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STICK EXPERIMENT

CDRL ITEM NO. T111
DATA ITEM NO. UT-485

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ABSTRACT

SECTION 1

ABSTRACT

The purpose of this experiment was to evaluate and compare a rate stick, a rate plus end-stop acceleration stick, and a rate plus acceleration stick in the presence of AVE Digital Processing and system noise for the Primary Optics (PO) System.

Phase I of the Stick Experiment utilized initial rate errors of approximately 50 and 215 μ rad/sec while Phase II utilized approximately 50 and 540 μ rad/sec. Phase II also investigated the effect of removing the extrapolation term from the stick computation.

The conclusions of this experiment are:

a. The rate stick is preferred with respect to time-to-null below 17μ rad. The rate plus end-stop stick resulted in a lower average rate error during steady state because the stick gain in the rate only region was less than that used for the rate stick. The rate plus acceleration stick is the most unsatisfactory of the three types.

b. The results of Phase I are consistent with those obtained by Aerospace in a similar experiment.

c. No appreciable difference in performance occurs without the extrapolation prediction technique. Some crew members did not care for the overshoot effect associated with extrapolation.

d. Training (time spent practicing before measurements were recorded) is the most significant of all problem variants

e. Normal distribution theory is not applicable in the statistical analysis of performance in this experiment in that the data are not normally distributed.

f. Further simulation experiments are required to determine the optimum time to enable stick input during slew settling time.

Practically, it is not necessary to choose between the rate stick and the rate plus end-stop stick. The concept of having an end-stop control for exceptionally high initial rate errors is sound. The rate plus end-stop stick should be used as a rate stick most of the time, and the coefficients used reflect the expected error rates. If, however, the rates are found to be consistently higher than expected, the crew has the capability to adjust the coefficients so that the rate portion of the stick handles the majority of cases. To meet the time-to-null specification, a higher gain in the rate only region appears warranted. Since the average rate errors in the experiment were well within system specification, this increase in gain for rate nulling is acceptable.

SECTION 2

NARRATIVE

SECTION 2

NARRATIVE

2.1 SYSTEM CONFIGURATION

The Elemental Development Simulator was operated as a part task system for this stick experiment. The effect of each system section was evaluated and fidelity of the experiment preserved. The simulation model is described in Appendix A.

2.2 PHASE I

Two levels of rate errors were used with components defined by:

$$\dot{X} = \pm \left| 33.0 - 82.4 \cos^2 \sum \right| \mu \text{ rad/sec}$$
$$\dot{Y} = \pm \left| 99.0 - 82.4 \cos^2 \sum \right| \mu \text{ rad/sec} \qquad \text{Easy}$$

$$\dot{X} = \pm \left| 33.0 + 82.4 \cos^2 \sum \right| \mu \text{ rad/sec}$$
$$\dot{Y} = \pm \left| 99.0 + 82.4 \cos^2 \sum \right| \mu \text{ rad/sec} \qquad \text{Hard}$$

where $\sum \equiv$ pitch angle. For each level there are four possible combinations of signs, giving four directions in which the initial rate vector appeared.

Six MOL flight crew members participated as subjects in the Phase I experiment. The scenes were presented at an effective scale factor of 1000 power only and the task was that of rate nulling only. Position error was ignored. The subjects were instructed to "freeze" the scene, regardless of position, the instant it appeared.

Data were collected for two payload pass sequences. Fourteen scenes were presented in each sequence with seven easy and seven hard initial rates in random order and with the initial direction also in random order. In one payload pass sequence a geometrical pattern

was presented with an easy rate, and in the other payload pass sequence the geometrical pattern was presented with a hard initial rate. Thus, for each subject and each stick type, fourteen scenes and the geometrical pattern were exposed at each level of initial rate.

The training of the subjects may be roughly divided in two parts. During the first part, task familiarization and practice were given with all three stick types. During the second part, training was continued on each stick type until the subject was judged to be ready, and then data were taken immediately on that particular stick type. The level of training achieved when data were taken was judged to be adequate for the purposes of the experiment. This judgment was based on consistency and level of performance and upon the comments of the subjects. Owing to time limitations, it is probable that the data recorded for some subjects reflect the effect of fatigue.

To eliminate the effect of the order in which stick types were studied, the subjects used the stick types in different orders. These orders were:

Subject 1: Rate, Rate and End-Stop, Rate and Acceleration.

Subject 2: Rate, Rate and Acceleration, Rate and End-Stop.

Subject 3: Rate and End-Stop, Rate, Rate and Acceleration.

Subject 4: Rate and End-Stop, Rate and Acceleration, Rate.

Subject 5: Rate and Acceleration, Rate, Rate and End-Stop.

Subject 6: Rate and Acceleration, Rate and End-Stop, Rate.

2.3 PHASE II

In this phase, two levels of initial rate error were used: the easy rates used in Phase I.

and difficult rates defined by:

$$\dot{X} = \pm \left| 143.0 + 82.4 \cos^2 \sum \right|$$
$$\dot{Y} = \pm \left| 410.0 + 82.4 \cos^2 \sum \right|$$

Two MOL flight crewmen participated as subjects in Phase II, and training proceeded as in Phase I. Stick types were used in the following order:

Subject 7: Rate, Rate and Acceleration, Rate and End-Stop.

Subject 8: Rate and End-Stop, Rate and Acceleration, Rate.

Data collection was the same as in Phase I.

In addition, Phase II included a study of the rate stick and the rate and end-stop stick without extrapolations of stick output.

2.4 ENGINEERING WORK

The values used for the stick coefficients were the same values used by Aerospace in their simulation. However, the following rate plus acceleration sticks were also evaluated in Phase II.

1. $\left(\frac{20}{S} + \frac{4}{S^2} \right) \delta \mu$ rad/sec

2. $\left(\frac{3}{S} + \frac{15}{S^2} \right) \delta \mu$ rad/sec

where:

δ = degree of stick deflection

S = Laplace transform variable

A rate plus acceleration stick of the above type is suggested when the man-model used in control system analysis has no lead in its transfer function. The lead induced in the system by adding the acceleration term should make the task easier.

The other major evaluation of Phase II involved letting the crew have stick control before end-of-slew. An exponential end-of-slew characteristic was added to the system with an initial value of 5000 μ rad/sec and a time constant of 0.25 seconds. This exponential normally terminated at end-of-slew, leaving the servo bias plus altitude error. The system has the capability of enabling stick control at any time within this one second. The operating procedure of this function was dictated by crew comments.

Phase II also included a brief study of the proposed α stick (rate plus end-stop rate).

SECTION 3

RESULTS

SECTION 3
RESULTS

3.1 DATA COLLECTION METHOD

For each stick type, each subject nulled the rate error on thirty aiming points, with each aiming point presented for a period of 14 seconds.

The components and the magnitude of stick deflection, and the components and magnitude of rate error were recorded on a strip chart recorder to aid in monitoring performance during training.

The instantaneous rate error was recorded ten times per second on the digital data tape. The rate error was averaged over a period of 4 to 14 seconds for each aiming point. That average rate error, the time required to first drive the rate error below 17 μrad/sec, and total time during which the rate error exceeded 17 μrad/sec were printed out in the control room at the end of each aiming point.

3.2 DATA ANALYSIS

For average rate error and average time with rate error exceeding 17 μrad/sec, the mean, median, and 95th percentile are shown in Table 3-1. These data are shown in their entirety in Appendix B.

The instantaneous rate errors were averaged over a period of 4 to 14 seconds after the scene was unblanked.

$$\text{Average rate} = \frac{1}{10} \int_{4}^{14} R(t)dt$$

Time to reduce the initial rate error to less than 17 μrad/sec was stripped from the data tape. The total time during which the rate error was greater than 17 μrad/sec was also computed to indicate whether or not the subject remained below 17 μrad/sec.

Statistical tests, applied to compare results, are discussed in Appendix C. The basic test used was the non parametric Mann-Whitney U-test. This test was chosen instead of parametric tests because the data appeared to depart severely from normality.

The variation of instantaneous rate as a function of time is shown in Appendix D.

Cumulative distributions of instantaneous rate were also obtained. These results are discussed in Appendix E.

Questions associated with the following items were discussed with each crew member after Phase I. Their comments are recorded in Appendix F.

a. Noise
b. Light intensity
c. Extrapolation
d. Stick feel
e. Stimulus
f. Stick types
g. Stick preference
h. General Simulator impression

TABLE 3-1. DATA ANALYSIS*

		RATE					RATE + END STOP					RATE + ACCEL.				
		AVERAGE RATE ERROR (4 RAD/SEC)		TIME ABOVE 1/4 RAD/SEC (SEC)			AVERAGE RATE ERROR (4 RAD/SEC)		TIME ABOVE 1/4 RAD/SEC (SEC)			AVERAGE RATE ERROR (4 RAD/SEC)		TIME ABOVE 1/4 RAD/SEC (SEC)		
		AVG.	MED.	95%	AVG.	MED.	95%	AVG.	MED.	95%	AVG.	MED.	95%	AVG.	MED.	95%
PHASE I	EASY	2.64	2.53	3.68	1.08	1.00	1.88	2.40	2.35	3.20	1.03	1.00	1.63	3.42	3.28	4.75	1.10	1.02	1.87
	HARD	3.11	2.96	4.60	1.73	1.65	2.60	3.04	2.57	6.58	2.14	1.90	4.19	4.82	4.52	7.06	2.73	2.52	4.78
EXTRA-POLATION	EASY	3.22	3.03	4.40	1.24	1.28	1.87	2.36	2.26	3.26	1.06	1.08	1.45	4.07	4.32	3.50	1.18	1.18	1.68
	DIFFICULT	3.49	3.49	4.86	2.14	1.92	2.66	2.52	2.28	3.99	2.03	1.96	2.98	6.62	6.60	7.99	3.49	3.38	4.65
NO EXTRA-POLATION	EASY	2.91	2.78	4.08	1.26	1.32	2.13	2.67	2.66	3.30	0.96	0.88	1.49						
	DIFFICULT	3.65	3.58	4.84	1.88	1.74	2.57	2.57	2.54	3.64	2.22	2.20	2.94						

* EXPERIMENT PROCEDURE AND STATISTICAL DATA SUPPLIED BY J. JEWETT
** AVERAGE RATE ERROR FOR EACH OF 14 SCENES DURING THE INTERVAL 4-14 SEC

APPENDIX A

SYSTEM CONFIGURATION

APPENDIX A

SYSTEM CONFIGURATION

A.1 STICK

The stick, used in this experiment, was an analog type with 27 degrees full travel. It was sampled ten times a second by the digital computer at ▽1 as shown in Figure A-1. To make this stick comparable to the actual AVE stick, quantization (shown at ▽2 in Figure A-1) was then performed, giving resolution of 833 counts for a 27 degree deflection (representing 30 degrees in the AVE).

A.2 SAMPLING

The sampling of the stick input was ten times per second.

A.3 STICK GAINS

The section between ▽2 and ▽3 of Figure A-1 represents the possible stick gains and stick types. The combinations can be set by data card input. Gain K_1 allows proper adjustment so that the 27 degree mechanical stick has an electrical output equivalent to a 30 degree stick. The end-stop implementation is $\frac{25}{27}$ of full travel and is implemented electrically. This simulates an end-stop at 27.8 degrees (electrical).

A.3.1 GAINS FOR PHASE I

Stick transfer functions for the three types of sticks are as follows:

Rate stick: $\frac{8\delta}{S}$

Rate stick with end-stop acceleration: $\frac{4\delta}{S} + \frac{K\delta}{S^2}$, $K = \begin{cases} 0 \text{ if } \delta_1 < 29 \text{ deg} \\ 8 \text{ if } 29 \text{ deg} \leqq \delta_1 < 30 \text{ deg (electrical)} \end{cases}$

Rate and acceleration stick: $\frac{4\delta}{S} + \frac{2\delta}{S^2}$

where:

S = Laplace transform variable

δ = stick deflection in degrees (electrical) in either axis

δ_1 = two dimensional stick deflection (i. e., the RSS of the stick deflections along the X and Y axis)

Units of the transfer function (in each axis) are μ rad/deg of stick travel

A. 3. 2 GAINS FOR PHASE II

Rate stick: $\frac{20\,\delta}{S}$

Rate stick with end-stop acceleration: $\frac{8\,\delta}{S} + \frac{K\,\delta}{S^2}$, $K = \begin{cases} 0 \text{ if } \delta_1 < 29 \text{ deg} \\ 24 \text{ if } 29 \text{ deg} \leqq \delta_1 \leqq 30 \text{ deg} \end{cases}$

Rate and acceleration stick: $\frac{12\,\delta}{S} + \frac{6\,\delta}{S^2}$

where:

S = Laplace transform variable

δ = stick deflection in degrees (electrical) in either axis

δ_1 = two dimensional stick deflection (i. e., the RSS of the stick deflections along the X and Y axis)

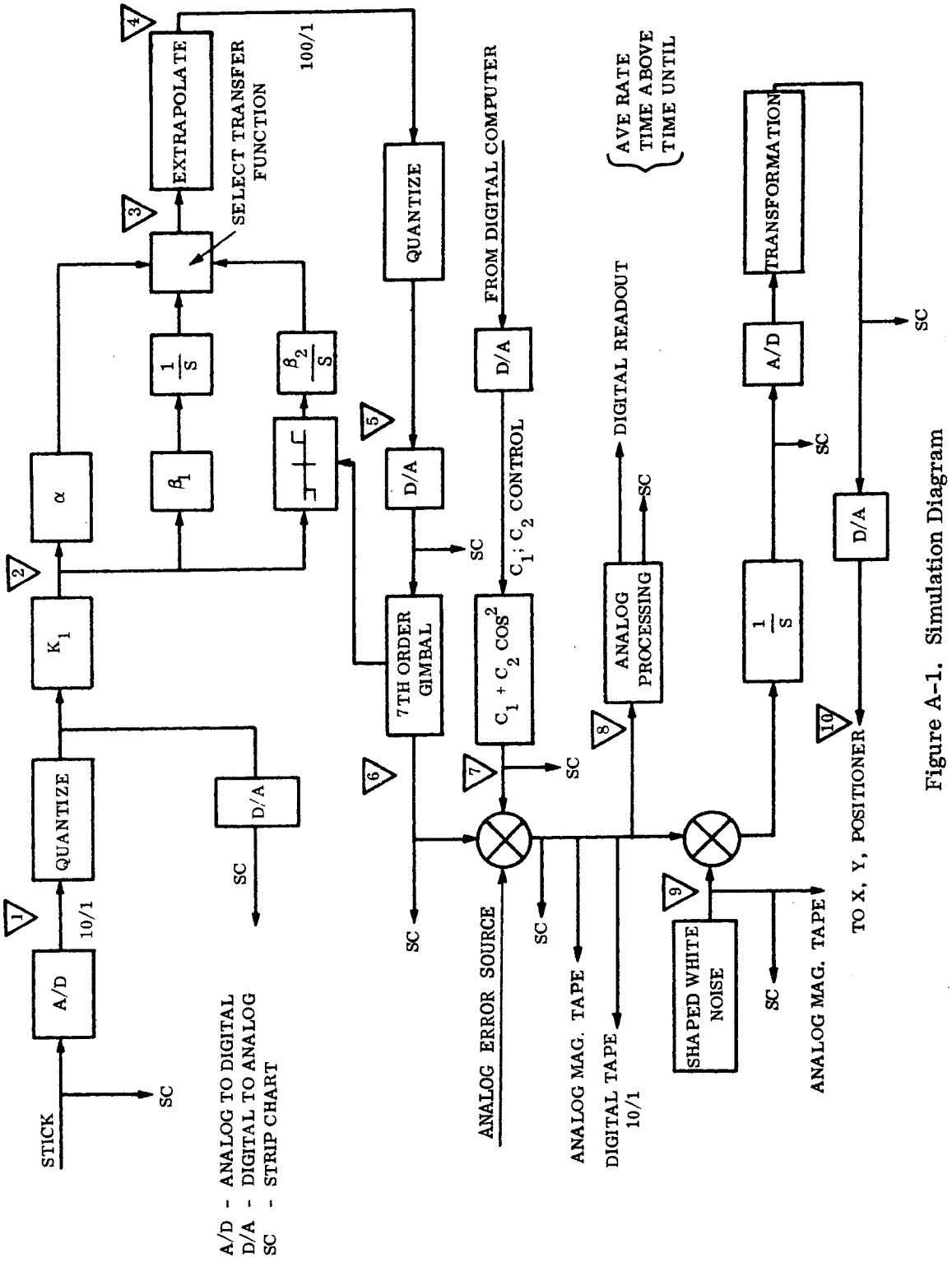


Figure A-1. Simulation Diagram

A.4 EXTRAPOLATION

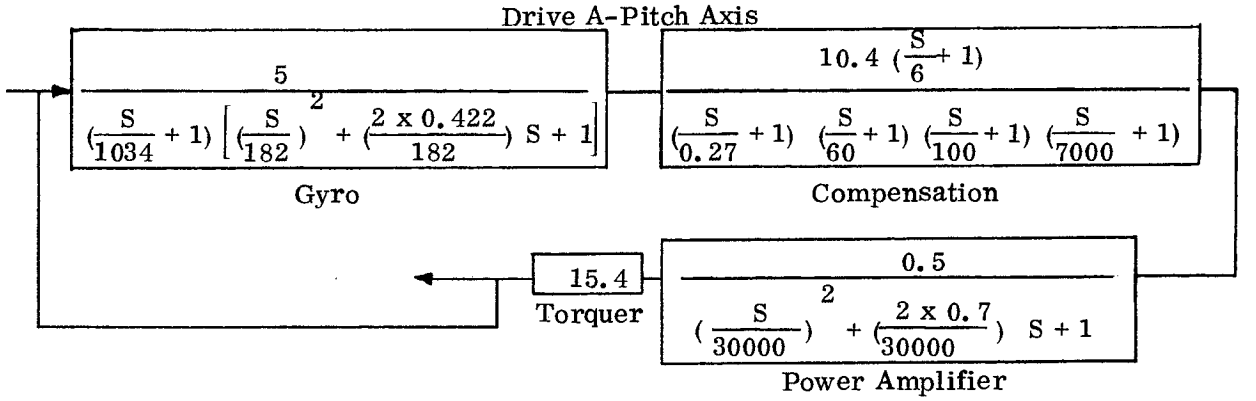
The extrapolator proposed for the AVE, and as implemented in the simulation ▽4▽ (Figure A-1), is a linear predictor whose output is computed 100 times a second from an input of 10 times a second. There is no limit on maximum signal after extrapolation. The system is scaled at 1000 μ rad/sec.

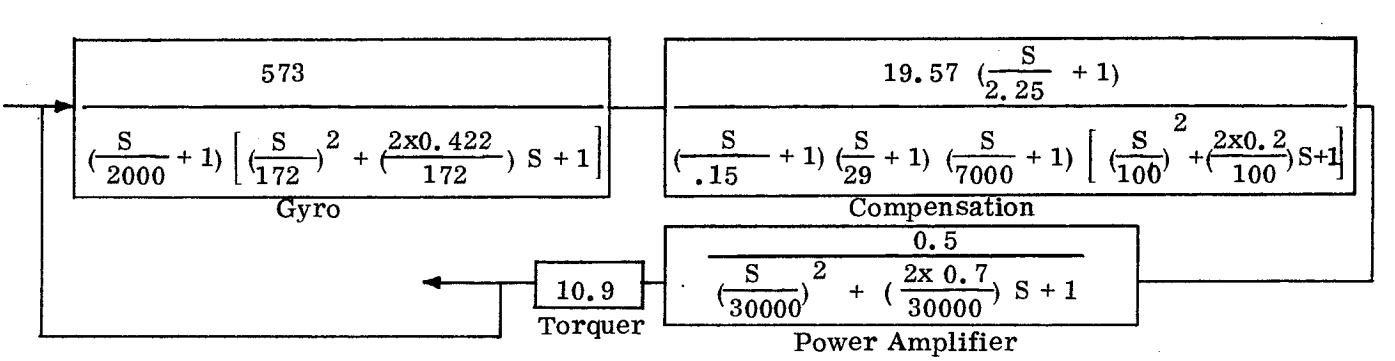
A.5 QUANTIZATION

There are two quantizers in the system. The first is located at ▽1▽ (Figure A-1), giving proper resolution to the stick input command. The second is located before ▽5▽ (Figure A-1), and represents the resolution of the AVE digital analog converters for the commanded gimbal rate. The effective resolution of the AVE converters is 2 μ rad/sec in pitch and 1 μ rad/sec in roll (LOS numbers).

A.6 DYNAMICS

The dynamics of the system before ▽6▽ (Figure A-1) are of the seventh order models.





A.7 ERROR SOURCES

The error sources are added into the system at ▽7 (Figure A-1). The function contains a constant (servo bias) and an altitude error varying with Σ; for the runs in this experiment, Σ varies from plus 21 degrees (0 sec) to minus 17 degrees (14 sec). The values and signs of this function are inputted by data cards. The values used for Phase I are 215 μ rad/sec and 42 μ rad/sec. The values used in Phase II are 540 μ rad/sec and 50 μ rad/sec.

A.8 NOISE

Noise is fed into the system at ▽9 (Figure A-1) after scoring has been accomplished. The implementation of this noise included a white noise generator, a shaping filter (effect PSD), and a dynamic loop (pitch) where the noise is inserted. The PSD used was:

$$\frac{1.265}{10^4} \left[\frac{\frac{S}{95} + 1}{\frac{S}{7.5} + 1} \right]^4 \frac{(\text{ft lb})^2}{\text{cps}}$$

The average of absolute noise was 5 μ rad/sec over 14 seconds in pitch. This was coupled to roll through the inertias giving 2.5 μ rad/sec average absolute.

A.9 X, Y POSITIONER

This positioner closes the simulator loop and gives the man a presentation. A position servo system is used and driven from the digital computer at ▽10 (Figure A-1). The bandwidth of this is 6 cps on X and 10 cps on Y. For linear and equal responses in both X and Y a transformation is required in the digital computer. The resolution of the command is 0.125 μ rad X and 0.2 μ rad Y.

A.10 STIMULUS MATERIAL

The same stimulus material was used in both phases of the experiment. It consisted of fourteen photographic scenes and one geometrical pattern. Five target sequences were

used, with the scenes appearing in different random orders and the geometrical pattern appearing last.

The experiment was run at 1000 power; actual stimulus scale was 7385 to 1. From preliminary light measurements, illumination was between 1 and 10 foot lamberts. No accurate light measurement was made. The light level was high enough so that it was not a major factor on the experiment.

A.11 TIME DELAY

A time delay of 15 milliseconds was inserted in the output command to simulate the AVE Computation Delay. This effect was applied to the extrapolated signal.

A.12 VALIDATION PROCEDURE

To help in the evaluation of the system, strip chart records were utilized at many places as shown in Figure A-1. The recorded parameters were:

Channel	Signal
0	Stick position X
1	Stick position Y
2	X (to gimbal)
3	Y (to gimbal)
4	X (to digital computer)
5	Y (to digital computer)
6	X (to position drive)
7	Y (to position drive)
8	Stick X axis (quantized)
9	Stick Y axis (quantized)
10	RSS stick
11	X error

Channel	Signal
12	$\dot{Y}$ error
13	RSS rate error
14	Integral of RSS rate error (4-14 sec)
15	Time above 17 μ rad/sec
16	Integrated noise measurement
17	Instantaneous noise
18	RSS stick (End-Stop) (binary signal added)
19	$\cos^2 \Sigma$ (X)
20	$\cos^2 \Sigma$ (Y)
21	10 $\dot{X}$ error
22	10 $\dot{Y}$ error
23	Time

To ensure that the analog patch board and the complete analog were operating, a "check" program (digital diagnostic) was written checking continuity and individuals units (multipliers, amplifiers, etc.). For the complete system, a test case was set up that was run before crew members operated the system.

To evaluate the X Y positioner, frequency response data was obtained and a calibrated clip of film was used for actual positioning.

Linearity plots were obtained on the stick for X and Y movement and a general mechanical "cleaning" of the stick was accomplished (see crew comments section for stick evaluation).

A.13 EARLY CONTROL IMPLEMENTATION

To evaluate the effects of letting the crew in ahead of end-of-slew (Phase II) an exponential function was generated. This represented end-of-slew rate error. The magnitude of the implemented exponential varied from approximately 5000 μ rad (pitch) at t = 0, to the servo bias error at t = 1 sec allowing a smooth transaction at end-of-slew. This was added at ▽7 (Figure A-1). Stick control could be enabled at any time.

APPENDIX B

NUMERICAL RESULTS OF STICK EXPERIMENT

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NUMERICAL RESULTS OF STICK EXPERIMENT

Table B-1 shows the numerical results of the stick experiment for Phases I and II. The abbreviation IC indicates initial condition (i.e., the rate error to be nulled) as follows:

Easy IC: approximately 50 μ rad/sec
Hard IC: approximately 215 μ rad/sec
Difficult: approximately 540 μ rad/sec

The columns with an "R" heading show, for each scene, the quantity $\bar{R}$ defined by - -

$$\bar{R} = \frac{1}{10} \int_4^{14} R(t)dt$$

where R (t) is the instantaneous rate error in μ rad/sec at time (t), measured from the time of unblanking the scene.

The columns with a "T" heading show the total amount of time during which $R(t) \geqq 17$ μ rad/sec.

The last three lines (bottom) of each table are titled AV (average), MED (median), and GP (geometrical pattern). The lines titled AVG and MED show, respectively, the average and the median of the 14 scores of each column. The line titled GP gives the score of the geometrical pattern for the condition specified in the particular table caption.

TABLE B-1. NUMERICAL RESULTS OF STICK EXPERIMENT (PHASE I)

STICK:RATE

INITIAL CONDITION EASY

	SUBJECT 1		SUBJECT 2		SUBJECT 3		SUBJECT 4		SUBJECT 5		SUBJECT 6	
	R	T	R	T	R	T	R	T	R	T	R	T
	4.28	0.70	3.22	2.42	2.47	1.12	3.00	2.05	3.44	1.56	2.89	1.30
	5.58	1.21	3.71	1.47	2.19	1.09	1.76	0.97	2.90	0.85	2.85	1.22
	2.31	0.80	3.11	3.40	2.60	0.71	2.18	1.09	2.46	0.18	2.28	0.72
	3.72	1.42	2.30	0.74	2.52	0.59	2.81	1.35	1.95	1.20	2.41	0.87
	2.94	0.99	2.93	1.11	2.65	0.70	2.75	0.73	2.76	1.07	2.40	1.26
	1.83	1.35	2.31	0.78	2.49	1.31	2.68	1.11	2.56	0.89	2.24	1.14
	2.43	1.27	3.14	1.77	3.39	0.80	2.59	2.08	1.70	0.56	2.29	0.84
	2.46	1.01	2.52	1.10	2.68	1.06	2.32	0.98	2.47	1.14	3.24	1.26
	3.19	1.29	2.59	1.51	1.90	0.45	2.73	0.95	2.11	1.11	1.71	0.74
	3.53	0.53	3.52	0.95	2.40	0.66	1.80	0.68	2.57	0.98	2.54	0.84
	2.73	0.89	4.00	0.69	2.01	0.58	2.42	1.07	1.84	0.76	2.88	0.60
	2.49	1.60	1.74	1.89	2.27	1.17	3.35	0.60	2.18	1.29	1.94	0.80
	2.24	0.71	3.54	0.79	3.13	0.74	2.85	1.13	2.47	1.26	2.21	0.85
	2.84	0.91	2.30	1.73	3.21	0.89	2.61	0.79	2.30	1.86	2.55	1.08
AV	3.009	1.05	2.924	1.45	2.494	0.85	2.561	1.11	2.406	1.05	2.459	0.97
MED	2.78	0.96	3.02	1.29	2.48	0.77	2.64	1.02	2.46	1.09	2.40	0.86
G P	4.32	1.28	2.66	1.80	3.43	1.14	3.13	1.68	2.28	1.49	4.76	1.14
	INITIAL CONDITION HARD											
	3.13	2.65	2.41	1.74	2.26	1.89	2.84	1.21	3.37	1.70	2.77	2.46
	3.88	1.65	3.27	2.13	2.41	1.26	4.06	1.38	1.77	2.17	2.08	2.15
	4.61	1.27	2.81	2.45	2.78	1.35	4.15	2.18	2.39	1.40	2.60	1.94
	3.31	2.30	4.12	1.42	2.76	2.35	4.25	2.62	4.23	3.09	2.50	1.83
	3.61	1.52	3.34	2.15	3.19	1.10	3.42	0.98	3.39	1.57	1.76	1.83
	3.12	1.66	1.68	2.27	3.55	1.51	2.57	2.21	2.23	1.91	3.24	1.81
	4.28	1.25	4.87	1.65	3.34	1.61	4.08	1.42	2.97	1.56	2.60	1.44
	4.95	1.46	3.77	2.51	2.23	1.24	4.02	3.15	3.09	1.69	3.33	1.38
	3.21	2.09	2.50	1.55	4.11	2.98	1.72	1.61	2.64	0.72	2.73	1.39
	2.33	1.31	3.57	1.86	3.26	1.81	4.65	2.02	2.71	1.24	2.85	1.95
	2.20	2.61	5.52	1.68	2.95	1.25	3.25	1.63	2.78	1.44	2.21	1.29
	3.27	0.80	2.92	1.35	2.41	1.82	5.10	1.50	2.33	1.30	3.33	0.68
	4.54	1.79	2.97	1.42	2.81	1.29	2.76	1.60	2.66	1.67	2.13	1.47
	4.44	1.42	2.50	1.28	3.22	1.84	2.93	1.84	2.95	2.39	2.40	1.47
AV	3.734	1.72	3.304	1.82	2.949	1.67	3.343	1.81	2.822	1.70	2.609	1.65
MED	3.46	1.66	3.12	1.71	2.88	1.56	3.34	1.62	2.74	1.62	2.60	1.69
G P	3.56	1.69	4.35	1.96	2.84	1.47	3.43	1.80	3.32	2.52	3.40	1.91

TABLE B-1. NUMERICAL RESULTS OF STICK EXPERIMENT (PHASE I) (Cont)

STICK:RATE + END-STOP

INITIAL CONDITION EASY

	SUBJECT 1		SUBJECT 2		SUBJECT 3		SUBJECT 4		SUBJECT 5		SUBJECT 6	
	R	T	R	T	R	T	R	T	R	T	R	T
	3.09	2.00	2.53	1.39	1.67	1.28	2.12	0.95	3.08	0.78	2.25	1.27
	1.94	0.97	1.84	1.00	2.20	0.62	2.94	1.00	1.65	1.48	1.74	0.69
	2.35	0.78	2.44	2.13	2.64	1.45	3.20	0.60	2.11	0.92	1.98	0.64
	1.92	1.07	1.78	1.27	1.90	1.54	2.28	1.07	2.11	1.07	2.65	0.70
	2.86	0.92	3.29	0.92	1.68	0.79	1.77	0.62	2.35	1.00	3.18	1.04
	2.28	1.16	1.92	0.92	2.33	0.71	2.47	0.71	2.52	0.88	2.65	0.70
	2.38	0.67	2.54	1.63	1.98	0.70	2.87	1.24	2.09	0.97	2.06	0.68
	3.61	0.92	2.45	1.17	2.18	1.43	1.62	0.84	2.23	0.62	2.96	1.02
	2.20	1.31	2.72	1.15	3.01	0.77	1.70	0.74	1.81	1.18	3.28	1.00
	2.51	1.47	2.63	1.19	2.35	0.68	2.64	1.09	2.75	1.06	2.28	0.60
	1.52	0.82	2.03	1.02	2.56	0.74	2.10	0.85	2.96	1.02	2.11	1.06
	3.02	2.16	2.24	0.92	2.38	1.63	3.06	1.36	2.09	0.96	2.31	1.18
	3.20	0.67	2.66	1.08	2.27	1.13	3.08	1.77	2.01	1.13	1.62	0.63
	2.38	1.14	3.04	0.72	1.85	0.75	3.06	0.70	2.97	1.09	2.40	0.85
AV	2.59	1.15	2.924	1.18	2.214	1.02	2.494	0.97	2.338	1.01	2.426	0.86
MED	2.38	1.02	3.02	1.05	2.24	0.78	2.56	0.90	2.17	1.01	2.34	0.80
G P	3.77	1.36	2.66	1.03	2.59	0.72	3.37	0.51	2.75	0.93	3.16	0.61
	INITIAL CONDITION HARD											
	2.60	2.23	2.03	1.73	2.14	2.03	2.65	1.99	3.36	2.43	2.79	1.94
	5.08	4.01	2.43	1.63	2.58	1.68	2.77	1.99	3.36	2.06	2.25	1.75
	2.29	1.83	1.02	1.67	2.65	2.06	2.86	1.91	2.79	1.88	2.66	3.54
	10.83	6.19	2.26	2.06	5.01	4.29	2.22	1.56	12.41	5.16	1.77	1.57
	3.51	1.76	2.09	1.55	2.70	1.68	2.79	1.90	3.44	1.73	3.09	1.68
	3.07	2.12	3.35	1.67	2.64	2.38	2.35	1.85	5.24	2.59	8.37	4.24
	3.50	2.08	2.22	1.66	1.88	2.14	2.78	1.08	2.37	2.08	1.60	1.72
	2.25	2.49	2.86	1.74	2.08	1.94	2.28	1.96	2.57	2.84	2.11	1.77
	2.25	1.94	2.48	2.13	2.13	1.72	3.31	2.18	2.39	1.75	2.18	1.63
	3.23	1.72	1.79	1.60	1.92	1.46	3.22	1.67	4.59	2.81	2.15	2.24
	2.87	2.03	1.97	1.72	2.45	1.71	3.65	2.61	1.95	1.37	2.21	1.51
	2.90	1.94	2.77	1.50	2.22	1.67	2.59	1.49	2.48	2.78	2.43	1.53
	3.03	2.92	2.29	1.34	1.62	1.89	2.42	1.54	6.92	2.01	2.86	2.60
	7.25	5.04	3.56	1.63	2.56	2.02	2.37	1.51	2.25	2.53	1.82	2.30
AV	3.904	2.74	2.366	1.69	2.256	2.05	2.733	1.80	4.009	2.43	2.735	2.14
MED	3.05	2.10	2.28	1.67	2.18	1.92	2.71	1.88	3.08	2.26	2.23	1.76
G P	4.85	1.81	2.78	2.34	2.24	2.17	1.88	1.75	2.54	2.67	2.61	1.65

TABLE B-1. NUMERICAL RESULTS OF STICK EXPERIMENT (PHASE I) (Cont)

STICK:RATE PLUS ACCELERATION

INITIAL CONDITION EASY

	SUBJECT 1		SUBJECT 2		SUBJECT 3		SUBJECT 4		SUBJECT 5		SUBJECT 6	
	R	T	R	T	R	T	R	T	R	T	R	T
	3.57	1.50	5.26	1.84	3.20	0.89	4.84	1.03	3.31	0.77	3.98	0.75
	3.75	0.63	4.25	1.51	2.71	1.41	4.53	1.88	4.23	0.89	2.97	0.52
	3.54	0.70	4.09	0.74	2.92	1.59	2.87	0.91	2.68	1.05	2.55	0.64
	4.44	1.59	2.53	1.43	2.29	0.62	3.90	0.92	3.16	0.85	3.79	2.19
	3.19	0.69	4.46	1.85	3.17	0.65	3.43	1.13	4.17	0.62	2.48	1.83
	4.17	1.42	3.15	1.58	2.25	0.66	3.19	1.07	4.02	0.97	3.10	0.97
	3.89	2.16	4.80	1.18	3.93	1.28	2.67	1.64	3.26	1.65	2.24	0.61
	2.38	0.65	2.96	0.91	2.65	0.77	4.42	1.46	3.31	0.72	3.75	0.89
	3.40	1.36	4.20	1.25	3.18	0.75	2.76	1.26	3.72	0.86	2.37	0.66
	3.04	0.77	2.91	0.79	2.34	0.72	3.83	1.00	3.41	1.07	3.26	0.97
	3.11	1.12	3.27	1.27	3.58	0.64	3.97	1.10	3.24	1.57	2.71	0.70
	2.28	0.52	5.92	0.90	3.00	1.35	2.86	0.66	3.05	0.87	4.28	1.19
	4.38	1.58	3.28	0.97	4.82	1.18	2.97	2.12	4.14	0.84	2.65	0.66
	4.08	1.16	3.32	1.87	1.87	1.31	3.53	1.68	3.15	1.69	3.29	0.70
AV	3.503	1.13	3.886	1.29	2.990	0.99	3.555	1.28	3.489	1.03	3.103	0.95
MED	3.55	1.14	3.70	1.12	2.96	0.83	3.48	1.12	3.31	0.88	3.04	0.74
G P	4.62	1.21	2.09	0.87	2.44	1.20	4.44	1.57	3.94	1.90	3.06	0.85
	INITIAL CONDITION HARD											
	5.70	3.70	3.54	1.76	3.48	1.48	6.66	2.41	6.17	4.89	2.30	2.21
	4.01	3.08	3.44	1.69	4.19	2.00	6.73	2.98	6.39	4.26	3.17	1.70
	10.36	9.52	3.75	2.02	3.27	1.75	5.57	2.43	7.11	4.85	3.71	2.85
	4.65	1.85	6.05	4.21	3.84	2.34	5.16	3.30	5.30	3.45	3.76	2.21
	4.03	1.93	4.40	1.96	3.88	1.64	4.59	3.46	6.04	3.34	4.35	1.89
	5.00	3.02	4.49	2.51	3.13	1.36	5.37	3.24	5.79	3.44	3.89	2.01
	12.73	6.57	4.58	2.10	3.19	1.96	4.38	2.06	4.58	3.81	3.40	2.06
	5.25	2.17	6.32	2.50	3.93	1.95	3.31	1.82	4.04	3.15	4.83	2.89
	6.28	4.00	4.27	1.59	4.11	1.94	6.88	3.52	5.74	3.58	4.16	2.20
	4.87	3.45	3.27	1.87	4.29	1.56	7.33	4.39	4.07	2.83	3.67	1.63
	4.83	2.51	5.53	2.55	5.09	1.37	3.71	2.83	3.63	3.04	2.90	1.88
	4.29	2.28	5.54	2.20	4.04	1.94	4.82	3.13	5.37	2.63	4.80	1.75
	5.12	2.15	3.71	2.91	4.94	2.99	4.35	2.82	8.99	4.49	5.34	3.11
	3.76	2.77	4.01	2.86	4.75	1.76	5.46	2.53	4.88	2.90	2.97	1.91
AV	5.777	3.50	4.493	2.34	4.009	1.86	5.244	2.92	5.579	3.62	3.804	2.16
MED	4.94	3.05	4.34	2.15	3.98	1.82	4.99	2.90	5.56	3.44	3.74	2.04
G P	7.48	4.54	6.04	3.55	4.22	1.68	4.31	1.90	5.47	3.34	3.00	1.76

TABLE B-1. NUMERICAL RESULTS OF STICK EXPERIMENT (PHASE II)

INITIAL CONDITION EASY (WITH EXTRAPOLATION)

STICK TYPE

	RATE				RATE PLUS END-STOP				RATE PLUS ACCELERATION			
	SUBJECT 7		SUBJECT 8		SUBJECT 7		SUBJECT 8		SUBJECT 7		SUBJECT 8	
	R	T	R	T	R	T	R	T	R	T	R	T
	2.80	1.31	3.50	1.00	3.02	1.40	1.99	1.68	3.65	1.40	2.97	1.73
	3.01	1.17	3.02	0.72	3.36	0.99	2.63	0.85	4.44	1.21	4.93	1.27
	2.98	1.81	3.42	1.53	2.61	0.77	2.69	1.30	2.91	1.07	3.57	1.30
	3.64	1.90	2.72	0.74	3.60	1.20	2.04	1.13	4.91	0.96	5.07	1.01
	3.04	1.40	2.19	1.17	2.61	1.19	1.83	1.23	3.06	1.01	3.14	1.27
	3.32	0.85	3.08	0.68	2.76	1.20	2.35	1.32	2.65	1.39	4.05	0.97
	4.44	1.49	4.34	0.98	3.06	0.92	1.95	1.28	4.35	1.90	4.30	0.57
	3.11	1.50	2.48	0.62	2.29	1.48	1.83	1.17	4.50	1.34	2.28	0.97
	3.73	1.45	2.85	1.28	1.39	1.22	1.47	0.79	5.78	1.21	5.43	1.19
	4.72	1.30	2.73	0.92	2.14	1.01	1.74	0.75	3.77	1.19	4.46	1.24
	3.21	2.67	2.37	1.56	2.10	0.86	2.22	0.58	2.95	1.06	4.84	0.80
	2.71	0.96	2.99	0.80	2.55	0.71	2.09	0.71	3.50	0.87	3.17	1.36
	2.98	0.93	2.66	1.36	3.12	1.02	2.17	0.93	5.55	0.69	4.46	1.15
	4.15	1.29	3.59	1.36	2.57	1.21	1.87	0.88	4.49	1.60	4.76	1.16
AV	3.417	1.43	3.017	1.05	2.656	1.08	2.062	1.04	4.036	1.21	4.102	1.14
MED	3.16	1.35	2.92	0.99	2.61	1.01	2.02	1.03	4.06	1.20	4.38	1.18
G P	4.91	0.75	2.20	1.06	3.47	0.63	2.10	0.61	5.15	0.70	3.05	1.33
	INITIAL CONDITION DIFFICULT (WITH EXTRAPOLATION)											
	2.93	2.64	3.52	2.71	2.10	1.44	2.18	1.71	6.53	3.64	6.75	3.35
	4.07	2.40	3.71	1.89	2.26	2.28	2.41	1.22	5.10	2.89	5.94	3.03
	3.56	2.55	2.54	1.78	2.29	1.73	1.94	1.88	7.08	3.62	6.14	3.60
	3.91	1.92	2.80	1.61	2.02	2.39	1.79	2.06	7.68	3.58	6.07	4.59
	4.08	2.30	3.46	2.18	4.15	2.68	2.66	1.61	9.60	3.92	6.72	3.25
	2.37	2.21	2.82	1.48	2.54	3.03	2.06	1.53	7.89	2.57	7.26	4.69
	4.01	2.18	2.81	2.14	2.82	2.02	2.69	1.60	8.05	4.13	5.48	3.26
	3.63	1.87	4.64	1.97	2.19	1.84	2.19	1.39	7.44	3.81	6.26	2.39
	3.86	1.53	4.44	1.85	2.26	2.58	2.83	1.34	5.69	2.50	7.57	2.79
	2.17	1.35	3.32	1.12	3.26	2.91	2.29	1.88	6.67	3.50	7.35	3.74
	2.84	2.01	3.39	2.09	2.22	2.32	2.57	2.03	6.23	2.63	5.19	3.64
	3.81	2.58	5.32	1.53	1.87	2.01	4.14	3.50	6.59	3.98	6.62	2.80
	3.08	1.77	2.36	1.63	3.75	2.13	1.76	1.57	6.63	3.03	4.93	3.21
	3.20	1.93	5.00	1.62	2.26	1.90	2.98	2.31	6.05	3.42	5.93	3.10
AV	3.394	2.09	3.581	2.19	2.571	2.23	2.464	1.83	6.945	3.59	6.301	3.39
MED	3.60	2.10	3.42	1.81	2.26	2.20	2.35	1.66	6.65	3.54	6.20	3.26
G P	3.31	2.06	4.6	1.40	1.98	1.93	3.54	3.18	5.93	2.77	5.59	4.17

TABLE B-1. NUMERICAL RESULTS OF STICK EXPERIMENT (PHASE II) (Cont)

INITIAL CONDITION EASY (WITHOUT EXTRAPOLATION)

STICK TYPE

	RATE				RATE PLUS END-STOP				RATE PLUS ACCELERATION			
	SUBJECT 9		SUBJECT 10		SUBJECT 9		SUBJECT 10					
	R	T	R	T	R	T	R	T	R	T	R	T
	3.40	1.35	2.72	0.78	3.35	1.23	2.64	1.25				
	2.94	1.13	3.35	1.59	3.04	0.66	1.95	1.32				
	2.55	2.14	3.18	1.49	2.09	0.90	1.94	0.56				
	2.28	1.11	1.79	1.57	2.53	1.72	2.49	0.85				
	2.61	1.82	2.61	0.91	2.93	0.74	2.83	0.74				
	4.01	0.19	2.30	1.20	2.57	0.79	2.83	1.24				
	2.46	1.48	3.31	1.71	2.28	0.75	2.67	1.31				
	2.15	1.03	4.10	1.36	2.63	1.02	3.03	0.48				
	2.79	1.52	2.06	1.21	3.56	0.58	2.54	1.00				
	2.89	0.77	4.52	0.90	2.72	1.02	2.46	0.96				
	2.76	1.68	4.04	1.30	2.23	0.84	3.01	1.51				
	3.62	2.11	2.12	0.82	2.67	0.60	2.89	0.64				
	3.36	0.86	2.17	0.23	2.70	0.79	3.22	1.18				
	3.32	2.22	2.01	0.65	2.32	0.87	2.69	1.43				
AV	2.939	1.39	2.877	1.12	2.685	0.89	2.656	1.03				
MED	2.84	1.42	2.66	1.20	2.64	0.82	2.68	1.09				
G P	3.66	1.20	2.33	0.75	2.04	0.76	2.64	0.49				
	INITIAL CONDITION DIFFICULT (WITHOUT EXTRAPOLATION)											
	2.93	1.63	3.66	1.69	**2.32**	3.03	**2.91**	1.94				
	3.52	1.70	5.00	1.74	**2.61**	1.60	**3.39**	2.79				
	4.18	2.91	3.17	2.25	**2.62**	2.30	**2.21**	2.09				
	2.68	2.39	4.14	1.70	**3.21**	2.35	**2.68**	2.09				
	3.22	1.44	4.06	2.28	**3.80**	2.42	**2.06**	1.81				
	2.39	1.29	2.84	1.88	**3.83**	2.36	**2.48**	2.95				
	3.34	1.66	4.51	1.95	**1.66**	2.22	**2.15**	1.44				
	2.70	2.02	3.25	1.35	**2.27**	2.04	**2.24**	2.11				
	3.31	1.75	6.02	1.51	**1.95**	2.93	**2.91**	1.90				
	4.18	2.00	4.01	1.55	**2.96**	2.46	**2.33**	2.44				
	2.58	2.05	3.64	2.53	**2.09**	2.14	**1.86**	2.24				
	4.12	2.28	3.73	2.60	**2.17**	2.44	**2.51**	2.18				
	3.07	1.64	4.59	1.61	**2.59**	2.11	**2.56**	1.71				
	3.53	2.06	4.04	1.24	**2.81**	1.85	**2.84**	2.34				
AV	3.255	1.92	4.047	1.85	**2.64**	2.30	**2.51**	2.14				
MED	3.26	1.88	4.02	1.72	**2.60**	2.32	**2.50**	2.10				
G P	2.88	1.80	3.72	1.69	**1.20**	2.22	**2.07**	2.06				

APPENDIX C

STATISTICAL COMPARISON OF RESULTS

APPENDIX C

STATISTICAL COMPARISONS OF RESULTS

The statistical comparisons reported here are based on the non-parametric Mann-Whitney U-test with correction for ties as described in "Non-parametric Statistics for the Behavioral Sciences," Sidney Siegel, McGraw-Hill Book Co., 1956. Computation to apply this test utilized the IBM scientific subroutine U-test, as described in IBM Programmer's Manual H20-0205-3.

Table C-1 summarizes the results of all comparisons made. In each case, results for all subjects upon scene material only were lumped to form a single sample for each stick type and each level of initial rate error. Thus, in Phase I the sample size is 84, and in Phase II the sample size is 28. Included in results for Phase II are the cases where extrapolation was not used.

The statistic Z tabulated in Table C-1 is the standard normal deviate corresponding to the comparison being made. If S_1 and S_2 denote the samples being compared, let H_o denote the hypothesis that S_1 and S_2 are drawn from populations which do not differ in central tendency. If $Z > 1.96$, then Z is significant at the 5 percent level; if $Z > 2.58$, then Z is significant at the 1 percent level. If H_o is rejected at significance level α, the probability is α that a true hypothesis is rejected.

Table C-1. Standard Normal Deviate Z Computed for Comparisons by Mann-Whitney U-test

SAMPLES COMPARED	EASY IC		HARD IC	
PHASE I	AVG. RATE	TIME ABOVE 17	AVG. RATE	TIME ABOVE 17
Rate stick vs Rate + E. S.	2.473	0.509	3.385	3.885
Rate stick vs Rate + Acc.	6.744	0.419	9.380	7.390
Rate + Acc. vs Rate + E. S.	8.397	0.806	8.921	4.741
PHASE II	EASY IC		DIFFICULT IC	
With Extrapolation				
Rate vs Rate + E. S.	4.646	1.639	4.343	0.156
Rate vs Rate + Acc.	3.425	0.500	6.358	6.195
Rate + Acc. vs Rate + E. S.	5.678	1.377	6.424	5.802
Without Extrapolation				
Rate vs Rate + E. S.	1.024	2.483	4.933	3.056
Extrapolation Compared to No Extrapolation				
Rate stick vs Rate stick	1.885	0.344	0.778	0.795
Rate + E. S. vs Rate + E. S.	2.385	1.270	0.811	1.991

APPENDIX D

RATE ERROR AS A FUNCTION OF TIME

APPENDIX D

RATE AS A FUNCTION OF TIME

Figures D-1 through D-6 show the variation of rate error, as a function of time, for subjects 3 and 6. $\overline{R}$ (t) denotes the average of the 14 rate errors in Phase I for hard initial conditions obtained and time (t) for each subject and each stick type. Thus, the graph of $\overline{R}$ (t) (Figures D-1 through D-6) gives a picture of the average instantaneous rate error throughout the rate nulling task.

Figures D-7 through D-9 show the rate error averaged over one second intervals for all six crewmen, namely

$$\hat{R}_n = \frac{1}{6} \Sigma \int_{t_n}^{t_{n+1}} R(t)\, dt,$$

where $t_1 = 2$, $t_{n+1} - t_n = 1$, and the summation is over the scores of the six crewmen. Inspection of Figures D-7 through D-9 shows that steady state rate errors were not, in fact, achieved within four seconds.

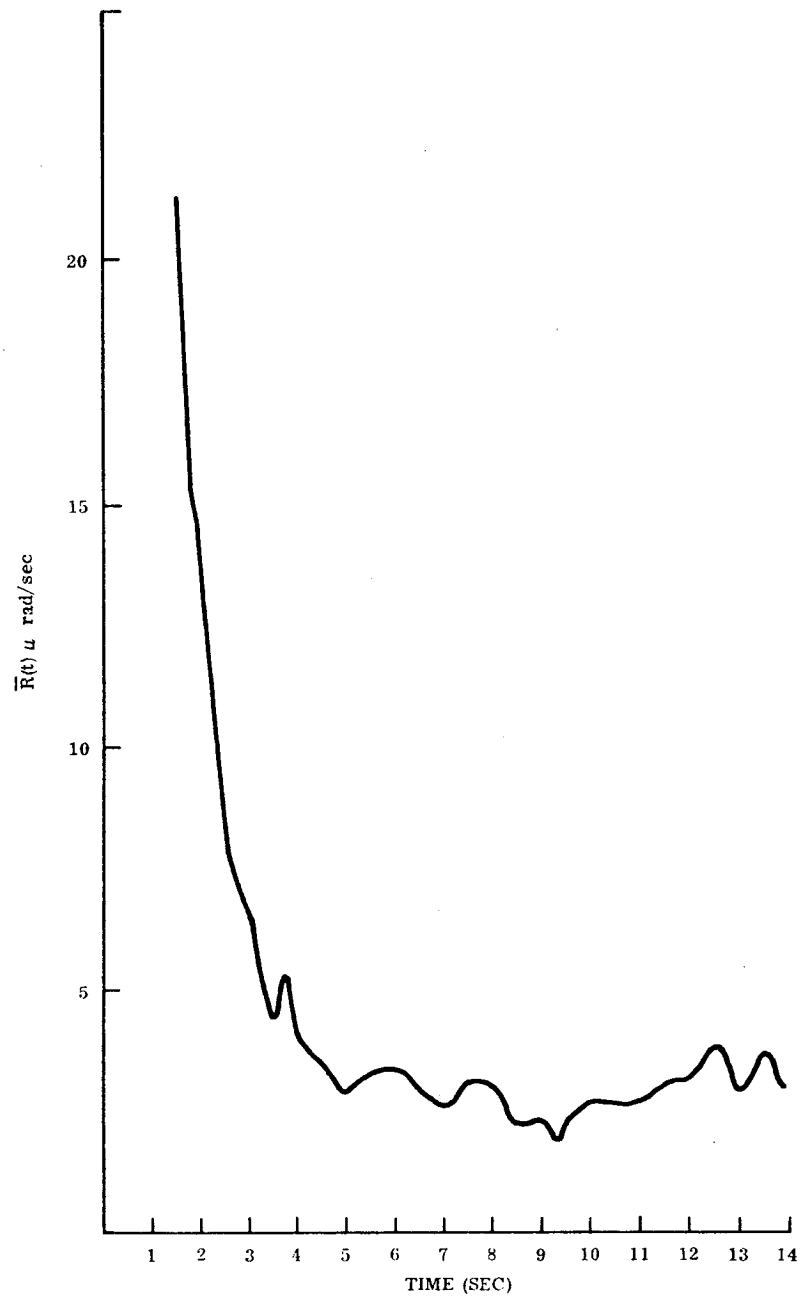

Figure D-1. $\bar{R}(t) \equiv$ Average Instantaneous Rate Error at Time (t) (Subject 3, Phase I, Rate Stick, Hard IC)

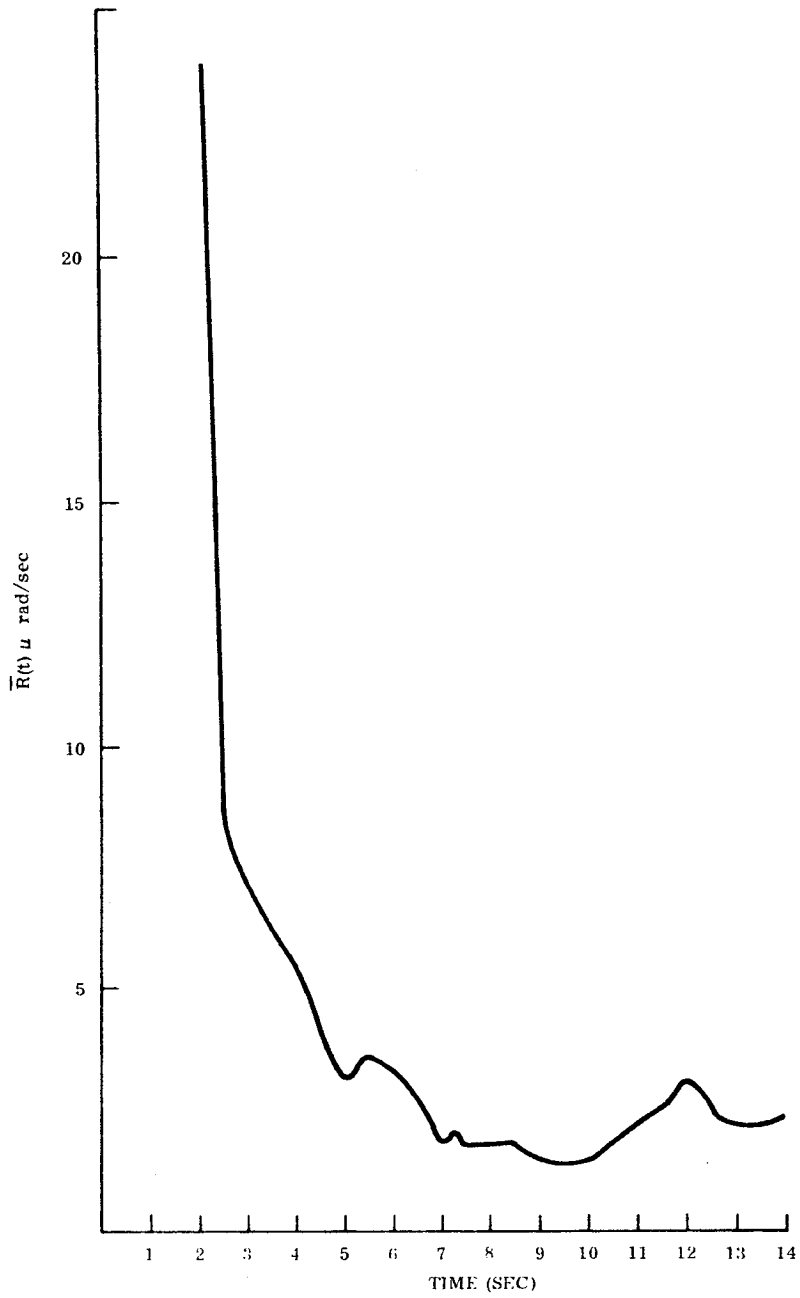

Figure D-2. $\bar{R}(t) \equiv$ Average Instantaneous Rate Error at Time (t) (Subject 3, Phase I, Rate Plus End-Stop, Hard IC)

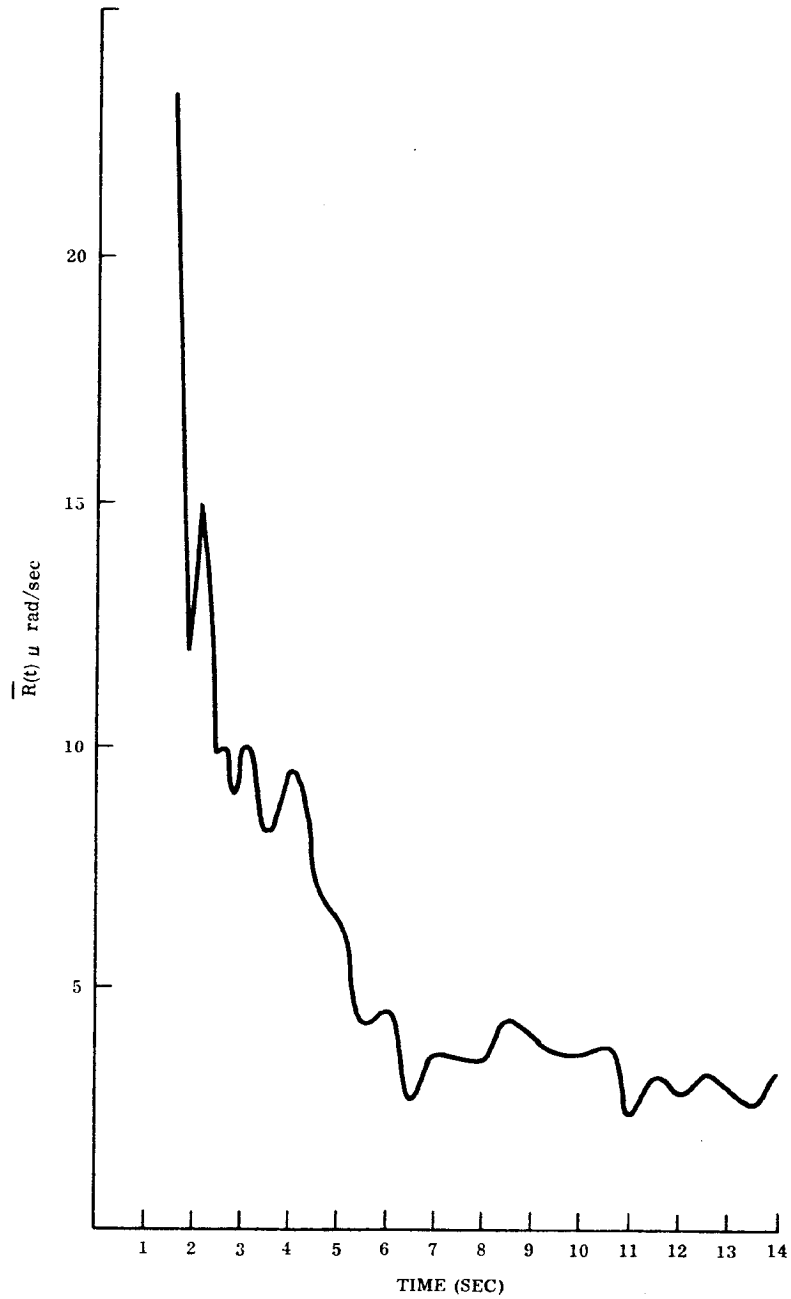

Figure D-3. $\overline{R}$ (t) ≡ Average Instantaneous Rate Error at Time (t) (Subject 3, Phase I, Rate Plus Acceleration, Hard IC)

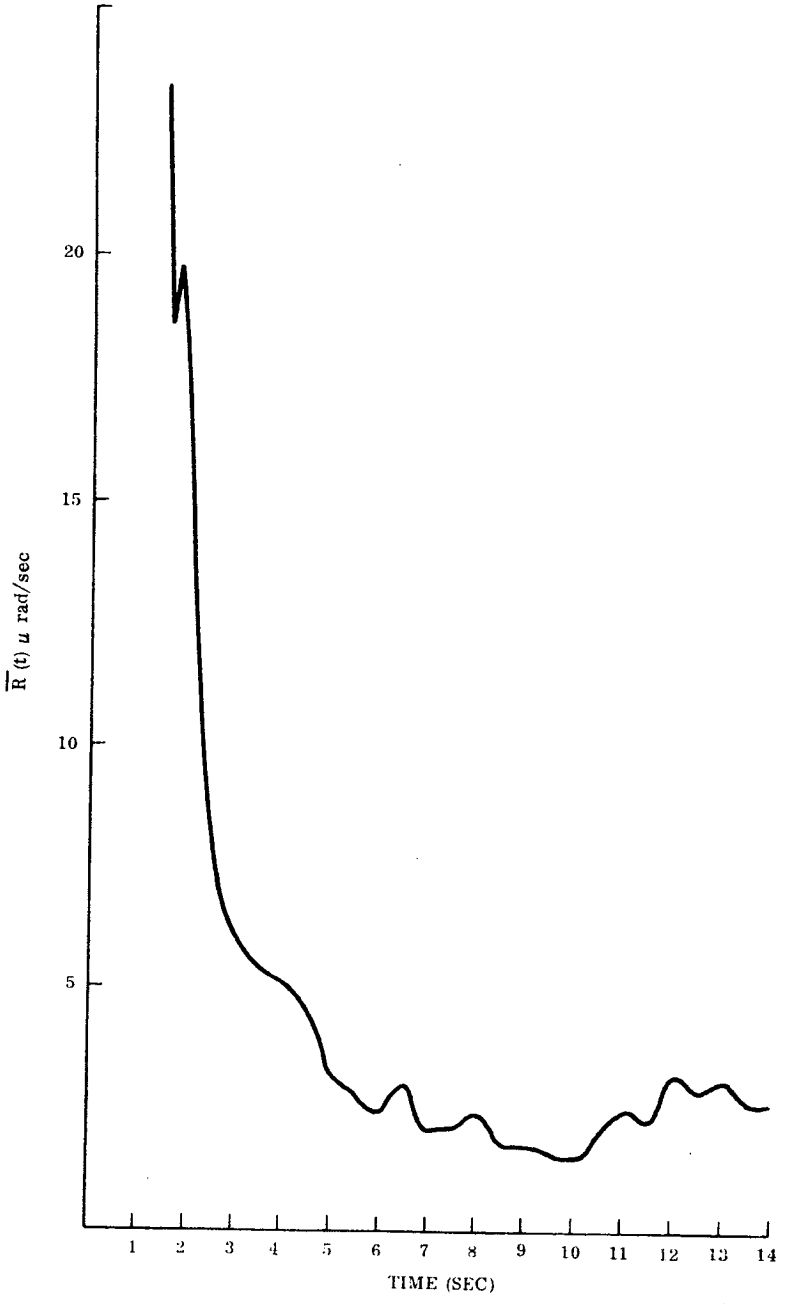

Figure D-4. $\overline{R}$ (t) ≡ Average Instantaneous Rate Error at Time (t) (Subject 6, Phase I, Rate Stick, Hard IC)

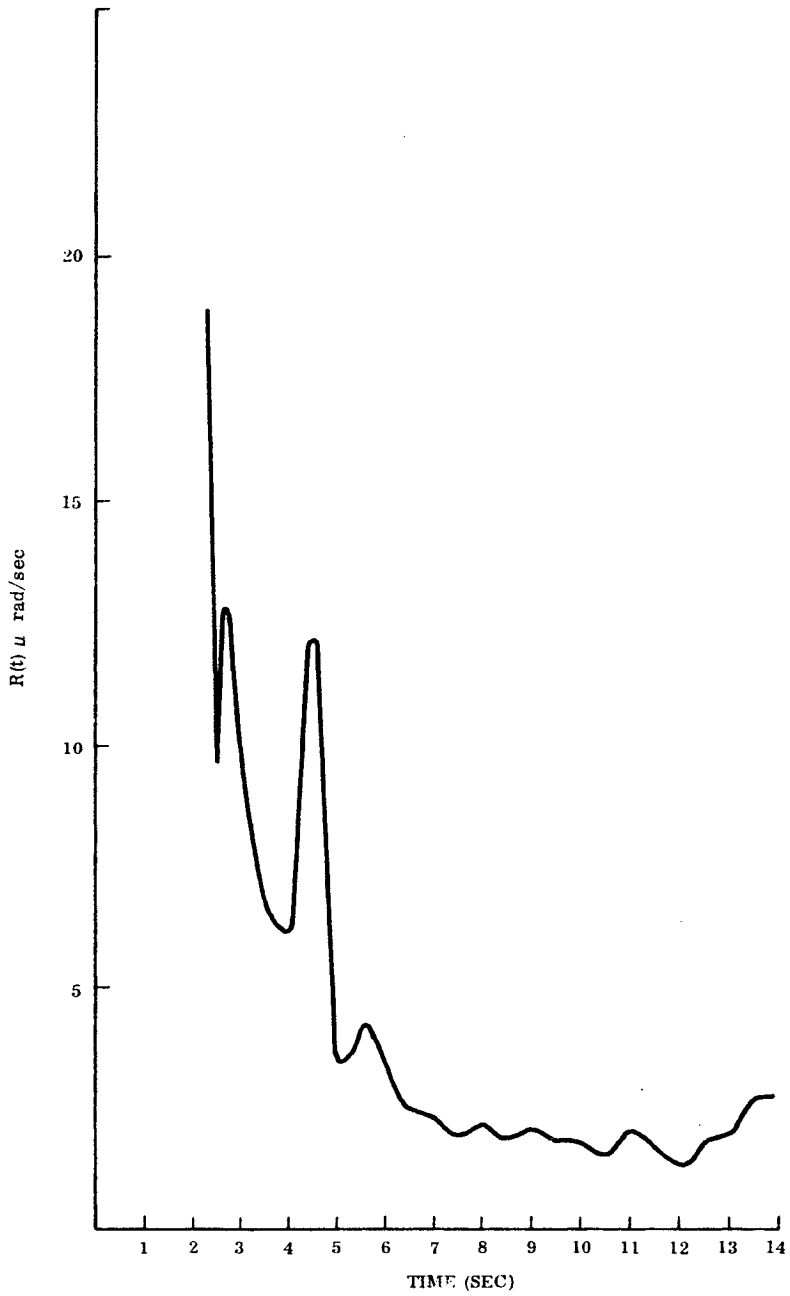

Figure D-5. $\bar{R}$ (t) ≡ Average Instantaneous Rate Error at Time (t) (Subject 6, Phase I, Rate Plus End-Stop, Hard IC)

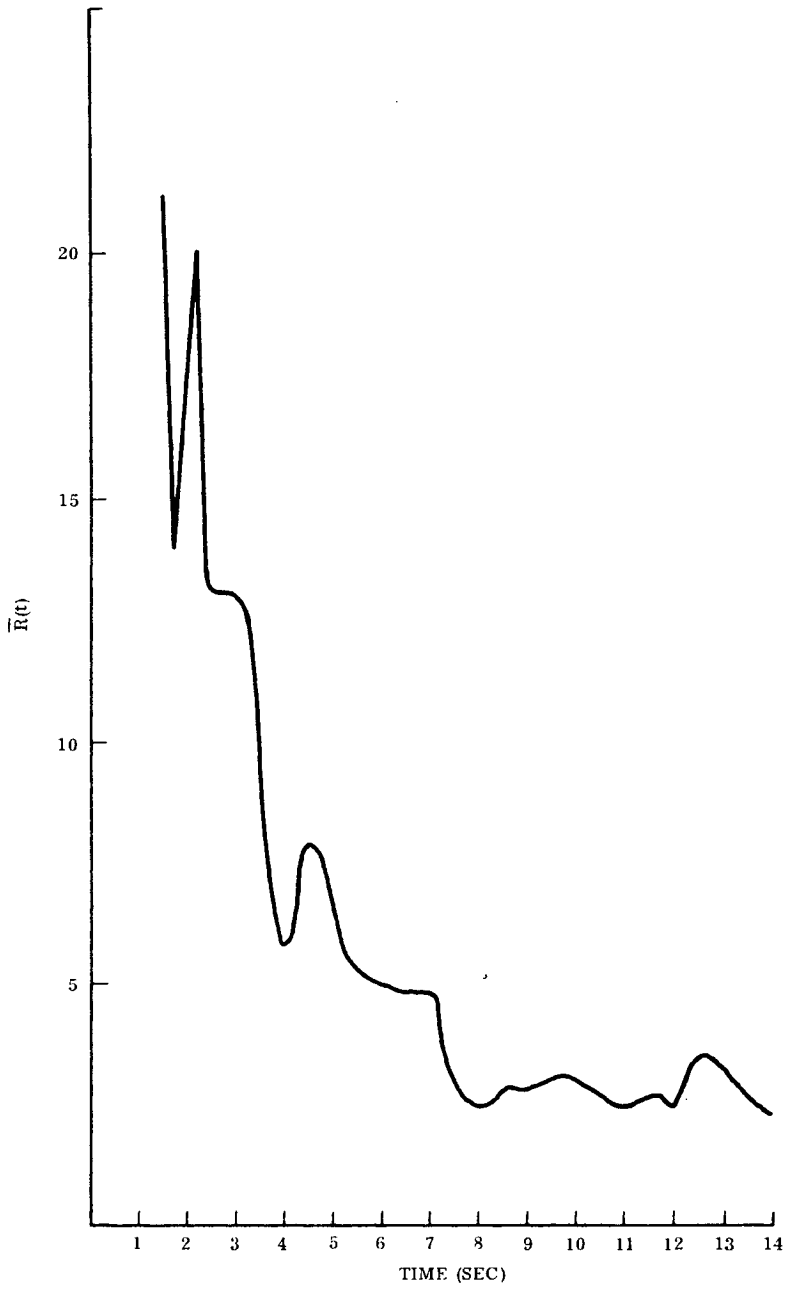

Figure D-6. $\bar{R}$ (t) ≡ Average Instantaneous Rate Error at Time (t) (Subject 6, Phase I, Rate Plus Acceleration, Hard IC)

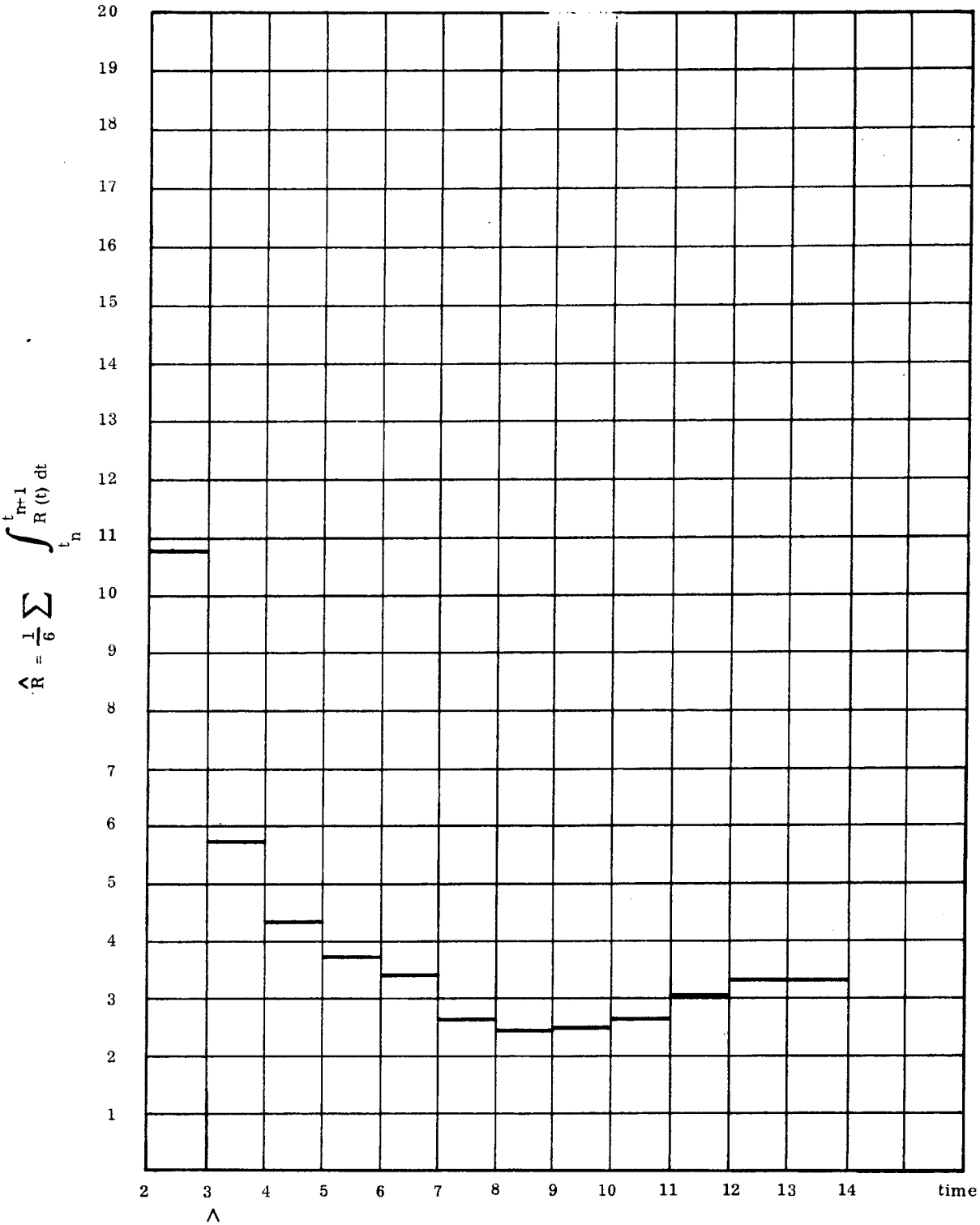

Figure D-7. $\hat{R} \equiv$ Rate Error Averaged Over 1 Second Interval (Six Crewmen, Phase I, Rate Stick, Hard IC)

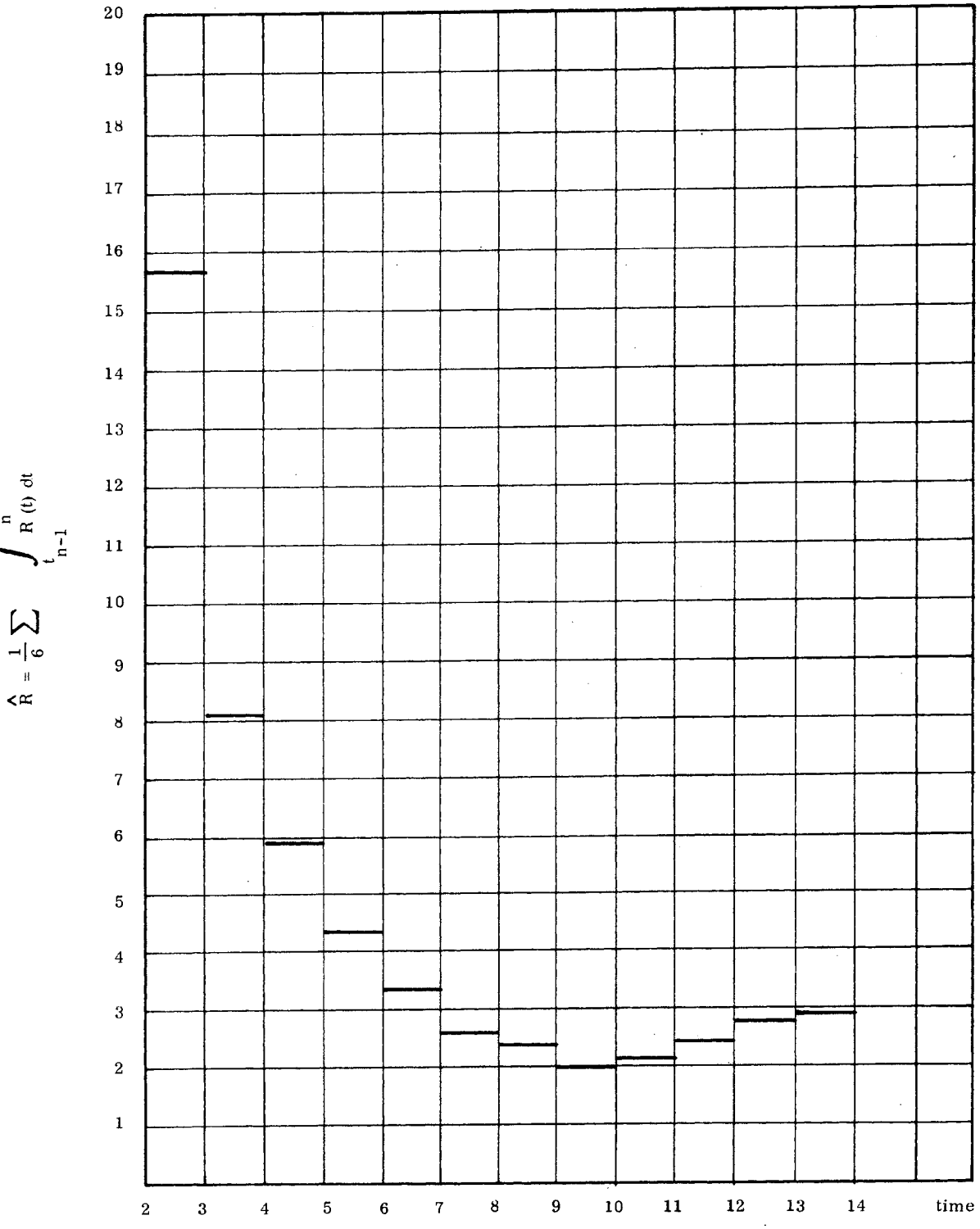

Figure D-8. $\hat{R}$ ≡ Rate Error Averaged Over 1 Second Interval (Six Crewmen, Phase I, Rate Plus End-Stop, Hard IC)

$$\hat{R} = \frac{1}{6}\sum \int_{t_{n-1}}^{t_n} R(t)\,dt$$

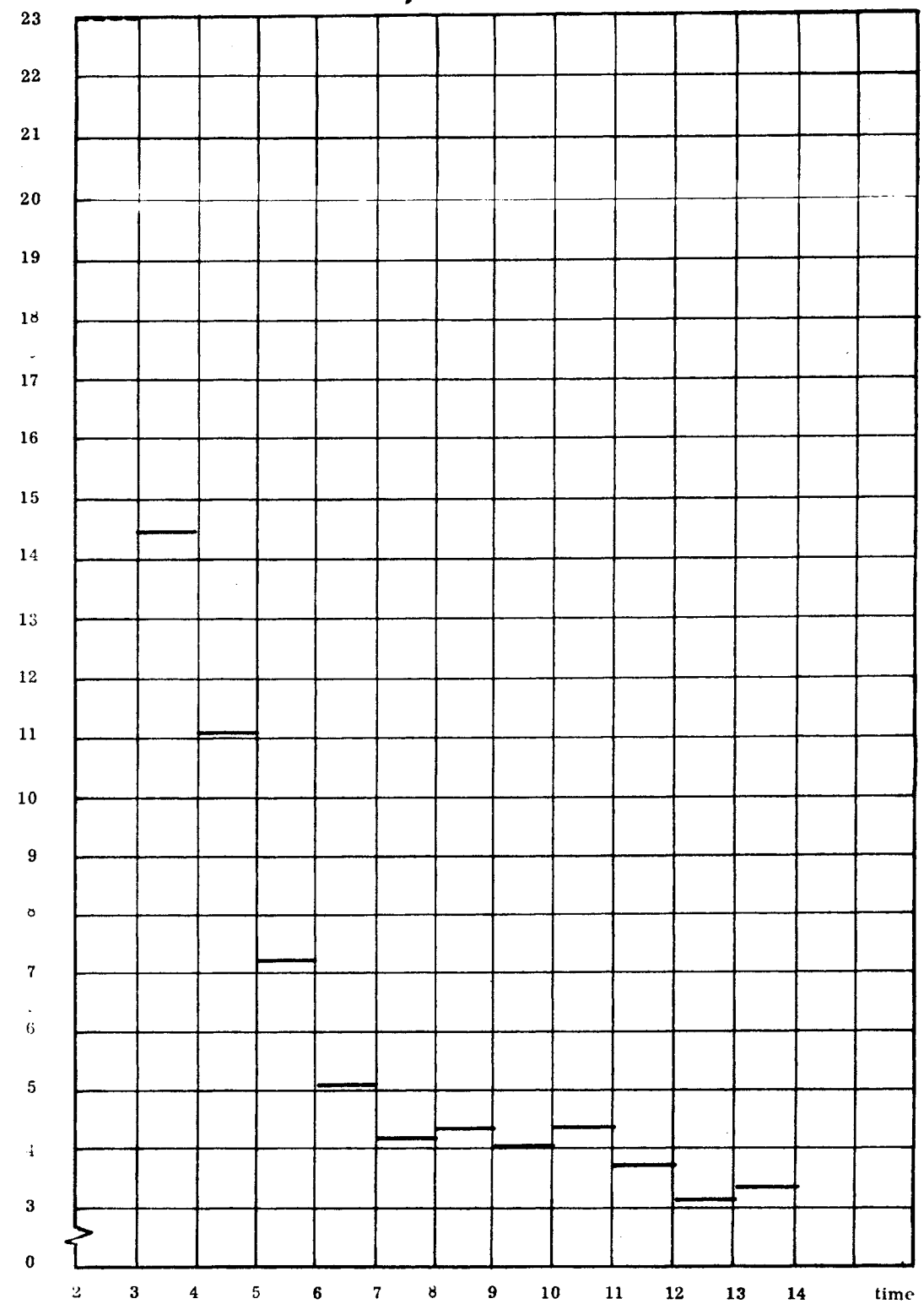

Figure D-9. $\hat{R} \equiv$ Rate Error Averaged Over 1 Second Interval (Six Crewmen, Phase I, Rate Plus Acceleration, Hard IC)

APPENDIX E

DISTRIBUTION OF RATE ERRORS DURING STEADY STATE

APPENDIX E

DISTRIBUTION OF RATES DURING STEADY STATE

Figures E-1 through E-6 show the cumulative distribution of instantaneous rate errors during the time interval 4-14 seconds for subjects 3 and 6. The distributions were derived by considering the instantaneous rate error, sampled 10 times per second, for all scenes run by a particular subject with a particular stick during Phase I. Thus, each distribution is based on a sample of 1400 observed instantaneous rate errors (obtained by a single subject for a single stick type).

The abscisses of the graphs in Figures E-1 through E-6 are rate errors in μ rad/sec. The ordinate F(x) is defined by:

$$F(x) = \frac{N(x)}{N}$$

where:

N = total sample size

N(x) = total number of observed instantaneous rate errors equal to or less than x.

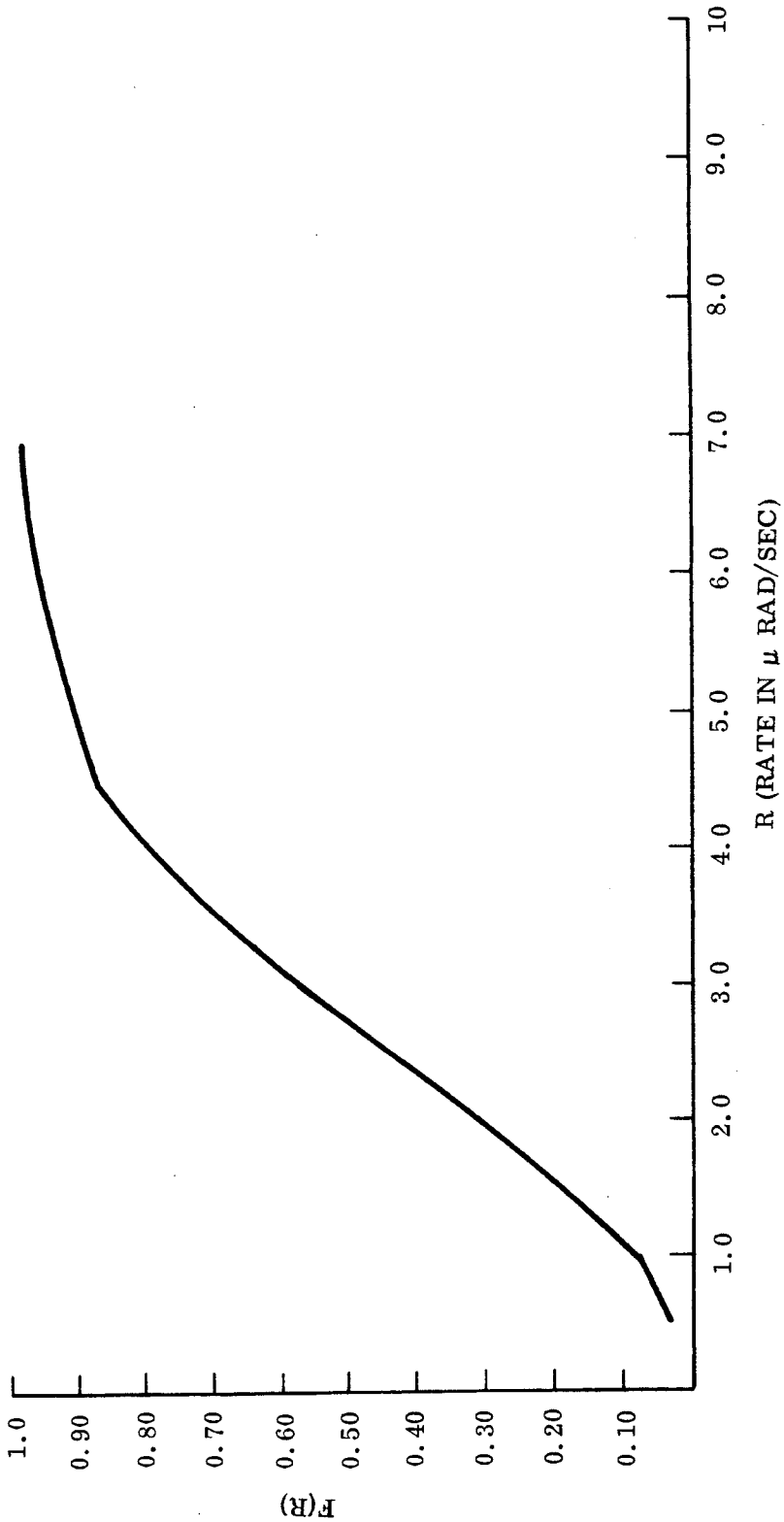

Figure E-1. F ≡ Cumulative Distribution of Instantaneous Rate Errors
(Subject 3, Phase I, Rate Stick, Hard IC)

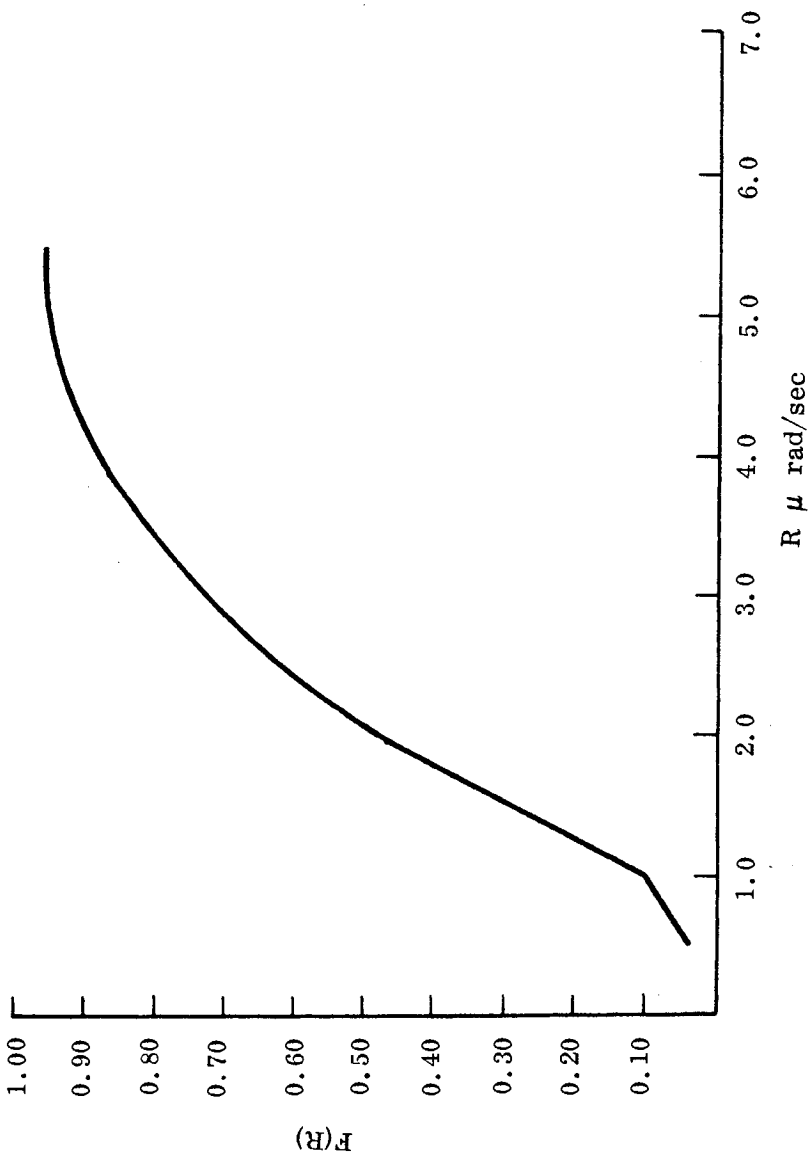

Figure E-2. F ≡ Cumulative Distribution of Instantaneous Rate Errors
(Subject 3, Phase I, Rate plus End-Stop, Hard IC)

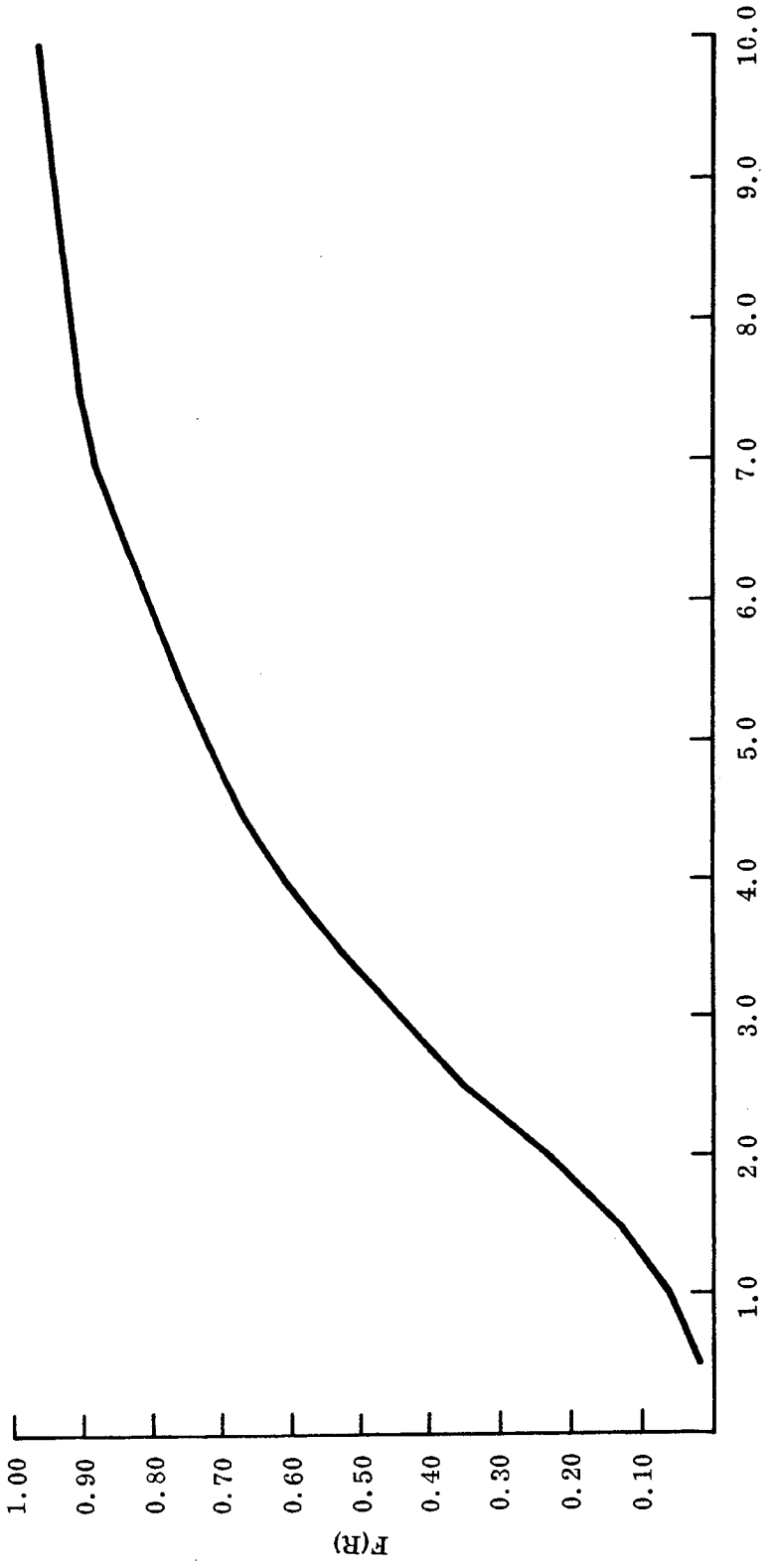

Figure E-3. F ≡ Cumulative Distribution of Instantaneous Rate Errors
(Subject 3, Phase I, Rate plus Acceleration, Hard IC)

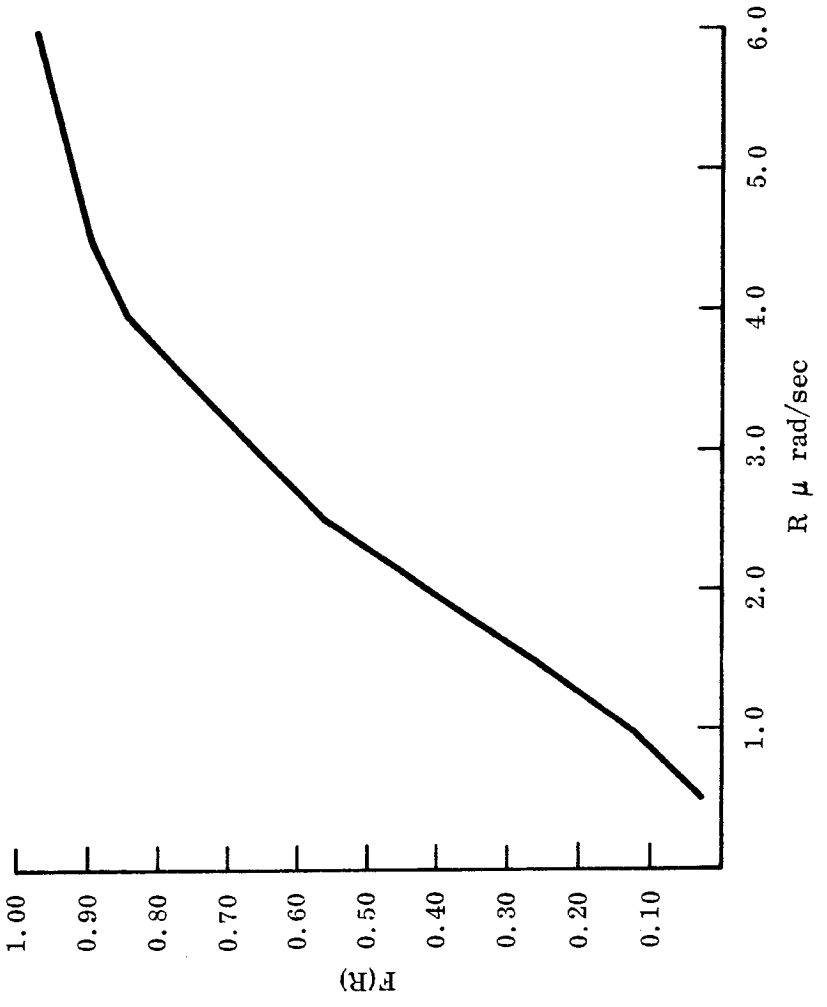

Figure E-4. F ≡ Cumulative Distribution of Instantaneous Rate Errors
(Subject 6, Phase I, Rate Stick, Hard IC)

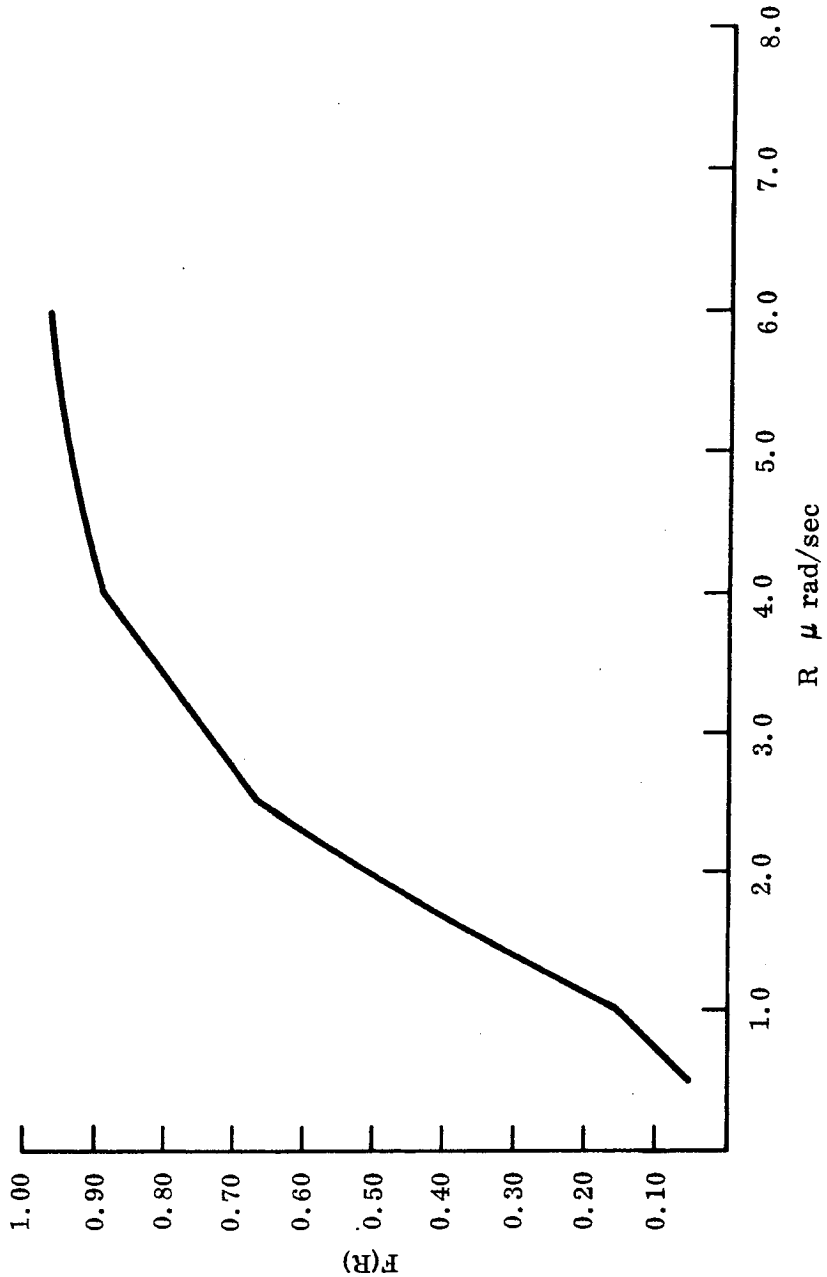

Figure E-5. F ≡ Cumulative Distribution of Instantaneous Rate Errors
(Subject 6, Phase I, Rate plus End-Stop, Hard IC)

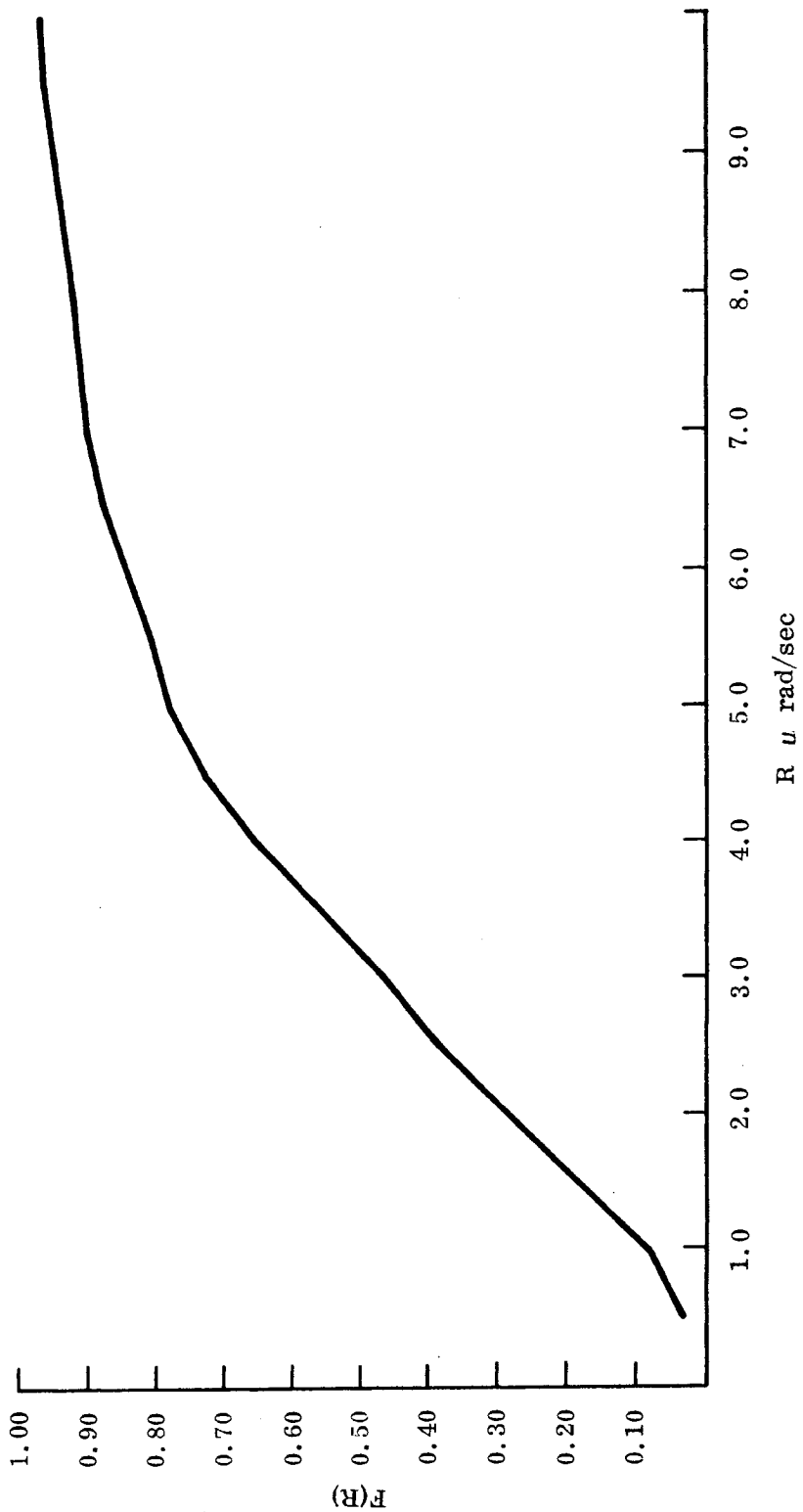

Figure E-6. F ≡ Cumulative Distribution of Instantaneous Rate Errors
(Subject 6, Phase I, Rate plus Acceleration, Hard IC)

APPENDIX F

CREW COMMENT RESPONSE

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CREW COMMENT RESPONSE

Questions associated with the following items were discussed with each crew member after Phase I:

a. Noise

b. Light intensity

c. Extrapolation

d. Stick feel

e. Stimulus

f. Stick types

g. Stick preference

h. General Simulator impression

F.1 NOISE

Four crew members indicated that the noise was of lower frequency than Aerospace and had some trouble tracking. One had no problem and one felt it was less noticeable.

F.2 LIGHT INTENSITY

Five crew members felt it was adequate for the task and one felt it may be unrealistically bright but did not interfere with the work.

F.3 EXTRAPOLATION

Three members definitely commented negatively on this effect. Two did not notice and one learned it quickly and had no problem.

F.4 STICK FEEL

The general comments on this stick indicate that stiction was still a problem. The Y axis definitely was easier to move than X. One member did not like the pencil stick.

F.5 STICK TYPES

The rate plus end-stop acceleration stick had the following comments:

a. Can handle unexpected conditions.

b. End-stop band could be too wide.

c. Requires more training but can be learned.

d. Mistakes can be quite bad (hitting end-stop twice, going into end-stop with wrong vector, etc.)

e. One man learned quickly on this stick and liked it quite well.

The rate stick had the following comments:

a. Easy to learn.

b. Extrapolation has most effect on this stick.

c. Most crew members like a rate stick. One did not like this stick because of extrapolation and non-centered nulling.

The rate and acceleration stick is disliked intensively because it makes the task much harder and the crew has had little experience with this type of stick.

F.6 STIMULUS

While the presentations were adequate, there definitely were bad scenes where dirt on the film was used for tracking. One member felt that the presentations were a variable in the experiment while one other indicated a strong difference between the scenes and the geometrical pattern.

F.7 STICK PREFERENCE

Stick preference appears to be basically a rate stick with acceleration end-stop capability.

F.8 GENERAL SIMULATOR IMPRESSION

A general term could range from good to excellent for the simulation capability and creditability. The physical set up of the stick, however, makes the task very tiring and for some crew members quite objectionable.

Miscellaneous comments were related to the following:

a. Dirty presentations and glass.

b. Objection of material focusing and reticle focusing being different.

c. Recommend crew member time in cabin be limited to less than one hour.

APPENDIX G

CONCLUSIONS

APPENDIX G

CONCLUSIONS

A list of specific conclusions and recommendations is as follows:

a. Rate plus acceleration stick is generally poorest.

b. Rate stick is best with respect to time-to-null rates.

c. Rate plus end-stop stick is best with respect to rate nulling.

d. Results of Phase I are consistent with Aerospace in comparison of average rate errors and average null time. This infers that the AVE digital processing has no major detrimental effect.

e. No appreciable difference occurs with or without extrapolation. Some crew members did not like the overshoot effect associated with extrapolation.

f. The results are not normally distributed.

g. Training is quite important.

h. Cabin conditions were quite tiring on many of the crew members.

i. Rate plus end-stop stick type has best overall capability and flexibility.

j. An increase in gain will be required to meet the time-to-null specification.

k. The end-stop should be implemented as close to the actual physical stick stop as possible.

Some more discussion on individual items is in order. The reason that a rate and acceleration stick was originally suggested is related to the man model used in analysis tasks. The model has no lead, and lead compensation seems appropriate from servo analysis. This appears definitely so in the sampled system (compared to analog). However, the man actually can predict and does not require additional lead. In fact, this is another variable (acceleration term) and makes the task more difficult. It must also be realized that the crew members are used to a rate type stick.

It should be pointed out that the 95 percent value for the end-stop stick may not be a fair measure since a bad run can easily occur, particularly since the end-stop was implemented at 27.8 degrees rather than at the desired end-stop 30 degrees. This stick, when used with the gains in this experiment, was prone to crew member mistakes. Along these same lines, the 95 percent value for any stick may not be a useful number since not all the crew members were trained to the same level. Phase II with 540 μ rad/sec initial rates involved the more experienced crew.

Allowing the crew member in before end-of-slew did not affect his basic scoring. One second ahead was not acceptable due to the large, quickly changing end-of slew exponential. Because of the exponential, allowing the crew in ahead of time may cause confusion. If early control is desired, it appears that no more than 0.5 second should be used. The simulation did not include the man's position error during early entry.

It possible, extrapolation should not be used in this task. It can be considered an unnecessary effect.