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CONTROL OF A REMOTE MANEUVERING UNIT DURING SATELLITE INSPECTION

HERBERT J. CLARK, PhD

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Foreword

This study was conducted by Dr. Herbert J. Clark of the Presentation of Information Branch, Human Engineering Division, Behavioral Sciences Laboratory. The research was performed under Project 7184, "Human Performance in Advanced Systems," Task 718401, "Criteria for the Design and Arrangement of Displays."

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Finally, Dr. Melvin J. Warrick's careful review and suggestions are greatly appreciated.

This technical report has been reviewed and is approved.

WALTER F. GRETHER, PhD
Technical Director
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Abstract

Operator performance in flying a simulated remote maneuvering unit (RMU) on a coplanar satellite inspection mission was evaluated under two conditions of RMU attitude control and two conditions of cockpit instrumentation. The maneuver was repeatedly performed successfully using either an on-off acceleration-command attitude control system or an on-off rate-command attitude control system, each with either a full panel of cockpit instruments (six) or only one cockpit instrument. The rate-command system was found to be superior for pitch control during station keeping and for roll control in general. The acceleration-command system was superior for pitch control during the trajectory portions of the mission. Because both control systems had disadvantages, consideration of a variable rate-control system is recommended. More economical and precise RMU control was obtained under the full-panel cockpit instrumentation condition irrespective of the control system used. The instruments of most value were found to be those which provided X (longitudinal) and Z (vertical) distance information. The limitations of the simulation and the advantages and disadvantages of an "inside-out" versus an "outside-in" television display of the target and its surrounds are also discussed.

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SECTION I.
Introduction

A remote maneuvering unit (RMU) is a proposed, small, remotely controlled, unmanned spacecraft. One possible RMU mission is the inspection of objects in space. For such a mission a television (TV) camera, mounted on the RMU, would transmit scenes of the object and its surrounds back to a parent spacecraft to provide control and other information to the operator.

The purpose of this experiment was to compare operator performance under two control and two display conditions. The principal questions asked of the data were:

1) Which is better, an on-off rate-command attitude control system or an on-off acceleration-command attitude control system?

2) What and how many navigational instruments does the operator need to fly an inspection maneuver?

SECTION II.
Method

SUBJECTS

Two male Air Force pilots served as subjects. Both had extensive experience with a simulator used in this experiment and had served as subjects in related experiments.

APPARATUS

The fixed-base simulator diagramed in figure 1 included the RMU controls, navigational instru-

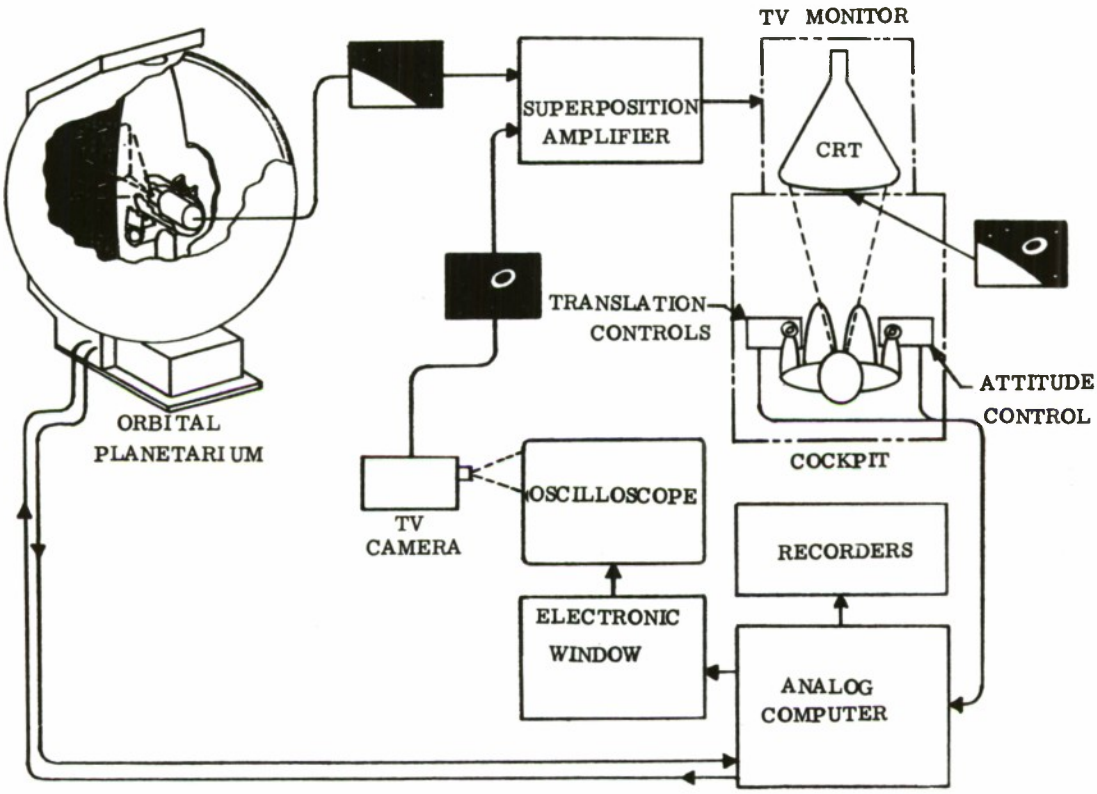

Figure 1 — Pictorial Diagram of Simulator

ments, a clock, and a TV display. The TV display presented a fully illuminated toroid target and a stellar and earth-horizon background, all of which moved and interacted realistically in relation to each other.

Cockpit characteristics, simulator details, and the assumptions underlying the equations of motion used in the associated analog computer were the same as previously described by Clark (1966). The RMU, as simulated, had a mass of 3.8 slugs and moments of inertia for pitch, yaw and roll of 2.82, 1.82 and 3.88 slug-ft^2, respectively.

MISSION FLOWN

The specific inspection mission flown is diagramed in figure 2. The RMU's starting position

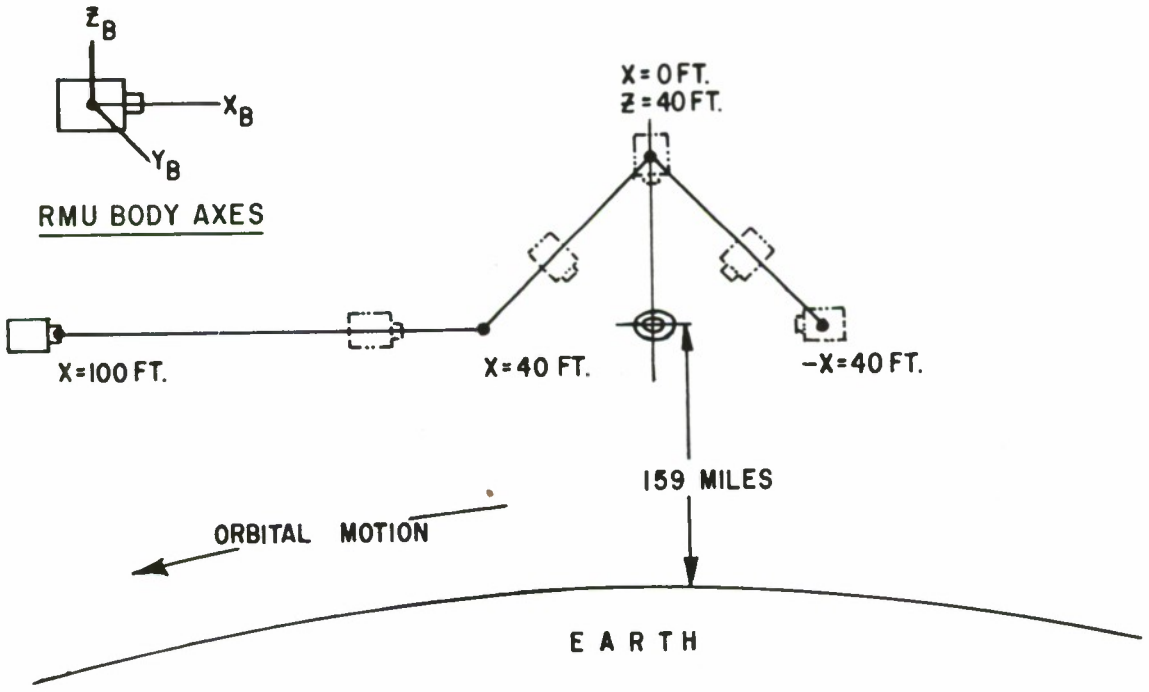

Figure 2 — The Test Mission

was 100 ft in front of and at the same orbital attitude (159 statute miles) as the target. The subject's task was to navigate the RMU along the prescribed path, stopping it once above and once behind the target, to perform simulated inspection. Total mission time was specified at 5 min; 1 min for each of the three legs of the mission, 1 min for station keeping above the target, and 1 min for a 180° roll maneuver and station keeping at the end of the mission. The subject followed this time schedule and a specified thrust regimen by reference to a sweep second clock on the instrument panel and a buzzer which sounded briefly at 1 min intervals. The subject was required to keep the target in sight on the TV display throughout the entire mission.

EXPERIMENTAL CONDITIONS

Each subject flew 40 test missions. Twenty were flown using an acceleration-command (A) system and 20 using a rate-command (R) system. Within each control system condition 10 missions were flown using a full panel (FP) of cockpit instruments (six) and 10 were flown using a partial panel (PP) of instruments. The PP consisted of only one instrument, X distance, plus the clock which was available under all conditions.

Attitude Control. Under the A condition, fore-aft (pitch) or right-left (roll) displacement of the subject's control stick produced full acceleration ($4°/sec^2$ in pitch; $6°/sec^2$ in roll) or deceleration of the RMU until the spring loaded stick was released. When released, it returned to a

neutral position and the rate attained by the RMU at that time continued.[1] To null the rate, the stick had to be displaced in the opposite direction and held there an appropriate period of time. Figure 3 shows the location of the subject's controls and the instruments in the parent spacecraft.

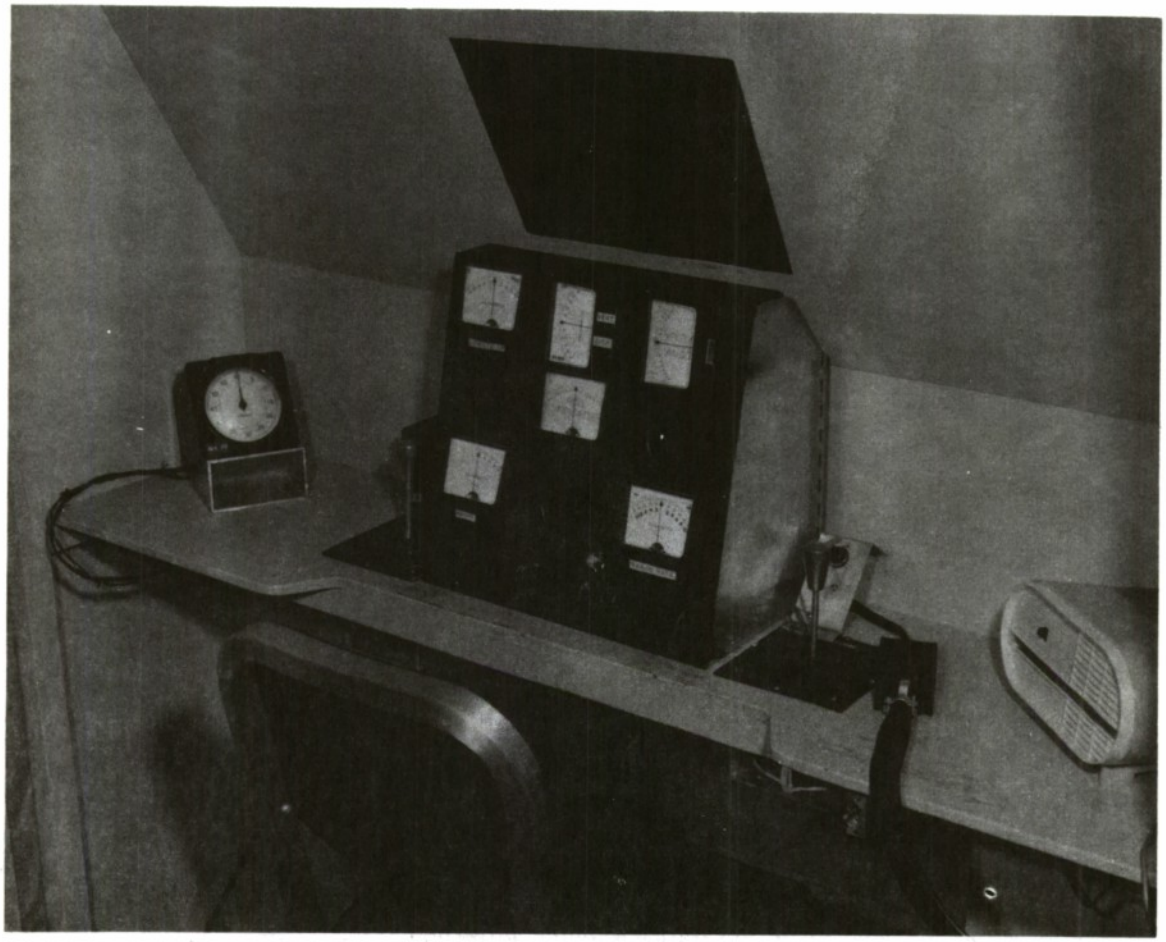

Figure 3 — Interior of Parent Spacecraft

Under the R condition displacement of the attitude control stick commanded a rate (4°/sec in pitch; 6°/sec in roll) which was automatically nulled when the stick was released. Because the mission was coplanar, no yaw control was provided under either the A or R conditions.

Attitude hold was not simulated in either the A or R condition. However, because the analog computer drift was quite small, the RMU may be thought of as being, in effect, attitude stabilized, particularly under the R condition where the operator was able to completely null the rates. No perturbations were intentionally introduced into the motion of either the RMU or the target. What little computer drift there was, as reflected in the relative motion, was systematic and did not compromise the experiment or its results in any way.

1. The rate limit of 20°/sec was not attained under either the A or the R condition.

Translation Control. Two translation controls were located at the subject's left hand. One was located on a vertical panel and could be moved up or down to give corresponding thrust along the RMU Z body axis. The other, which was similar to the attitude stick, could be moved fore and aft for corresponding thrust along the RMU X body axis.

Translation control of the RMU was *always* on-off, acceleration-command. The X acceleration was 1.0 ft/sec^2, and the Z acceleration was 0.5 ft/sec^2. Lateral acceleration ($\ddot{Y}$) was not provided because the maneuver was coplanar.

Under the FP instrumentation condition the subject was provided six cockpit instruments. Under the PP condition only one of these six instruments operated. All instruments were scaled galvanometers and are shown in figure 3.

The FP of instruments provided the following information:

1. X (longitudinal) distance between the RMU and target measured with reference to a target centered, rotating, rectangular, coordinate system (ft).
2. Z (vertical) distance between the RMU and target (ft).
3. R (straight-line distance) between the RMU and target (ft).
4. Range-rate (ft/sec).
5. RMU pitch angle to $\pm$ 90°.
6. RMU roll angle to $\pm$ 180°.

For the PP condition, only instrument No. 1 (above) was operational.

OPERATOR THRUST SCHEDULE

The same thrust schedule was specified for all test missions, and if a subject followed it perfectly he could complete a mission in 5 min.

The first leg of the mission was flown using a line-of-sight (LOS) transfer technique. It was specified that an initial +X thrust[2] be applied (as precisely as possible) for 4.0 sec using the cockpit timer for reference. During the transfer, appropriate up (+Z) thrusts were applied to maintain the LOS. No thrust schedule was specified for the application of these up-thrusts or for the thrust (–X) required to stop the RMU 40 ft from the target.

The second leg of the mission was begun after 1 min at the signal of the buzzer. It was flown using a trajectory transfer technique. One +X thrust was applied for 0.6 sec, and one +Z thrust was applied for 1.4 sec. During the trajectory, pitch angle was varied arbitrarily so as to keep the target in sight. Upon approaching a point 40 ft above the target, a –Z and a +X thrust were applied for 0.6 and 1.2 sec, respectively. An attempt was made to stop the RMU directly above the target when 2 min had elapsed (as signaled by the buzzer). The subject then attempted to station keep for the ensuing 1 min.

The third leg of the mission was begun when the buzzer sounded again. This leg was also flown using a trajectory transfer technique. One +X and one +Z thrust were applied for 0.6 and 1.4 sec, respectively. Pitch angle was again varied during the trajectory. Upon approaching a

2. All thrusts specified are referenced to the RMU body axes shown in figure 2. A +X thrust resulted in translation in the +X direction referenced to the X_B body axis.

point 40 ft behind the target on the LOS, a –Z and a +X thrust were applied for 1.4 and 0.6 sec, respectively. An attempt was made to stop the RMU on the LOS.

When the buzzer sounded again the RMU was rolled 180° counterclockwise. Station keeping was then established until the last buzzer sounded. Then the subject terminated the mission by lifting a switch which placed the computer in the "hold" mode.

Each subject was specifically instructed not to begin any leg of the mission until the buzzer sounded. Thus, he could not rush one leg of the mission so as to have extra time during a subsequent leg. He was also told to adhere to the thrust schedule as best he could.

PROCEDURE

Each subject was tested first under the A system, and then, approximately 40 days later, under the R system. Both the FP and the PP conditions for the particular control system were flown on the same day. The order of flying the FP and PP conditions was counterbalanced between subjects.

Time between missions (trials) was 60 sec with a 5-min break following every fifth trial. The beginning of each trial was signaled by a buzzer and a small red light. The light indicated that the computer was in the "operate" mode and that the subject should begin the trial.

Before flying the A or the R test missions, each subject engaged in a training session on that particular control system. Missions similar to that in figure 2 for the test mission were flown. Just as for the test mission, a specific thrust schedule was prescribed for the training mission. The difference between the training and test missions was the range between the RMU and target. For the test missions, the initial RMU range was 100 ft, while it was 200 ft for the training missions. Similarly, the inspection distance was 40 ft for the test missions, but 80 ft for the training missions.

The training missions were flown first using the six cockpit instruments and the clock (FP), and then using only the X distance cockpit instrument and the clock (PP). The transition from FP to PP training was made after the FP mission was flown successfully. The PP mission was practiced until four out of five successive missions were flown within a boundary of ± 10 ft perpendicular to the specified RMU flight path.

SECTION III.
Results

The subjects were able to fly 79 of the 80 test missions within 7 min and without ever losing sight of the target. Mean A mission time was 333.7 sec and mean R mission time was 324.4 sec. Actual mission times were longer than the prescribed mission time (5 min) because extra time was spent correcting for deviations from the flight path. The one unsuccessful mission was aborted at the beginning of trajectory 1, mission 7 (A – FP condition) when the subject applied a –Z instead of a +Z thrust and lost sight of the target. This abort was most likely a consequence of the subject's stage of practice, rather than of the particular experimental condition.

The quality of mission performance was evaluated by examining the analog computer X-Z plot (flight path) and by analyzing the performance data for each successful mission. Examples of X-Z plots are shown in figure 4.
These plots are representative of the least and most precise missions flown. The performance measures are listed in tables I and II.

FLIGHT PATH ANALYSIS

Seventy-seven of the 79 successful missions were flown within a ± 10-ft boundary of the prescribed flight path. On each of the two remaining missions there was an excursion from the flight path of 25 ft or more. One subject made a 25-ft overshoot on mission 11 (A-PP), and the other made a 30-ft overshoot on mission 11 (A-FP).

The 25-ft excursion is shown in figure 4, sample C. The subject failed to terminate trajectory 2 soon enough and, therefore, overshot the mission terminal point. He was, however, able to return the RMU from the overshoot point to within approximately 10 ft of the terminal point. The other subject, who overshot the terminal point by 30 ft, was able to return the RMU to within 5 ft of the designated terminal point. This subject's recovery was more precise probably because he was flying an FP mission whereas the other subject was flying a PP mission.

Visual inspection of the flight paths, along with subjects' comments, indicated that the degree of mission success was highly related to the subjects' ability to accurately apply the X and Z thrusts required for the trajectory portions of the mission. The LOS portion of the mission and the station keeping (once the RMU was stopped) were not as difficult as the trajectories.

Visual inspection of the flight paths did not reveal differences between FP and PP performance, but did indicate that the R trajectories were slightly more precise than the A. Although all R missions were flown after all A missions, the obtained difference between trajectories was probably not due to practice. There was an approximate 40-day interval between the A and R missions, and as long (30-50 trials) a practice session was required for the subjects to meet the criterion for beginning the R test missions as was required initially for beginning the A test missions.

PERFORMANCE MEASURE ANALYSIS

Tables I and II show medians (Md), ranges (R), means ($\overline{X}$), and standard deviations (SD), averaged over subjects, for three categories of performance: (1) Mission Duration, (2) Accumulated Velocity (ΔV_X, ΔV_Z, $\Delta\omega_X$, $\Delta\omega_Y$), and (3) Thrusts Applied (X, Z, ϕ, Θ). Mission 7 (A-FP condition) was not included in the statistical anlysis because the subject failed to complete it.

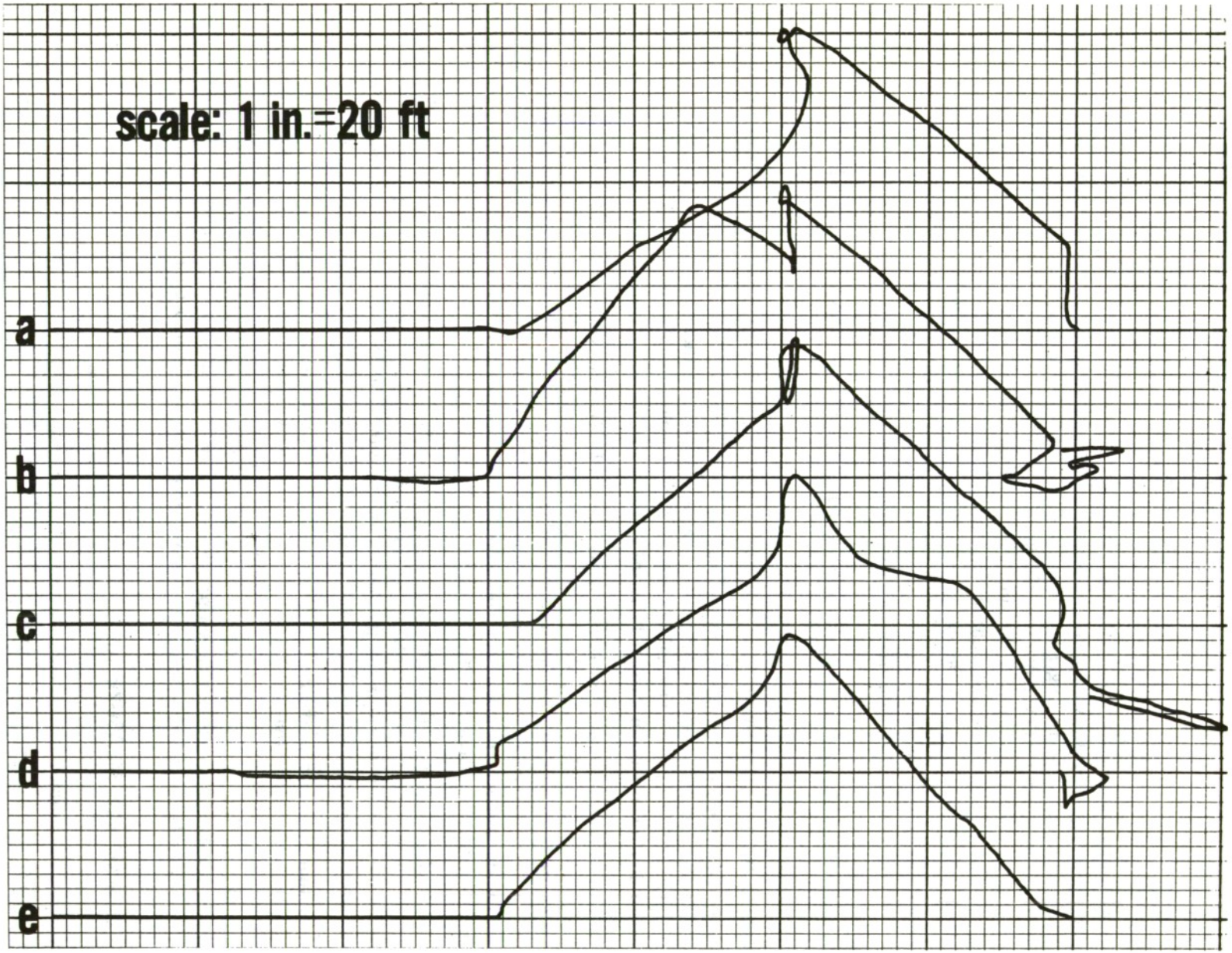

Figure 4 — Representative Flight Paths

TABLE I.

ACCELERATION COMMAND VERSUS RATE COMMAND PERFORMANCE (N=36)

	A	*R*
1. Mission Duration (sec)		
Md	331.2	331.5
R	300.0-419.1	229.0-364.0
$\overline{X}$	333.7	324.4
SD	26.4	25.1
2. Accumulated Velocity		
a. ΔV_X, Fore-Aft (ft/sec)		
Md	10.7	10.0
R	7.2-20.2	6.9-14.9
$\overline{X}$	11.4	10.3
SD	3.2	1.9
b. ΔV_Z, Up-Down (ft/sec)		
Md	4.8	5.3
R	2.4-7.4	2.9-11.7
$\overline{X}$	5.0	5.7
SD	0.9	1.9
c. $\Delta\omega_X$, Roll (deg/sec)		
Md	30.5	24.0* ($p=.012$)
R	11.5-99.9	12.0-60.0
$\overline{X}$	38.0	25.0
SD	20.0	14.0
d. $\Delta\omega_Y$, Pitch (deg/sec)		
Md	32.7	304.0* ($p<.001$)
R	19.4-55.5	192.0-488.0
$\overline{X}$	33.3	317.1
SD	9.5	80.6
3. Thrusts Applied		
a. X, Fore-Aft		
Md	20.0	21.0
R	10.0-33.0	11.0-33.0
$\overline{X}$	19.6	21.1
SD	5.0	4.5
b. Z, Up-Down		
Md	34.0	25.5
R	15.0-65.0	16.0-47.0
$\overline{X}$	33.4	27.7
SD	12.2	7.4
c. ϕ, Roll		
Md	10.0	2.0* ($p<.001$)
R	3.0-35.0	1.0-5.0
$\overline{X}$	11.3	2.1
SD	6.3	1.2
d. Θ, Pitch		
Md	47.0	38.0* ($p=.021$)
R	27.0-76.0	24.0-61.0
$\overline{X}$	48.6	39.6
SD	12.7	10.1

*An asterisk denotes that the difference between the two medians directly to the left of the asterisk is statistically significant. The level of significance is given in parentheses.

TABLE II.

FULL PANEL VERSUS PARTIAL PANEL PERFORMANCE (N=18)

	A		R	
	FP	PP	FP	PP
1. Mission Duration				
Md	332.5	331.2	318.5	333.3
R	301.0-419.1	300.0-381.3	229.0-364.0	303.0-359.8
$\bar{X}$	335.3	332.1	318.3	330.5
SD	27.4	25.3	31.0	15.0
2. Accumulated Velocity				
a. ΔV_X, Fore-Aft (ft/sec)				
Md	10.0	11.8* (p=.008)	10.0	10.3
R	7.2-18.0	8.0-20.2	6.9-12.9	7.9-14.9
$\bar{X}$	10.2	12.7	9.8	10.8
SD	2.4	3.4	1.8	1.8
b. ΔV_Z, Up-Down (ft/sec)				
Md	4.7	5.1	5.1	5.8
R	4.0-7.4	2.4-6.6	3.5-11.7	2.9-10.1
$\bar{X}$	5.0	5.0	5.7	5.8
SD	0.9	1.0	2.1	1.6
c. $\Delta\omega_X$, Roll (deg/sec)				
Md	32.2	30.5	18.0	24.0
R	11.5-86.0	15.0-99.9	12.0-60.0	12.0-60.0
$\bar{X}$	37.1	39.0	23.3	26.7
SD	19.1	20.8	14.1	13.6
d. $\Delta\omega_Y$, Pitch (deg/sec)				
Md	26.0	38.0* (p=.012)	272.0	348.0* (p=.030)
R	19.4-54.5	29.0-55.5	192.0-424.0	232.0-488.0
$\bar{X}$	28.0	38.6	284.4	349.8
SD	8.5	7.3	65.9	80.7
3. Thrusts Applied				
a. X, Fore-Aft				
Md	20.0	20.0	20.5	22.0
R	11.0-26.0	10.0-33.0	11.0-33.0	16.0-29.0
$\bar{X}$	18.9	20.3	20.7	21.6
SD	4.0	5.7	5.4	3.3
b. Z, Up-Down				
Md	33.5	34.0	24.0	27.0
R	15.0-54.0	16.0-65.0	16.0-41.0	19.0-47.0
$\bar{X}$	32.3	34.5	26.7	28.7
SD	10.4	13.7	8.1	6.6
c. ϕ, Roll				
Md	8.0	12.0* (p<.002)	1.5	2.0
R	3.0-27.0	6.0-35.0	1.0-5.0	1.0-5.0
$\bar{X}$	9.3	13.4	1.9	2.2
SD	5.2	6.6	1.2	1.1
d. Θ, Pitch				
Md	43.0	57.0* (p<.002)	34.0	43.5* (p=.03)
R	27.0-66.0	34.0-76.0	24.0-53.0	29.0-61.0
$\bar{X}$	42.3	54.9	35.6	43.7
SD	10.5	11.6	8.2	10.1

*An asterisk denotes that the difference between the two medians directly to the left of the asterisk is statistically significant. The level of significance is given in parentheses.

Since an equal number of observations per condition was required for certain statistical tests performed (sign tests), mission 7 was deleted across all conditions.

Acceleration command performance versus R performance is described in table I. Each statistic in the table is based on 36 observations, 18 trials for each subject. The sign test (Siegel, 1956) for a difference between medians was used to compare A and R performance. A statistically significant difference is denoted by an asterisk next to the median in the R column. Thus, in table I, there is a significant difference between the A and R medians for $\Delta\omega_X$, $\Delta\omega_Y$, number of roll thrusts applied, and number of pitch thrusts applied.

The significant difference between $\Delta\omega_X$ (in effect, roll fuel expended) for the A and R conditions indicates that less roll fuel was used under the R condition. Table I also shows that significantly fewer roll thrusts were applied under the R condition. In addition, terminal roll angle error (departure from a no-roll condition) was slightly less under the R condition. Mean terminal R roll angle error was 0.34 deg, with an SD of 0.40 deg. Mean terminal A roll angle error was 2.64 deg, with an SD of 2.96 deg. Overshooting or undershooting the terminal roll point was more common under the A system. In addition, one subject expressed a strong preference, and the other a slight preference, for the R roll system over the A roll system for performing the 180° roll maneuver.

The R system was also preferred for pitch control during station keeping. Pitch rates could be completely nulled, and that simplified discriminating between rotation and translation of the RMU. However, no differences between A and R station keeping were revealed in the X-Z plots. However, the mean number (23.2) of A pitch thrusts applied during station keeping did exceed the mean number (10.8) of R pitch thrusts applied during station keeping, suggesting that station keeping was, in fact, easier under the R condition.

Although both subjects preferred the R system for performing the 180° roll maneuver and for pitch control during station keeping, neither liked it for the trajectory portions of the mission. The rate commanded (4°/sec) was too fast for the target tracking required during the mission trajectories when it was necessary to slowly vary the RMU pitch angle to keep the target in sight. To do this, it was necessary to command the rate, null it, and then repeat the sequence. This repetitive procedure was more difficult than that required when using the A pitch system which permitted sufficiently slow pitch rates to allow fewer tracking thrusts to be applied. Thus, the simpler A tracking procedure was preferred by both subjects. The mean number of A pitch thrusts applied during the trajectories was 25.4; the mean number of R pitch thrusts applied during the trajectories was 28.8.

Pitch fuel consumption was much higher with the R system than with the A system. The median $\Delta\omega_Y$ for the A system was 32.7 deg/sec, while it was 304.0 deg/sec for the R system (table I). This large difference resulted primarily from the necessity of having to command an unnecessarily high rate each time an R system rate was commanded. Had provision been made for different pitch rates to be commanded, this result might not have been obtained.

Although the mean number of pitch thrusts applied during the R trajectories slightly exceeded the mean number of pitch thrusts applied during the A trajectories, the mean number of all A pitch thrusts (48.6) exceeded the mean number (39.6) of all R pitch thrusts (table I). The A value exceeds the R value because few R thrusts were applied during station keeping.

Full panel versus PP performance is described in table II. Each statistic in the table is based

on 18 observations, 9 trials for each subject. As in table I, an asterisk indicates a significant difference between medians.

Each of the six significant differences shown in table II indicates better FP than PP performance. A smaller quantity of ΔV_X (A condition only) and $\Delta\omega_Y$ was commanded under the FP condition, and fewer roll (A condition only) and pitch thrusts (both conditions) were applied under the FP condition. Subject opinion was that the application of few thrusts reflected ease of RMU control. Thus, it would appear that RMU control was easier, and perhaps more positive, under the FP condition.

Both subjects commented that the major advantage of the FP instrument condition over the PP instrument condition was the availability of Z distance information in addition to the X distance information provided under the PP condition. The remaining four FP instruments were seldom referred to. Therefore, the superior FP performance was probably primarily a consequence of the availability of Z distance information.

SECTION IV.
Discussion and Conclusions

The principal finding of this study was that both subjects repeatedly executed the prescribed maneuver successfully under all four experimental conditions. Differences between the A and R conditions were as follows:

(1) The R system was superior to the A system for roll control. It permitted less roll fuel expenditure, less operator control action, and more precise RMU roll positioning. The R system was also preferred for pitch control during station keeping, because it simplified discriminating between rotation and translation since R rates were completely nulled. In general, the most helpful characteristic of the R system as compared with the A system was its automatic rate nulling when the attitude controller was returned to the neutral position. This feature eliminated the operator having to gage the amount of retrothrust to apply to null an existing rate.

(2) The A system was superior to the R system for pitch control during the trajectories. While only one R rate could be commanded, various A rates could be commanded. The possibility of commanding a low rate with the A system simplified target tracking and permitted a lower A than R pitch fuel expenditure.

A variable R system might have been superior to either of the attitude systems simulated in this study. It would have had the favorable characteristics of both the A and R systems used in this study. A variable rate system of this type has been simulated by Hatch, et al (1964). In his system, deflection of the hand controller commanded an attitude rate proportional to stick deflection. Zero deflection held the attitude drift to within 0.2°/sec. This system was judged superior to an A system for performing a Gemini docking maneuver. Attitude fuel consumption was about the same under both systems, but there was a tendency to use more time under the A system.

Had a proportional R system been used in the present study, it very likely would have required fewer R thrust applications during the trajectories, thus making R fuel consumption as low as A fuel consumption. In addition, station keeping might have been as simple as on-off R station keeping, and simpler than on-off A station keeping. In short, a proportional R system should have been at least as simple to use as the on-off R system, and as economical as the on-off A system.

Differences between the FP and PP conditions were as follows:

(1) Significant differences between FP and PP performance all indicated better performance under the FP condition. There was a tendency for better fuel economy and more precise RMU control under the FP condition.

(2) The principal advantage of the FP condition over the PP condition was the availability of Z distance information. Instruments other than those providing X and Z distance information were seldom referred to. Perhaps the pitch and roll indicators would have been used more often had they operated through 360° and had they been more accurate.

Much of the success in flying the mission successfully under the PP condition must be attributed to subject knowledge of target size and shape. The scribe marks on the TV monitor allowed subjects to know when target range was 40 ft. The circular target shape allowed the subject to know when the RMU was above the target. Had the target been tumbling or spherical, the operator's task would have been more difficult.

The prescribed thrust schedule also simplified the subject's task. However, subjects did deviate from the schedule, especially when terminating a trajectory. Rather than applying a single long slowing-down thrust, they found it easier to lead with short counterthrusts, which slowed the RMU in gradual increments. It can also be noted from figure 4 that the prescribed thrusts for entering a trajectory were sometimes over- or underestimated. The resulting deviations from the flight path were corrected by applying appropriate counterthrusts. This ability of subjects to perform such corrective maneuvers, and to recover from unexpected situations, indicates that they were not flying the mission by rote memory alone.

Several naive observers who attempted to fly the inspection maneuver commented that the "inside-out" view presented on the TV monitor was confusing. The direction of required thrust application for attitude and translation control seemed unnatural. For example, when the target translated up on the screen, it seemed more natural to move the thruster "down" than "up" to stop up movement. In other words, an "outside in" view might have been preferred by these observers. The subjects were less concerned with this orientation problem, perhaps because they were accustomed to flying the artificial horizon of the typical aircraft.

Although changing the TV display from an "inside out" to an "outside in" view was suggested by some observers, there appears to be at least one disadvantage to such a change. If the target were close to the parent spacecraft, the operator might wish to navigate the RMU by referring to both the TV display and the out-of-the-window view of the target and the RMU. Since the window provides an "inside out" view, it would seem wise also to have the TV display an "inside out" view. Otherwise, the relationship between the control action and the apparent movements of the RMU would be reversed on the TV display.

The $6°/sec^2$ roll acceleration used in this study was judged to be too fast by both subjects. Each thought that he would have preferred the $4°/sec^2$ acceleration which he had used in a previous RMU study (Clark, 1966). In view of the results of the present study, however, a proportional R system might best be used as the primary attitude control system for the RMU, using the A system for back-up.

Although the mission prescribed in this experiment was flown successfully with only time and X distance information to supplement the TV display, it should be remembered that the operator knew target size, shape and distance, and the RMU thrust schedule. An astronaut would be confronted with a much more difficult task if the target were at a different orbital altitude than the RMU, out of its plane, and of unknown size or distance. Although the programmed maneuvers in this study were realistic, they were not the only ones possible, nor the most difficult.

References

Clark, H. J., 1966. *Optimum Angular Accelerations for Control of a Remote Maneuvering Unit.* AMRL-TR-66-20, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. Also appears in *Human Factors,* Vol. 8, June 1966.

Hatch, H. G., Riley, D. R. and Cobb, J. B., 1964. *Full-Scale Gemini-Agena Docking Using Fixed and Moving Base Simulators.* NASA, Hampton, Virginia. Paper presented at the 1st AIAA Annual Meeting, Washington, D. C.

Siegel, S., 1956. *Nonparametric Statistics for the Behavioral Sciences,* New York: McGraw Hill, Inc.

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13. ABSTRACT

Operator performance in flying a simulated remote maneuvering unit (RMU) on a coplanar satellite inspection mission was evaluated under two conditions of RMU attitude control and two conditions of cockpit instrumentation. The maneuver was repeatedly performed successfully using either an on-off acceleration-command attitude control system or an on-off rate-command attitude control system, each with either a full panel of cockpit instruments (six) or only one cockpit instrument. The rate-command system was found to be superior for pitch control during station keeping and for roll control in general. The acceleration-command system was superior for pitch control during the trajectory portions of the mission. Because both control systems had disadvantages, consideration of a variable rate-control system is recommended. More economical and precise RMU control was obtained under the full-panel cockpit instrumentation condition irrespective of the control system used. The instruments of most value were found to be those which provided X (longitudinal) and Z (vertical) distance information. The limitations of the simulation and the advantages and disadvantages of an "inside-out" versus an "outside-in" television display of the target and its surrounds are also discussed.

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