circular orbit 298 kilometers high, the spacecraft in a lower elliptical orbit. Since the spacecraft was closer to Earth, it took less time to circle the globe and could catch up for rendezvous. Aldrin and Grimm worked out the trajectories and maneuvers that would allow the spacecraft to intercept the target.[5]

A two-week review in April 1965 convinced Grimm and Aldrin that MSC's plans for an active human role in rendezvous were in poor shape. Most work seemed to stress a closed-loop concept that relied more on machines than on men. Radar and computer would make rendezvous nearly automatic. Of course, if either failed, so did the mission. Aldrin and Grimm believed the pilots should have options if the equipment malfunctioned. Grimm went to St. Louis and persuaded McDonnell to rig a device that could simulate trajectories, orbital insertion, and spacecraft-target rendezvous.* A computer allowed flight profiles to be set up that varied the series of maneuvers leading to target interception. Crewmen learned what to do if any piece of equipment failed, and they profited from merely going through the motions as they tried to decide which procedures were useful and valid. Schirra and Stafford rejected, for example, an early concept for doing rendezvous with the spacecraft inverted—head toward Earth—using the inertial guidance system to judge spacecraft attitude. They both disliked this method because they lost their sense of direction. Overall, the prime crew participated in 50 complete rendezvous simulations. As Schirra and Stafford trained on the simulator, they took notes and discussed with Aldrin and the others the best procedures to use. These were then incorporated into charts that would be carried in flight.[6]

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*Grimm and Aldrin had help in setting up rendezvous procedures: at MSC, Branch Chiefs Paul C. Kramer (Crew Safety and Procedures) and Edgar C. Lineberry (Rendezvous Analysis); at McDonnell, Charles A. Jacobson, Marvin R. Czarnik, William Murphy, Walter Haufler, and William E. Hayes. Gordon Cooper and Charles Conrad, the *Gemini V* crew, acted as engineering test pilots until the Gemini VI crews could take over.

[5] Edwin E. Aldrin, Jr., "Line of Sight Guidance Techniques for Men in Orbital Rendezvous" (Ph.D. dissertation, Massachusetts Institute of Technology, 1964); Schirra interview; Dean F. Grimm, interview, Houston, 13 April 1967; Aldrin, interview, Houston, 4 April 1967.

[6] Grimm interview (additional information from telephone interview, 12 Feb. 1969); Schirra interview; Marvin R. Czarnik, interview, St. Louis, 15 April 1966; "Preflight Training Plan for Fourth Manned Gemini Flight Crew (GTA-6)," NASA Program Gemini working paper No. 5031, 23 Aug. 1965.

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GT-5 Will Test Rendezvous System

Transponder test assembly will replace Agena vehicle in first in-orbit evaluation of radar equipment; details of flight plan

by Charles D. LaFond

FIRST ORBITAL testing of the *Gemini/Agena* rendezvous radar system will be in the *Gemini-Titan 5 (GT-5)* mission now scheduled for late August.

The *Gemini 5* vehicle will carry the operational L-band radar interrogator, which includes an *Agena* command link. Replacing the *Agena* target vehicle, however, will be the mating transponder and blinker light system installed within the *Gemini* adapter ring. The transponder test assembly, called the Rendezvous Evaluation Pod (REP) will be ejected from the spacecraft after orbital injection and will be used to check out system performance and provide rendezvous maneuvering experience for the astronauts.

The transponder subsystem is identical to those that will be carried later in the *Agena* target vehicle.

In discussing the upcoming *GT-5* flight with MISSILES AND ROCKETS, Albert Wiegand, manager of Crew Station Integration for *Gemini* prime contractor McDonnell Aircraft Corp. in St. Louis, pointed out that the problems ahead now in the manned space program are concerned more with what the on-board equipment can do, rather than what man can do. Man, he said, has demonstrated his inherent flexibility and adaptability.

GT-5, he said, will serve as a test bed for several new systems, including the fuel-cell power supply and its associated instruments. The primary equipment test, however, will provide the first integrated testing of the rendezvous radar system with the onboard computer, inertial reference, displays, thrusters and the pilots.

Also, *GT-5* will carry an Air Force experimental radiometer package for passive tracking in several infrared ranges.

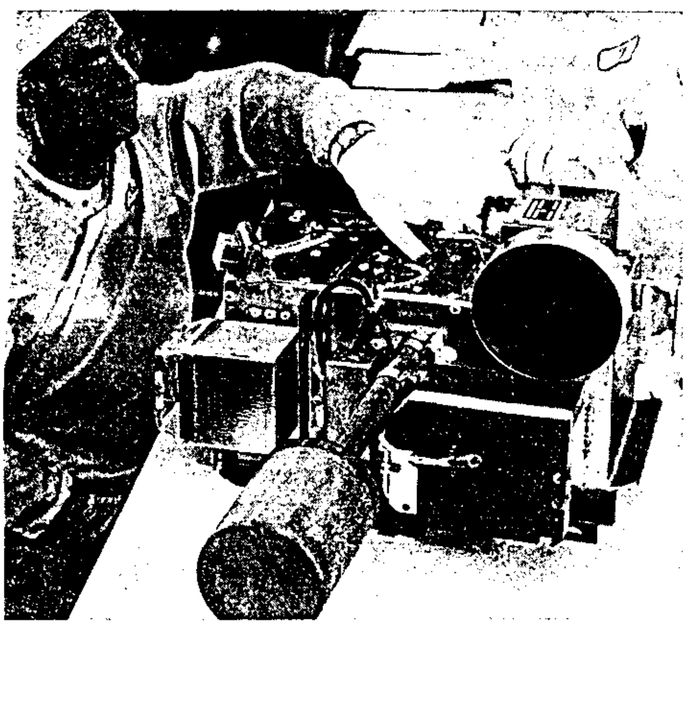
Considerable confidence in the radar system has been acquired in past months with the rendezvous and docking simulator developed by McDonnell and used by the astronauts at St. Louis and at the Manned Spacecraft Center in Houston.

As a matter of fact, Wiegand emphasized, it was through use of the big simulator that the capability for docking was effectively proved.

Also, the radar system was extensively tested using an aircraft at White Sands Missile Range. In recent tests there, running several months, the transponder was carried in an Air Force T-33 jet, which was flown in carefully planned patterns at different altitudes and speeds. The radar interrogator was operated from a fixed ground installation and range and range-rate data were compared with those obtained from WSMR optical instrumentation.

• **Westinghouse radar**—In February, 1962, the Aerospace Division of Westinghouse Electric Corp. in Baltimore, Md., was awarded a cost-plus-incentive-

LEFT: Rendezvous Evaluation Pod, employing same transponder to be used in the Agena target vehicle, will be ejected by Gemini 5 for rendezvous system exercise. Developed by Westinghouse, the two opposed spiral antennas and dipole antenna (foreground) obviate tumble problems with radar transmission. RIGHT: Gemini-installed radar interrogator employs novel spiral receiving antenna design for obtaining accurate target range and angle measurements.



fee contract to develop and produce the complete *Gemini/Agena* rendezvous radar system. Total contract value is about \$18 million, including nearly \$2 million for spares and service.

The program calls for delivery of 16 radars: nine operational units, four production prototypes, and three engineering models. Seventeen transponders, including two for use in REP's, eleven command-link encoders, plus panel indicators and antennas comprise the remainder of the systems production order.

The *Gemini* radar subsystem weighs 73 lbs. and requires 80 watts input power. The transponder subsystem weighs 43 lbs. and requires a 69-watt input. Total weight of the REP, which includes antennas, transponder, boost regulator and power supply is 76 lbs.

• **GT-5 radar test**—The radar exercise will only duplicate the terminal phase of rendezvous as planned with the *Agena* during *GT-6* late this year. The distances will be scaled down by "a factor of three," according to Howard W. Tindall, Jr., of the Manned Spacecraft Center's Flight Operations Div.

It will start from that part of rendezvous when spacecraft radar "locks on" target. By that time, the plane changes and catch-up maneuvers will have been completed and the spacecraft will be in plane with the *Agena* and moving up on it, Tindall explained.

The pilots will first sight the flashing xenon lights, then point the rendezvous radar in the pod's direction. The L-band transponders on the REP will receive the signal from the radar and will respond to it with a fixed delay at a different frequency. Read-out onboard the spacecraft will be range, range rate, azimuth and elevation of the target.

Edgar C. Lineberry of the Flight Operations Division Rendezvous Analysis Branch told M/R how the maneuvers will be performed.

—The *Gemini-Titan 5* combination will be launched due east at a launch azimuth of 90 degrees into an 87 to 146-n.mi. or higher orbit with an inclination angle of 28.3 degrees;

—At a second apogee, the command pilot will make a translational "burn" using the Orbital Attitude Maneuvering System's (OAMS) thrusters in posigrade to raise the perigee 10-15 n.mi. Shortly afterward, he will yaw the spacecraft 90 degrees from his orbital path to eject the pod sideways from the adapter.

Lineberry estimates that the 5-fps velocity imparted from the spring release mechanism will move the pod slightly out of plane "about a half mile" at maximum distance, or anti-nodal point.

At the second perigee, the spacecraft will increase its distance from the pod with a 20-fps posigrade maneuver. This will raise the spacecraft's apogee about 11 n.mi.

• **Back to the pod**—As the spacecraft nears agopee (140 degrees of orbital travel later), the command pilot will move the spacecraft into a lower energy orbit. Burning the OAMS thrusters in retrograde (13 fps), he will start the spacecraft on a trajectory that will eventually return it toward the pod. However, before the effect of the OAMS burn takes place, the spacecraft will move to a 45-n.mi. separation point from the pod at mid-point of darkness on the night side of the orbit.

Up to this point, the spacecraft will have moved half way within the orbit of the pod. As the spacecraft nears perigee, the command pilot will make another burn (30 fps) in retrograde to move the spacecraft totally inside the orbit of the pod to set up the concentric rendezvous trajectory that will be used during *GT-6*. The altitude separation between orbits will be equidistant at approximately six nautical miles. The spacecraft, however, will be in the lower and faster moving orbit and will be gaining steadily on the pod.

The spacecraft will stay in this orbit for about 30 minutes while picking up the pod on radar, Lineberry said.

The terminal phase will begin about 130 degrees of orbital travel back from the rendezvous point, he explained.

There, with the spacecraft in a 27-degree pitch-up attitude, the pilot will begin to initiate thrust along the line of sight, also correcting for the small out-of-plane maneuver set up at pod ejection. The pod will be at mid-point of darkness on the night side of the orbit and against the star background.

The command pilot can stop the roll of motion sideways by sighting the target against the inertially-fixed star background, Lineberry said.

As the spacecraft moves up into the pod's orbit, the pilot will apply a braking thrust (16 fps) in retrograde and will close the distance between the two objects to within 50 ft. for the DOD-Air Force radiometer tracking experiment, Tindall said.

Finally, the spacecraft will fire the OAMS thrusters to move away from the pod and raise perigee to establish a seven-day orbital lifetime.

Several rendezvous attempts will be made during the *GT-5*, seven-day mission, including use of the radar only and use of pilot visual approach at close range. Rendezvous may also be attempted using ground radar data.

Depending on target orientation, Westinghouse engineers said, initial radar acquisition can be made at about 200-mi. range. Visual contact will be made from 10 to 20 mi., and full visual control will be possible at about one mile range. The radar, however, can be employed to zero range, they disclosed.

• **Radar details**—The radar will provide a pulsed, L-band signal with a peak output power of 1,150 watts. Average radar interrogator power is 0.3 watts, producing a 1-μsec. pulse with a 2-μsec. delay between pulses. The transponder signal, operating with a 100-mc frequency separation will employ a 1.8-watt average power and a 6-μsec. pulse.

Although no command link will be used with the REP exercise, it will be employed later with the *Agena* rendezvous. Transmission will be superimposed on the radar signals. Up to 62 digital commands will be available to adjust *Agena* position relative to *Gemini*.

The *Gemini* radar will employ three radome-covered spiral antennas for receiving and one spiral antenna for transmitting. The REP will carry two opposed transmit/receive spirals and one dipole will be illuminated and return its signal regardless of tumble.

• **Interferometric technique**—The *Gemini* spacecraft must locate the target vehicle, determine range and bearing, and then determine and make the necessary changes in position and orbital velocity for rendezvous and docking.

The particular radar design approach taken by Westinghouse was based in large part on three conditions: the target would be cooperative, relative closing velocities would be small, and dynamic inputs resulting from expected maneuvers would be very small.

Thus, the use of low-power, low-gain, wide beamwidth antennas could be used with both vehicle and considerable weight savings could be provided. A signal-to-noise ratio of at least 16 db is provided.

The system provides accurate digital angle and range data to the onboard computer from 180 n. mi. to 500 ft. Analog range and range-rate data are displayed from 300,000 to 20 ft.

The designed time delay between transponder reception of each radar pulse and retransmission of the translated signal permits the *Gemini* receiver to track the target to essentially zero-range, said Westinghouse. There is never an overlap of signal transmissions. Range determination is simply a measurement of round trip time minus the transponder delay.

An interferometric technique is used to determine angle measurements. Thus the difference in time of arrival of the *Gemini*-received signal between two spiral antennas is used with each compared against a common third antenna.

The three antennas are installed in the front of the spacecraft (see photo) in such a manner that the boresight axis is parallel to the roll axis. One pair (using the common or reference spiral) lies in the pitch plane, the other pair in the yaw plane. ■

Plans for the **Gemini-V** (Aug 1965) rendezvous experiment with the REP (Rendezvous Evaluation Pod), as described in the pre-mission press kit (pp. 7-10), were soon cancelled when the Gemini's fuel cells began acting up. The radar was later locked onto a ground transponder at Cape Kennedy.

The REP will be ejected 13 minutes after the spacecraft enters darkness in the second revolution at GET of two hours and 25 minutes. For ejection, the spacecraft will be yawed right 90 degrees, and the REP will go north from the spacecraft at a rate of about five fps. The out-of-plane ejection will not affect the inplane motion between the two vehicles.

Because the spacecraft must remain within 900 feet of the REP for four minutes as part of the Celestial, Space and Terrestrial Object Radiometery experiments (D-4 and D-7), it will be necessary to decrease the range rate between the two vehicles. To accomplish this, two fps will be applied to the spacecraft toward the REP using the aft thrusters one minute after REP ejection.

At a GET of two hours and 59 minutes, the crew will execute a posigrade 16 fps horizontal maneuver using the aft thrusters. Purpose is to increase the spacecraft orbital period enough to allow it to trail behind the REP. The maneuver increases the spacecraft period by .17 minutes to 89.87 minutes. It also raises the apogee to approximately 229 miles.

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At a GET of three hours and 39 minutes the crew will execute a retrograde and radially-up burn of 14 fps. This will lower the spacecraft perigee altitude about seven miles. below the perigee altitude of the REP, which is 106 miles, and adjust the phase angle desired at the time of the co-elliptical maneuver. The maneuver will be performed in a pitched-up attitude using the forward-firing thrusters. The orbital parameters after thrust will be approximately 100-229 miles with a period of 89.75 minutes. The spacecraft period will be .073 minutes larger than the REP period, and the spacecraft will lag behind. The spacecraft remains in this orbit for 52 minutes during which it achieves a maximum range from the REP of 52 miles.

A retrograde and radially-down maneuver of 29.8 fps will be performed at a GET of four hours and 31 minutes. This will place the spacecraft into an 99-212 mile orbit co-elliptical with the REP's orbit with an approximate altitude difference of seven miles between the two. The maneuver will be executed with the spacecraft pitched up, and the forward firing thrusters will be used. The spacecraft period will become 89.43 minutes, which is .24 minutes smaller than the REP's period. The spacecraft will stay in the co-elliptical orbit about 33 minutes, resulting in a phase angle of .183 degrees at terminal phase initiation.

The pilot will switch the computer mode to rendezvous at a GET of four hours and 35 minutes. At five hours GET, with a range of 17.5 miles and a look-angle of 22.69 degrees, he will press the start computer button. Approximately four minutes later, when the range is 14.9 miles and the look-angle is 27.2 degrees, the terminal phase initiation maneuver of 15 fps is applied. At this time the in-plane thrust angle is equal to the REP look-angle, and the result is a line-of-sight burn.

At a GET of five hours, 16 minutes and 11 seconds, the first mid-course correction maneuver of 81.8 degrees is displayed to the crew on the Incremental Velocity Indicator (IVI). The vector components are displayed separately to maintain line-of-sight at a delta V cost of three fps.

The second mid-course correction maneuver is applied at a GET of five hours, 28 minutes, 11 seconds. This 33.6 degree maneuver costs five fps. After its completion, the closed-loop phase is completed and the crew will control the spacecraft throughout the rest of the exercise via a semioptical technique.

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The magnitude of the theoretical braking maneuver at a GET of five hours, 36 minutes, 32 seconds is about 16 fps. However, since the command pilot will be controlling final approach from about 1.7 miles by semioptical techniques, additional fuel will be used controlling the inertial line-of-sight rates and the range/range rate. The braking maneuver occurs about 10 minutes prior to leaving darkness in the fourth revolution and about six minutes prior to loss of signal at Carnarvon, Australia, tracking station.

After the braking maneuver, the spacecraft will be maneuvered in the near vicinity of the REP for the Nearby Object Photography experiment (D-2) until time for the final separation maneuver of a GET of six hours, 49 minutes. At that time the spacecraft will be at fifth apogee, and the crew will perform a five fps posigrade maneuver to separate from the REP. The orbital lifetime of the spacecraft following this maneuver is expected to be from 10 to 13 days. The remainder of the mission will be carried out with spacecraft exercises that do not involve in-orbit maneuvering.

Scheduling of experiments and other activities in the flight following completion of the REP exercise will be on a real-time basis.

From <u>Missiles and Rockets</u>, August 30, 1965, pp. 16-7

Gemini-V "phantom rendezvous" with point in sky

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From Missiles and Rockets, August 30, 1965, pp. 16-7

Gemini-V "phantom rendezvous" with point in sky

GT-5 Proves U.S. Rendezvous Ability

Longest manned spaceflight also demonstrates military value of orbital manned vehicles; fuel cell, hit earlier by pressure drop, exceeds expectations

by Hal Taylor

• **Rendezvous exercises**—Loss of oxygen pressure in the fuel-cell tanks did nullify to a certain extent space agency plans to check out the spacecraft radar with the Rendezvous Evaluation Pod (REP). The pod was successfully jettisoned from the spacecraft and it trailed *Gemini 5* by about 1,000 ft. Because of the low power supply, NASA officials scrapped plans to use the Orbital Attitude Maneuvering System (OAMS) to move the spacecraft closer to the pod. The experiment was not a total loss, however, because the *Gemini 5* crew tracked the pod for about a half hour with the radar. Useful range and range-rate data was obtained and Kraft declared that the radar system was qualified for use in *GT-6*, the first actual rendezvous and docking mission in the *Gemini* program.

• **Shadow rendezvousing**—Of far more importance to *GT-6*, however, were the rendezvous maneuvers initiated as the spacecraft made its 32nd revolution around the Earth on Aug. 23.

NASA officials decided to have the *Gemini 5* rendezvous with a phantom *Agena* upper stage as a replacement for the lost opportunity to rendezvous with the pod.

The test assumed that the *Agena* was launched on time into a nominal orbit ranging from 123.5 mi. perigee to an apogee of 183.2 mi. It also assumed that the rendezvous maneuver was being attempted on the spacecraft's fourth apogee, as it will be during the *GT-6* mission.

First phase of the maneuver took place at 12:50 p.m. As the spacecraft reached its 32nd perigee, the aft thrustors of the OAMS system were fired for 28 seconds to reduce its apogee from 207 mi. to 194 mi.

The second step—called a phasing maneuver—began at 1:34 p.m., while the spacecraft was reaching its 33rd apogee. The aft thrustors were again fired for 22 seconds, achieving a velocity of 15.6 fps and putting the spacecraft into a perigee of 113 mi. The OAMS burn also established an orbit insuring a flight-duration capability of at least 11.5 days.

At 13 minutes prior to the 33rd perigee, the *GT-5* astronaut crew completed a plane-changing maneuver. The spacecraft was yawed 90 degrees left and the aft thrustors were fired for 19 seconds. This successfully changed the orbital plane by the desired 0.2 degrees.

The last maneuver occurred at 3:06 p.m. when the spacecraft reached its 34th apogee. The co-elliptic maneuver required a 22-second burn of the thrustors as the spacecraft pitched down 16 degrees to increase its perigee to 124 mi. At the end of the maneuver, *Gemini 5* was in an orbit ranging from 124 to 194 mi. with a period of 95 minutes. Officials estimated that the phantom *Agena* orbit at that point was 141 mi. perigee and 210 mi. apogee. This placed the *Gemini 5* only 16 mi. behind the ghost *Agena*, very close to the planned 15-mi. separation which NASA hopes to have on *GT-6* just prior to the final closing and docking maneuver. This last maneuver was not attempted on *Gemini 5* because of the need to conserve OAMS fuel.