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A STUDY OF ANTIAIRCRAFT TRACKING

Final Report under Contract OEM sr 165

Iowa State College

Ames, Iowa

SUPPLEMENTARY REPORT

John V. Atanasoff
Official Investigator

Harold V. Gaskill
Special Consultant

Clifford G. Anderson

Fred A. Brandner

Sam Legvold

SUPPLEMENTARY REPORT

This report supplements our report on tracking. It may be considered as addenda and corrigenda to the detailed report submitted in July.

The present supplement is concerned principally with the topics of accelerational following and magnification. There is also presented a revised and more complete analysis of psychological results.

A. Accelerational Followers

Fig A is a schematic circuit diagram of an experimental tracking mechanism whose behavior is described approximately by the operational equation

$$y = \left(d + \frac{v}{D} + \frac{a}{D^2} \right) x ,$$

where x is the control voltage coming from a control potentiometer manipulated by the tracker and y is the resulting tracking voltage. d, v, and a are the direct, velocity and accelerational tracking components respectively. To be sure, this apparatus does not duplicate the operations indicated in the equation exactly. Actually, as in our previous experimental followers, the operators are more nearly of the form $\frac{v}{D+\beta}$, $\frac{a}{(D+\beta)^2}$. These are the operators which describe the charging of a condenser through a series resistor. However, by means of a vacuum tube arrangement, it is possible to reduce the number β (the reciprocal of the time constant of a resistance-capacitance element) to such a low value that the manipulations required of the trackers are not noticeably different from what they would be with the operators strictly equal to $\frac{v}{D}$ and $\frac{a}{D^2}$.

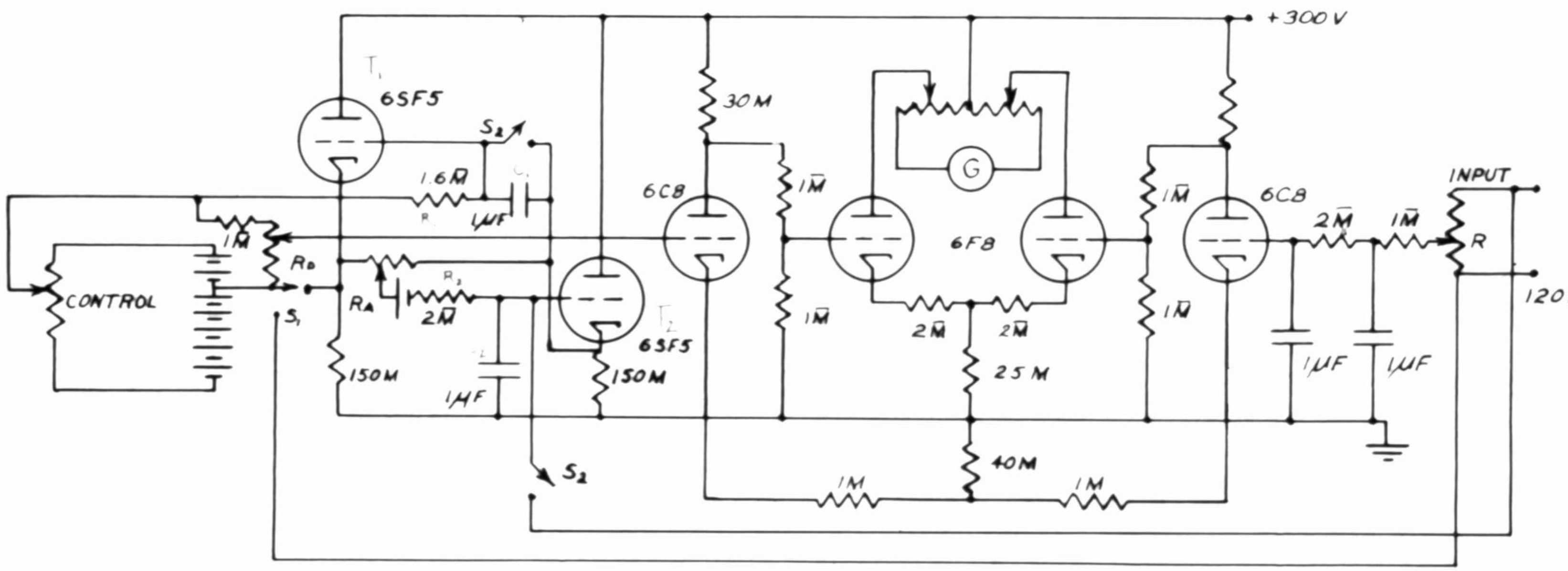

+300V
T1
6SF5
S2
1.6M̄
1µF
1M̄
Rb
RA
2M̄
CONTROL
S1
150M
1µF
6C8
30M
1M̄
1M̄
T2
6SF5
150M
S2
G
6F8
2M̄
2M̄
25M
40M
1M
1M
1M̄
1M̄
6C8
2M̄
1M̄
INPUT
R
120V
1µF
1µF

Fig. A

The basic circuit element by which the long time constant is achieved is the same as in the followers 5 and 6 described in our previous report, and may be seen by referring to page 19 of that report. The operator $\frac{a}{D^2}$ is achieved by employing two such circuits successively. Referring to Fig. A, the circuit containing R_1, C_1, and the control potentiometer, together with the tube T_1 constitute a long time constant circuit, such that the rate of change of potential difference across C_1 is nearly proportional to the potential difference from the control potentiometer. The elements R_2, C_2 are related to tube T_2 in a similiar manner, but the voltage that here controls the rate of change of voltage across C_2 is proportional to the voltage between the cathodes of T_1 and T_2 which is to a high degree of accuracy a linear function of the potential across C_1. The proportion may be adjusted by means of the tapped resistor R_A, which thus determines the accelerational component. Now since the voltage across C_1 is given by $\frac{m}{D}x$, the voltage across C_2 is $\frac{n}{D^2}x$ where m and n take account of the various proportionality factors. The voltage of the cathode of T_1 is a linear combination of these two voltages, namely

$$\left(\frac{v}{D} + \frac{a}{D^2}\right) x,$$

to high accuracy because of the strong degeneration of the circuit. The direct component d is added directly to this from the tapped resistor R_D.

The velocity component is thus fixed in this circuit, and the other two may be varied sufficiently to give all the desired experimental ratios.

The remainder of this follower is much like the previous followers

5 and 6. It need only be mentioned that a D.C. amplifier stage has been added to increase the current variations in the output.

Switch S_1 is to facilitate the measurement of course amplitude, and S_2 to facilitate getting on, by bringing C_1 and C_2 to approximately the right voltages momentarily. This is a time saving convenience.

B. Dynamical Analysis of Accelerational Tracking

Application of the dynamical formula

$$e = K D L^{-1}(z) \quad \text{(See page ten previous report)}$$

(where L is the follower operator and z is the target motion) to the acceleration-velocity-direct follower gives

$$e = K D \frac{D^2}{a + vD + dD^2}(z).$$

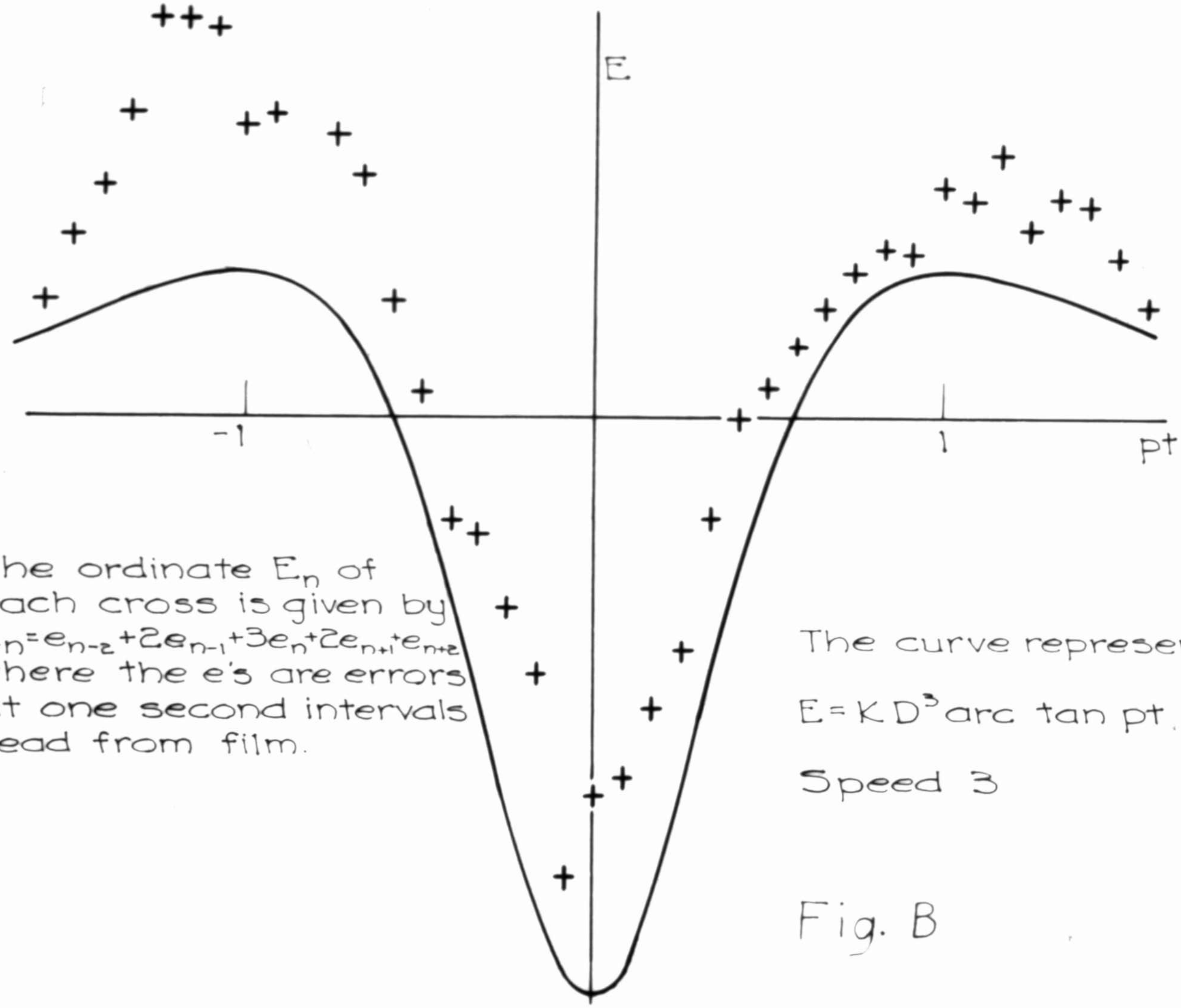
By approximation,

$$e = k D^3(z).$$

A comparison of this formula with actual tracking results (as recorded on film) for the sum of five individual runs, followed with the taking of three point running averages twice, is shown in Fig. B. This diagram and the one presented previously for velocity tracking give striking evidence of the approximate validity of the hypothetical assumption that the error is the greatest when the subject is required to turn the control the fastest; i.e., approximately

$$e = K\dot{x},$$

where x is the control coordinate.



The ordinate E_n of each cross is given by $E_n = e_{n-2} + 2e_{n-1} + 3e_n + 2e_{n+1} + e_{n+2}$ where the e's are errors at one second intervals read from film.

The curve represents

$E = KD^3 \arctan pt.$

Speed 3

Fig. B

C. Accelerational Tracking Results

A study of the effect of an accelerational term in the tracking device was made in the manner outlined in the previous report. With the velocity component held fixed, the accelerational and direct components were varied. The results of these tests are shown in Figs. C and D. In the diagrams the abscissa gives the direct component and the ordinate the accelerational component. The error for a test is written in at the proper place for that test.

From the diagrams it may be concluded that:

1. The use of an accelerational component reduces the error considerably.
2. The most advantageous direct component (and consequently $\frac{d}{v}$ ratio) is fairly independent of the accelerational term.

The advantage of an accelerational component is most readily apparent for speed 4. In this case the subject has the sensation of tracking a much slower course with a velocity follower. In the case of speed 3 we feel that the residual "noise" in the apparatus (slight voltage fluctuations, an imperfect course, microphonic tubes etc.) obscures the true advantage of acceleration. Furthermore, the smoothness of tracking with acceleration, as mentioned previously, is particularly important in prediction.

In the laboratory it has been difficult to get on the target because of the fact that the tracker could not tell where he was relative to the target. We have concluded that this difficulty will not occur in the field particularly for trackers experienced in accelerational followers.

D. The Visual Problem

As pointed out in the previous report the visual equivalence of the

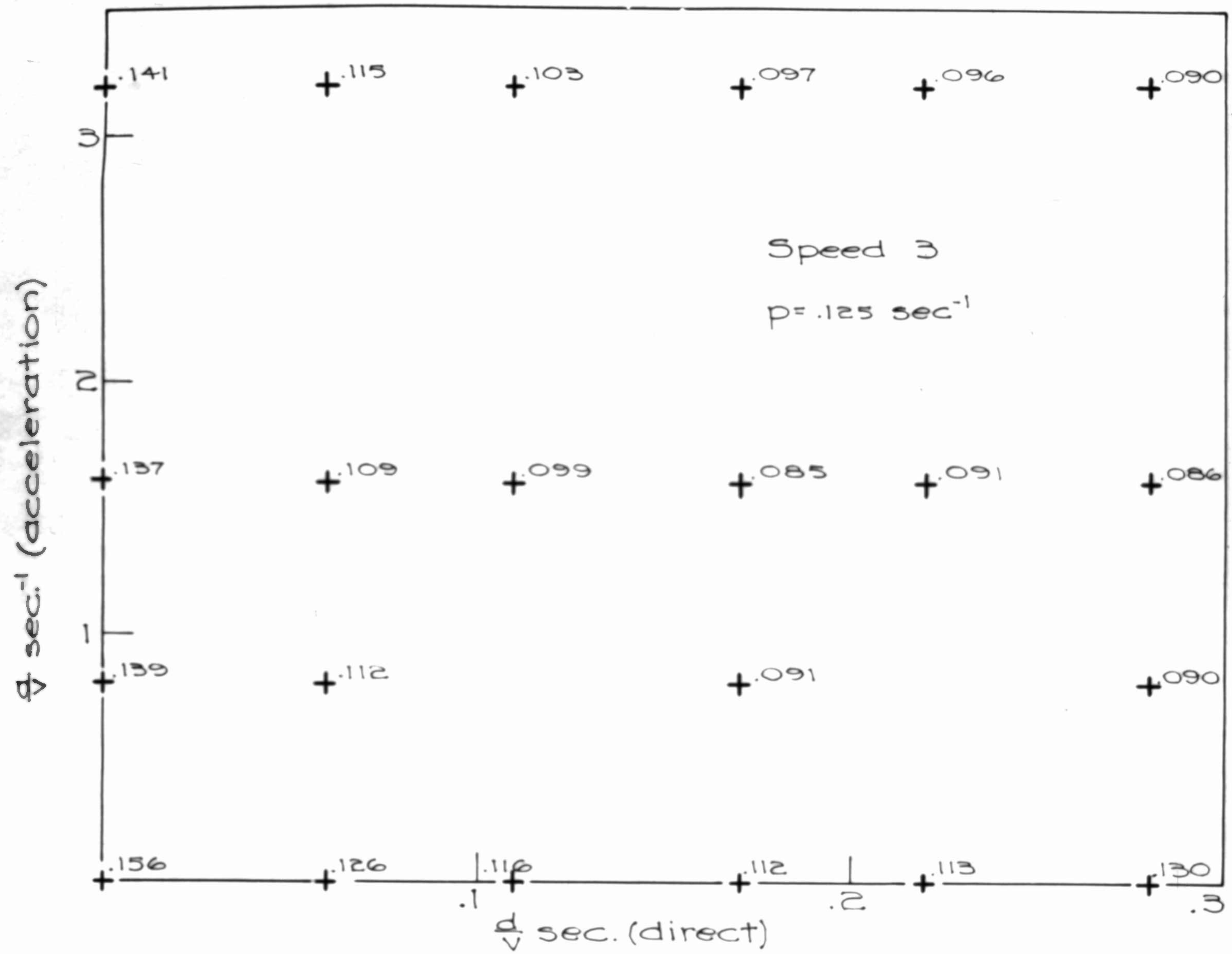
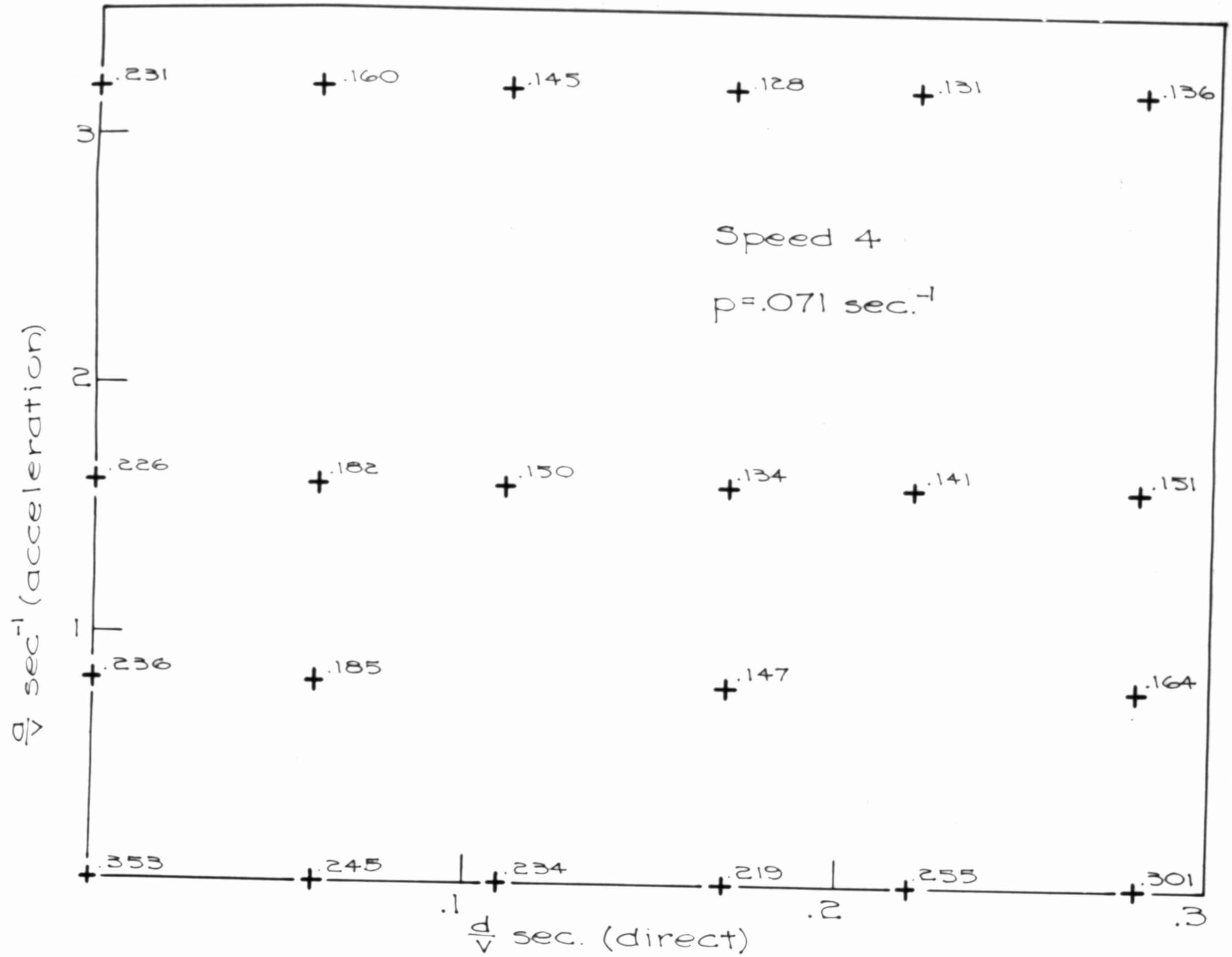

.141
.115
.103
.097
.096
.090
Speed 3
p= .125 sec^{-1}
.137
.109
.099
.085
.091
.086
.139
.112
.091
.090
.156
.126
.116
.112
.113
.130
3
2
1
.1
.2
.3
$\frac{a}{v}$ sec.$^{-1}$ (acceleration)
$\frac{d}{v}$ sec. (direct)

Fig. C



.231
.160
.145
.128
.131
.136
Speed 4
p=.071 sec.⁻¹
.226
.182
.150
.134
.141
.151
.236
.185
.147
.164
.353
.245
.234
.219
.255
.301
3
2
1
.1
.2
.3
a/v sec⁻¹ (acceleration)
d/v sec. (direct)

Fig. D

laboratory miniature and tracking in the field is questionable. In order to gain some insight into the problem in the laboratory a number of experiments were conducted with small field (opera) glasses. Two groups of subjects on successive weeks ran the same test without opera glasses, with glasses of m 1 and with glasses of m 1. The average results were as follows:

	Error Speed 3	Error Speed 4
without glasses	.107	.223
with glasses 2.5 x	.113	.226
with glasses .4 x	.156	.310

Without glasses the magnification was 30x. The results show that an increase in magnification to 75x with opera glasses is not helpful. On the other hand, a reduction of magnification to 12x is definitely a hindrance. This suggests a threshold for optimum magnification somewhere between 12x and 30x for ordinary aided laying with $\frac{g}{v}$ = .17 sec. It may be, however, that the illumination in the laboratory was so low that when the negative glasses were used insufficient clarity of vision for some subjects resulted; although there seemed to be very little complaint of eyestrain on the part of the subjects.

In order to investigate the problem further two groups of subjects ran tests as follows: one group tracked at a distance 2.5 greater from the screen then normal and the other tracked at this same distance (2.5 normal) and employed the 2.5x opera glasses. The results were as follows:

	Error Speed 3	Error Speed 4
normal	.128	.309
at a distance 2.5 normal	.175	.306
at a distance 2.5 normal with 2.5x glasses	.145	.310

A test of the effect of using sighting tubes shows that they have a "nuisance" value of .02 mil on speed 3 and on speed 4. This explains some of the anomolies in the first set of data presented above. The above described experimental results can roughly be explained in the following terms: The human mechanism has a dynamical visual resolution limit which is greater than the static resolution usually defined in a study of visual acuity. An examination of our experimental results seems to indicate that for our group this resolution falls between 2 and 3 R.M.S. visual mils for ordinary aided laying on speed 3. However, with speed 4, this limit is raised to the range from 3.5 to 6 mils. Obviously the limit of dynamical resolution depends on the speed of the course. Our experimental results on accelerational following would indicate that the visual resolution is better in this case; this would correspond to the more leisurely rate at which action must be taken in accelerational following.

X. Psychological Results

In the previous report it was mentioned that a number of psychological tests were being given. Results were obtained for each of the operators in each of the following tests: strength preferred hand, strength non preferred hand, percent difference of these strength measurements; tapping preferred, non preferred, and difference; dexterity preferred, non preferred, and difference; stopping preferred, non preferred, and difference; time of reaction from a given signal; clerical tests; and drivers test. From this group of fifteen tests only three showed anything but trivial correlation with the excellence number (slow speed) for the fourth week. In the previous report it was stated that the sample was homogeneous. There is an indication that this statement is questionable especially since our men and women operators seem to give different psychological reactions.

Results on the tests exhibiting somewhat significant correlations with excellence numbers are as follows:

Test	Mens Correlation	Womens Correlation
strength preferred hand	-.228	.015
%difference of strength	.180	-.209
stopping preferred hand	.446	.016

Out of the thirty correlations made only that between the value N_3 and stopping preferred hand for men proved highly significant. A multiple correlation was computed with the excellence number as the dependent variable and the above mentioned values as independent for each of the sets of values for men and women. For the men this value was $r_{1.234}$ = .519, and for the girls, $r_{1.234}$ = .228. For the boys this correlation coefficient gives a high level of significance. However, the value for the girls is such that it might be secured about one time in three due to random sampling.

Each of the operators was also tested on a direct mechanical follower. The photographs, Figs. E and F shows this testing apparatus which it was hoped would give high correlation with the results on the electrical followers. It is essentially a simplified mechanical model follower, employing only the direct component. The crank A makes one revolution in about twenty seconds pulling a string back and forth with approximate sinusoidal motion. The string goes around a pulley mounted on the pivoted needle B and thence back around pulley C to a drum D on a shaft which the tracker turns. This constitutes a simple kind of differential by which the difference between the driving motion and the motion put in by the subject appears as a displacement of the needle. The difference actually is magnified about six times by lever action.

A measure of the error in trying to keep the needle on a fixed center line is obtained by an electric timing device which records the time the needle is outside of certain bounds. That is, when the needle moves about 1/8" to left or right of the center line it comes into contact with one of the long springs E and F, closing the clock circuit. The general principle is the same as that of the error counter on the electric tracking apparatus.

Each subject was given only one test with this machine, since the purpose was only to investigate the possibility of correlation between this simple machine and the more intricate electrical devices, not to plot new learning curves, etc. After about three minutes of practice, each subject took five short tests in quick succession, each test consisting of

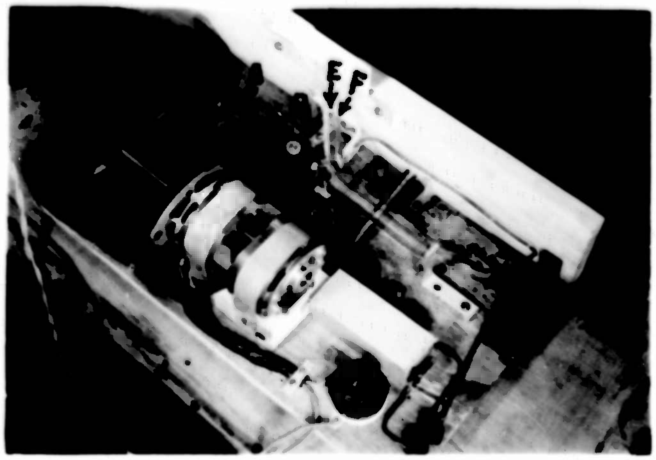


Fig. E

Fig. F

two revolutions of the driving crank. The averages of the readings for the last three trials were used as a measure of the individual's ability; these were found to be generally consistent within about 10%, whereas the first two readings were considerably poorer.

The scatter diagram between the excellence numbers and these scores is shown in Fig. 6. The correlation turned out to be .54, which was quite significant. However, it would be wise to mention the fact that this device was tried out mostly on old operators since time did not allow the training of a new group. Thus the high relationship obtained in this case may in part be the result of their previous training.

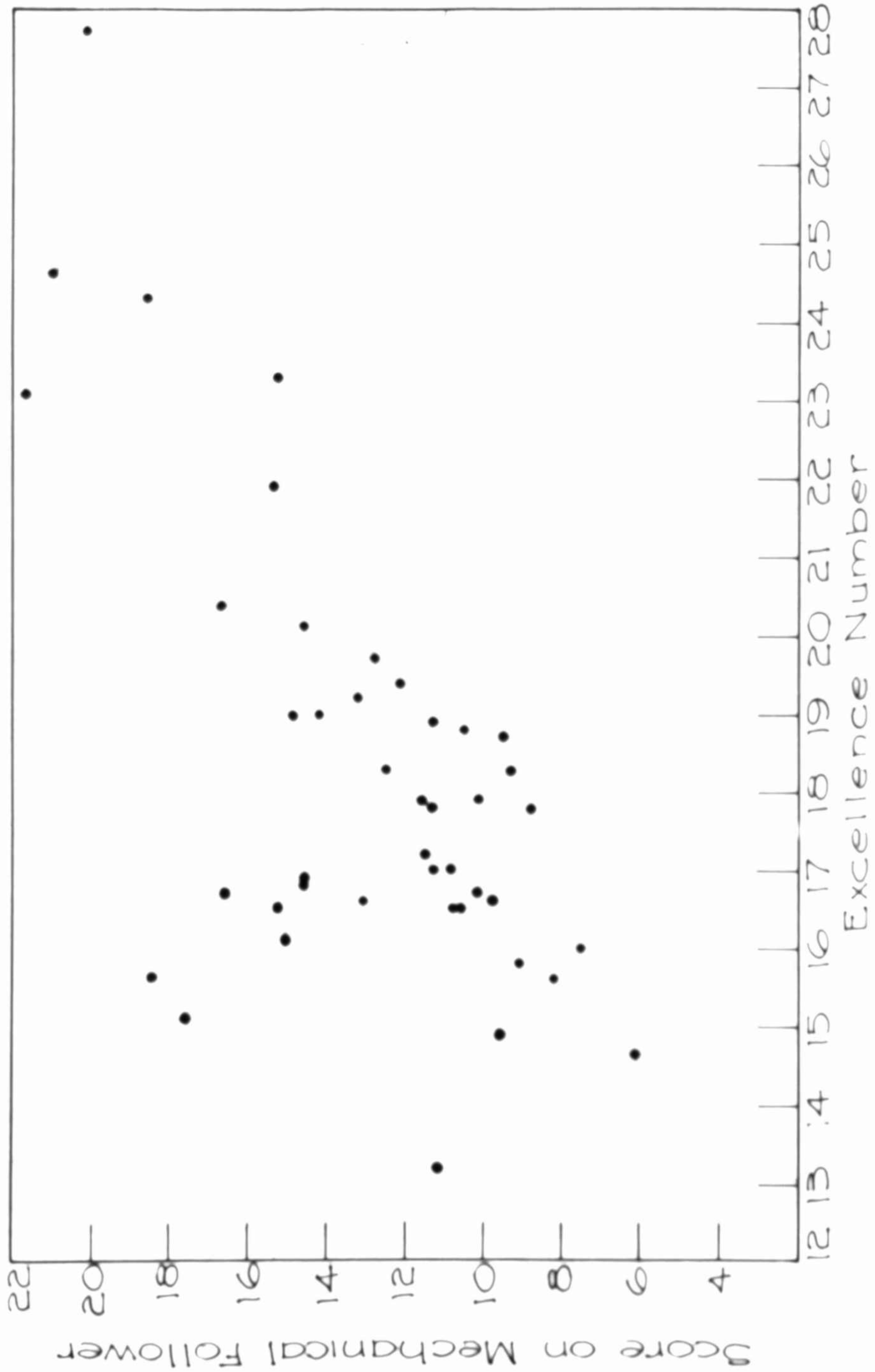

Excellence Number
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Score on Mechanical Follower
4 6 8 10 12 14 16 18 20 22

Fig. G

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ABSTRACT:

A supplementary report is presented on antiaircraft tracking concerned principally with accelerational following and magnification. A revised and more complete analysis of psychological results is also included. An operational equation is given describing approximately the behavior of an experimental tracking mechanism of which the circuit diagram is given. It was concluded that the use of an accelerational component reduces the error considerably. Results of psychological tests given show that out of a group of fifteen tests given operators only three: strength preferred hand, per cent difference of strength between two hands, and the stopping of the preferred hand, showed anything but trivial correlation with the excellence number (slow speed) for the fourth week.

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