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PRELIMINARY INVESTIGATION FOR DEVELOPMENT OF AN ELECTRONIC PSYCHOMOTOR SKILL TESTER OF V/STOL PILOTS

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HUMAN ENGINEERING LABORATORIES

ABERDEEN PROVING GROUND,
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ABSTRACT

This is an initial report from a program of studies of V/STOL handling qualities. Simple electronic equipment was used to assess psychomotor capabilities. The task provided a zero-input compensatory rate-tracking test with variable system sensitivity. Two groups of ten subjects each were placed on different schedules for training and testing. The integrated absolute-error scores suggested that the rate-tracking task had face validity and discriminated reliably among subjects. Preliminary indications were that the test was insensitive to flight time.

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PRELIMINARY INVESTIGATION FOR DEVELOPMENT OF AN ELECTRONIC PSYCHOMOTOR SKILL TESTER OF V/STOL PILOTS

INTRODUCTION

It is commonly accepted that air vehicle handling qualities may be defined as "those aerodynamic properties which, when coupled with a pilot through primary flight and power control systems, affect the probability of mission success." (5) The aerodynamic properties of an air vehicle are quantitatively defined by the vehicle's stability derivatives and other specifications.

In the past, decisions concerning the acceptability or unacceptability of an air vehicle's handling qualities were based on the subjective impressions of a test pilot who flew the craft in a test mission. The test pilot would self-grade his "pilot work" required to perform a mission-oriented maneuver. If he judged that he expended little effort (or an effort within "reasonable limits") to successfully complete a maneuver, he would assume that the small effort required indicated that the handling qualities associated with that maneuver were acceptable. If the pilot felt that the expended effort was excessive to successfully complete a maneuver, he would assume that the handling qualities associated with that maneuver were unacceptable. Obviously, a pilot's likes and dislikes, relative to handling qualities, will influence the performance exhibited with the aircraft. Unfortunately, these prejudices will also strongly influence the final judgment that the pilot hands down concerning the acceptability or unacceptability of the aircraft and its handling qualities.

To remove the judgment of handling qualities from the subjective realm, an objective (quantitative) measurement of pilot/aircraft performance must be evolved. An initial consideration in quantifying the performance would be to assess the psychomotor skill of the pilot who is to fly the aircraft, since the intrinsic psychomotor capability of the pilot will be one of the factors influencing his performance. A measure of psychomotor capability may be defined, for this purpose, as the result of a test of motor skill in which the test score depends upon the precise coordination of perceptual (sensory, ideational) process with a given motor activity.

It may be possible to grade a pilot not only according to his psychomotor capability, but also according to his total flight experience. Total flight experience may be defined to consist of accumulated flight time, types of aircraft flown, types of missions flown, and types of flight conditions experienced. Further, it may be hypothesized that there will be no direct coorelation between a pilot's basic psychomotor capability and his total flight experience. Thus, using these two indices, which have been hypothesized to be independent, it may be possible to quantitatively describe a pilot's (any pilot's) performance with an aircraft. A quantitative index of total handling qualities may be obtained by combining several factors for consideration: (a) the stability characteristics, control characteristics, and dynamic characteristics of the aircraft; (b) the pilot's performance in terms of his control usage movement of control(s), frequency and amplitude of movement relative to performing or not performing a maneuver; (c) the precision of maneuvers performed by the pilot; (d) the pilot's psychomotor score (which may have been weighted by flight experience). From this objective grading of total performance, it will be possible to quantitatively assess the acceptability or unacceptability of the aircraft's handling qualities. Furthermore, the quantified performance of a test pilot with a given aircraft will make it possible to anticipate the probability of another pilot, with less or different flight experience, using the aircraft to successfully complete a mission (5).

PURPOSE

The purpose of this preliminary study was to investigate one possible form of psychomotor test which could serve as a foundation for a more complete test array in the total handling-qualities program. Since only a small number of subjects was available--all were laboratory personnel--it was decided to obtain general indications of ranges of performance related to system (equipment) sensitivity. These sensitivities would serve as initial limits in the construction of the final equipment. Further, this study sought to find indications that a subject's performance in this type of test task is independent of flight experience.

METHOD

Apparatus

The analog circuit (Fig. 1) was constructed on a 10-amplifier Donner unit. Variable resistances between and including 100K Ω and 10K Ω were provided by a decade resistor. Changing the resistance changed the system's sensitivity so that with resistance set at 100K Ω the system was least sensitive, and with resistance set at 10K Ω the system was most sensitive. Difficulty of the task was directly proportional to system sensitivity. The analog computer's readout voltmeter was used as the display. A small joy-stick was provided for the control. Only one of the two available degrees of freedom of the joy-stick was used, requiring left or right stick deflection. (Appendix A gives a detailed description of the equipment.)

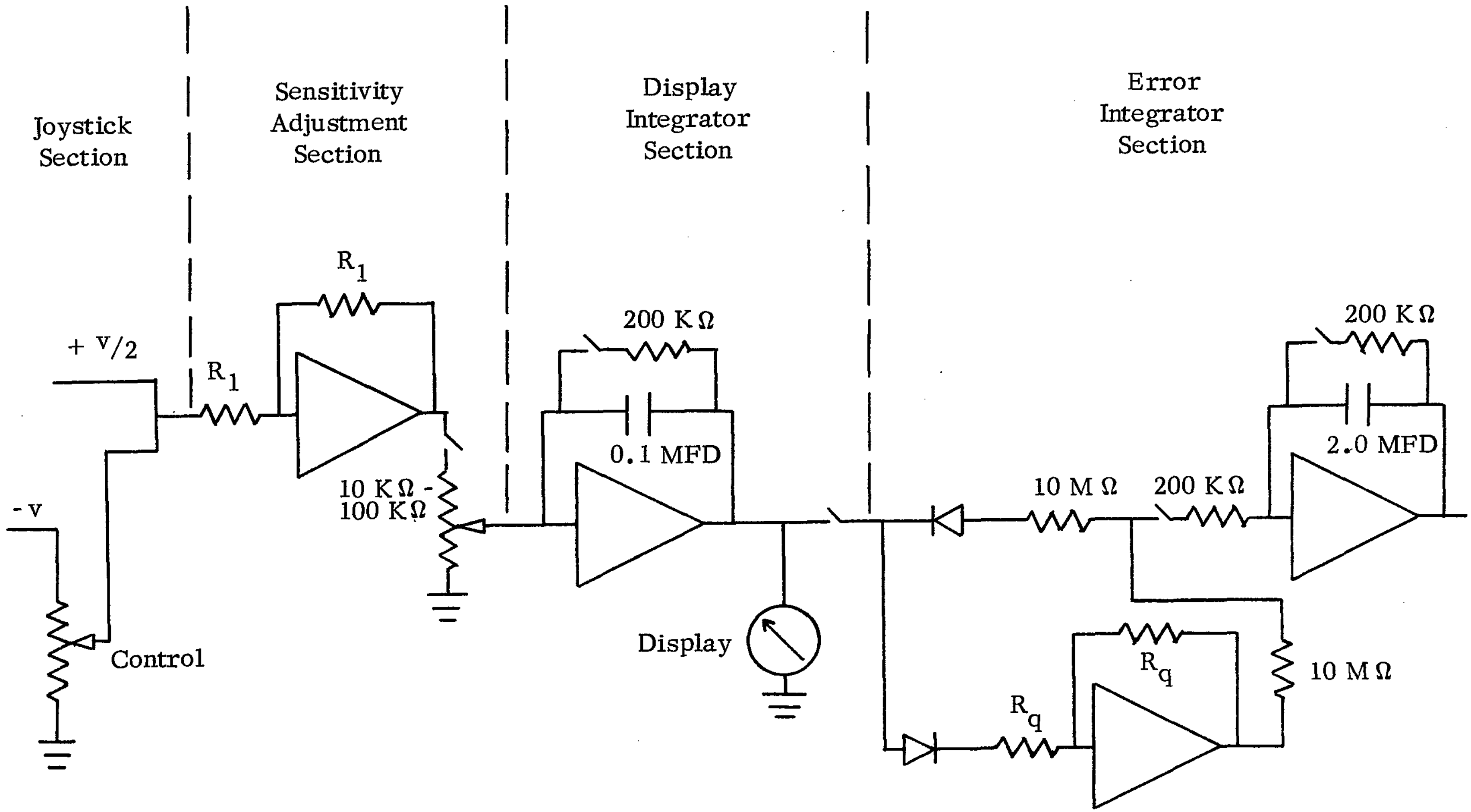


Fig. 1. ANALOG CIRCUIT

Rather than define system sensitivity by the rate integrator's time constant, it was decided to use a display rate sensitivity. The units of the adopted measure were defined as percent of display deflection per second per percent of control deflection. Thus, a given stick deflection produced a certain rate of display needle deflection. Changing the resistance but maintaining the same amount of stick deflection produced a different needle deflection rate. With a high resistance setting, low deflection rates were obtained, and high deflection rates were obtained with low resistance settings. (Specific numerical definitions and a description of empirical methods of obtaining display rate sensitivity values for each resistance setting are given in Appendix B.) The specific system sensitivity associated with each resistance setting is given in Table 1.

TABLE 1

Display Rate Sensitivity Associated With Each Resistance Setting

Resistance (K Ω)	Display Rate Sensitivity %DD/sec/%CD	
	100 V Scale	20 V Scale
100	9.80	49.0
90	10.89	54.5
80	12.25	61.3
70	14.01	70.0
60	16.34	81.7
50	19.61	98.0
40	24.51	122.5
30	32.68	163.4
20	49.02	245.1
10	98.04	490.2

The task was similar in certain respects to performing a precision hover in that the subjects were required to keep the display nulled. Performance was graded in terms of amount of absolute integrated error obtained by the subject during a scored test period. The system was not driven by a forcing function; however, the joy-stick did not self-seek its mechanical (nor electrical) center. Therefore, at the start of a scored run there existed an electrical imbalance proportional to the subject's ability or inability to find and maintain null condition while in the reset mode prior to the scored run. Thus, the obtained error was the result of overcontrol or undercontrol tendencies of the subject as he attempted to compensate his initial error, which was as close to zero as the subject could set and maintain prior to the scored run. The time required to switch the system from the reset mode to the operate mode was never greater than three seconds.

Subjects

Subjects were taken from among laboratory personnel. The primary and secondary groups consisted of 10 subjects each. Because of limited availability of personnel, it became necessary to include subjects who had only a few flight hours (some unlogged) in the general pilot category. Five subjects in the primary group were classified as pilots (with an average of 2,400 flight hours); only three in the secondary group were classified as pilots (with an average of 2,100 flight hours). None of the pilots in either group were on current flying status, having accumulated their flight time during past years of military service. The ages of the pilots ranged from 39-46 years, with one exception of 24 years. Average pilot age was 38 years. Most of the non-pilots were enlisted men ranging in age from 23 years to 30 years, with one exception (civilian) of 45 years. Average non-pilot age was 28 years. Only two subjects--both were non-pilots-- in the primary group had any previous experience performing experimental tracking tasks. None of the subjects in the secondary group had any experimental tracking-task experience. It was assumed that pilots were familiar with tracking-type tasks from aircraft flight; for example, instrument flight is a tracking-type task.

Procedure

For training and testing, the subjects were seated in a chair facing the display which was approximately at eye level and three feet from the eye. The control was located approximately at elbow level before the subject.

Training of the primary group was kept to a minimum. A brief explanation of a rate display was given, and the subjects were told that the display should be kept nulled. Then a two-minute training period at the lowest rate sensitivity was given prior to the two scored runs. A time limit of four minutes was assigned for each single scored run. It was felt that the four minutes were long enough to provide meaningful data, yet short enough to avoid fatiguing or boring the subjects. Each subject performed for two scored runs per sitting. Elapsed time between the two runs was only long enough to permit taking error reading and re-zeroing the analog circuitry. Subsequent sessions on succeeding days consisted of a brief reminder of the task and a two-minute practice period using the lowest rate sensitivity of the two rate sensitivities to be used during the two scored runs. Rate sensitivity was changed for each scored run; however, it remained constant during each scored run. Rate sensitivity was incrementally increased from lowest (corresponding to 100K Ω) to highest (corresponding to 10KΩ). Only one subject was trained and tested at a time.

The secondary group was tested only at selected rate sensitivities corresponding to resistance settings of 90KΩ, 60KΩ, 40KΩ, and 20KΩ. Further, the secondary group was divided into two subgroups with five subjects each. One subgroup was tested at decreasing rate sensitivities; the other was tested at increasing rate sensitivities. Again, training was minimal. It was explained to each subject that the system presented a rate-tracking task, and that the display should be kept nulled. The subjects of the decreasing rate sensitivity subgroup were given a two-minute training period with the lowest (100K Ω) rate sensitivity, then tested for four minutes at each selected rate sensitivity. The increasing rate sensitivity subgroup was first given a 30-second familiarization run using a medium rate sensitivity (50K Ω), before the two-minute training period using the high rate sensitivity (20K Ω). After training, the subjects were tested for four minutes at each selected rate sensitivity. For both subgroups, elapsed time between scored runs was only long enough to permit taking error reading and re-zeroing the analog circuitry. Also, all secondary group subjects were tested one at a time, and all four scored runs were performed at one sitting.

RESULTS

Data was obtained by reading voltage, in terms of percentage of full-scale meter deflection, accumulated by the error integrator. These percentage readings were converted into error scores as described in Appendix B.

Basic calculations gave average error and standard deviation for each rate sensitivity, and overall average error and standard deviation for the primary group as a whole (Table 2). Also shown in Table 2 are the averages and standard deviations of the pilots and non-pilots of the primary group.

Similarly, averages and standard deviations were calculated for the secondary group (Table 3). Also shown there are the results for the two subgroups.

For these and subsequent computations it was decided to consider no data for the whole group at sensitivities higher than the lowest one at which any subject of the group first overloaded the error integrator. For the primary group the cutoff rate sensitivity was the one associated with 50KΩ (Table 2); for the secondary group the cutoff sensitivity was at 60KΩ (Table 3). Note that the overload point (error integrator reaches 100% of allowable voltage) corresponds to an error score of 36.40.

TABLE 2

Averages and Standard Deviations for the Primary Group, and its Subgroups

Subjects	Flight Time (hrs)	Absolute Accumulated Error — Display Rate Sensitivity 49.0	54.4	61.3	70.0	81.7	98.0	122.5	163.4	245.1	490.2
1	0	18.93	7.28	7.64	13.47	15.28	10.56	10.56	22.57	36.40	36.40
2	4	7.28	5.46	4.73	11.65	8.74	14.20	11.28	14.56	20.38	36.40
3	0	9.46	7.28	8.74	13.10	14.56	14.20	18.93	36.40	36.40	36.40
4	0	6.55	4.73	6.19	6.55	12.38	19.29	20.02	16.02	26.21	36.40
5	5,000	8.37	5.82	7.28	6.55	11.65	8.01	12.01	19.66	21.84	36.40
6	1,000	6.92	6.55	10.92	20.02	17.47	16.38	20.75	22.93	31.30	36.40
7	0	13.10	9.46	9.46	7.28	6.92	17.11	12.74	18.93	36.40	36.40
8	6,000	9.46	7.64	11.65	16.02	19.93	18.20	36.40	36.40	36.40	36.40
9	4	8.73	7.28	13.47	9.83	9.10	11.65	14.56	14.56	23.30	36.40
10	0	18.20	18.93	20.02	21.11	26.57	27.66	36.40	36.40	36.40	36.40
	$\bar{x}$	10.70	8.04	10.01	12.56	14.26	15.73				
	$\bar{X}$			11.87					Entire Primary Group		
	s.d.	4.31	3.84	4.16	5.00	5.63	5.21				
	S.D.			5.40							
	$\bar{x}$	8.15	6.55	9.61	12.81	13.18	13.69				
	$\bar{X}$			10.67					Pilot Subgroup		
	s.d.	0.93	0.83	3.16	4.73	4.53	4.58				
	S.D.			4.34							
	$\bar{x}$	13.25	9.54	10.41	12.30	15.14	17.76				
	$\bar{X}$			13.07					Non-Pilot Subgroup		
	s.d.	4.82	4.93	4.93	5.25	6.42	5.75				
	S.D.			6.06							

TABLE 3

Averages and Standard Deviations for the Secondary Group, and its Subgroups

Subjects	Flight Time (hrs)	Absolute Accumulated Error Display Rate Sensitivity 54.5	81.7	122.5	245.1	Order of Sensitivity Changes
1	0	6.55	7.28	13.83	28.39	High to Low
2	0	8.01	8.01	23.66	36.40	High to Low
3	25	5.10	8.74	17.84	36.40	Low to High
4	0	4.73	6.92	10.92	36.40	Low to High
5	0	9.83	14.56	36.40	36.40	Low to High
6	0	9.46	12.38	26.67	36.40	Low to High
7	0	6.55	12.38	31.67	36.40	High to Low
8	3,400	8.01	13.10	21.48	36.40	High to Low
9	0	12.38	17.47	21.84	36.40	High to Low
10	3,000	8.01	16.74	36.40	36.40	Low to High
	$\bar{x}$	7.86	11.76			
	$\bar{X}$	9.81 (54.5–81.7)				Entire Secondary Group
	s.d.	2.19	3.67			
	S.D.	3.59 (54.5–81.7)				
	$\bar{x}$	7.43	11.87			
	$\bar{X}$	9.65 (54.5–81.7)				Subgroup tested High to Low
	s.d.	2.14	3.62			
	S.D.	3.71 (54.5–81.7)				
	$\bar{x}$	8.30	11.65	22.49		
	$\bar{X}$	14.15 (54.5–122.5)				
	$\bar{X}$*	9.97 (54.5–81.7)				Subgroup tested Low to High
	s.d.	2.14	3.71	5.69		
	S.D.	7.32 (54.5–122.5)				
	S.D.*	3.46 (54.5–81.7)				

*Denotes information calculated using data only to the imposed limits

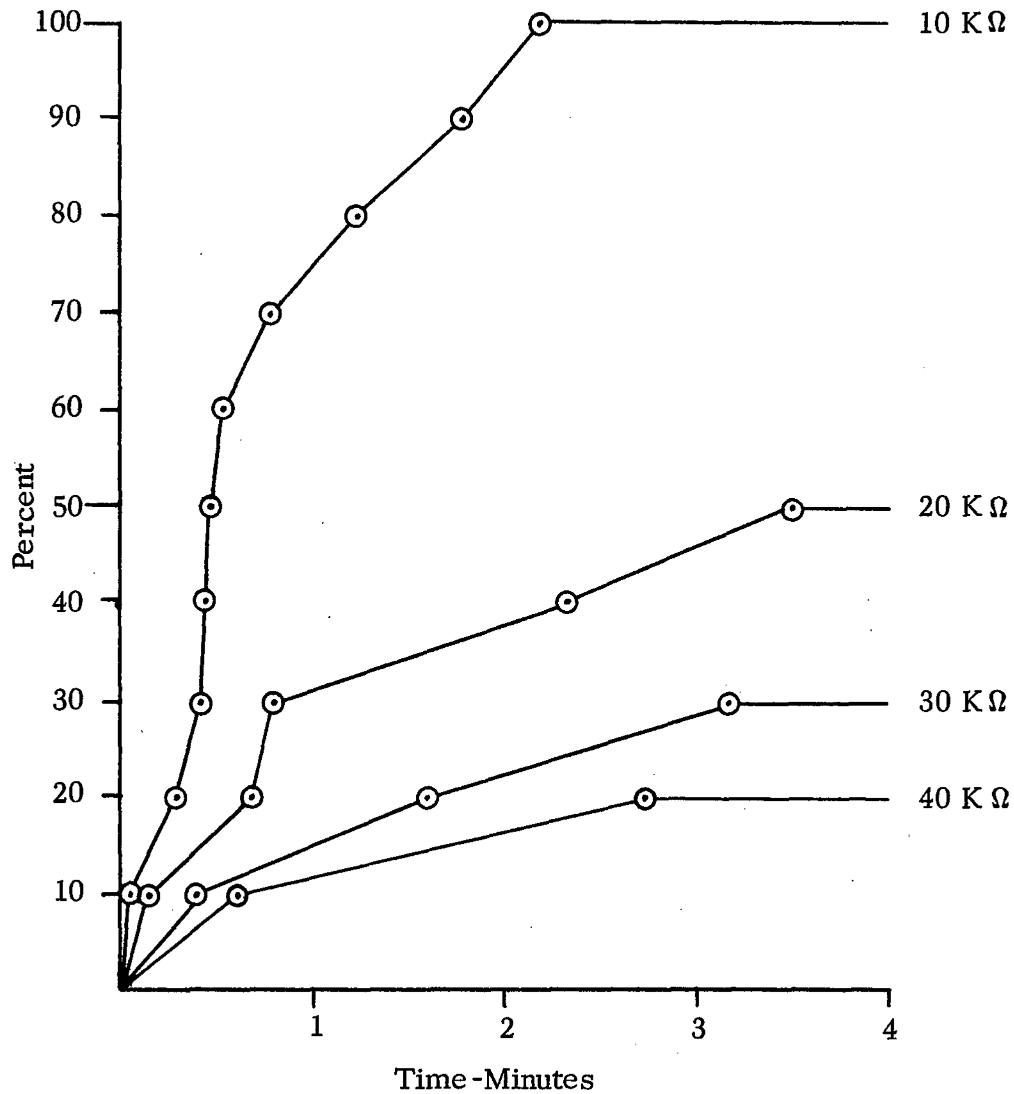
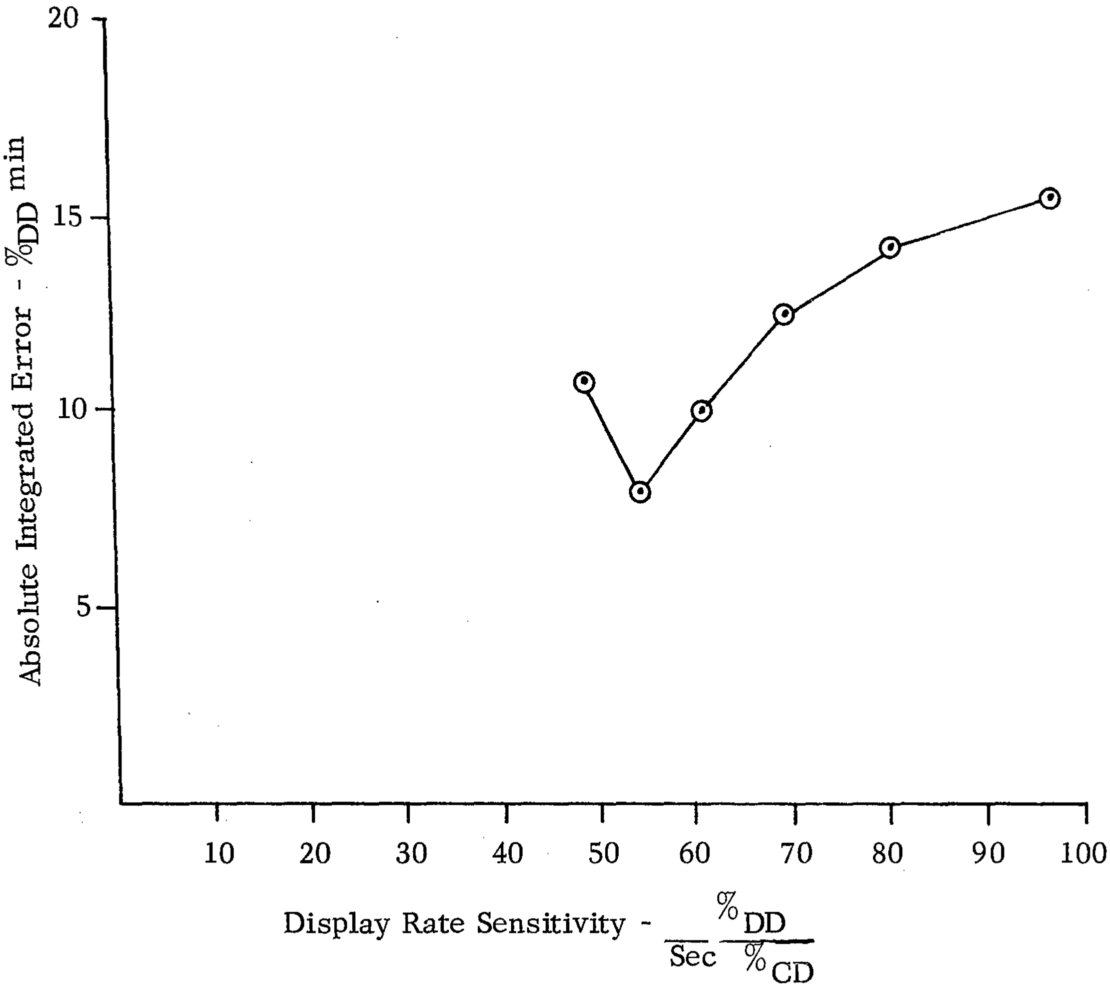


Fig. 2. PERCENT OF SUBJECTS, IN THE PRIMARY GROUP, OVERLOADING THE ERROR INTEGRATOR BEFORE THE ALLOTED TESTING TIME EXPIRED



DD - Display Deflection
CD - Control Deflection

Fig. 3. AVERAGE ABSOLUTE INTEGRATED ERROR FOR THE PRIMARY GROUP

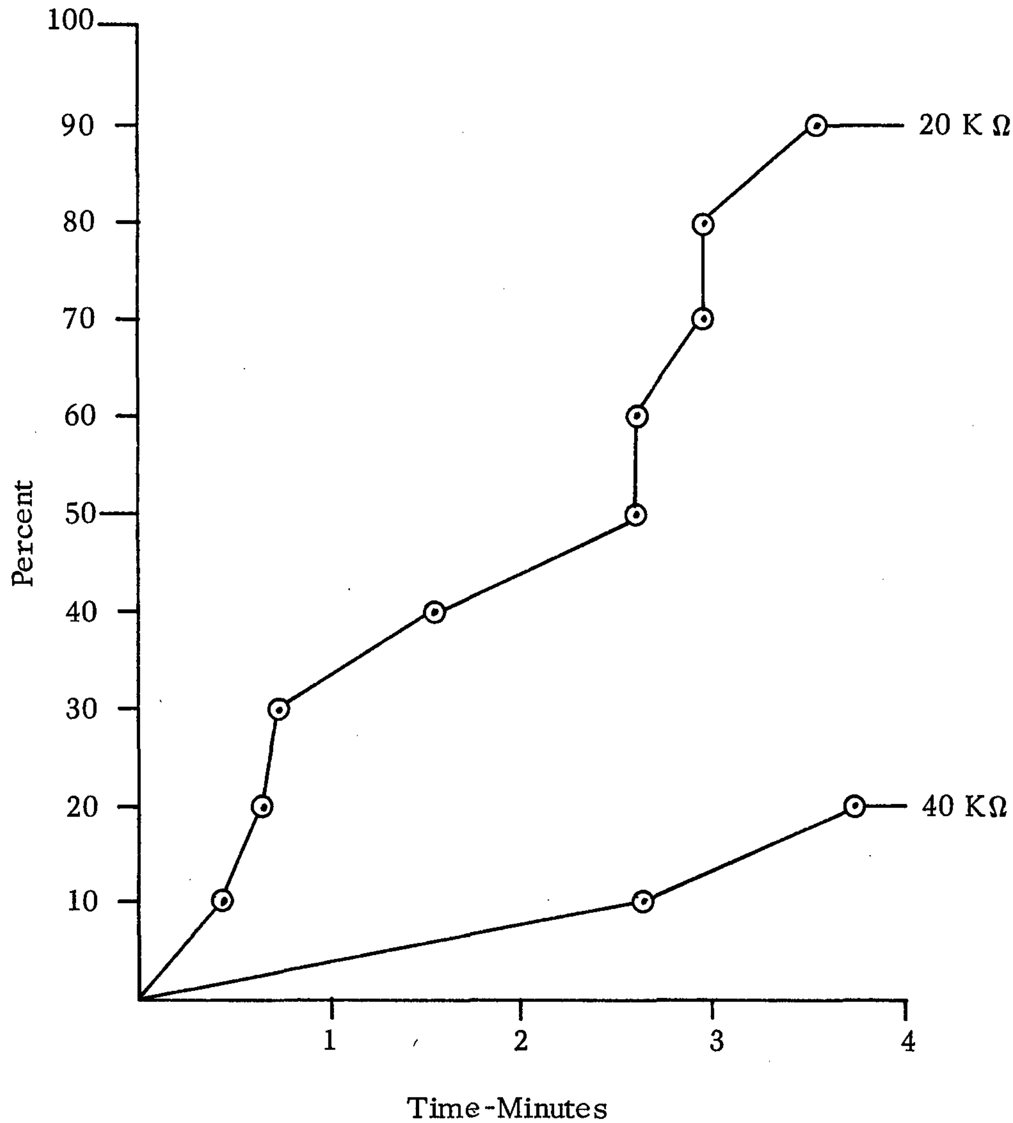
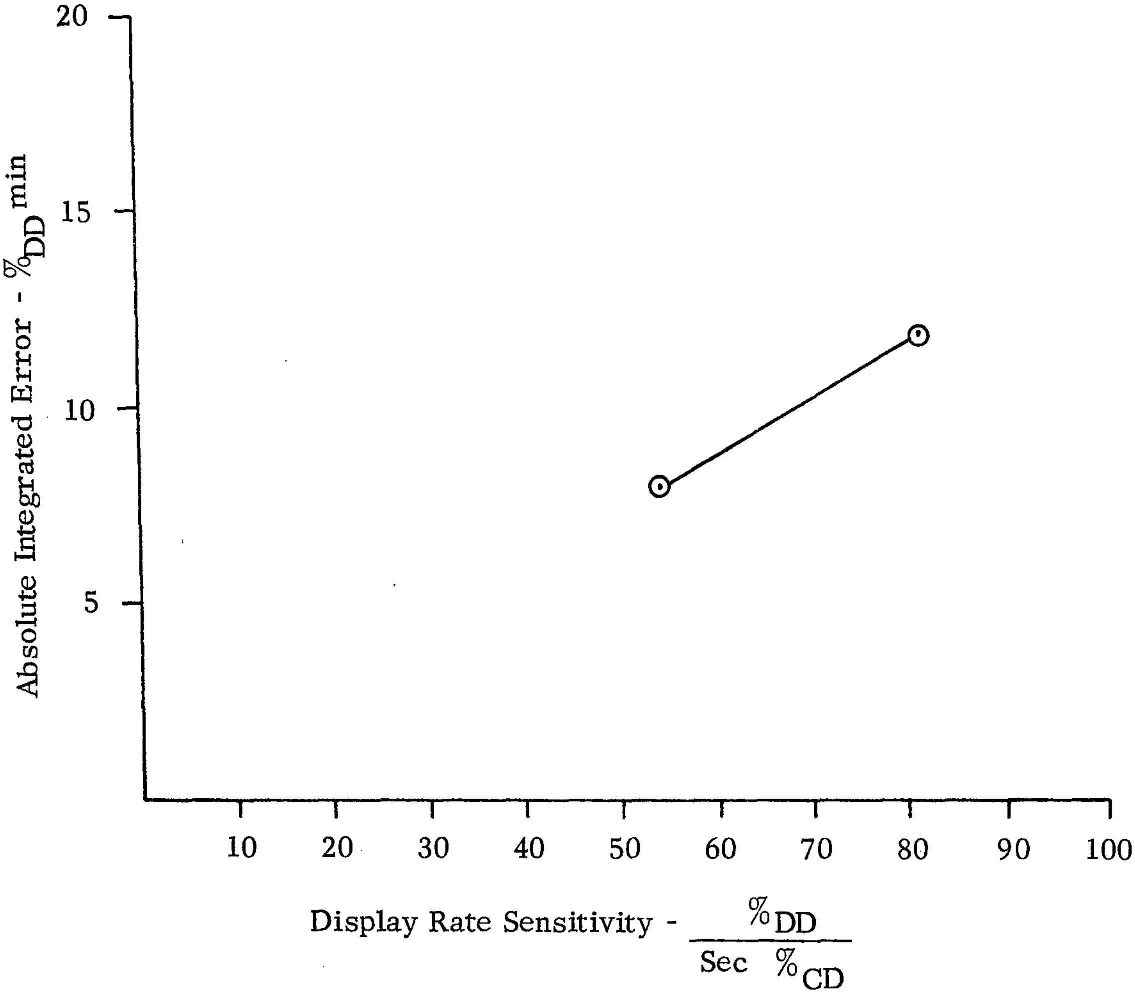


Fig. 4. PERCENT OF SUBJECTS, IN THE SECONDARY GROUP, OVERLOADING THE ERROR INTEGRATOR BEFORE THE ALLOTED TESTING TIME EXPIRED



DD - Display Deflection
CD - Control Deflection

Fig. 5. AVERAGE ABSOLUTE INTEGRATED ERROR FOR THE SECONDARY GROUP

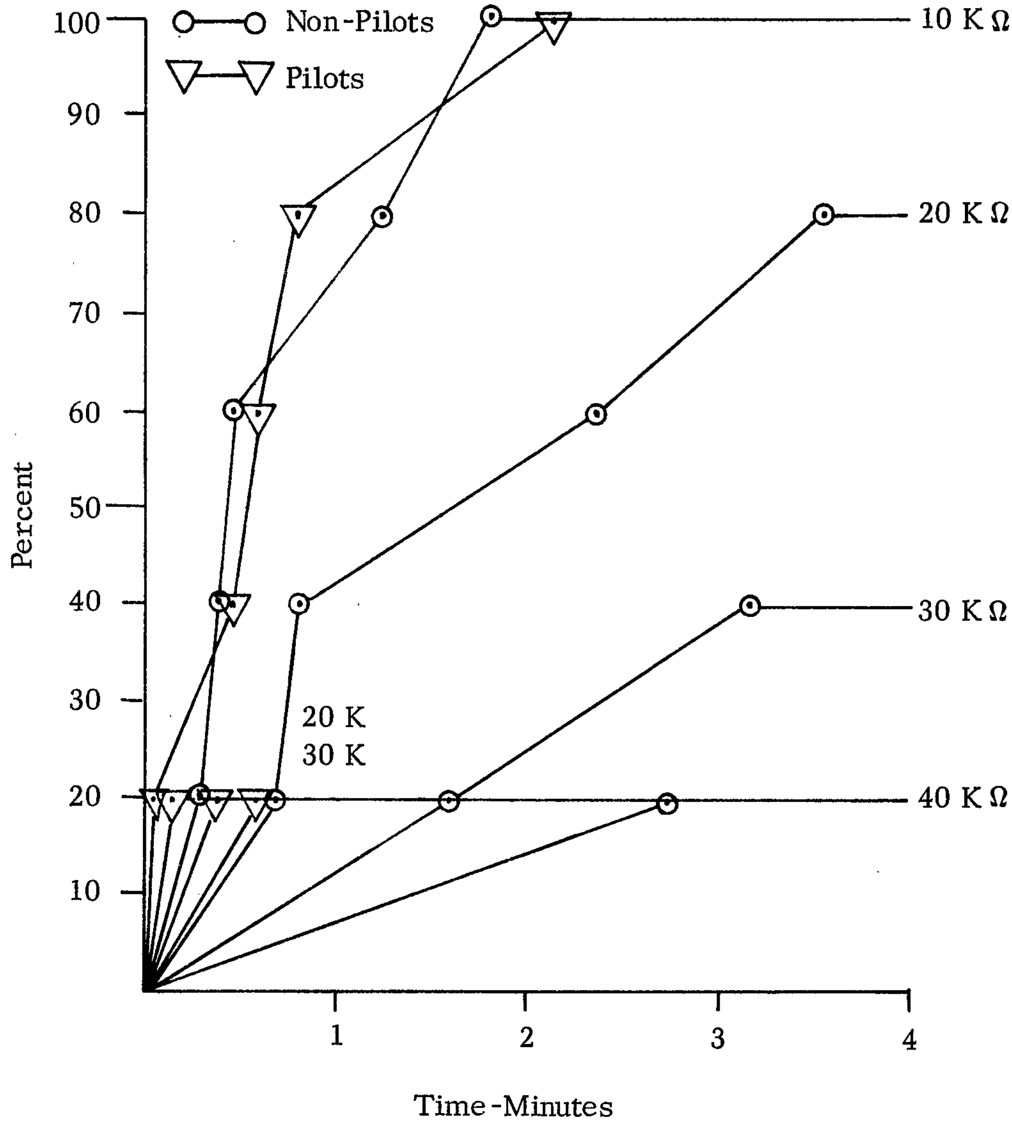
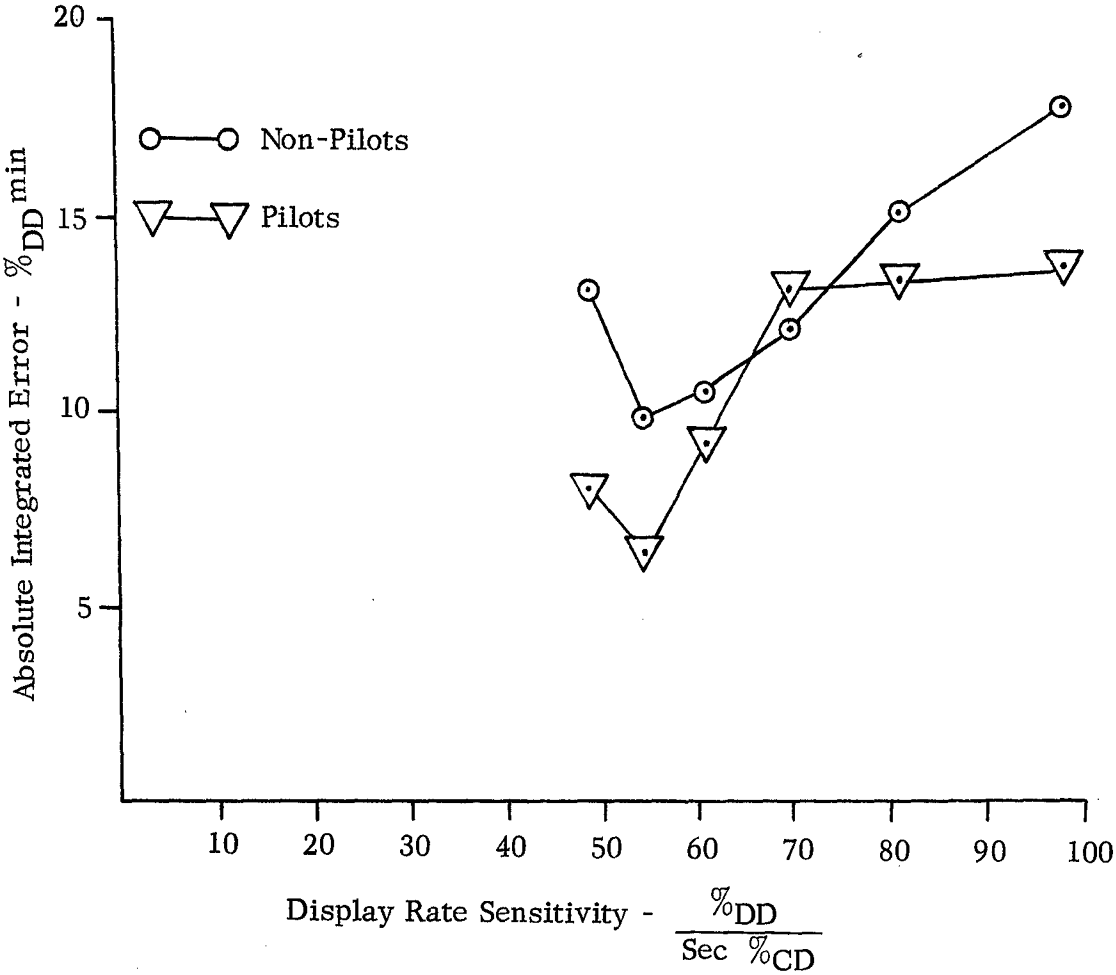


Fig. 6. PERCENTAGE OF PILOTS AND NON-PILOTS IN THE PRIMARY GROUP OVERLOADING THE ERROR INTEGRATOR BEFORE THE ALLOTED TESTING TIME EXPIRED



DD - Display Deflection
CD - Control Deflection

Fig. 7. AVERAGE ERROR OF PILOTS AND NON-PILOTS OF THE PRIMARY GROUP

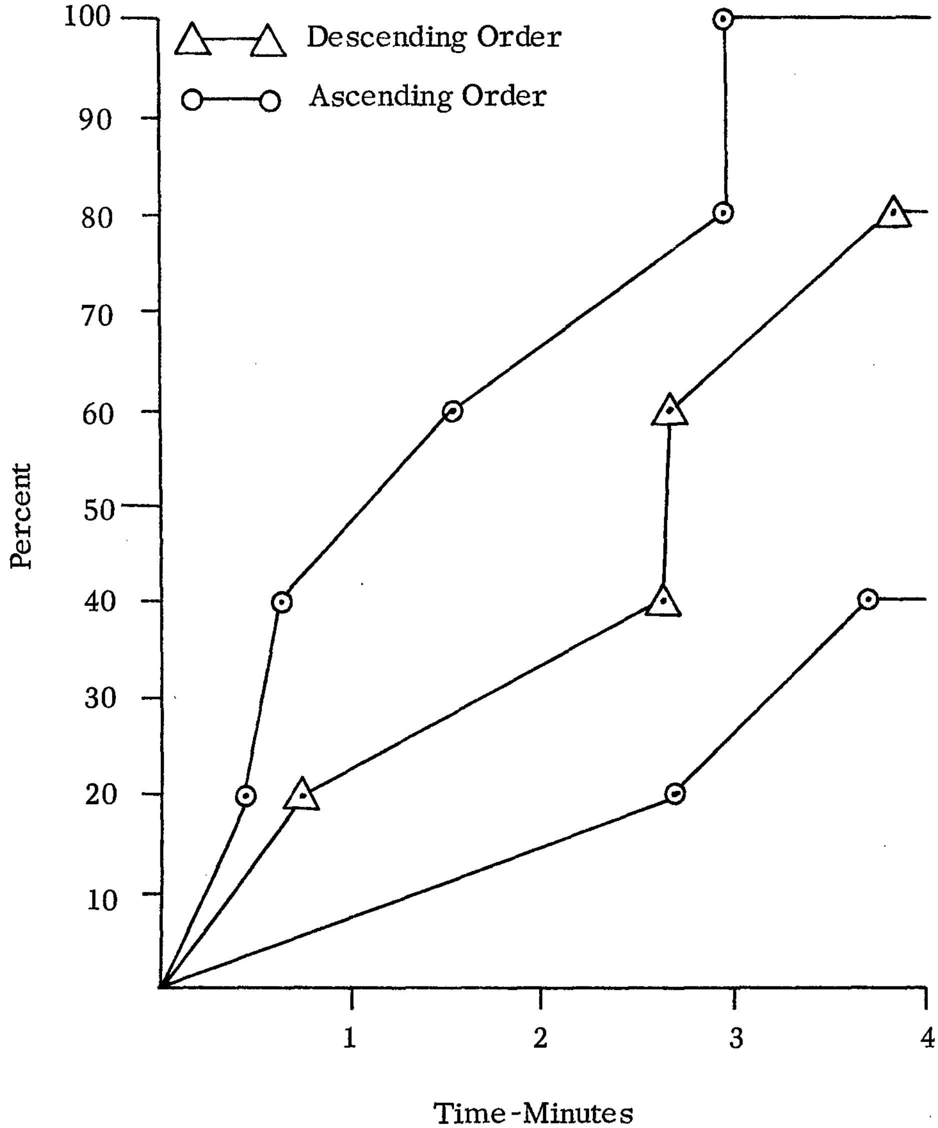


Fig. 8. EFFECT OF VARYING ORDER OF RESISTANCE CHANGES (DESCENDING VS. ASCENDING) UPON THE PERCENTAGE OF SUBJECTS IN THE SECONDARY GROUP OVERLOADING THE ERROR INTEGRATOR BEFORE THE ALLOTED TESTING TIME EXPIRED

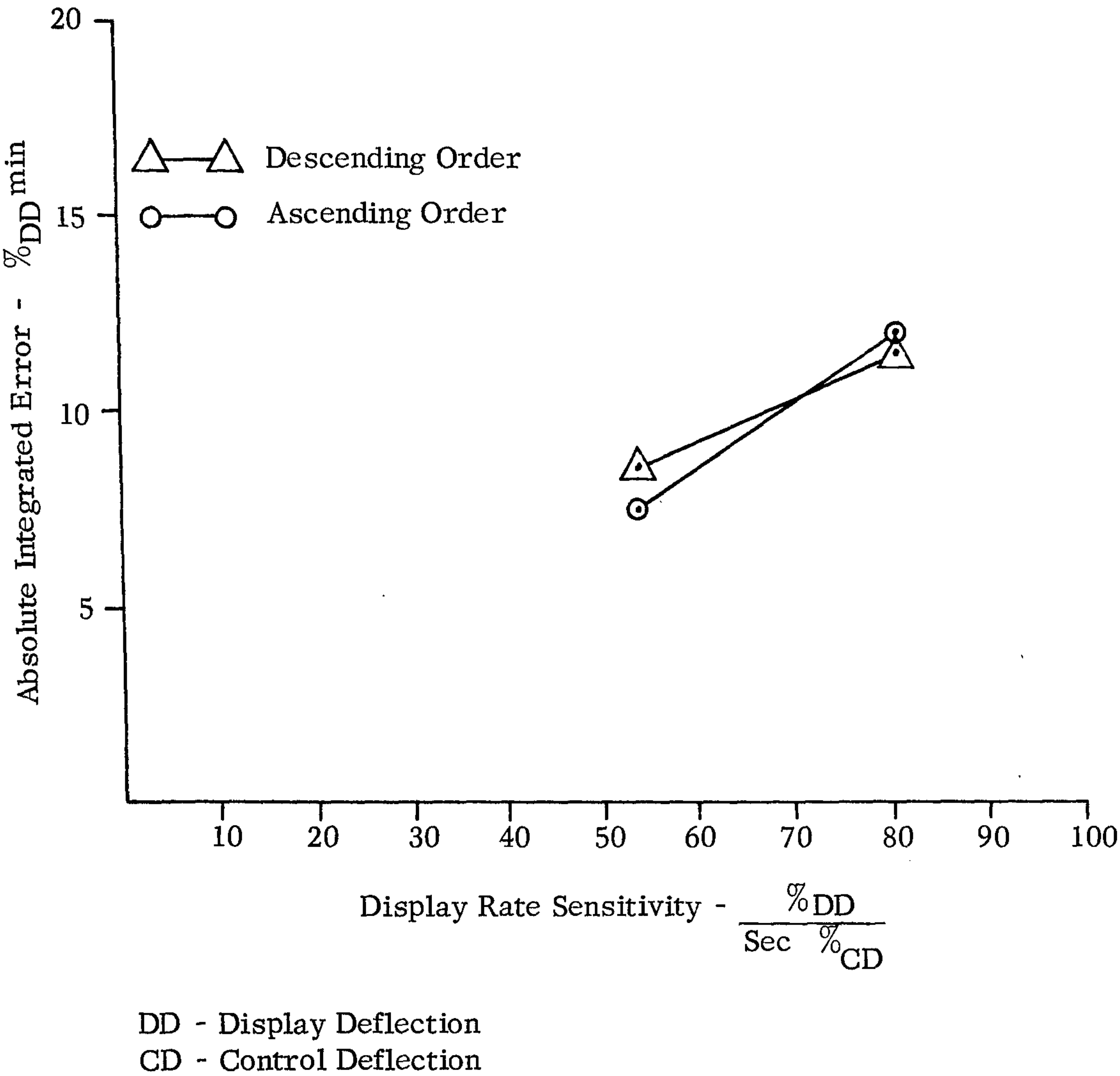


Fig. 9. AVERAGE ERROR OF SUBGROUPS OF THE SECONDARY GROUP TESTED AT DIFFERENT ORDER OF RESISTANCE CHANGES

ANALYSIS OF RESULTS

An analysis of variance was done using the error scores collected from the primary group to examine the effect of accumulated flight time on a subject's performance with this tester. The results (Table 4) suggested that flight time was not a significant factor. As suspected, the test indicated that changes of sensitivity were significant. There were no apparent interactions.

TABLE 4

Results of Analysis of Variance for the Primary Group

Source of Variance	df	SS	MS	F	
Sensitivity (S)	5	397.68	79.54	3.22	Significant
Subgroups (G)	1	81.78	81.78	3.31	Not Significant
(Cells)	(11)	532.49	---	---	
(S) X (G)	5	53.03	10.61	0.43	Not Significant
Within Cells	48	1,185.74	24.70	---	
Total	49	1,718.23	---	---	

Looking further at the effect of accumulated flight time on performance, a biserial correlation coefficient (4) to accommodate the dichotomous flight time distribution was calculated, using average error scores of each subject in the primary group. The results (Table 5) gave a value of -0.3868 for the coefficient. However, the standard error and the t-test for dichotomous distributions suggested that in this case no significance could be assigned to this value of the coefficient.

TABLE 5

Biserial Correlation Coefficient for Categorized Primary Group

r_b = -0.3868 (biserial correlation coefficient)

σ_{rb} = 0.2467 (standard error)

t = 0.929 (t-test)

To see between which rate sensitivities changes significantly affected performance, a multiple range test (3) was performed using the primary group's data. The results (Table 6) disclosed four significant rate-sensitivity changes.

TABLE 6

Results of Multiple Range Test for the Uncategorized Primary Group

	Sensitivity						Shortest Significant Range
	54.5	61.3	49.0	70.0	81.7	98.0	
Means	8.04	10.01	10.70	12.56	14.56	15.67	
8.04		1.97	2.66	4.52	6.22	7.59	4.47
10.01			0.69	2.55	4.25	5.62	4.70
10.70				1.86	3.56	4.93	4.86
12.56					1.70	3.07	4.97
14.26						1.37	5.05

Any two treatment means <u>not</u> underscored by the same line <u>are</u> significantly different.

Any two treatment means <u>underscored</u> by the same line are <u>not</u> significantly different.

An analysis of variance was performed on the secondary group's error scores to obtain an indication of the effect of rate sensitivity change order upon performance. The results (Table 7) suggested that the order of sensitivity changes was not significant. Again, it was found that changes were significant, and there were no significant interactions.

TABLE 7

Results of Analysis of Variance, With Respect to Order of Rate Sensitivity Changes, for the Secondary Group

Source of Variance	df	SS	MS	F	
Sensitivity (S)	2	1,114.10	557.05	18.04	Significant
Order (O)	1	0.10	0.10	0.0	Not Significant
(Cells)	5	1,122.86	56.43	---	
(S) X (O)	2	112.85	30.88	1.83	Not Significant
Within Cells	18	555.79	---	---	
Total	23	1,678.65	---	---	

Thus, it became possible to collapse the two subgroups of the secondary group for certain statistical comparisons with the primary group. The two main groups were compared to examine the effect of time spent on the tester (massed) versus distributed performance). Two rate sensitivities were chosen for the comparison; one sensitivity value was low (90K Ω), the other was high (60K Ω). The preliminary F-test (1) on the means indicated non-homogeneity; therefore, the weighted t-test (1) was performed. The results (Table 8) suggested that time spent performing the task was not significant.

TABLE 8

Result of t-Test Between Groups to Determine Effect of Time Spent on the Tester

Sensitivity	Primary Group				Secondary Group			
	$\bar{\bar{x}}$	$\bar{\bar{X}}$	s.d.	S.D.	$\bar{\bar{x}}$	$\bar{\bar{X}}$	s.d.	S.D.
54.5	8.04		3.84		7.86		2.19	
		11.15		5.73		9.81		3.59
81.7	14.26		5.63		11.76		3.67	

$$F = (S.D.)^2/(S.D.)_2^2 = 2.55$$

Significant

Then: $t' = 0.8862$ With $\nu = 33$

Not Significant

It was noted that the average age of pilots and non-pilots differed by 10 years. To examine the effect of age on performance, a rank-difference correlation coefficient (4) was calculated. The two main groups were pooled and compared at a low (90K Ω) and high (60K Ω) rate sensitivity. At the low sensitivity the coefficient value was -0.1418; however, at the high sensitivity the coefficient value was 0.3243 (Table 9). Neither value was significant. Because of limited subjects in each age group, it was not possible to calculate the correlation ratio to test the linearity of the regression; subsequently, a linear correlation coefficient was calculated to serve as a rough check, and it indicated that the rank coefficient was "reasonable."

TABLE 9

Rank-Difference Correlation Between Subject Age and Accumulated Error

Subjects	Sensitivity					
	Low		Medium			
	Score	Rank	Score	Rank	Age	Rank
1	7.28	11.0	15.28	6.0	26	15.5
2	5.46	17.0	8.74	15.5	39	6.5
3	7.28	11.0	14.56	7.5	45	2.0
4	4.73	19.5	12.38	10.5	26	15.5
5	5.82	16.0	11.65	13.0	46	1.0
6	6.55	14.0	17.47	4.0	39	6.5
7	9.46	4.5	6.92	19.5	27	13.0
8	7.64	9.0	19.93	2.0	44	3.5
9	7.28	11.0	9.10	14.0	24	18.5
10	18.93	1.0	26.57	1.0	30	8.5
11	5.10	18.0	8.74	15.5	30	8.5
12	4.73	19.5	6.92	19.5	27	13.0
13	9.83	3.0	14.56	7.5	28	10.5
14	9.46	4.5	12.38	10.5	24	18.5
15	8.01	7.0	16.74	5.0	44	3.5
16	6.55	14.0	7.28	18.0	27	13.0
17	8.01	7.0	8.01	17.0	23	20.0
18	12.38	2.0	17.47	3.5	25	17.0
19	6.55	14.0	12.37	12.0	28	10.5
20	8.01	7.0	13.10	9.0	41	5.0

$\rho_{Low} = -0.1518$ $\rho_{Medium} = 0.3243$

$r_{Low} = -0.1718$ $r_{Medium} = 0.3041$

NOTE: Subjects numbered 11 through 20 are the Secondary Group.

DISCUSSION OF RESULTS

The results of analysis of variance for the primary group showed that there was no significant difference in performance relative to flight time. The biserial correlation coefficient supported the independence between accumulated flight time and test performance. Thus, it may be inferred that the performance on the final proposed psychomotor tester will also be independent of the subject's total flight experience.

As may be intuitively guessed, changing the system sensitivity affects the subject's performance. Further, only certain definite sensitivity changes affects performance, and the direction of the change (either increasing or decreasing the sensitivity) is not significant. This point suggests that the final tester may be tailored to specific needs.

There was no preliminary indication of significant correlation between age and performance. However, the effect of age should be more closely investigated in the final program.

CONCLUSIONS

It was possible to draw several general conclusions which will serve as basic guidelines for the final program. First, the task performed by the subjects represents a zero-input compensatory rate-tracking test which is scorable by measuring total accumulated absolute error. Second, the test score provides an index which is in agreement with the suggested (for this program) definition of psychomotor skill. Third, indications were found which suggested that performance in the test is independent of flight time (flight experience).

It should be kept in mind that these conclusions are based on a study with a limited number of subjects, and that these conclusions are to be taken as encouraging signs indicating that the approach taken is correct.

RECOMMENDATIONS

A sufficiently large number of subjects should be pooled to provide a continuous distribution of accumulated flight time.

Two minor circuitry changes should be incorporated into the final circuitry. First, a floating reference rather than a common ground will simplify the method of power supply. Second, the time constant of the error integrator should be increased to eliminate possibility of overload.

The display rate sensitivity values found in this preliminary investigation may be used as crude estimates. It has been found that control-feel, or control resistance, is desirable for "easier" control of display (2)--this system will use controls that will be virtually free of resistance. Also, the necessity for a pilot to divide his attention among several tasks makes sensitive control/display characteristics undesirable and difficult to control (2)--the final tester will have four displays. Therefore, a medium rate sensitivity value would represent the maximum starting point. This value will probably have to be decreased to accommodate the time-sharing requirements. Also, it is quite possible that each of the four degrees of freedom may require a different rate sensitivity value. The specific values will be found empirically when the final tester is operational.

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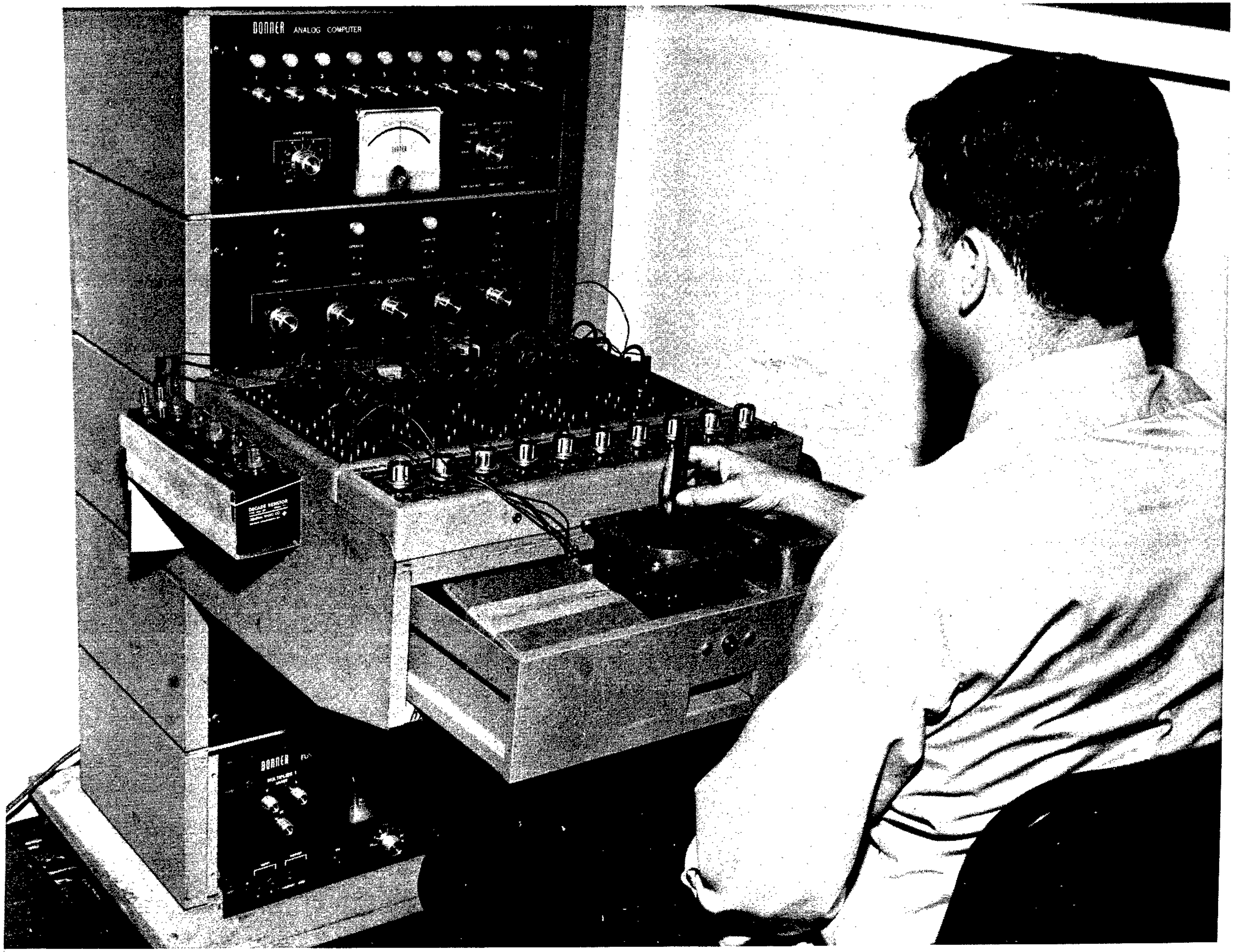

Fig. 1A. DONNER ANALOG COMPUTER, MODEL 3000

APPENDIX A

The analog circuit (Fig. 1) was constructed on a 10-amplifier Donner unit, model 3000. Two amplifiers were made into integrators; the first one was used to drive the rate display, and the second one was used to integrate absolute error. A General Radio Co. Decade Resistor, type 1434-QC, provided variable resistances for the display driving integrator. The feedback capacitance across the display driving integrator was held constant at 0.1 MFD while the resistance was varied. For the error integrator, the time constant was held constant at 0.417 seconds.

The analog computer's readout voltmeter, measuring 4 1/2 x 4 inches with a 2 1/2-inch pointer, is capable of $\pm 45^{\circ}$ deflection from zero position at vertical.

The control was a small joy-stick, seven inches from tip to pivot point. Maximum off-center deflection was $\pm 30^{\circ}$. Only one of the two available degrees of freedom was used, requiring left or right stick deflection for control. Retention springs and detents were removed to void the control of feel and of self-centering; accordingly, there was no breakout force in the stick. However, a constant 3.5 oz. push or pull force was required for deflections between zero degrees and $\pm 20^{\circ}$. The resistance was due mainly to the rubber boot--which had not been removed--and internal gearing. The control was located so that a subject sitting facing the display had the control approximately at elbow level before him.

APPENDIX B

Rather than use the rate integrator's time constants to describe the system sensitivity, it was decided to use a measure called rate sensitivity. The rate sensitivity primarily reflected quickness of display deflection for a given stick deflection. Therefore, rate sensitivity was proportional not only to the rate integrator's time constant, but also to the scale (range) of the readout voltmeter.

In equation form, rate sensitivity may be stated as:

$$DD = RS \int /CD/dt$$

or:

$$RS = \frac{DD}{\int /CD/dt}$$

where:

RS = Rate Sensitivity
DD = Display Deflection
CD = Control Deflection

and:

$$\text{Units}_{RS'} = \%DD/\text{sec}/\%CD$$

Numerical values of display sensitivities (Table 1) were found empirically. The analog circuit was set up so that the rate integrator was driven by a constant ± 0.1V, which represented one percent of full left or right stick deflection. Full stick deflection produced ± 10V respectively by design. Time to reach 50 percent of full scale deflection using the 100V readout range was recorded. Thus:

$$DR = C/T \text{ (T in minutes)}$$

where:

$$C = \left(\frac{50\%DD}{1\%CD}\right)\left(\frac{1 \text{ min}}{60 \text{ sec}}\right)$$

$$C = 0.833\,\%DD/\%CD$$

Dividing C by the time to reach 50 percent deflection gave the associated display sensitivity, for the 100V scale, for each resistance setting in terms of percent of display deflection per second per percent of control deflection (PSP). Dividing these values by five gives display sensitivities for the 20V scale. This was verified by two random spotchecks by using the 20V scale to find time to reach 50 percent scale deflection and calculating the sensitivity.

Parenthetically, it should be pointed out that the readout meter had, as mentioned, a selector dial for the read-range of the meter. The ranges were 100V, 20V, and 2V scale. Preliminary runs with the first group (Table 1B) showed that using the 2V scale the subjects were unable to control the display. Of the other two scales, the data (Table 1B) indicated that the subjects were better able to control the display (accumulate less error) with the 20V scale. Therefore, it was decided to use the 20V scale for all subsequent testing.

TABLE 1B

Effect of Scale Selection for Read-Out Meter (Display)

Subjects	Absolute Accumulated Error Meter Scale (V)	
	100	20
1	16.74	18.93
2	8.74	7.28
3	12.38	9.46
4	11.28	6.55
5	12.38	8.37
6	14.20	6.92
7	24.75	13.10
8	20.02	9.46
9	10.92	8.74
10	18.20	18.20
$\overline{x}$	14.96	10.70
s.d.	4.6	4.3

Next, the percent of error reading was converted to minutes-percent display deflection. Error (E') was defined as:

$$E' = \int /DD/dt$$

with $Units_{E'} = (\%DD)(min)$

A constant of conversion from percent reading to accumulated error was found empirically. To represent a constant static display deflection of 10 percent (using the 100V range), 10V were used to drive the error integrator. Time to reach 50 percent of full scale deflection was recorded. Restating expression for accumulated error (E):

$$E = BE' \quad (E' \text{ in } \% \text{ def})$$

where:

$$B = \text{Conversion Constant}$$

Time to reach 50 percent deflection was 1.82 minutes; therefore:

$$B = \left(\frac{10\%DD}{50\% \text{ def}}\right)(1.82 \text{ min})$$

$$B = 0.364 \ \frac{\%DD \text{ min}}{\% \text{def}}$$

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13. ABSTRACT

This is an initial report from a program of studies of V/STOL handling qualities. Simple electronic equipment was used to assess psychomotor capabilities. The task provided a zero-input compensatory rate-tracking test with variable system sensitivity. Two groups of ten subjects each were placed on different schedules for training and testing. The integrated absolute-error scores suggested that the rate-tracking task had face validity and discriminated reliably among subjects. Preliminary indications were that the test was insensitive to flight time.

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