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EDITORIAL

GEMINI DESIGN AND OPERATIONS

SPECIAL ASTRONAUTICS REPORT

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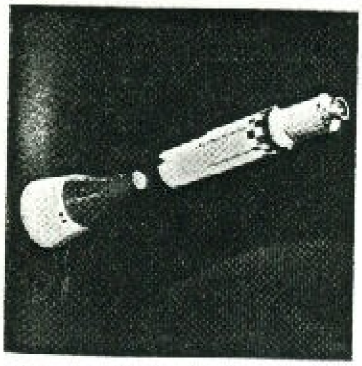

COVER: The Gemini program reinstitutes manned space flight at a new level of engineering, operations, and scientific experimentation, and forms a major stepping stone toward future space endeavors such as Apollo, space stations, and lunar-transportation systems. Cover, courtesy of Lockheed Missiles & Space Co., depicts the key operational maneuver in the mission, rendezvous of the Gemini spacecraft and Agena target vehicle.

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Simulating Gemini-Agena docking

Moving- and fixed-base simulator experiments show that the astronauts will be able to develop the skill for visual docking day or night

By HOWARD G. HATCH JR., DONALD R. RILEY, and JERE B. COBB
NASA Langley Research Center

Developing the necessary techniques and demonstrating the ability of human pilots to use them for docking two vehicles in space represents a prime mission of the Gemini program. Accomplishing this will not only insure success of the lunar-orbit-rendezvous technique for exploration of the Moon but other space missions as well.

At present, man's capabilities and limitations in space operations are relatively unexplored. Project Mercury experience has shown that man can contribute significantly to a successful mission. In Project Gemini, man's role will be expanded. Besides duties as an observer, systems monitor, and systems backup, the astronaut will be utilized as a primary system in the docking phase of orbital rendezvous. For this operation, he will serve as the primary system for information gathering, guidance logic, and control application.

Although final verification of the success of this increased human participation in space operations must await actual flights, ground-based simulators are being used extensively to explore the wide range of operational situations that the astronaut could encounter. Full-scale simulations of the docking of the Gemini spacecraft and Agena target have recently been completed at the NASA Langley Research Center using both fixed- and moving-base simulators. This article presents research results with both simulations for pilot ability to dock successfully, piloting techniques, and performance with the pilot using only visual observation of the Agena target for guidance information. Both rate-command (primary) and acceleration-command (backup) modes for attitude control have been investigated, as well as the effects of control-jet malfunctions and target lighting conditions.

The Simulators. The moving-base simulator, shown on page 75, consisted of a full-scale Gemini model mounted in a hydraulically driven gimbal system suspended by eight supporting cables from an electrically driven overhead carriage.[1] A dolly mounted on the main carriage provided lateral motion while the whole system moved longitudinally. A cable drum on the dolly reeled and unreeled the cables for vertical motion. The cable arrangement and attachment angles were designed to prevent penduluming. The system allowed the pilot to move in six degrees of freedom, which he controlled from the capsule through a ground-based analog computer.

The full-scale Agena target model did not move. It was suspended by a single cable and held in place by four stabilizing cables. Three models of the Agena, shown on page 75, were used during the program. The first was a lightweight model of wood and paper used during the initial checkout and familiarization to reduce chances of pilot injury in the event of a high-speed collision. After the familiarization period, the metal model was used because it had a more realistic spring-mounted docking ring. The third model, constructed by McDonnell Aircraft, was an actual mockup of the Agena docking ring.

The fixed-base simulator, illustrated on page 76, employed a modified Air Force F-151 gunnery trainer and a full-scale wooden mockup of the Gemini vehicle housed in a 20-ft-diam spherical projection screen. A closed circuit television system and a two-axis mirror projected a full-size image of the Agena target on the screen. A small model of the Agena target having three angular degrees of freedom was mounted on a range bed in front of the TV pickup camera. By a combination of model and mirror movements, a full six degrees of freedom was obtained and commanded through analog computing equipment.

Gemini Orbital-attitude and Maneuvering Control System (OAMS). This is the propulsion system used to control Gemini in orbit. The OAMS control jets reside in the adapter attached to the re-entry module, as shown in the sketches on page 76. There are 16 jets, eight for translation and eight for attitude. Because of CG location, having all the control jets on the adapter allows control coupling between translation and rotation. Thus, in terms of motion of the body axes, when a vertical or lateral translation is commanded, a pitch or yaw rotation will also occur. Similarly, when pitch

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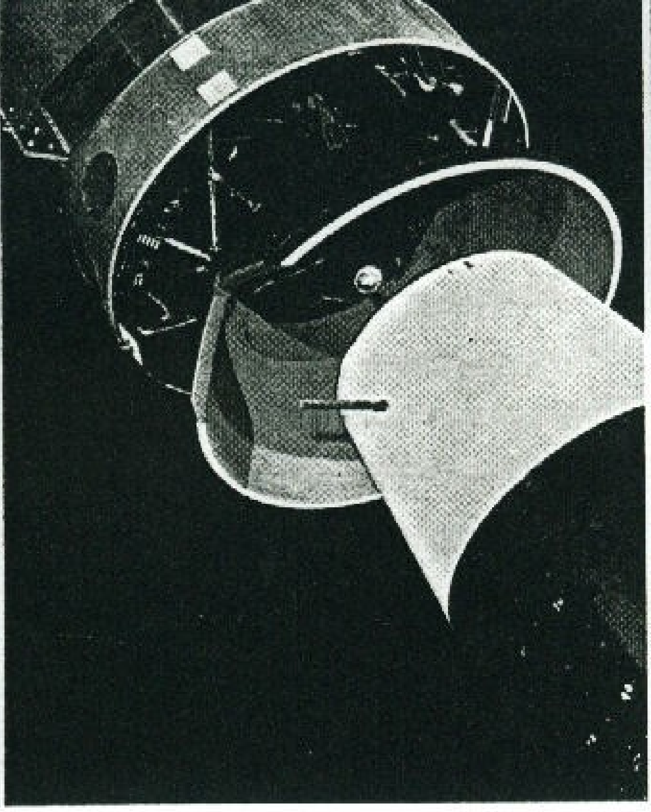
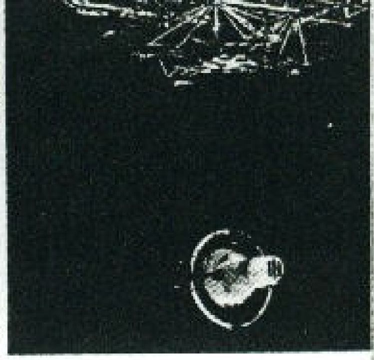




Moving-base simulator, above, consisted of full-scale Gemini model mounted in a hydraulically-driven gimbal system suspended by eight cables. The three photos below show pilot's view of the Agena target at various distances with vehicles aligned; this is the paper-and-wood target used at first. The photo at far left shows the first metal Agena model, and the photo at left shows the final actual mockup of the Agena docking ring constructed by McDonnell Aircraft.

or yaw are commanded, a vertical or lateral translation takes place.

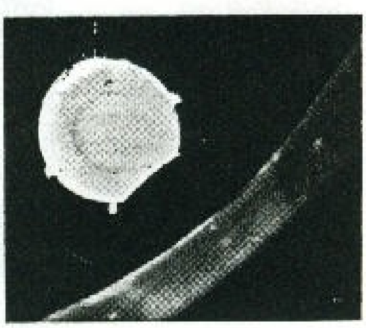
Two of the OAMS attitude-control modes were studied in the simulations. One was the rate-command mode, in which a deflection of the hand controller commands an attitude rate proportional to the controller deflection; zero deflection holds the attitude drifts to within 0.2 deg/sec. The other was the direct-control mode, in which a deflection of the hand controller actuated a microswitch that commanded full thrust from the jets. With both modes, on—off acceleration control was used for translation.

Gemini has two three-axis hand controllers, one for attitude and one for translation. The grip-type attitude controller sits in front of the right arm rest. Pitch is obtained by tilting the control handle fore and aft; roll, by tilting the handle right and left; and yaw, by twisting the handle right and left. The lever-type translation controller attaches to the instrument panel just in front of the left arm rest. For translation, the control handle is moved in the direction of the desired acceleration along the three principal axes. In the simulations, three-axis grip and lever controllers were used, but usually they were not the actual Gemini models. Two three-axis fingertip controllers were used in the fixed-base simulator.

Gemini-Agena Docking Arrangement. Docking will be performed by guiding the Gemini nose into the docking ring mounted on the orbiting Agena. The docking ring has a conical inner surface to channel the Gemini nose into latching position and is shock mounted to absorb the contact momentum. A V-slot in the docking ring and an index bar on the Gemini will provide the necessary roll alignment for the latching mechanism. Once Gemini latches on, the two vehicles will be drawn together and made rigid automatically.

To latch, the center of the Gemini nose must be within 1 ft of the center of the docking ring, and the relative attitudes must be within 10 deg. The ring will accept a radial velocity of 0.5 fps and a longitudinal velocity of 1.5 fps. Exceeding these tolerances may not mean an unsuccessful mission. For example, if the Gemini nose position and attitude were out of tolerance but the contact velocity low, the two vehicles would bump together and Gemini simply could not latch. The pilot could back away and try again. But if contact velocities are high, there could be structural damage.

In these simulations, runs were terminated when the Gemini made first contact with the docking ring. A run was considered out of tolerance if any variable exceeded the tolerances, even though the conditions in actual flight might not have caused a failure.



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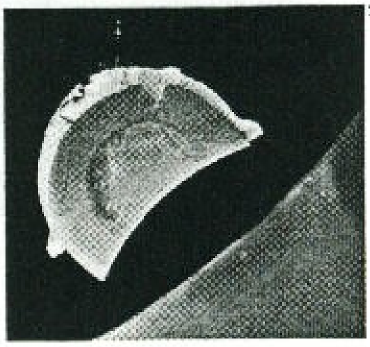

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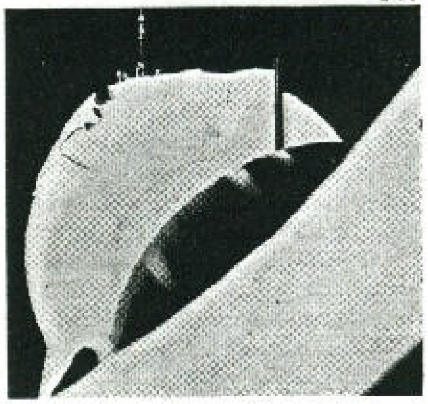
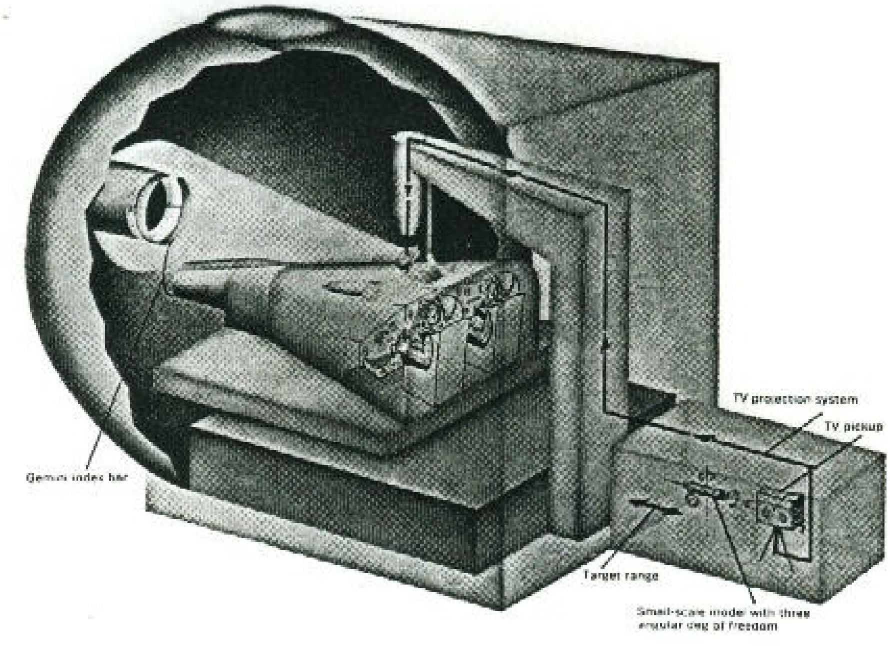


5 FT



The fixed-base simulator employed a modified F-151 gunnery trainer with a full-scale wooden mockup of Gemini, in the manner indicated in the illustration above.

The pilots, flying from the left seat, took control of the Gemini from the initial conditions and tried to maneuver the vehicle until it entered the docking ring within the specified tolerances. The pilot could use whatever technique he preferred without particular regard to fuel or time. During the simulations described here, the pilots used only out-of-the-window reference for guidance information—that is, no instrumentation.

The range of initial conditions were defined by construction and safety requirements for the moving-base simulator and by TV and model-scaling requirements for the fixed-base. The moving-base simulator's maximum initial displacements were 125 ft longitudinally, ±10 ft vertically, and ±5 ft laterally. The fixed-base simulator's maximum initial displacements were 250 ft longitudinally, ±75 ft vertically, and ±100 ft laterally. In addition, various initial Gemini attitude angles, attitude rates, and translation velocities were investigated in both simulations.

Most of the subjects used in these studies were NASA research test pilots.

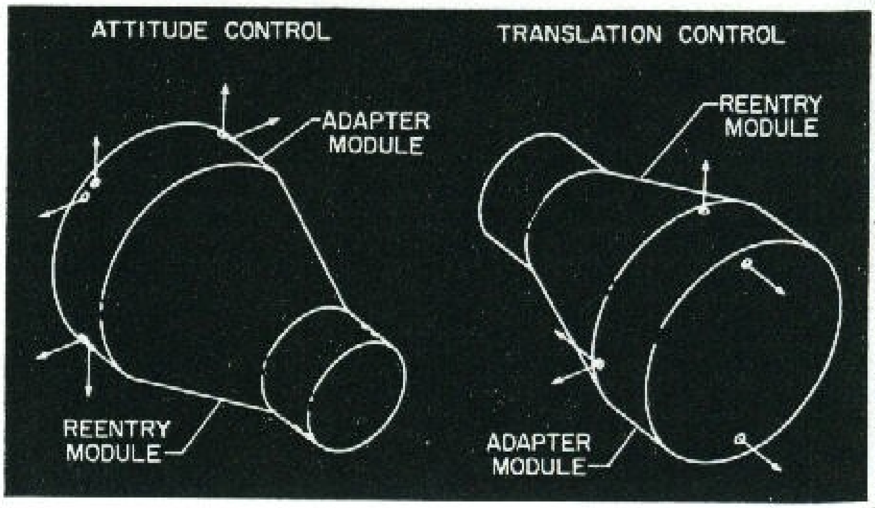
Rate-command Results. Results of rate-command studies with the fixed-base simulator showed that with a fully illuminated target a pilot could consistently complete visual docking within the specified tolerances.[1] The task was not exceedingly difficult, but it did take a number of runs to reach a high level of proficiency. The tight deadband (0.2 deg/sec) employed in the automatic attitude-control system simplified the pilot's control and visual tasks, because the problem was reduced to one of three degrees of translational freedom except for an occasional attitude correction. Thus, all motions between the vehicle and the target could be considered primarily as translation. Rate-command control was found to be well-suited for the docking task.

Direct-control Results. In direct-control visual docking, studied with both simulators, it was found that, although successful daytime docking could be consistently obtained, it was difficult to learn and numerous flights were required to become proficient.

In the direct mode, the normal difficulties with on–off acceleration control (requirement of separate control inputs to start and stop a motion, and the lack of damping) were complicated by the control coupling and control power. The coupling was bothersome because a corrective control input in one degree of freedom could upset another which was properly aligned. The control power, particularly for attitude, added complexity because it was high enough to make precise control difficult. As a consequence of these various control difficulties, the pilots found they could not make rapid or large corrections about more than one or two axes at a time without overshooting or overcontrolling. These control difficulties were most annoying during final approach with the Agena, because the pilot was trying to control precisely for accurate alignment. The difficulties were particularly disturbing if numerous last-second corrections were required.

Visual Difficulties. The basic visual task involved separating general motion between the target and vehicle into six separate degrees of freedom. The pilots found this task difficult for small rates, especially if the motion was coupled, such as yawing left and translating right, so that the Gemini nose did not move vertically or laterally with respect to the target. It was also difficult to determine zero rate. Consequently, there were usually residual rates in all degrees of freedom. These difficulties were attributed partially to the pilot being to the left of the vehicle's centerline. From this viewing point, the pilots felt it was

ORBITAL ATTITUDE AND MANEUVERING SYSTEM



harder to estimate alignment than it would be from directly over centerline.

This problem of parallax can be seen in the set of three photos of the paper-and-wood Agena model on page 75, which shows the pilot's view with the vehicles aligned at various distances. The pilot's visual-alignment capability, as determined with the moving-base simulator,[3] was 2–3 deg in attitude and 2–4 in. in nose position at ranges closer than 50 ft. Since the residual rates were normally very slow, it took some time for these positional errors to develop, and thus some time for the pilot to recognize the rates present. The pilots were always a little late, therefore, in their corrections. If they were late in several degrees of freedom, especially when near the target, and tried to correct multiple errors rapidly, then they would encounter the control difficulties.

To recapitulate, the main difficulties in direct-mode docking without instruments were a small uncertainty in visually determining relative alignment and inability to make numerous rapid corrections. These difficulties were most prevalent during final alignment with the Agena.

Pilots' Solution of Difficulties. The pilots found several methods of avoiding or remedying the difficulties in direct-control visual docking—the control method, the visual tracking method, and the technique used to maneuver toward the Agena.

The control problems were avoided by using very small inputs to reduce the coupling effect and handle the control power. By controlling in one degree of freedom at a time, moreover, they could handle the acceleration-type control.

Since the pilots preferred to use small control inputs, the resulting rates were very slow and required some time for the correction to be completed. If pilots concentrated on one correction too long, then other errors could build up because of residual rates. Instead, the pilots would scan from one degree of freedom to another. If a correction was necessary, they would make the control input, continue in the scan, and then observe the results of that input in the next scan cycle. In this manner, they could prevent errors from building up in all axes and yet control in one degree of freedom at a time.

Reviewing the techniques used to maneuver toward the target, it was found that a preferred approach had evolved, and many of its characteristics could be attributed to avoiding or remedying some of the areas of difficulty. A set of graphs atop page 78 show a time history of the preferred type of approach, as taken with the moving-base simulator. One of the distinguishing features is the use of a constant closure velocity of approximately 1/2 fps. Data from the fixed-base simulator also showed a constant

DOCKING TERMINAL CONDITIONS

Initial conditions: Range 50 ft; range rate, 0 fps; nose misalignment, 2.5 ft.

VARIABLE	AVERAGE OF ABSOLUTE VALUES	STANDARD DEVIATION
PITCH ANGLE, DEG	2.28	1.95
ROLL ANGLE, DEG	4.00	2.65
YAW ANGLE, DEG	3.19	1.99
VERTICAL NOSE POSITION, FT	0.31	0.29
LATERAL NOSE POSITION, FT	0.22	0.24
VERTICAL NOSE RATE, FT/SEC	0.12	0.15
LATERAL NOSE RATE, FT/SEC	0.09	0.09
LONGITUDINAL VELOCITY, FT/SEC	0.54	0.22
ATTITUDE FUEL, LB	0.95	0.69
TRANSLATION FUEL, LB	1.95	1.85
FLIGHT TIME, SEC	120.9	55.4

EFFECT ON FUEL AND FLIGHT TIME OF ALTERING APPROACH VELOCITY

Initial conditions: Range 50 ft; range rate, o fps; nose misalignment, 2.5 ft.

CLOSURE VELOCITY	FUEL, LB		FLIGHT TIME, SEC		PERCENT OF TOTAL RUNS
	AVERAGE	STANDARD DEVIATION	AVERAGE	STANDARD DEVIATION	
CONSTANT	2.1	0.7	107	29	69.4
DECREASED	3.0	1.1	106	39	18.5
STOPPED AND REVERSED	7.0	5.1	222	85	12.1

VERTICAL AND LATERAL TRANSLATION WITH JET FAILURE

Failures initiated at 125 ft were noticed 100% of the time.

	VERTICAL JET FAILURE			LATERAL JET FAILURE		
RANGE MALFUNCTION INITIATED, FT	40	10	2.5	40	10	2.5
NUMBER OF RUNS	11	11	11	11	11	11
NUMBER RECOGNIZED	9	3	1	9	4	2
PERCENT RECOGNIZED	82	27	9	82	32	14

JET-MALFUNCTION EFFECT ON FUEL CONSUMPTION AND FLIGHT TIME

	MOVING BASE SIMULATOR		FIXED-BASE SIMULATOR			
CONTROL MODE	DIRECT		RATE COMMAND		DIRECT	
NUMBER OF PILOTS	5	5	3	3	2	2
INITIAL RANGE, FT	50	50	280	280	290	280
FLIGHT CONDITION	NORMAL	JET MALFUNCTION	NORMAL	JET MALFUNCTION	NORMAL	JET MALFUNCTION
FUEL, LB	2.8	11.1	16.8	29.6	18.8	26.5
FLIGHT TIME, SEC	121	252	239	431	306	480
PERCENT OF RUNS IN TOLERANCE	97.6	93.8	86.0	79.5	84.5	58.0
NUMBER OF FLIGHTS	124	32	123	20	56	13

closure velocity of 1/2 fps was desirable during the last 50–100 ft. At the greater ranges up to 280 ft, however, closure velocities of 1–2 fps were found desirable. A constant closure rate, in effect, allowed the pilot to disregard that (longitudinal) degree of freedom and concentrate more on alignment. Another reason for use of constant closure rate is that the pilots found a tendency to overcontrol if they stopped just in front of the target. This occurred because the results of control inputs were more apparent with the Gemini nose close to the docking ring.

Another feature of this approach is the pilots' preference to align on the target during the final part of the approach, as the time history illustrates. The distance at which they attempted a close alignment depended on the initial range and off-set conditions, but was usually of the order of 25 to 75 ft. By having the Gemini aligned during the last of the approach, the small rates were easier to separate and small errors were easier to distinguish. Also, by having the attitude aligned, vertical and lateral translation inputs led to motions in the vertical or lateral planes, rather than in some combination of these planes. Finally, by being aligned as close as possible before the vehicle reached the target, the pilot could avoid making numerous last-second control inputs and could thus avoid the control difficulty. Although the rates were brought as closely as possible to zero at contact, it was practically impossible to have all the rates zero, especially with the direct-control mode. Learning to accept small in-tolerance rates and positional errors at contact was difficult.

The characteristics of the preferred approach helped solve problems created by a jet malfunction, as will be discussed later.

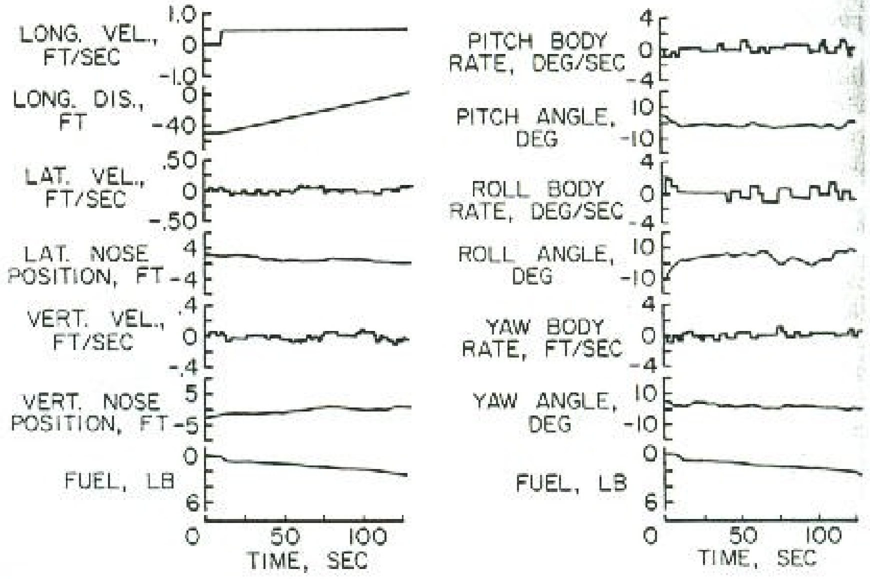
Thus, the pilots found ways of overcoming the difficulties associated with docking visually with the direct-control mode, and were able to become very proficient.

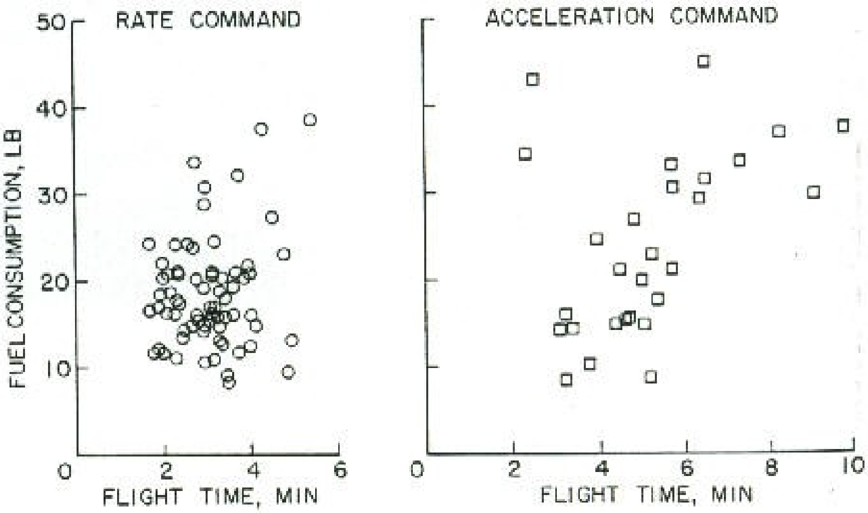
The top table on page 77, summarizes the results of 124 runs made by five pilots, each of which had 40–50 previous practice runs. Since the pilots were asked only to dock within the specified tolerances, these results may not represent the absolute accuracy that is possible. The runs were made on the moving-base simulator from an initial range of 50 ft with a nose offset of 2.5 ft and no initial velocity. Included are runs in which translation-jet failures were simulated but produced no detectable effect.

These results represent averages of the absolute error at first contact and are well within the tolerances. A review of the data showed that there was a tendency to be yawed to the left and to have the CG positioned to the right of the target's centerline at first contact. This tendency was apparent in 75% of the runs. The average angle was 3.3 deg and the average CG displacement was 0.5 ft. The tendency was attributed to difficulty in judging the parallax angle.

The pilots preferred to use a constant closure velocity, but occasionally they had to stop to prevent out-of-tolerance terminal conditions. The second table on page 77 illustrates the effect of altering the approach velocity. There is a sharp increase in fuel consumption and flight time if stopping becomes necessary, but this condition occurred only 12% of the time. The main reason for the sharp increase is the pilot's preference of backing away 20 ft or so before attempting to start toward the Agena again. This distance allowed them to use the desired approach rather than trying to align just in front of the target.

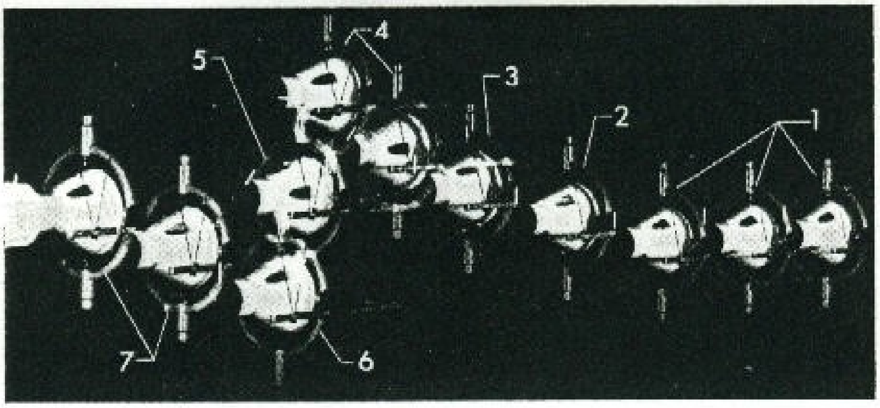
TIME HISTORY OF RUN ON MOVING-BASE SIMULATOR





One pilot's fuel and flight-time results on fixed-base simulator for two different attitude-control modes (initial range, 280 ft).

Docking success, as defined here based on first contact, was 97.6%. At no time was a contact velocity out of tolerance. All runs could have



Technique used to dock with the "down" vertical jet failed. Sequence shows (1) vehicle approach below centerline, (2) pilot applies an upward thrust, (3) pilot tries to stop upward rate, (4) vehicle overshoots centerline, pilot brakes and rolls to 90 deg, (5) downward velocity achieved with lateral jets, (6) pilot rolls back to zero degrees and stabilizes, and (7) pilot continues by approaching from below centerline and adjusts closure rates to eliminate further need of downward thrust.

been successfully completed if the pilot had been allowed to back away and try again.

Comparison of Control Modes. The effect of attitude-control mode on fuel consumption and flight time was studied on the fixed-base simulator. The pair of graphs on page 78 represent one pilot's experience with both control modes from an initial range of 280 ft. The large scatter in fuel consumption—up to 45 lb, as compared with the fuel usage cited in the table just mentioned—is due to the much larger initial range and the resulting longer flight times. The fuel usage as a function of initial range is not expected to continue to increase at the same rate as it did between 50 and 280 ft. At the much larger ranges, terminal-rendezvous studies have shown that the pilots would not try to control as precisely as they did at the closer ranges. The larger fuel and time usages resulted from runs in which the pilot had to stop the closure to prevent out-of-tolerance terminal conditions. The graphs show that the pilot was able to dock with the direct mode as efficiently fuelwise as he could with the rate-command mode, although there was a tendency to use more time in the direct mode. The scatter of the direct-mode data and the fewer runs indicate that the pilot had not reached peak proficiency.

Control-jet Malfunction with Direct-control Mode. In studying this, the OAMS jets were divided into three classes—attitude, speedup and braking, and vertical and lateral translation jets. Each class presents a different type of problem. In addition, two cases of jet malfunction were considered. One was the "stuck-open" case, in which the jet fired continuously, and the other was the "stuck-shut" case, in which the jet would not fire. A few preliminary stuck-open cases were simulated, and it was found that the pilot could not control the vehicle under these circumstances. Actually, if the pilot experienced a stuck-open jet failure, he could isolate the bum jet and then turn it off. Thus the problem reduces to the stuck-shut case.

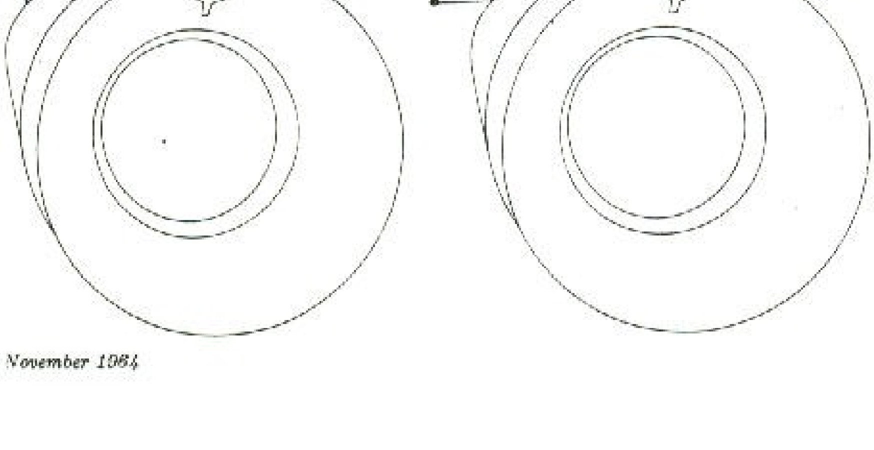
Attitude-jet Failure. There are eight OAMS attitude jets—four primarily for pitch and four primarily for yaw. Roll is time-shared with either set at pilot option by means of a selector switch in the vehicle. In normal operation, the jets fire in pairs If one pair fails, coupling can occur because of the jet arrangement. For example, consider that the left pitch-down jet failed. A pitch-down command will be accompanied by a rolling acceleration to the left during the command. As the desired pitch angle is obtained, the coupled roll angle can easily be corrected if roll is being time-shared with yaw. However, if roll is being time-shared with pitch, then a more complex problem exists. A pitch-down command will still cause a roll to the left while pitching downward; but when the vehicle is rolled right to correct the coupling, it will also pitch back up in the roll. The failed jet is actually one of the roll jets. This problem of having a failed jet in roll control can be handled easily by throwing the switch to have the roll time-shared with yaw.

Since pitch- and yaw-jet failures present similar problems, only pitch failures were considered in the study with roll time-shared with yaw. When surprise pitch-jet failures were simulated, they were seldom noticed. Out of eight pitch-jet failures, only one was recognized. Since very small control inputs were used, and there were normally small residual rates present, the pilot did not observe that a roll couple was associated with a pitch input in his visual-scanning process.

So a pitch-jet failure did not cause any serious problems. It is possible that a large pitch rate commanded at the last second before contact could cause the index bar to miss the slot; but this situation was avoided by having the Gemini well-aligned during the final part of the approach.

Speedup and Braking Jets. The speedup and braking jets also fire in pairs, and are arranged such that failure of a speedup jet gives a pitching acceleration while the speed is increasing. Failure of a braking jet produces a yawing acceleration while braking. The resulting angular acceler-

Docking aids used on the Agena-target models included illuminated rods on the line of sight and lights on the end of posts on the line of sight.



ations approach the available control power in pitch and yaw; and when the pilot attempts to speed up to or brake from the normal closing velocity of 1/2 fps, significant angular coupling results. If a failure in either pair of jets was noticed at large ranges, the pilot could compensate for the induced pitch or yaw while speeding up or braking. The flight could be continued, but the pilot had to remember that any additional thrusting with the pair of jets in which the failure occurred would produce an abnormal pitch or yaw. If the pilot thrusted with a failed jet when very close to the target, then contact could occur before he could compensate for the induced coupling.

Consequently, there is a critical minimum range below which thrusting with a failed jet could cause out-of-tolerance terminal conditions. The critical range depends on closure velocity, acceleration capability, and pilot reaction. For these simulator programs, it was below 5 ft.

The pilots avoided the problems of thrusting at ranges closer than the critical minimum by using the constant-velocity approach and being well aligned at the critical range, so that out-of-tolerance errors would not build up and create a need for altering the approach speed.

When surprise braking-jet failures were simulated, only 5 out of 32 were recognized because the pilots only had to stop five times. None of the five were out of tolerance because the pilot had made his decision to stop before he reached the critical minimum range. The fuel consumption and flight time for the five runs were comparable to the data given in the second table on page 77 in which the pilot stopped and reversed his closure velocity.

Vertical and Lateral Translation Jet Failures. The vertical and lateral translation jets fire singly. When one fails, there can be no translation in that direction. This type of failure was found to be the most troublesome, and it was detected more readily than the other.

Surprise failures were simulated at ranges of 40, 10, and 2.5 ft on the moving-base simulator and at about 125 ft on the fixed-base simulator. The percentage of runs in which a failure was detected was a function of when the failure was initiated, as indicated by the third table on page 77. There was poor recognition of failures initiated at short ranges because, in the preferred approach, the pilots normally did not have to use the jet any more at close range.

The techniques used in performing the docking maneuver with a malfunctioned vertical or lateral jet being similar in principle, one illustrative example, with the down vertical jet, will serve to explain them all. There were several situations in which the vertical position and/or vertical rate required a downward thrust; but to simplify the discussion, only one instance will be discussed. This arose when the vehicle was below the target centerline and an upward thrust was applied. As the vehicle reached the centerline, the pilot attempted to decrease the rate with the down jet, but found he could not do so. As a result, he overshot the centerline. The overshoot depended on the upward velocity. At the larger ranges, where higher rates were used, the overshoot was quite large; but at close range where very small vertical rates were used, the overshoot was less. In either case, the vehicle ended up above the target centerline and required a downward velocity.

Two methods of achieving the emergency downward velocity are (1) pitch and use the longitudinal jets and (2) roll and use the lateral jets. There were several things to consider with these emergency methods. In the pitching method, only a 30-deg angle was necessary to obtain an acceleration component equal to that produced by the failed jet. However, the pitch angle required could cause the pilot to lose sight of the target. Moreover, use of the longitudinal jet affected the closure rate, and care had to be taken to keep the closure rate within acceptable limits. Thus, the pitching method would not be acceptable at ranges less than 30 ft, where the vehicle must be stopped before achieving a downward rate. In the rolling method, the roll angle required would normally be 90 deg, and much more time would be consumed while rotating through the large angle and then stabilizing. The time element was of particular concern with the direct-control mode; but with the rolling method, the pilot could roll either to the right or to the left and still keep the target in view.

Aside from obtaining the downward rate, the pilot also had to consider the lateral errors when one of the methods was chosen to obtain a downward velocity. Lateral errors would establish whether to yaw when using the pitch method, as well as the direction of roll and the desired angle.

DAYLIGHT AND DARKSIDE DOCKING PERFORMANCE

A. Moving-base simulator (direct-control mode; initial range, 50 ft).

Performance	Daylight	Dark	Dark with aids
Fuel, lb	2.8	8.7	5.0
Flight time, sec	121	208	177
Percent of runs in tolerance	97.6	73.3	88.9

B. Fixed-base simulator (rate-command control mode; initial range, 280 ft).

Performance	Daylight		Dark		Dark with aids	
	Pilot A	Pilot B	Pilot A	Pilot B	Pilot A	Pilot B
Fuel, lb	17.1	18.2	19.7	20.0	17.5	16.4
Flight time, sec	178	215	253	273	167	180
Percent of runs in tolerance	96.0	78.0	80.0	60.2	100	100

The approach technique used after making the initial correction depended to a certain extent on the range at which failure was noticed. Normally, at the larger ranges where the overshoot would carry the vehicle some distance above the target centerline, the pilot would remain above the centerline during the approach. After the corrective downward rate had been obtained, he would remain in position to adjust the vertical rate either upward or downward, until he was certain he had obtained a good correction. The ideal correction would be to pass through the target centerline at the same time that the vehicle nose reached the docking ring. For all practical purposes, however, it would be better to aim a little low. The good vertical jet would allow another correction and thus one overshoot would be possible. If the failure went unnoticed until very close to the target, where large vertical displacements are not desirable, an approach from above the target was not always possible. In the time it took to roll to 90 deg and back the vehicle could drift through the centerline. Then the pilot would have to approach from below it. The sequential photo on page 79 shows this situation.

During the approach, the pilot must adjust the closing velocity and vertical velocity so that the vehicle will pass through the centerline at contact with the docking ring; and he must carefully avoid a need to use the downward jet. If the vehicle does overshoot and requires a downward thrust, it is necessary to brake, back away, and repeat the whole process.

It can be readily seen that a lateral-jet failure can be treated in the same manner, the yaw of the vehicle being used instead of pitch or the 90 deg roll method being used again.

It was the experience of the pilots that, with proper training and practice, a docking could be completed with any of these failures without any undue difficulty and still remain within specified tolerances.

The method of closure used when compensating for a failed translation jet necessitated deviating from the "preferred-approach" technique. As a result, the pilots were not able to use some of the methods of avoiding the control and visual areas of difficulty—such as approach along the target centerline, use a constant closure velocity, and avoid multiple last-second corrections. This fact, together with the extra maneuvering involved, caused a large increase in fuel and time, as last table on page 77 shows.

There was also a decrease in the percentage of runs within tolerance. This decrease, and the increase in fuel and time usages, indicate the difficulty of the task. It was felt, however, that with more practice the percentage of in-tolerance runs would equal the normal operation's. The table just mentioned gives average results, including data taken from pilots who had not reached peak proficiency in normal operation and therefore could not be expected to achieve a high level of in-tolerance runs with a failed jet.

It can be seen that experience is a factor. Some of the pilots who flew the moving-base simulator achieved 100% in-tolerance daytime runs, both normal and with malfunctions. A high level of proficiency can be attained with direct-mode control if the pilots have enough training.

Control-jet Malfunction with Rate-command Mode. The OAMS jets can again be divided into the three classes —attitude, speedup and braking, and vertical and lateral translation. Data were obtained, however, only for vertical and lateral translation jet failures, and only the stuck-shut case was considered. For the first two classes of failure, the automatic system would eliminate most of the piloting problems. One exception concerns an attitude-jet failure with roll time-shared with the failed jet. If a pitch-down signal is commanded and only one of a pair of jets fires, a roll couple occurs. The automatic system immediately fires the opposing roll jet, at the same time creating a pitch-up force equal and opposite to the pitch-down force, thereby canceling it. Thus, to get pitch control, roll control must be switched to time-share with the yaw thrusters.

When translation-jet failures were simulated, it was found that the difficulties encountered were the same as with the direct mode; but as with normal operations, the task was easier in rate command.

Darkside Docking. Darkside docking probably will be an operational condition in the Gemini-Agena program. Initial considerations for lighting the Agena specified that only the docking ring be illuminated. A series of simulator runs made with this initial lighting arrangement showed a degradation in pilot performance as compared with daylight operation. The table on page 80 shows that both fuel consumption and flight time increased for darkside docking.

More importantly, however, the percentage of in-tolerance runs decreased. The basic problem was loss of visual-alignment cues, which made control more difficult. With only the docking ring lit, the pilot lost three-dimensional cues that provided relative alignment; and since the nose and index bar could not be seen unless it was silhouetted against the docking ring, it was difficult to estimate the vehicle's relative attitude.

Because of the loss of cues, larger errors developed before the pilot recognized them. Large multiple errors had to be corrected close to the target. Although this task was very difficult, one pilot using the moving-base simulator made better than 90% of his runs within tolerance. Nevertheless, some degradation can be expected, as evidenced by the average of 73.3% runs in-tolerance obtained by several pilots.

Results with the fixed-base simulator also showed that darkside docking was more difficult, even for the simpler rate-command attitude-control mode. The fixed-base simulator results include one pilot who had made only a few docking runs. Here again, then, the low percentage of in-tolerance runs can be attributed to the pilot not reaching peak proficiency. The results for pilot A are believed to be more representative of a highly trained man using the rate-command attitude-control mode.

To improve darkside-docking performance, particularly in-tolerance conditions at contact, a number of docking runs using both simulators were made with various visual aids. The drawings on page 79 show two of the more successful ones for the Agena, both giving the same basic boresight information. The aids were envisioned as spring-loaded rods and flip-out posts. Besides aids on the Agena, a light was mounted on the Gemini in the moving-base simulator to illuminate the index bar and vehicle nose. In the fixed-base simulator, only the index bar was illuminated. The table on page 80 includes test results using these aids. Darkside-docking performance approached daytime when the aids were used.

Concluding Remarks. These Gemini-Agena docking studies have shown the rate-command mode well suited for visual docking, and the direct-control mode within the capability of the pilots in spite of the control coupling. However, pilots need considerable training and practice to reach peak proficiency. Tests also show that visual-manual docking can be completed with a control jet inoperative. For darkside docking, visual aids enable the pilot to dock with success approaching daytime operation.

References

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