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A STUDY OF ANTIAIRCRAFT TRACKING

Final Report under Contract OEM sr 165

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I. GENERAL INTRODUCTION

In a typical treatment of the antiaircraft problem an observer looks through a "telescope" at the target and manipulates a manual control in such a way as to keep the crosshair of the telescope on the target. This process furnishes the angular position of the target. Usually two separate observers are used, one for elevation and one for azimuth. In determining the range of the target, another observer manipulates a control so as to superimpose two images in a coincidence range finder or so as to establish "contact" with the object in the stereoscopic range finder. Thus a typical antiaircraft installation will use three people whose role is essentially that of a servo-mechanism. Formerly human beings were sometimes used in other servo-roles in connection with antiaircraft fire (pointer matching), but an examination of tests will show that on the whole a man is much less efficient than a mechanical or electrical servo. On the other hand, human discernment qualified as it is by the patterns of memory and reason will do certain things that a servo-mechanism cannot do. Besides, the human eye possesses a sensitivity and a reliability that is not particularly easy to match in a mechanical way. For these reasons human beings are very useful and it is not likely that they will soon be replaced in antiaircraft work. We find human beings employed in this role even in connection with electromagnetic range finders and in submarine detection work.

It is the purpose of the present report to consider this problem of a human being in a servo capacity with special emphasis on the design of the associated apparatus by which the servo action is obtained. It is a secondary objective of the present study to furnish information on the selection and training of personnel for operating such devices. The study as a whole is aimed at the problem of angular tracking in antiaircraft work and even more specifically the problem of tracking in azimuth since this is the more difficult part of angular tracking. However, it is hoped that some of the matters presented here will find applications to other problems where human beings are used in a similar capacity.

It has been clear from the beginning that a human being is such a complex structure that his dynamical reactions are not well understood, and hence that theoretical considerations, while useful, must be supplemented and verified by experimental work. The difficulties of the psychological problem of coordination further dictate that tests should be made under conditions as nearly identical with those used in practice as is possible. For this reason the study has been carried out by the use

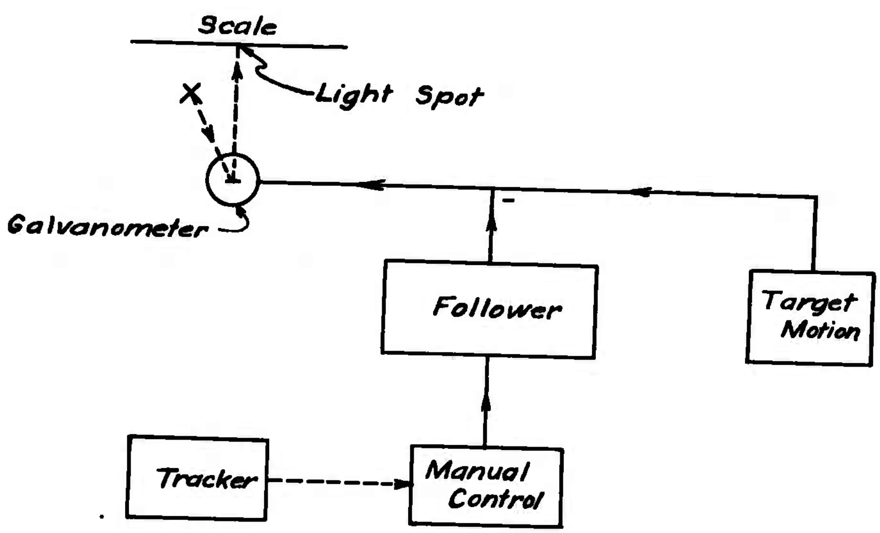


Figure 1

of a "job miniature." While a great effort has been made to accurately reproduce, in an idealized way, actual working conditions, the problem of how well this has been accomplished is a most difficult one.

Fig. 1 is a schematic drawing showing the fundamental structure of the "job miniature" used. A spot of light is reflected from the galvanometer mirror upon the scale as shown bv the dotted line. The galvanometer is actuated by a current supplied from a device designed to reproduce the target motion. The tracker observes the deviations of the spot from the center line of the scale and by way of a manual control and a device called a follower supplies a current which balances the effect of the target motion. Failure of the tracker to completely compensate for the target motion is indicated by the deviation of the light spot from the center line.

It will be instructive to compare this "job miniature" with the apparatus used in practice in following angular motion in antiaircraft fire. In the "job miniature" the tracker observes how closely the differences between the target motion and the motion he introduces by way of the follower comes to zero. In the field, the tracker observes how closely the crosshair of a telescope, the motion of which he controls by way of a similar follower, coincides with the target motion. It is rather clear that unless the tracker receives some kinesthetic cues by turning his head as the telescope moves, that the two processes are substantially equivalent in so far as the kinematical aspects of the problem are concerned. However, the question of the visual equivalence of the two systems is more difficult. The "job miniature" has been arranged so that angular displacements are identical with those in the field. Magnification is increased by increasing the galvanometer sensitivity by the factor desired. In spite of this angular agreement, psychological experience shows that ability to discern a lack of coincidence may vary widely under different conditions of vision and as a matter of fact, field conditions themselves present a wide range of conditions so that there is no clear standard by which the "job miniature" can be judged. We have considerable confidence that the results which have been obtained have validity in the practical situation, but it is clear that the proof of this validity must rest upon a demonstrated correlation with results obtained in the field.

II. PSYCHOLOGICAL ASPECTS OF TRACKING

The selection of subjects for the present study was conditioned by two facts. The first, a practical consideration, is that to be realistic the individuals selected should be the best available for the job. The second, a methodological consideration, is that any trend inherent in the data might tend to be obscured by large individual differences, and that a relatively homogeneous group would therefore be desirable. With these two facts in mind, the upper quartile of the sample was chosen as the one most nearly meeting both requirements.

In the field it has been the practice to use large handwheels of considerable moment of inertia operating against various resistances in the achievement of coordination. Theoretically this would tend to impede the development of the desired skill, since the serial reaction involved tends to differentiate from a "mass action" type of response to a delicately coordinated response of the finer musculature. Small fingerknobs allow normal progress in the acquisition of this skill. The subjects show a markedly uniform tendency to progress from a stage in which they rely mainly on gross arm movements to a stage in which they employ wrist and finger movements; and, finally, to a stage in which they seek support for their wrists and arms and operate entirely with their fingers. Obviously, handwheels would not favor such a course of development. In this context, it seems worthwhile to enumerate several hypothetical reasons for the superiority of the more minute type of response.

First, it may be noted that the position taken by the fingers in grasping a small knob rotating on a horizontal axis is practically identical with that position identified as the resting position of the hand. This is, of course, a position demanding a minimum of tension and allowing free movement in any direction. Second, from an evolutionary point of view, it is interesting to recall that the human animal has six muscles whose tendons extend just past the base of the wrist--the "tool using muscles"--which are much better developed in man than in any other animal. Man has also an especially well developed opposable thumb, and is the only animal capable of using the index finger separately from the other fingers. These emergences, and the vastly superior innervation which they imply, are suggestive evidences of mans digital specialization.

Third, it may be observed that the muscle and tendon spindles which mediate kinesthesis occur with much greater relative frequency in the fine muscles of the fingers and hands than in the gross muscles of the arms. This fact doubtless relates to the unquestioned superiority of the finer muscles in adjustments demanding delicacy, skill, and precision. Fourth it may be pointed out that a finger movement, as opposed to a gross arm movement, is less violent and distracting; and, thus, more easily integrated into a pattern of fine eye-hand coordinations.

Finally, it may be suggested that while experimental evidence indicates that under extreme stress, as in ergographic work, the finer muscles are more quickly paralyzed by fatigue, there is in the results of the present study no evidence of such extreme stress. Even in operating with a finger-knob of comparatively heavy resistance, (1500 gr. cm.) the typical subject seemed inclined to show only a very slight fatigue decrement in performance.

The testing conditions themselves approached the optimum. Each subject worked in isolation and silence. A preparatory signal was given at a regular interval prior to the actual administration of the test, all subjects were paid for their time, and their results were posted. Competition was keen and motivation in general appeared to be excellent.

The subjects were not informed of the fact that they were, to an extent, similating the actions of antiaircraft gunners. The existence of a problem of meaning might thus be posited. However, any testing situation involves the arbitrary isolation of a certain number of relevant variables from a universe of context. This idealization represents both the strength and weakness of the laboratory method. It is, nevertheless, true that the present test bears a closer superficial resemblence to the actual situation than do the great majority of tests successfully employed in other realms at the present time.

III. THEORETICAL STUDY OF FOLLOWING

A. Dynamical

In order to describe the fundamental nature of the errors of tracking it is advantageous to attack the problem from a theoretical viewpoint so as to select those experiments which best epitomize the contributory factors. One such study has to do with the instantaneous or dynamical errors of tracking. The basis for a study of this rests on the possibility of describing mathematically those reactions of a human being which determine his efficiency as a "servo-mechanism" in the tracking problem. The term "servo" perhaps best describes the part the subject portrays when he sees the crosshair of the telescope drift off the target and then reacts to make the two coincide.

From a brief study of the latter statement it is clear that when the subject must react the most, his difficulties, and therefore his errors, are greatest. If now x is the value of the control coordinate a simple hypothesis has the form

(1) $$e = K\dot{x}.$$

This states that the error is greatest when the velocity with which the control must be turned is greatest. It is now possible to employ this equation and the mathematical operators which characterize any given following device in determining the dynamical errors of tracking.

Let the coordinate of the course be z. Let the mathematical operator for a following device be L. Then, let y be defined by the equation

(2) $$y = L(x).$$

It is clear that y is the ouput of the follower and that the true error of tracking is

(3) $$e = y - z = L(x) - z.$$

From (3) comes

(4) $$X = L^{-1}(z + e).$$

In this it is clear that $e \ll z$ so that

(5) $$X \cong DL^{-1}(z).$$

From (1) and (5) there results

(6) $$e = KDL^{-1}(z).$$

Now there are weak points in the above analysis for equation (1) is probably too simple in form to be entirely accurate. It is likely that besides the direct cause and effect relation under consideration the description should have a random element. Then too it may well be that a time delayed operator should be employed in equation (5) for the proper description. In any event, however, the grosser effects should be apparent from this analysis.

For followers #5 and #6 the operator L is

$$L = a + \frac{b}{D}$$

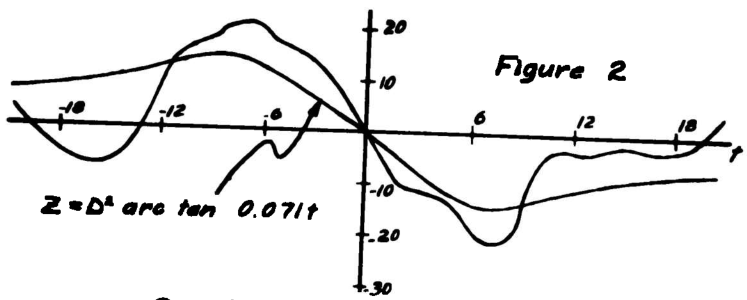
so that

$$e = K \frac{D^2}{aD + b}.$$

The larger effect here is simply

$$e = \frac{K}{b} D^2 z.$$

The readings for several films combined and smoothed are compared with the latter result in Fig. 2.



Graph of sum of 4 runs
Second half displaced and sign reversed with 3 point smoothing

An attempt to apply this theory to tracking with acceleration—velocity-direct followers will be made as soon as sufficient data for such tracking is available.

B. Dimensional Analysis

Since the problem of the behavior of a man in a servo role is a rather complicated one, it seems reasonable to attempt some restrictions on the functional relation between the various factors involved by the use of dimensional analysis. This type of approach seems especially appropriate to furnish the basis for an experimental investigation. The first step in a dimensional solution of a problem is an enumeration of all of the factors involved and the selection of a set of fundamental dimensions in terms of which the dimensions of these factors can be given. It is well known that these factors do not need to be those commonly used, namely, mass, length, and time. The following list enumerates first, the fundamental dimensions that we have chosen for a solution of the tracking problem, and next, the factors associated with each element of the tracking structure which is schematically represented in Fig. 3.

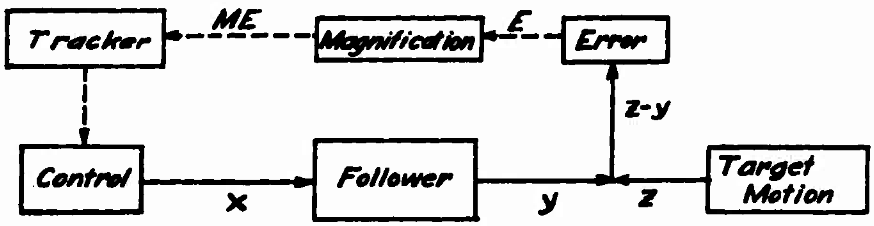


Figure 3

FUNDAMENTAL DIMENSIONS

Magnification	$[m]$	$= \gamma$
Course Coordinate	$[z]$	$= l$
Control Coordinate	$[x]$	$= \beta$
Time	$[t]$	$= \tau$

CONTRIBUTORY VARIABLES

Follower:	Velocity Component	$[b]$	$= \frac{l}{\beta\tau}$
	Direct Component	$[a]$	$= \frac{l}{\beta}$
Course:	Crossover Velocity	$[p]$	$= \frac{l}{\tau}$
Tracker:	Visual Acuity	$[u]$	$= \gamma$
	Manual Dexterity	$[V]$	$= \beta$
	Dynamic Reaction Time	$[t]$	$= \tau$
Magnification:	Magnification	$[m]$	$= \gamma$
Error:	Error	$[E]$	$= l$

It is well known that success of a dimensional study depends on the accuracy of the enumeration of the factors involved. No question can arise about this enumeration except in connection with those factors descriptive of the tracker. However, it is clear that the properties of the tracker which are pertinent to this problem are those which have dimensions in the field of the problem. Thus, we are inclined to attribute to the tracker a factor in each of the fundamental dimensions. We have done this, but the names which are given must be regarded as only suggestive of the meaning of these quantities. It is a weakness of the method as here applied, that there may be several quantities to be attributed to the tracker in any one dimension. It is also possible that the tracker should be described by factors of more complicated dimensions but these factors may be regarded as combinations of the simpler factors involved so that the validity of the method is not injured in this case.

By applying the pi theorem we find that the functional relation connecting the factors involved in the tracking problem is:

$$F\left(E, \frac{m}{u}, Rt, pt, av\right) = 0$$

where $R = \frac{a}{b}$.

When this equation is solved for E there results:

$$E = f\left(\frac{m}{u}, Rt, pt, av\right).$$

To make further progress it is necessary to determine experimentally the function f. The form of this function suggests that the following experimental relationships should be determined:

1. Error versus magnification holding other factors constant.
2. Error versu a, holding other factors constant.
3. Error versus p holding other factors constant.
4. Error versus R holding other factors constant.

IV. EXPERIMENTAL FOLLOWERS

The experimental followers used in this research were designed to approximate the conditions of aided laying by means of electrical circuits.

In the usual aided laying mechanism the relation between the coordinate y, associated with the output or driving shaft, and the coordinate x of the manual control may be expressed operationally as:

$$y = \left(a + \frac{b}{D}\right) x.$$

In the first followers, the circuit diagram for which is given in Fig. 4 page 15, the operator $\frac{b}{D}$ is approximated by the operator $\frac{1}{\alpha D + 1}$, which gives the voltage across a condenser when it operates on the voltage across the resistor and condenser in series. An additional RC circuit was added to give the operator $\left(\frac{1}{\alpha D + 1}\right)^2$, which provided an analogue to accelerational control. When these terms are added the operational equation for the follower is

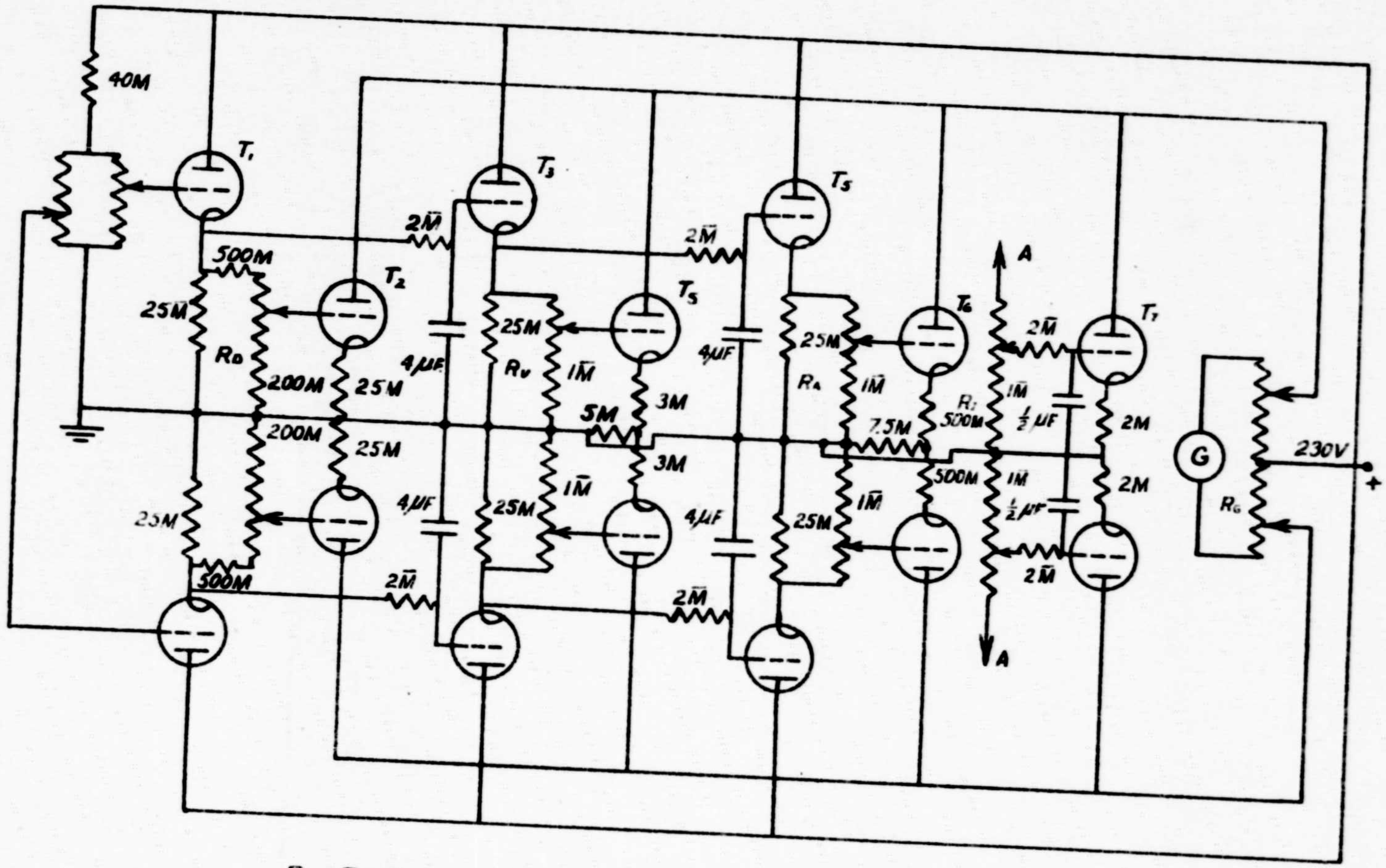
$$y = \left(a + \frac{b}{\alpha D + 1} - \frac{c}{(\alpha D + 1)^2}\right) x$$

which may be written

$$y = \left(a + \frac{m}{(D+B)^2} + \frac{n}{(D+B)^2}\right) x.$$

In these followers $B = \frac{1}{8}$ sec.$^{-1}$

The amount of direct control, indicated by a in the above equations, is determined by the tapped resistor R_D. The amount of "velocity" control is determined by the setting of the tapped resistor R_V, which takes fractions of the voltage swing on the first pair of condensers. This fraction is



R_A, R_V, R_T are 10-tap resistors, 100M per step
R_P is a 10-tap resistor, 20M per step

Figure 4

expressed by the letter b in equation (1). The aiding ratio, used in the sense of these operators, is $\frac{m}{a} = \frac{b}{da}$. The position of the tap on R_A gives the amount of accelerational aiding since it gives fractions of the voltage swing across the second pair of condensers. The accelerational aiding ratio is $\frac{n}{a} = \frac{c}{d^2a}$. These voltages are applied to the grids of three tubes connected in parallel with a relatively low common plate load resistance, so that the three components are nearly linearly superimposed or added. A fourth tube, whose grid voltage varies according to the function arc tan pt, is connected in parallel with the first three. A galvanometer connected between the opposite sets of plates in the push pull circuit serves to indicate when the sum of the first three voltages balances the arc tangent voltage.

Since the operator $\frac{1}{D + B}$ is only an approximation to $\frac{1}{D}$ there was some question as to whether or not the results of experiments with this follower would be truly comparable with results of experiments on aided laying in the usual sense. It is clear that if B is not sufficiently small the manipulation needed to track a given course may be considerably different from the limiting case $B = 0$. The charging of the condensers is exponential and the continual dropping off in the rate of charging adds to the difficulty of tracking when the rate of the course is increasing, and seems to help when the rate of the course is decreasing, apparently because in the first case greater and in the second case lesser hand motion is required.

In order to minimize the uncertainty of the validity of conclusions about aiding ratios, etc., an electrical circuit was designed in which the rate for a given control position is nearly constant. In the new circuit the rate still dies off exponentially, but comparatively slowly with a 160 second time constant. Two followers, called #5 and #6, were built on the new design. A schematic drawing of this circuit is shown in Fig. 5. The tracking voltage appears on the cathode of the first tube, and the average potential there is 120 volts. Fig. 6 shows the "constant rate" circuit reduced to its fundamentals and the accompanying equations give the approximate theory in detail. Roughly, the action is this: for variations of only plus or minus 10 volts the change in grid to cathode potential difference is relatively small. Since the voltage across R is the sum of this potential difference and the potential difference of the leads coming from the control potentiometer, the current through R varies only slightly as the cathode voltage varies between 110 and 130 volts. The voltage of the condenser, and that of the cathode, thus change at nearly constant rates between 110 and 130 volts for fixed control positions. If it seemed advisable the 160 second time constant of this circuit could be considerably increased.

Any desired fraction of the control voltage can be conveniently added directly to the cathode voltage. The fraction added is adjusted by the tapped resistor R_D, which thus determines the aiding ratio.

The arc tangent course comes from the potentiometer at the extreme right of Fig. 2. The average voltage here is adjusted to 120, and the tapped resistor R_A permits fractional values of the total variation (24 volts) to be used.

The double section filter takes roughness from the input without distorting the value of the input function appreciably.

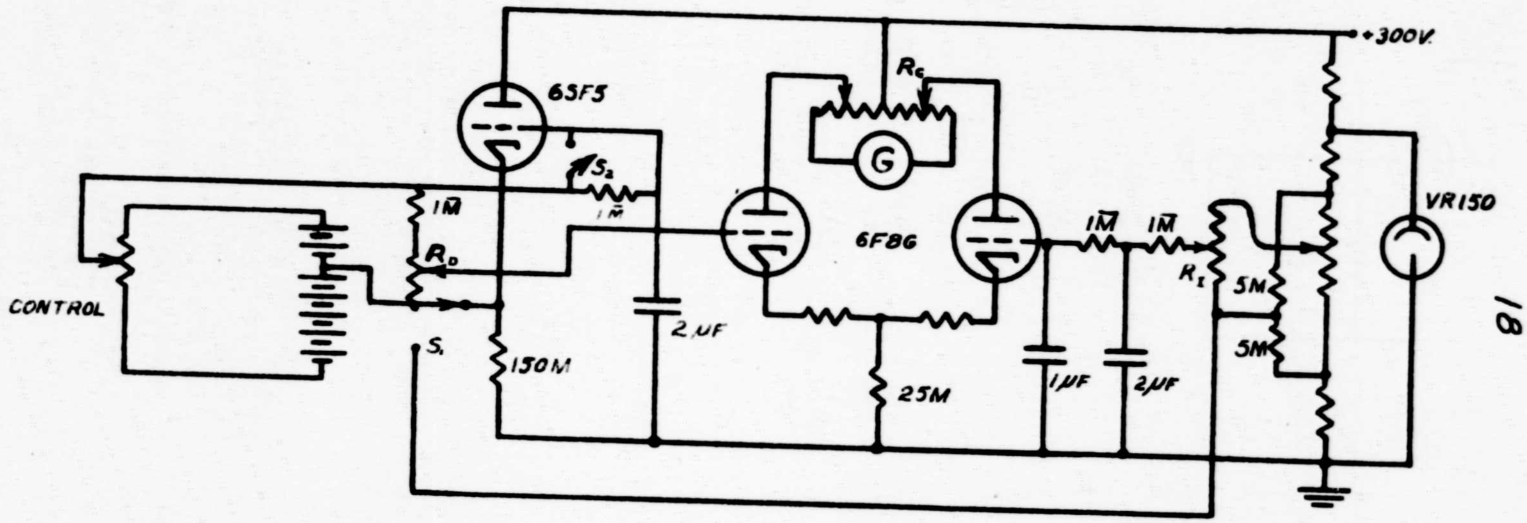
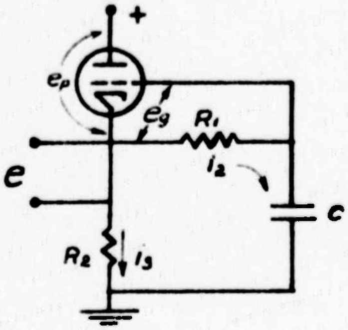

+300V.
6SF5
R_c
G
VR150
S_2
1M
1M
6F86
1M
1M
R_D
R_1
5M
5M
CONTROL
S_1
150M
2µF
25M
1µF
2µF

Figure 5



1. $\frac{di_1}{dt} = \frac{di_2}{dt} + \frac{di_3}{dt}.$

2. $\frac{R_2 di_3}{dt} = \frac{R_1 di_2}{dt} + \frac{i_2}{C}.$

3. $\frac{de_g}{dt} = -\frac{R_1 di_2}{dt}.$

4. $\frac{de_p}{dt} = -\frac{R_2 di_3}{dt} = -\frac{R_1 di_2}{dt} - \frac{i_2}{C}.$

5. $\frac{di_1}{dt} = \frac{1}{r_p}\frac{de_p}{dt} + g\frac{de_g}{dt}.$

$$\frac{di_3}{dt} = \frac{R_1}{R_2}\frac{di_2}{dt} + \frac{i_2}{R_2 C}.$$

$$\frac{di_1}{dt} = \left(1 + \frac{R_1}{R_2}\right)\frac{di_2}{dt} + \frac{i_2}{R_2 C}.$$

$$\frac{di_1}{dt} = -\frac{1}{r_p}\left(R_1\frac{di_2}{dt} + \frac{i_2}{C}\right) - gR_1\frac{di_2}{dt}.$$

Subtract:

$$0 = \left(1 + \frac{R_1}{R_2} + \frac{R_1}{r_p} + gR_1\right)\frac{di_2}{dt} + \left(\frac{1}{R_2} + \frac{1}{r_p}\right)\frac{i_2}{C}.$$

$$i_2 = Ke^{-\frac{t}{\alpha}},$$

Where

$$\alpha = \frac{R_1 C\left(\mu + \frac{r_p}{R_2} + 1\right) + r_p C}{1 + \frac{r_p}{R_2}}.$$

The predominate term

in α is $\frac{\mu R_1 C}{\frac{r_p}{R_2} + 1}$.

Figure 6

The galvanometer in the circuit in the center of the diagram indicates when the observer-controlled voltage balances the course voltage. The galvanometer circuit gives adjustable sensitivity with constant damping.

Switches S_1 and S_2 are for calibrating and for speeding the process of getting on, respectively. During tests S_2 is open, and S_1 turned to the position indicated on the diagram.

V. COURSES

It is well known that it is more difficult to track in azimuth than in elevation. If a plane is in linear flight traveling with a velocity V and having a ground range at nearest approach of D the azimuthal angle is given by

$$\varphi = \arc \tan \frac{V}{D} t.$$

Since $\frac{V}{D}$ is determined for a given plane on a given course it may be replaced by a single parameter, p., which is, as a matter of fact, the angular velocity of the plane at crossover. The formula is then

$$\varphi = \arc \tan pt.$$

In order to simulate azimuthal tracking in the laboratory a special resistor was constructed so as to give a voltage varying as the function $\varphi = \arc \tan pt$ with left and right hand limits of $\varphi = \arc \tan -2$ and $\varphi = \arc \tan +2$ respectively. This corresponds to maximum deviations to left and right of 63.43° from crossover. Two resistors, made on cards, were mounted on a bakelite drum of six inch diameter. The current through the resistor was supplied by means of steel fibre brushes on slip rings and the variable output voltage came from a specially constructed contact brush. The latter consisted of a bank of three brushes each made up of several pieces of steel piano wire about half an inch long extended from a flat flexible spring; the distance between brushes was about 3/32 inch. Several of the wires on each brush made simultaneous contact on the arc tan resistor. This brush structure was found satisfactory after considerable experimentation with single contacts, which gave inordinately rough output voltages. A schematic diagram of the brush arrangement is shown in Fig. 7.

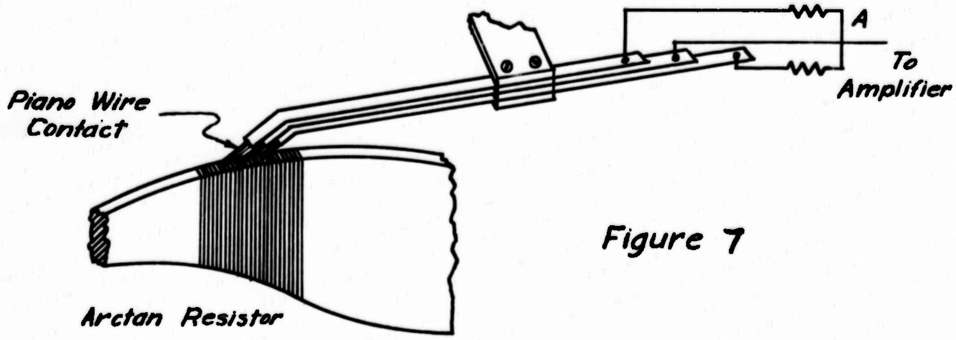


Figure 7

Should the middle brush lose contact the point A remains at about the same potential by interpolation. Should either outside brush lose contact the potential at A is unaltered. To smooth the course voltage still more it was necessary to employ a double section filter with a time constant per section of 2 seconds.

The resistor was motor driven through a pair of cone pulleys which made four values of p available. These together with typical crossover data for them were as follows:

	p	Plane Speed	Crossover distance
Speed 1	.025 sec^{-1}	240 mi/hr.	4693 yds.
Speed 2	.042 sec^{-1}	240 mi/hr.	2794 yds.
Speed 3	.071 sec^{-1}	240 mi/hr.	1653 yds.
Speed 4	.125 sec^{-1}	240 mi/hr.	933 yds.

VI. MEASUREMENT OF ERROR OF TRACKING

Initially in the experiments on tracking the error was measured directly from tracings. Film records were made of each individual test with a motor driven camera with two tests recorded simultaneously. These were subsequently read at second intervals with an ordinary microfilm reader and the average error computed from the observations. A sample record is shown in Fig. 8. Electrical impulses and a neon bulb were used to record the seconds which appear as light dots in the center of the figure. The thin dark parallel lines come from the ruled screen and subtend 10 mils at the subject's eye in testing. The track is the light double curve. The error for this track is read with respect to the broad dark central line.

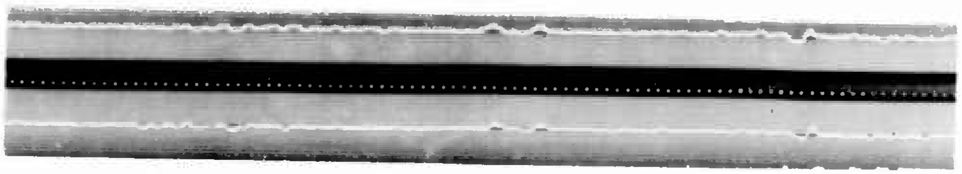
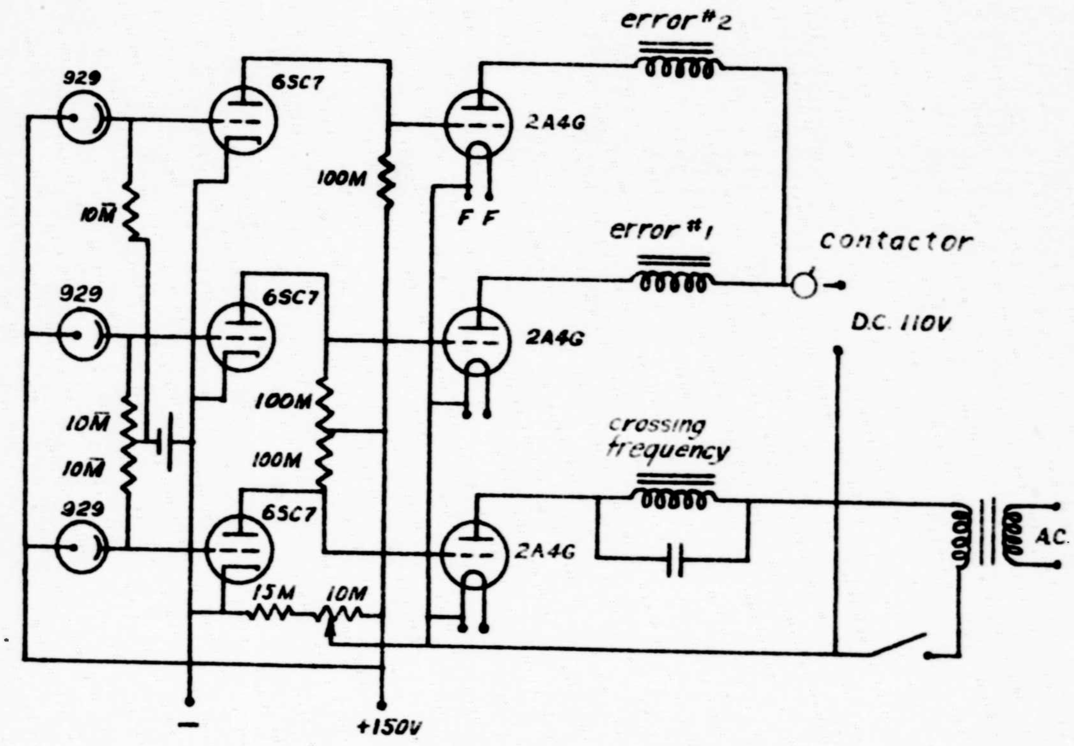


Figure 8

B. Counters

1. Apparatus

As is at once evident the process of reading film to determine error required an enormous amount of tedious effort. To alleviate this task a more convenient method for a large number of tests was devised. The electrical circuit by means of which this measurement is made is shown schematically in Fig. 9. Spots of light from sources, separate from those used to project the spots of light on the screen, are focused on shields before the upper two photo tubes at the left of the diagram. There are



Counter Circuit

Figure 9

slits in these shields located so that when the spots of light reflected from the galvanometers go through the centers of the slits, the tracking spots are centered on their screens. When the spot moves a certain distance to either side, the light is cut off from the photo tube and the grid of the thyratron becomes so negative that the thyratron will not pass current. Four times a second DC voltage (110 volts) is applied through the rotating switch S to the thyratron circuits, and each time the thyratron permits the passage of current a count is made by the counter in series with it. The number of these counts provides a simple method to estimate the fraction of time the light spot is beyond the limits of the slit.

A separate ungrounded power supply connected to the terminals - and + 150 provides power for the amplifying 6SC7's and the photo tubes. The bias of the thyratron is adjusted with the 10 M variable resistor.

Before the lowest photo tube there is a screen which cuts off the light when the spot is to one side of center. Continuous A.C. of 110 volts is supplied to the lowest thyratron. It passes current when the spot is on the shielded side of center, and breaks the current when the spot falls on the photo tube. Therefore this counter gives the frequency with which the error passes through zero in one direction.

2. Distribution Law

In order to ascertain the exact law of distribution of errors to be used in connection with the above apparatus, a number of films were analyized critically. The frequencies of errors for these films were plotted. The resulting distribution had a higher than normal peak at the zero position. Careful re-examination of the analysis at first gave no clue as to the cause. Then it was discovered that a slight but consistent and important bias toward zero on the part of the reader had distorted the film readings. By meticulously reading the film using a mechanical aid a normal distribution was found to fit the data and gave excellent agreement with errors properly read from film.

All in all, a great deal of time and attention has been given to the subject of the distribution law of errors which result from the tracker-follower combinations which are being tested. Since the bias in reading film has been corrected, the root-mean-squared error obtained from film and from our counting device with a measured photo tube slit agree in typical cases within ten percent. The counting circuits give much more consistent data than that obtained by using film. An effort is always made to operate the counting circuits where they are less sensitive to the form of the distribution law. Since the final results are only used on a comparative basis after averaging ten trials for each of ten individuals the use of the normal curve seems entirely justified.

3. Slide Rule

With the apparatus described earlier in this section it is possible to form an estimate of the error. In effect an estimate of the length of time the subject held the filament image within the slit width was made by the counting mechanism which recorded a success or failure on his part four times a second during a test. For a given course the number of "tries" was then fixed for all subjects and the number of times the filament image fell outside the slit width is functionally related to the error.

Let H be the number of times within the slit width, M the number outside and T the total number of tries; then

$$H + M = T,$$

$$Error = F\left(\frac{E}{T}\right).$$

In order to determine the corresponding root mean error it is merely necessary to assume that the one-half slit width a (easily measured) satisfies the relationship

$$\frac{H}{T} = \int_0^a f(x)\,dx,$$

where f (x) is the distribution law for a given test. The fact that the film runs indicate normally distributed error leads to the conclusion that to get the distribution law for an individual test from the normal law it is merely necessary to introduce a stretching factor, say λ , so that the following relationships hold:

(1)
$$\frac{H}{T} = \frac{\int_0^a \lambda e^{-\frac{x^2}{2\lambda^2}}dx}{\int_0^\infty \lambda e^{-\frac{x^2}{2\lambda^2}}dx},$$

(2)
$$P(\lambda a) = \frac{H}{T} = \frac{\int_0^{a/\lambda} e^{-\frac{u^2}{2}}du}{\int_0^\infty e^{-\frac{u^2}{2}}du}, \text{ with } u = \frac{x}{\lambda}.$$

(3)
$$\frac{a}{\lambda} = P^{-1}\left(\frac{H}{T}\right).$$

Furthermore, the R.M.S. error for a test is given by

(4)

$$R.M.S. = \sqrt{\frac{\int_0^\infty \lambda x^2 e^{-\frac{x^2}{2\lambda^2}}\,dx}{\int_0^\infty \lambda e^{-\frac{x^2}{2\lambda^2}}\,dx}}\;;$$

(5)

$$RMS = \sqrt{\frac{\lambda^2 \int_0^\infty u^2 e^{-\frac{u^2}{2}}\,du}{\int_0^\infty e^{-\frac{u^2}{2}}\,du}}\;;$$

(6)

$$RMS = \lambda\,\sigma,$$

where σ is the standard deviation for the normal curve.

Substitution from equation (3) into equation (6) gives

(7)

$$R.M.S. = \frac{\sigma a}{P^{-1}\left(\frac{H}{T}\right)} = \frac{\sigma a}{P^{-1}\left(1-\frac{E}{T}\right)}\,.$$

This equation gives the correspondence between error counts and R.M.S. error as ordinarily used.

Because of the nature of equation (7) a slide rule based on the following equation is used in reducing the data:

(8)
$$\log R.M.S. = \log \sigma + \log a + \log \frac{1}{P^{-1}\left(1-\frac{E}{T}\right)}\,.$$

The real advantage of this method of reduction rests in the fact that it lends itself well to slit width variations inasmuch as the slide rule is easily adjustable for such fluctuations. If it were not for this, the fraction of counts on, H, could have been used as a statistic in the analysis.

VII. STATISTICAL DESIGN AND THE REDUCTION OF DATA

A. The Learning Process

As a rule when an individual participates in an activity which involves muscular coordination, which is the case in antiaircraft work, his proficiency increases with successive trials. A composite learning curve for a group of subjects under test in tracking is shown in Fig. 10, and this illustrates the type of data which must be used in our analysis. It will be noted that the mean error for successive trials fluctuates considerably, but that there is an overall trend indicating improvement with time to a stabilized value. The lower curve is for a speed of $p = .071\ sec.^{-1}$ and the upper curve is for a speed of $p = .125\ sec.^{-1}$ It is evident that the learning period is longer for the higher value of p.

With data of this kind it is necessary to proceed cautiously so that the learning process does not obscure the results. A simple procedure is to plot composite learning curves for each group of subjects on each test given and use these curves to compare the efficiency of different adjustments of the apparatus. This method implies that the groups are of equal skill and that the size of the groups and number of tests taken are sufficiently great to overcome statistical fluctuations. These two hypotheses make testing by the use of learning curves by uncontrolled groups rather uncertain. Figs. 11 and 12 show learning curves for different controls. In this case an effort was made to employ groups of equal ability.

A composite curve for each quartile and those for the upper and lower halves of a sample group are shown in Fig. 13. After studying the behavior of these subgroups in succeeding weeks the following conclusions have been drawn.

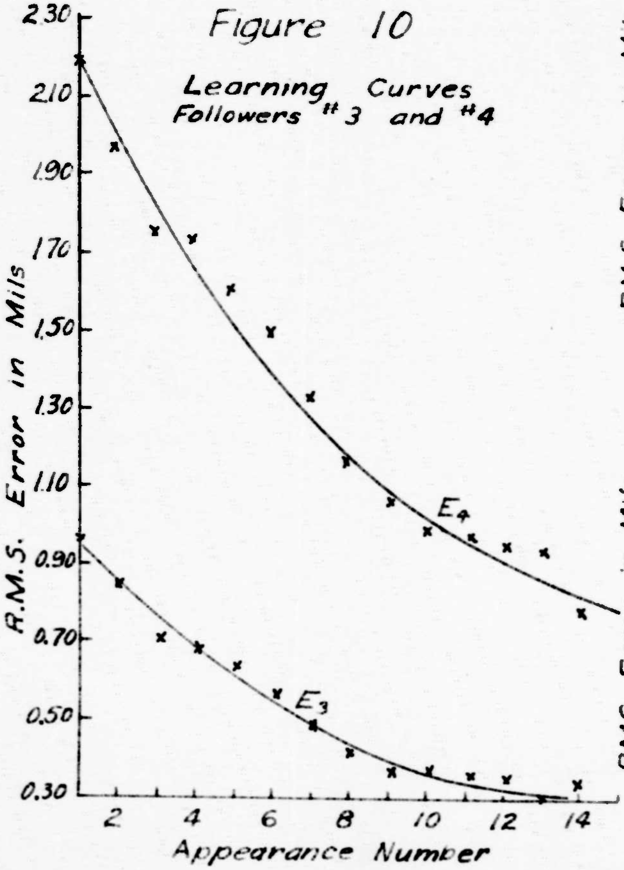


Figure 10

Learning Curves
Followers #3 and #4

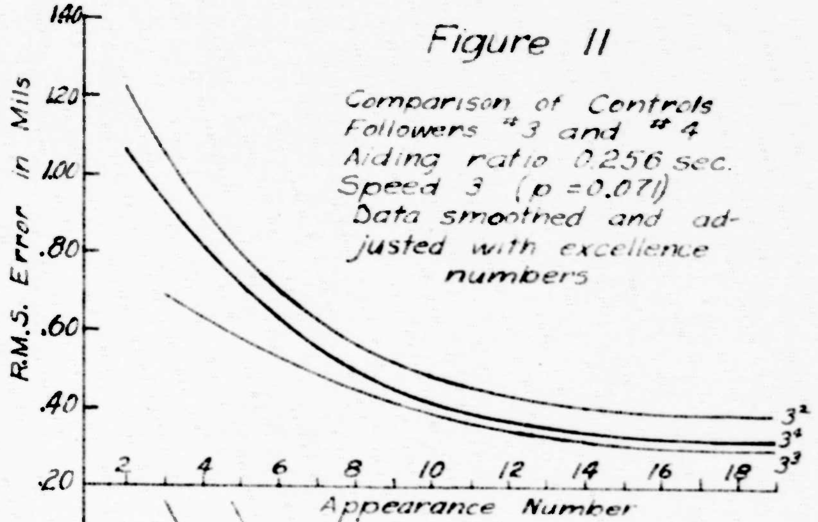


Figure 11

Comparison of Controls
Followers #3 and #4
Aiding ratio 0.256 sec.
Speed 3 (p = 0.071)
Data smoothed and adjusted with excellence numbers

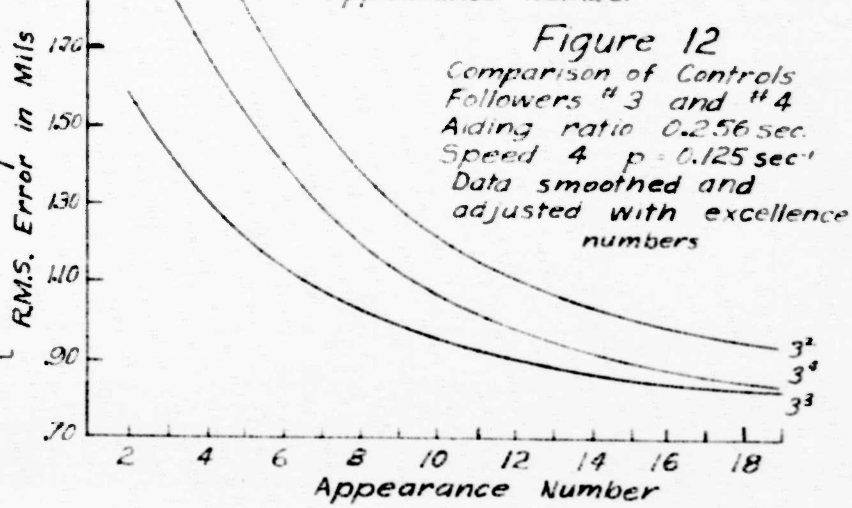


Figure 12

Comparison of Controls
Followers #3 and #4
Aiding ratio 0.256 sec.
Speed 4 p = 0.125 sec⁻¹
Data smoothed and adjusted with excellence numbers

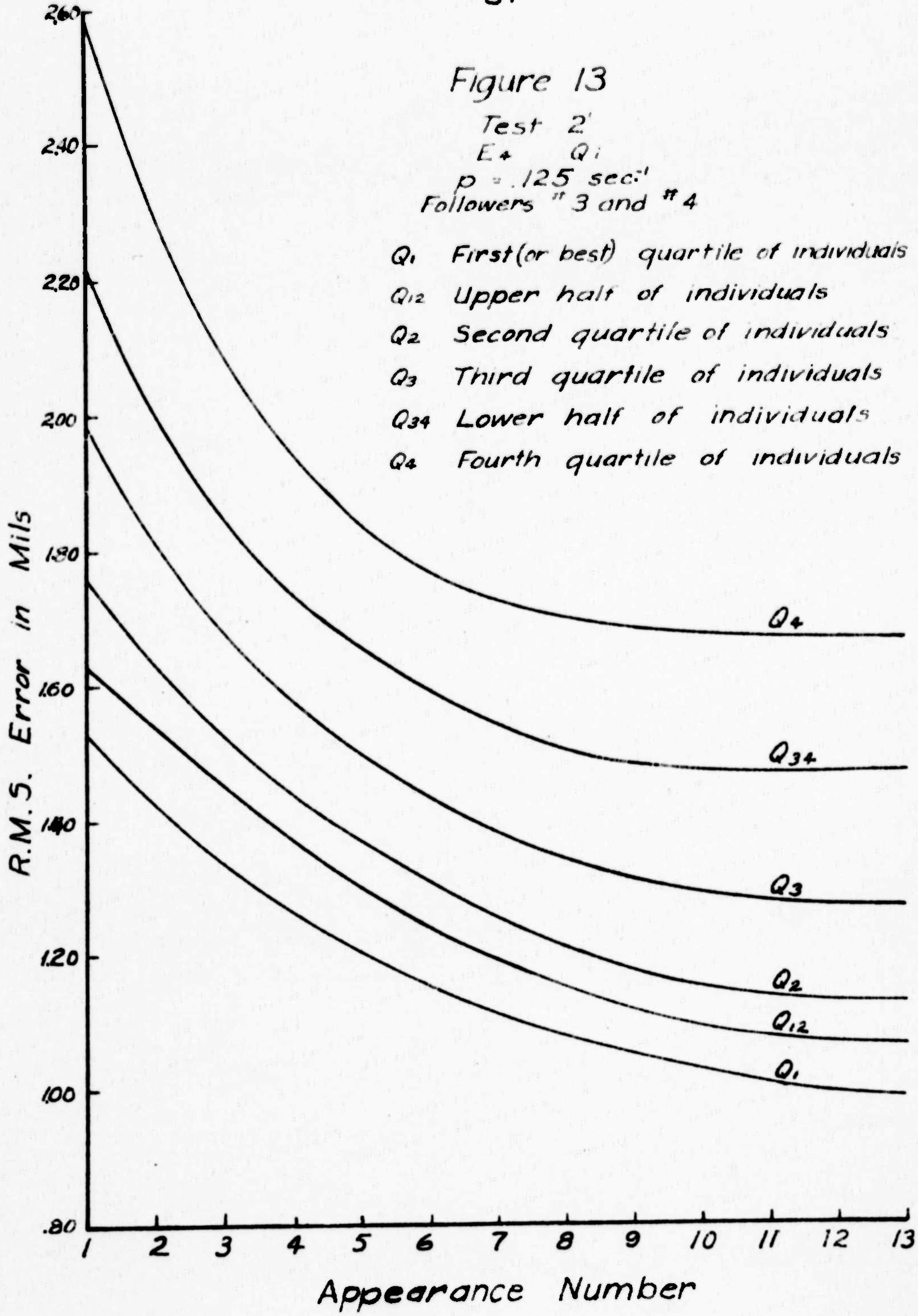


Figure 13
Test 2'
E4 Q1
p = .125 sec.'
Followers #3 and #4
Q1 First (or best) quartile of individuals
Q12 Upper half of individuals
Q2 Second quartile of individuals
Q3 Third quartile of individuals
Q34 Lower half of individuals
Q4 Fourth quartile of individuals
R.M.S. Error in Mils
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
.80
1 2 3 4 5 6 7 8 9 10 11 12 13
Appearance Number
Q4
Q34
Q3
Q2
Q12
Q1

1. In general the relative positions of the quartile averages are maintained.
2. Some individuals of a previously lower quartile in each case surpassed some of those of a higher quartile.
3. A poor operator is not in general a good operator who requires more tests to complete his learning process.
4. The better individuals were more discriminating as to differences in apparatus than the poorer ones; the percentage of differentiation in the mean scores is greater and the dispersion of the data is smaller.

B. Statistical Design

When the intensive program with followers #5 and #6 was instituted, the subjects, who were assigned to special tests, were paid for each set of twenty trials completed in a given week. The new operators were given a standardized test, without pay, and only the best of each group tested were retained for testing purposes. The learning curve became of secondary importance in the testing program but it was realized that for a change of adjustment of apparatus a certain number of trials were necessary before the subject was familiar with the new test. Accordingly the first ten trials were considered as the period necessary to become proficient in the test and the last ten trials were used for statistical analysis. For convenience a complete set of data for the last ten trials for each individual assigned to a special test was punched on cards. In order to adjust the data so that the average ability in a group could not affect the results, it was found necessary to assign to each subject under test a merit or excellence number.

In accordance with the findings of the previous section the testing program was organized as follows:

1. Each new operator first took a standard test so that excellence numbers could be assigned to him according to his ability both on speed three ($p = .071$ sec.$^{-1}$) and on speed four ($p = .125$ sec.$^{-1}$)

A regression was made using the results of the entire group so that numbers could be assigned to the old operators on that basis. The use of two excellence numbers was necessary for two reasons. First, most individuals could master speed three much more quickly than they could speed four. Second, some individuals were considerably better on speed three than they were on speed four even after they had seemingly reached their limit of proficiency, and vice versa.

The effect of using a single excellence number is shown by Fig. 14. Here the subscript G denotes the new group, while the subscript B denotes the old; $\bar{\bar{E}}$ is the mean of the group on the special test, while $\bar{\bar{N}}$ is the mean of a composite excellence number from both speeds three and four. It is easily seen that, in standardizing the data by use of the ratio $\frac{\bar{\bar{E}}}{\bar{\bar{N}}}$, for the fast speed too much credit is given the novice, making the result for the control appear worse than it really is. The reverse is true for speed three. Fig. 15 shows the result for the same set of data when two numbers are used. It will be noted that the two curves for each speed are almost coincident which indicates extremely reliable results.

2. Only those subjects were continued on the testing who fell in the upper quartile on the basis of the standard test.

3. The excellence numbers for each individual were corrected week by week. A regression equation was obtained for each speed by comparing the data of a group with the excellence numbers for the group for the previous week. This equation was used to obtain the individuals excellence number for the given

Figure 14

Test 2"
Date 148
Using $\bar{N}_B$ $\bar{N}_6$
Followers #5 and #6

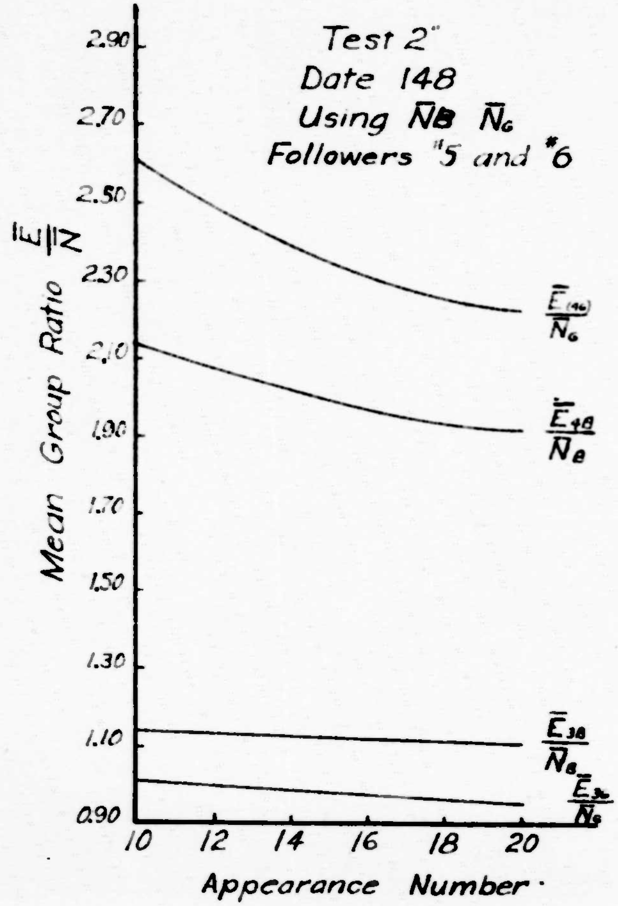
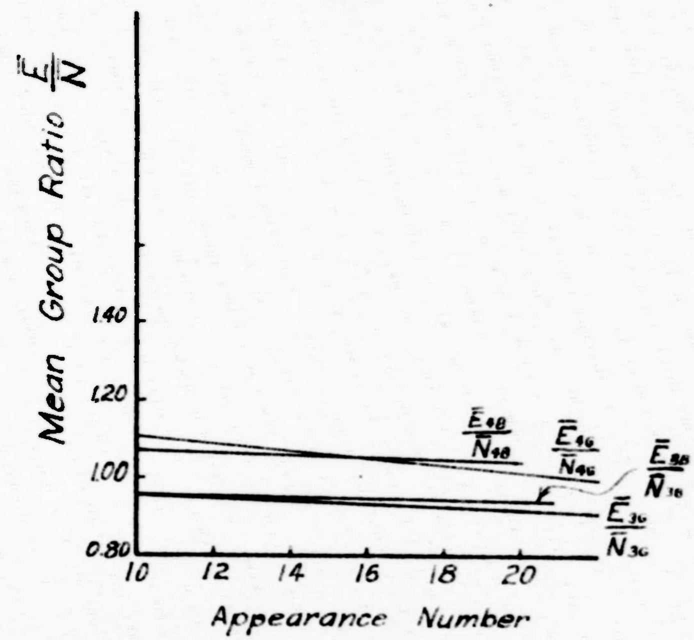


Figure 15

Test 2"
Date 148
Using
N_{38}, N_{36}, N_{48}, N_{46}
Followers #5 and #6



week from his weekly R.M.S. error.

An illustration of the extended learning process is shown in Fig. 16 which is a graph of the progress of two operators for a two weeks learning period of twelve runs per week on the standard test and control, followed by six weeks of twenty trials each on special tests. The graph shows that the fourth and fifth special tests did not require a long learning period either because they were easy or because they presented little contrast to previous experience. Special test three, on the other hand, showed the opposite tendency, particularly to operator 222. All the results of Fig. 16 are reduced to the units of the standard test so that a better comparison may be made. Practically no improvement is made by the operators after the third special test. Roughly, in this case, eighty-five runs are necessary to master speed four. Similar results were obtained for speed three, but the level was reached at the end of the first special test or after forty-five runs. These operators were two of the best of a new group of approximately seventy operators and it would not be safe to generalize on the above statements.

4. In order to stabilize excellence numbers the standard test was repeated by each individual at intervals of approximately five or six weeks.

5. Assignments to experimental groups were made each week on the following basis: (a) The mean excellence numbers for all groups shall be equal on both speeds three and four. (b) The dispersions of the excellence numbers of the groups shall be equal. (c) The number of individuals in each group shall be sufficient to give reliable results.

In compiling data for ease of presentation in the report the following procedure is used. The mean of the raw scores for a special test for a

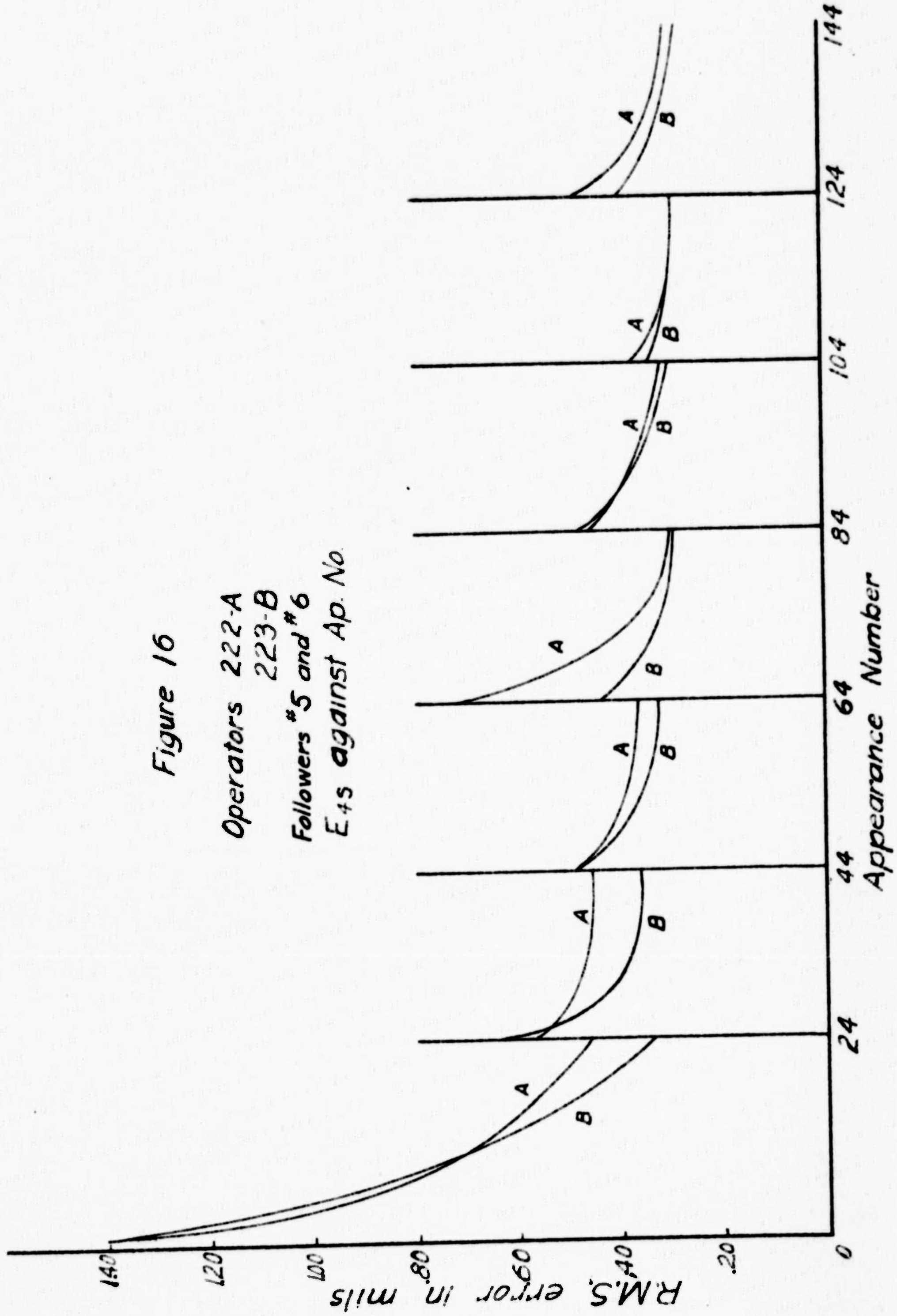


Figure 16

Operators 222-A
223-B

Followers #5 and #6

E_4s against Ap. No

given group is divided by a smoothed excellence number for that group. This gives a set of basic ratios by means of which all tests may be compared. Then to get the R.M.S. error in mils each test ratio is multiplied by the mean excellence number of the entire upper quartile under test. Mean error could have been used in the analysis. The distribution of errors is so nearly normal, that to reduce the results to that basis, it is merely necessary to multiply the R.M.S. error by .798.

This program has been found satisfactory. Typical standard errors of estimates of the mean R.M.S. error for a given test using raw scores run from .003 mil to .015 mil. In the reduction of the data individual excellence numbers (as contrasted with the mean excellence number for the group) could be taken into account, but this requires considerably more work without commensurate gain. When this is done the value of the standard error of estimate of the mean of the R.M.S. error is considerably reduced without changing the error itself, appreciably.

VIII. RESULTS OF TRACKING TESTS

A. Results with Followers #1 and #2

In the work done with followers #1 and #2 the subjects were asked to take one test per day. Their cooperation was voluntary and without remuneration. Numerous difficulties were experienced with this arrangement. It was difficult to get a large enough number of subjects; it was difficult to maintain the interest of the subjects and as their interest in the tests abated their appearances for tests became infrequent and sporadic. All this led to undesirable interruptions of the learning process with a resultant spread in the data. Moreover, it was necessary to continue individual subjects on a given test for a long period of time so that very few experiments could be carried out expeditiously.

In spite of the above mentioned difficulties a sufficient number of tests were made to compare controls, and to test different aiding ratios for different controls. The results for two values of p for three controls (a handwheel, a single fingerknob, and a double fingerknob) are shown in Fig. 17. These curves show: (1) that the error of tracking for the handwheel is half again as large as for the double fingerknob, (2) that the error for the double fingerknob is considerably lower than for the single fingerknob. The latter indicates that the use of two hands in cooperation gives better and more continuous control. Then too, the double fingerknob has the advantage that it permits the use of a larger number of turns. Other experiments carried on for a short time before the intensive program was initiated further substantiate the advantage of

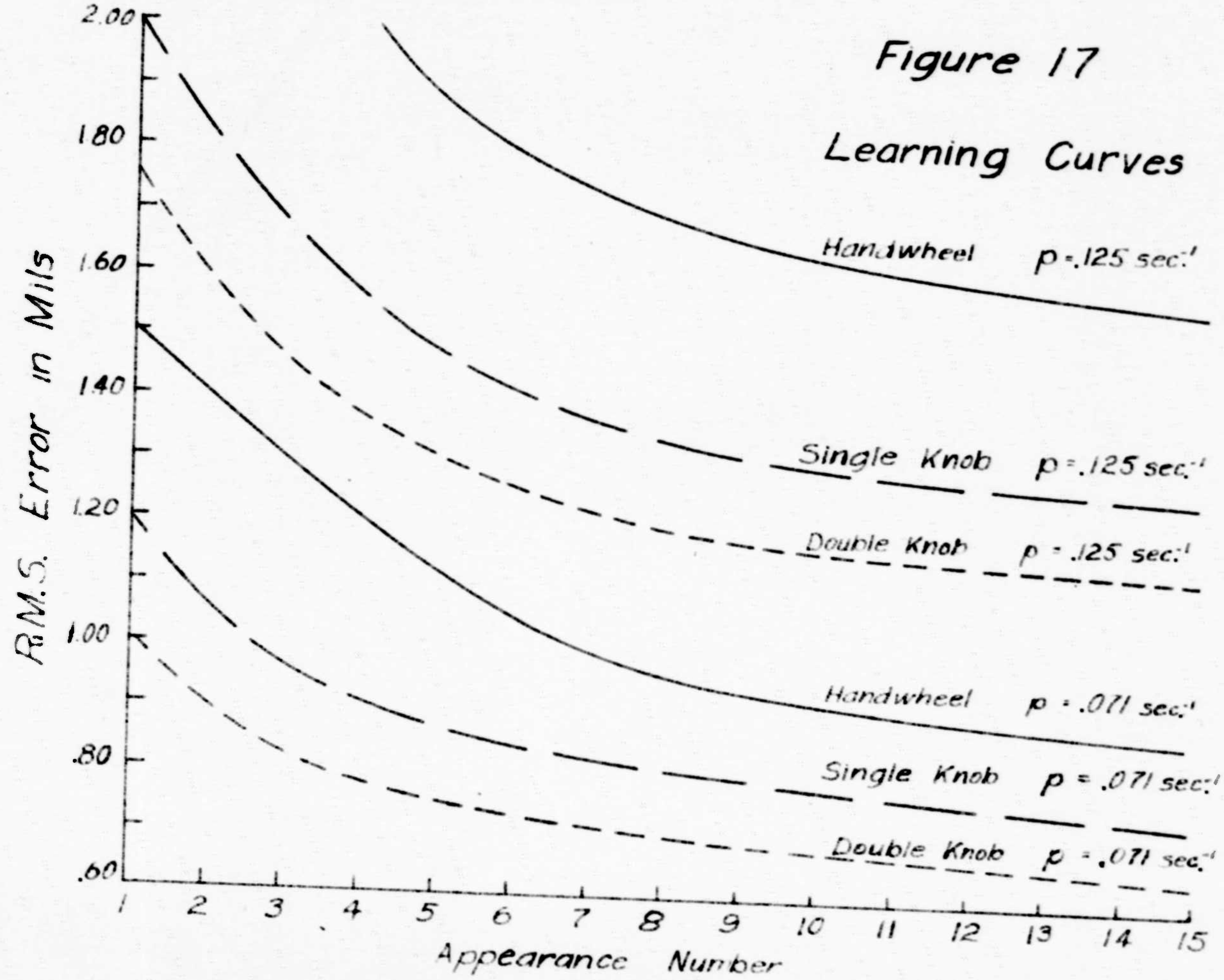


Figure 17
Learning Curves
Handwheel p = .125 sec.⁻¹
Single Knob p = .125 sec.⁻¹
Double Knob p = .125 sec.⁻¹
Handwheel p = .071 sec.⁻¹
Single Knob p = .071 sec.⁻¹
Double Knob p = .071 sec.⁻¹
R.M.S. Error in Mils
2.00
1.80
1.60
1.40
1.20
1.00
.80
.60
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Appearance Number

double fingerknob controls over single fingerknob controls.

B. Results with Followers #5 and #6

A large number of experiments have been conducted with followers #5 and #6 on a selected group of subjects who received compensation for each set of twenty tests completed each week. Generally, five groups of ten subjects each were taking tests; a certain test was assigned to each group each week. The first ten trials were, however, not used in computing the result for a given test because the data indicated almost invariably, as previously mentioned, that a subject was improving rapidly during his first six to ten appearances. The last ten tests of the twenty were generally very consistent, particularly for experienced subjects, and were the only ones used for computing results for a given test. Thus, the number of individual tests contributing to the result for a test assigned to a group was in the neighborhood of 100. This large number of tests led to very consistent results.

In order to check the statistical approach to the problem, one test was repeated with an entirely different group. The results of the two tests checked within two percent. A brief perusal of the consistent results shown in the graphs of this section will be convincing evidence of the reliability of the statistical structure employed in the reduction of the data.

The testing program was based to some extent on the dimensional analysis of section III and tests were made to determine the effects of the salient factors in the problem as revealed by:

$$E = f\left(\frac{m}{u}, Rt, pt, av\right).$$

The tests which have been completed are as follows:

1. Tests on the comparitive merits of controls of different kinds and different values.
2. Tests on the effect of magnification.
3. Tests on the effect of different aiding ratios.
4. A test with a handwheel of high moment of inertia.
5. Tests with frictionally loaded double fingerknobs.
6. Tests of the comparitive tracking abilities of men and women.
7. Tests on the effect of different course speeds.
8. Tests with an accelleration-velocity-direct follower.

The results of the tests are discussed under these headings. In all of the tests two or more values of p were used.

1. Comparison of controls

One of the aims of the testing program was to determine the optimum kind of control for antiaircraft tracking. In order to do this a series of tests was made on controls of different types and of different values where by the value of a control is meant the number of mils traversed by the telescope through the agency of the direct component of the follower per revolution of the control. In these tests the aiding ratio, $\frac{\text{direct}}{\text{velocity}}$, was fixed at .17 second.

Specifically, controls with handwheels nine inches in diameter and double fingerknobs* two inches in diameter were used. Results are shown graphically in Fig. 18. The ordinate gives the error in mils and the abscissa the reciprocal of value. The controls are described on page 42.

The results as here shown may be summarized in the form:

---

*Double fingerknob controls were previously found superior to single fingerknob controls for antiaircraft tracking, see Fig. 17.

PHYSICAL CHARACTERISTICS OF CONTROLS

The value for each control used is given here in terms of the direct component when the aiding ratio is $\frac{d}{v}$ = .17 sec.

Control Number	Kind of Control	Value in Mils per Rev.	$\frac{1}{\text{Value}}$
2	Handwheel	18.4	.054
8	Handwheel	3.5	.286
5	Double Fingerknob	110.0	.009
4	Double Fingerknob	46.0	.022
3	Double Fingerknob	18.4	.054
10	Double Fingerknob	5.5	.182
7	Double Fingerknob	3.5	.286
16	Double Fingerknob	2.6	.385
9	Double Fingerknob	1.7	.588
11	Double Fingerknob	1.1	.909

Inertia Handwheel - Number 8 loaded with lead

Friction Fingerknob - Number 3 loaded with friction

Inertia Fingerknob - Number 9 loaded with lead

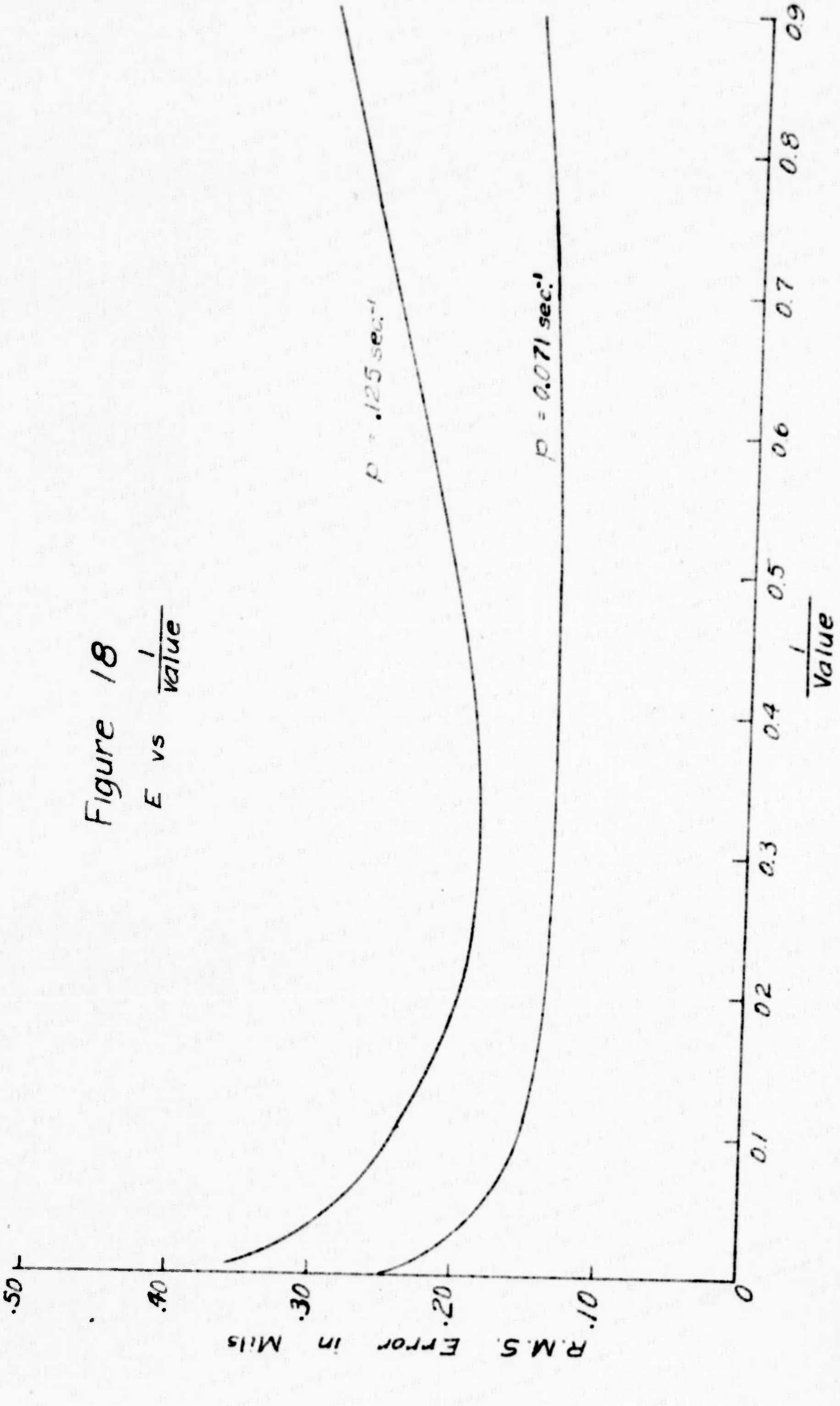


Figure 18

E vs $\frac{1}{\text{Value}}$

a. The double fingerknobs are definitely superior to handwheels.

b. For high values of p the advantage of fingerknobs over handwheels increases.

c. For high values of p there seems to be no appreciable change in error with value for handwheels.

d. The value for fingerknobs is not critical for low values of p but for high values of p the minimum error occurs at about 3.30 mils per revolution for the direct component.

2. Tests on the effect of magnification

As pointed out in the introduction there may be some question about the visual equivalence between the "job miniature" employed in this testing program and tracking in the field. In order to get the effect of greater magnification the galvanometer sensitivity was increased. A given displacement of the spot from the center line would obviously be multiplied by the galvanometer sensitivity factor in much the same manner as the apparent angular displacement of the crosshair of a telescope from the target depends on magnifying power.

The magnification factors used with followers #5 and #6 were 7.5x, 15x and 30x. Results of tests with these factors indicate that the effect on the error of tracking by different magnification factors is within the limits of accuracy which arise from an inexact knowledge of the distribution law of errors. Previous experiments with followers #1 and #2 show the same result.

A more realistic treatment of magnification can be obtained by employing telescopes of various magnifications. This has the further advantage of restricting the field of view in the same way as telescopes employed in the field. This experiment has been scheduled for immediate investigation.

3. Comparison of aiding ratios

For some time there has been a question about the proper ratio of $\frac{d}{v}$ in a follower for optimum tracking. Direct tracking is jagged; velocity tracking alone is smooth but erratic; a combination of the two is superior. To determine the best combination a set of tests with three values of p was made. Each test employed a different aiding ratio. Results are shown in Fig. 19 and Fig. 20. The curves show:

1. That the most advantageous combination is $\frac{d}{v} = .17$ seconds.
2. That there is no appreciable shift of the point of minimum error with p.

Other experiments indicate that this same combination is best for the handwheel. One is thus inclined to regard this .17 second time constant as a requirement of a typical man under test.

4. Test with a handwheel of high moment of inertia

One test was made with a loaded handwheel to determine the effect of inertia. Lead was fastened in an inconspicuous place on the nine inch wood handwheel used in other experiments. The aiding value was fixed in the two tests at .17 seconds. The results were as follows:

Loading	Error Speed 3	Error Speed 4
500 gm cm^2	.21 mil	.38 mil
87,000 gm cm^2	.25 mil	.45 mil

The table shows that inertially loaded handwheels cause the error to increase.

5. Tests with frictionally loaded double fingerknobs

In order to find what effect the friction in a control has on the error

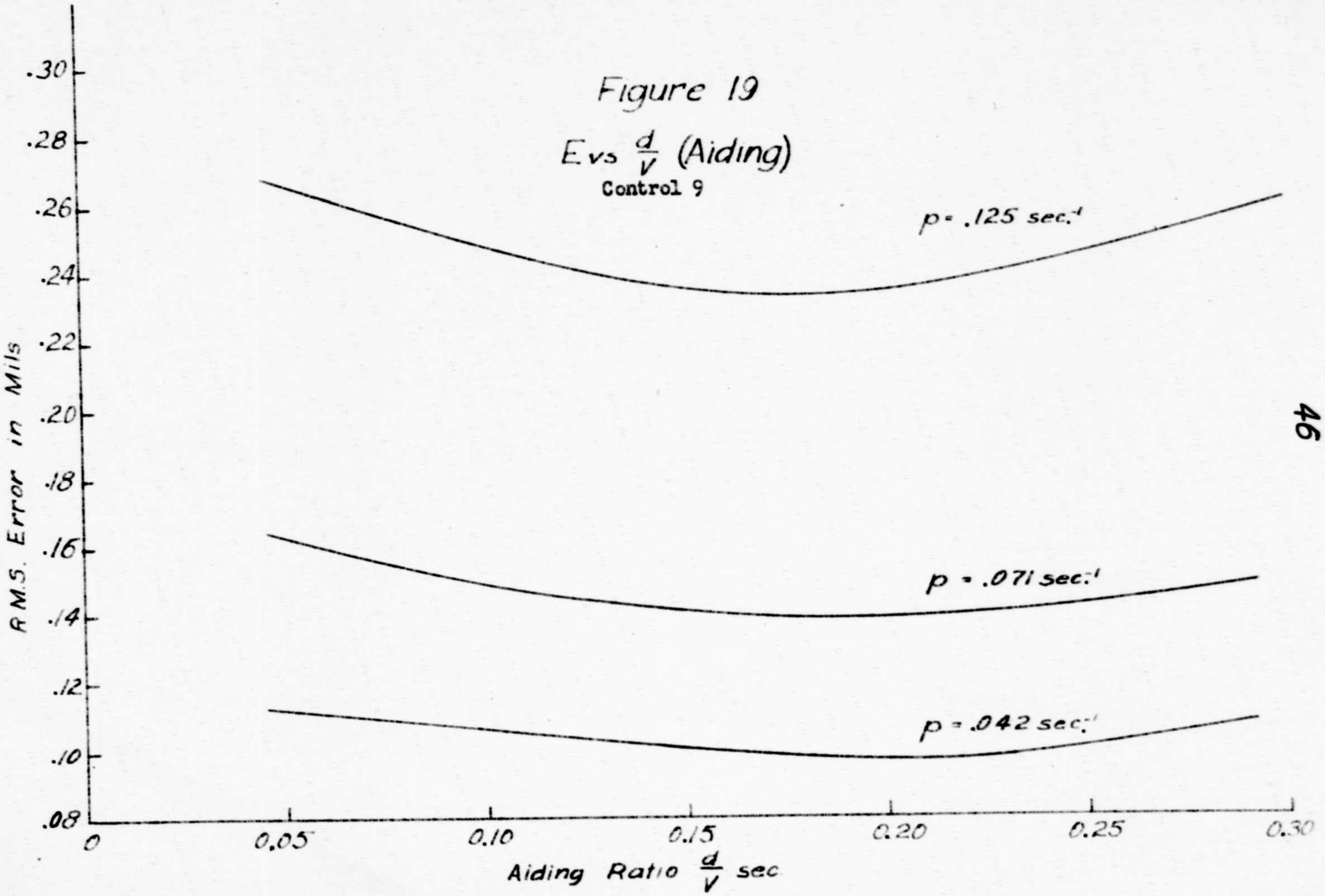


Figure 19

E vs $\frac{d}{V}$ (Aiding)

Control 9

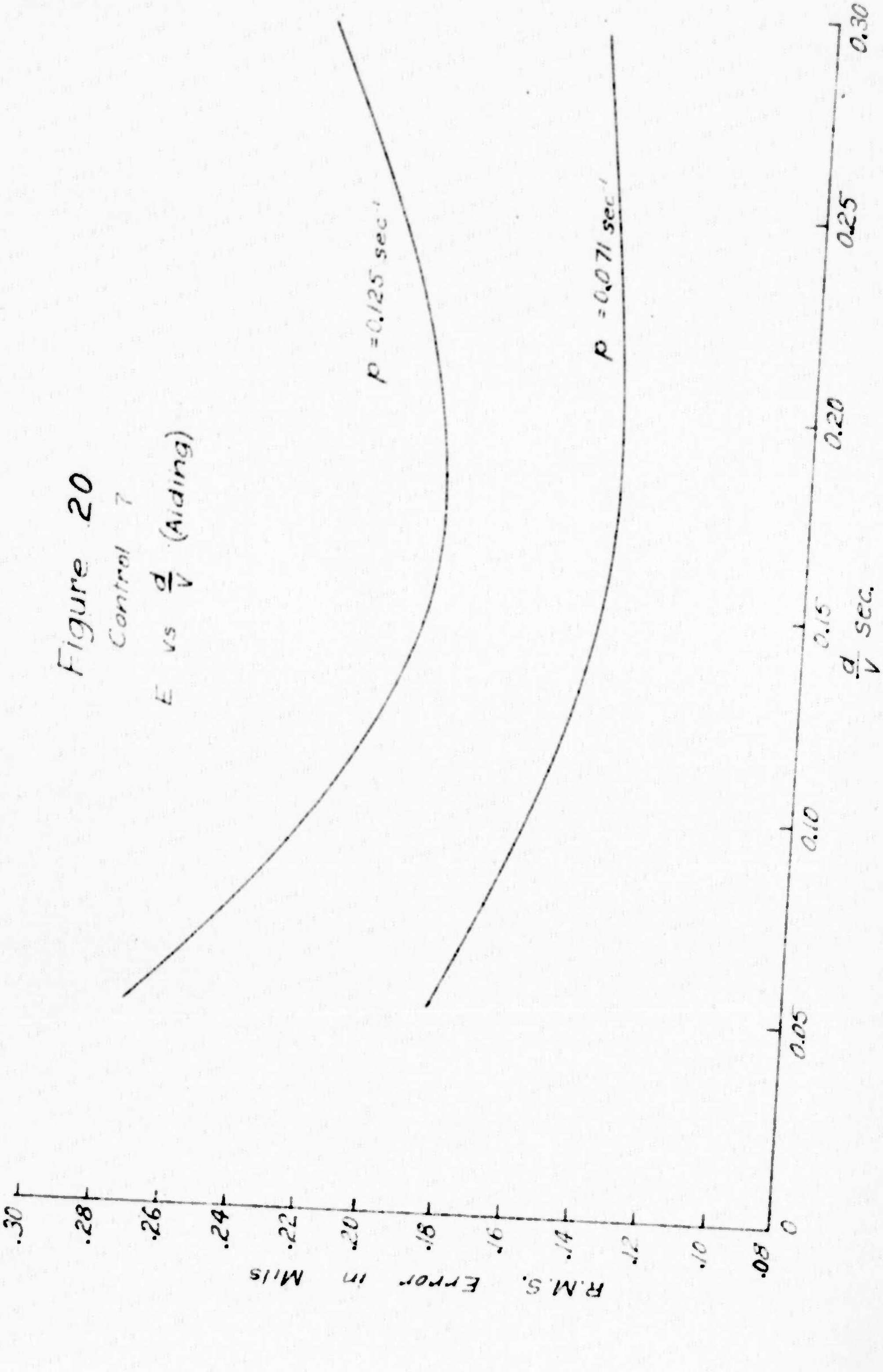


Figure 20
Control 7
E vs $\frac{d}{V}$ (Aiding)

of tracking a brake was applied to one of the controls. The results of three tests, one with practically no friction applied and the others with heavy amounts, are shown in Fig. 21. The torque necessary to overcome the frictional load on the 5 cm (2 inch) knobs is plotted as the abscissa and the error as the ordinate. The effects of these loads are seen to be very small.*

6. Comparitive tracking abilities of men and women.

In order to determine the range of ability of men and women as operators of a tracking device it would be necessary to draw samples from the general population of men and the general population of women and treat them in identical ways and then compare the results. This has not been acomplished in the present testing program for several reasons. The men employed in the intensive program were largely recruited from former tests and the manner of selection in the case of these operators is not very definite. Furthermore, these men were from a military group who possessed a certain standard of physical excellence and some other qualities. The selection process through which the women passed was quite different. At meetings in dormitories and so forth we asked for volunteers for the testing experiments. Even the volunteering process may have different effects applied to men and to women. As we have selected them our group of men is slightly better than our women, the group excellence for the men being .168 mil and that for the women being .171 mil. Since the men have had more experience and have undergone more selection on the basis of our tests we have no reason for a conclusion that there is appreciable sex difference in tracking ability.

7. Tests on the effects of different course speeds.

In Fig. 22 is shown the graph of error in mils against course speed p.

* In another test on loaded fingerknobs an inertial load of 41,000 gm.-cm.^{2} was applied to control 9. The error for speed 3 increased from .14 mil with no loading to .22 mil with loading and for speed 4 from .23 mil to .44 mil.

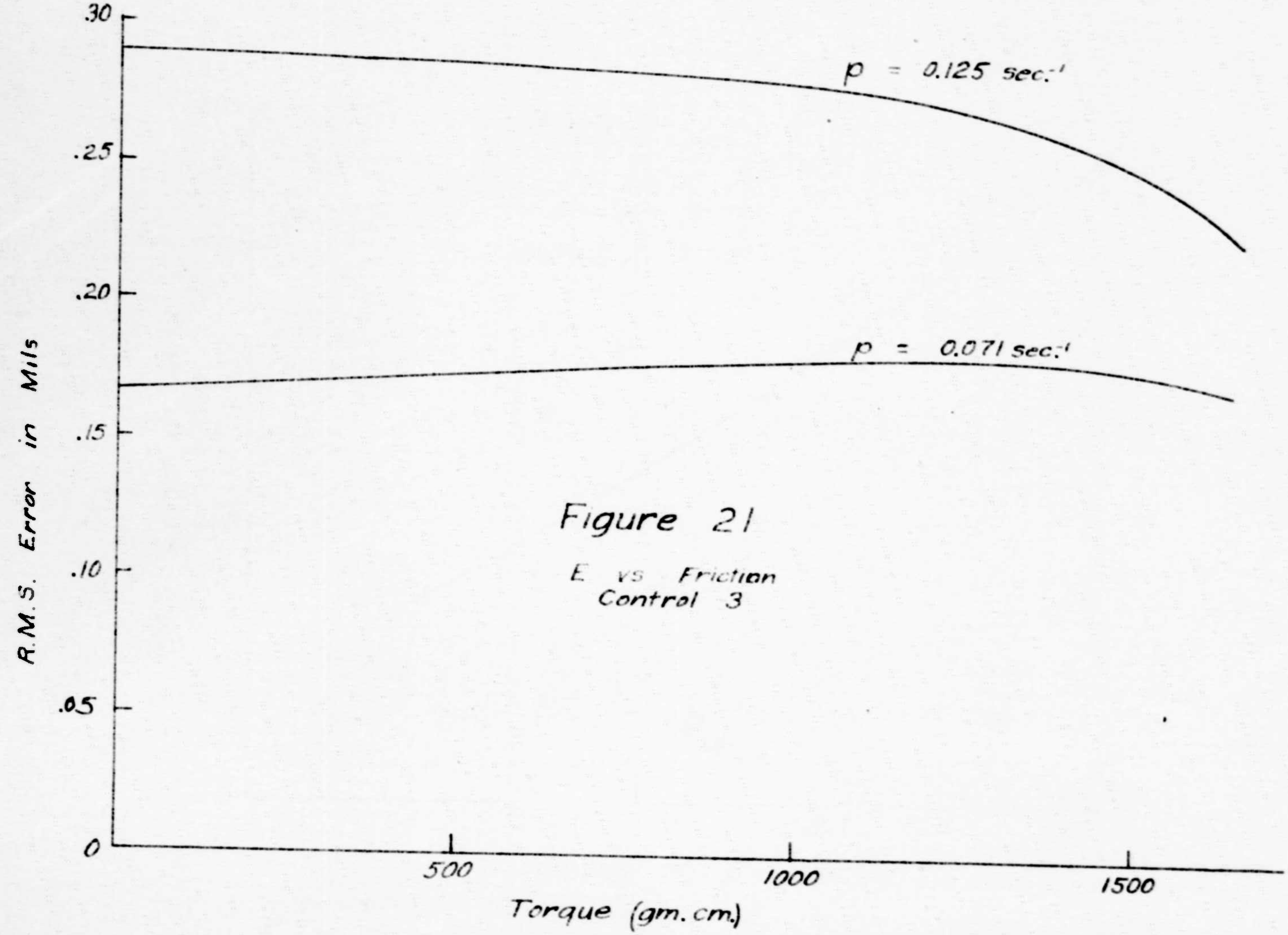


Figure 21

E vs Friction
Control 3

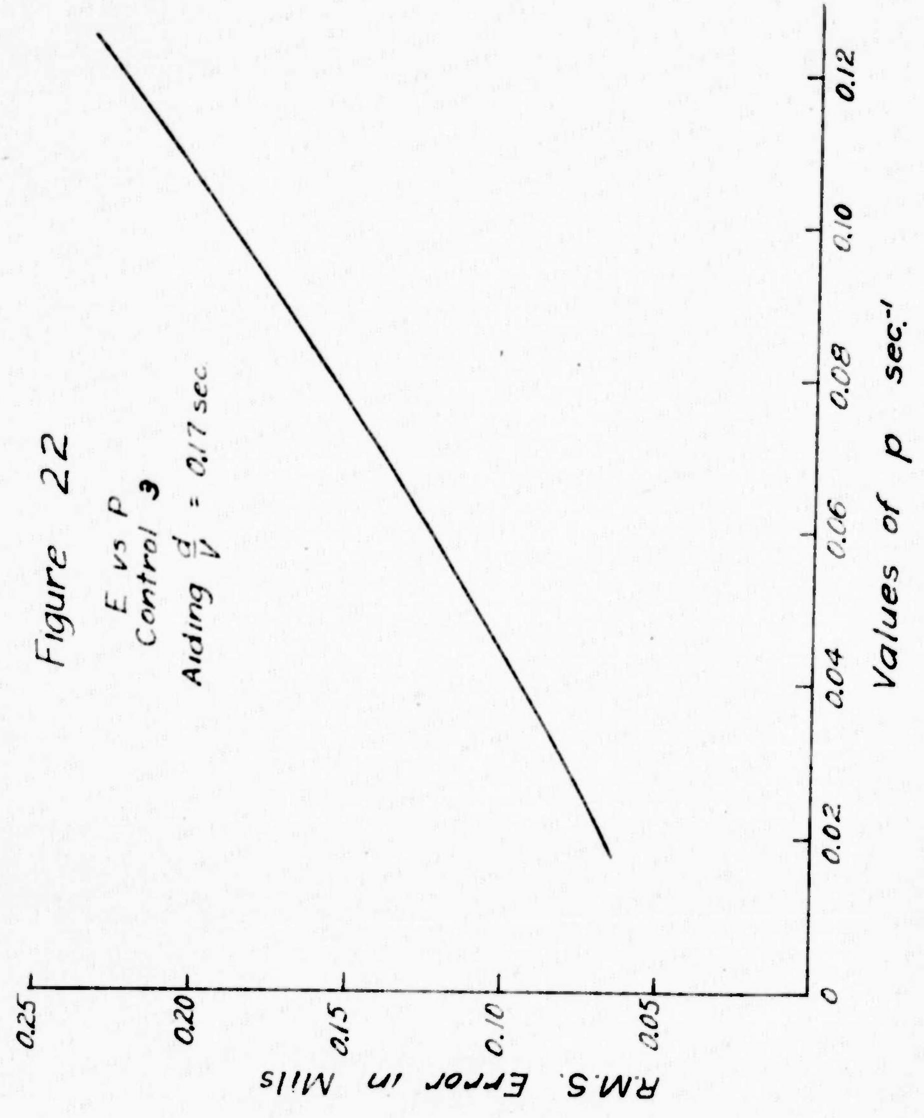


Figure 22
E vs P
Control 3
Aiding d/V = 0.17 sec
R.M.S. Error in Mils
0.25
0.20
0.15
0.10
0.05
0
0.02
0.04
0.06
0.08
0.10
0.12
Values of p sec⁻¹

There is a sufficient amount of curvature in the trace to indicate that the relationship between error and p is not quite linear.

8. Tests with an acceleration-velocity-direct follower

At the present time we are running tests with an accellerational term added to the velocity plus direct combination-followers #5 and #6. A few tests with $\frac{d}{v}$ fixed at .17 seconds have been completed and the results are:

$\frac{d}{a}$	Error Speed 3	Error Speed 4
0	.14 mil	.28 mil
.05 sec^2	.12 mil	.19 mil
.10 sec^2	.11 mil	.17 mil

The error is reduced quite markedly, particularly for speed 4.

C. Study of Tracking Oscillations

As pointed out in Section IV a counter circuit was arranged in one of the followers so as to record the number of times the target was crossed in one direction during a test. From this data and the length of time for the test the average period of oscillation in tracking was determined. This information is of particular importance in a study of the "noise" which plays such a critical part in predicting mechanisms. The results of our studies of tracking oscillation follow:

During the learning process we found that as a tracker's proficiency increased his average period of oscillation* decreased. This indicates that for a given tracking arrangement a man's accuracy of response increases and his time of response decreases as he becomes more adroit at tracking. It is also evident that the greater the length of time the tracker stays close

* The period of oscillation is the length of time elapsed between target crossings in the same direction.

to the center of the target the more likely it is that his smaller oscillations will be recorded.

In Table I. is shown an interesting set of results of the effect of different aiding ratios on tracking oscillations and error. The control was fixed with a direct value of 3.3 mils per revolution for an aiding ratio of .17 seconds. The table shows that there is a decrease in the period of oscillation with an increase in the direct component as might be expected. An attempt to keep the "noise" frequency down without increasing the error leads to the optimum aiding of .17 second as before selected.

Table I

Aiding Value	Period of Oscillation Speed 3	Period of Oscillation Speed 4	Error of Tracking Speed 3	Error of Tracking Speed 4
.057 sec.	2.49 sec.	2.30 sec.	.18 mil	.26 mil
.17 sec.	2.12 sec.	1.64 sec.	.14 mil	.19 mil
.29 sec.	1.80 sec.	1.50 sec.	.15 mil	.22 mil

Analysis of data with controls of different value shows there is no significant change of the period of oscillation with value until the value becomes so low that control begins to fail.

Preliminary results for a fixed control with accelleration-velocity-direct tracking give the results in the following table: $(\frac{d}{v} = .17$ sec.)

Table II

$\frac{d}{a}$	Period of Oscillation Speed 3	Period of Oscillation Speed 4	Error of Tracking Speed 3	Error of Tracking Speed 4
0	2.12	1.64	.14 mil	.28 mil
.05 sec^2	3.54	2.48	.12 mil	.19 mil
.10 sec^2	3.20	2.59	.11 mil	.17 mil

In order to reduce the amount of error and simultaneously increase the period of oscillation it is clearly necessary to employ accelleration in the following mechanism. The importance of tracking oscillations is apparent when one considers the fact that the errors of prediction depend upon the average frequency of the tracking "noise." Further analysis of accellerational tracking is in progress in the laboratory.

IX. PSYCHOLOGICAL RESULTS

The true validity of the coordination test is unknown, since it has so far been impossible to correlate results on the test with performance in the field. This is crucial and looms as a central problem in the study.

The weekly test-retest reliability of the present measuring instrument is $r = .69$ for speed 3 and $r = .75$ for speed 4. This result is obtained by averaging the last six trials, of the twenty per week, to establish a given subject's mean error score or excellence number. Thus the test, as a twenty trial unit, appears to be sufficiently reliable for group diagnosis.

The importance of differential rates of learning on the coordination test may be estimated from Fig. 23. This shows the relative accuracy of the selection of ultimately successful operators from their records after various amounts of training. This data was obtained by correlating the subject's present excellence number with his excellence number for each of the preceeding weeks. Any instability in the function may be attributed to the small number of cases (26).

The differential sensitiveness of the test is great. The mean error score of the <u>average</u> performer in the <u>top</u> quartile is only approximately 65% as large as that of the average performer in the total group. Since the test unquestionably involves a complex type of reaction very similar to the one demanded in the field, it is evident that it would be possible to reduce errors by one half through the selection of operators <u>alone.</u>

As this is written, a battery of psychological tests is being administered to the subjects of the experimental group. The work is incomplete, and the relationships mentioned should be viewed only as tentative. However, since the sample is homogeneous, the correlations reported are in all probability

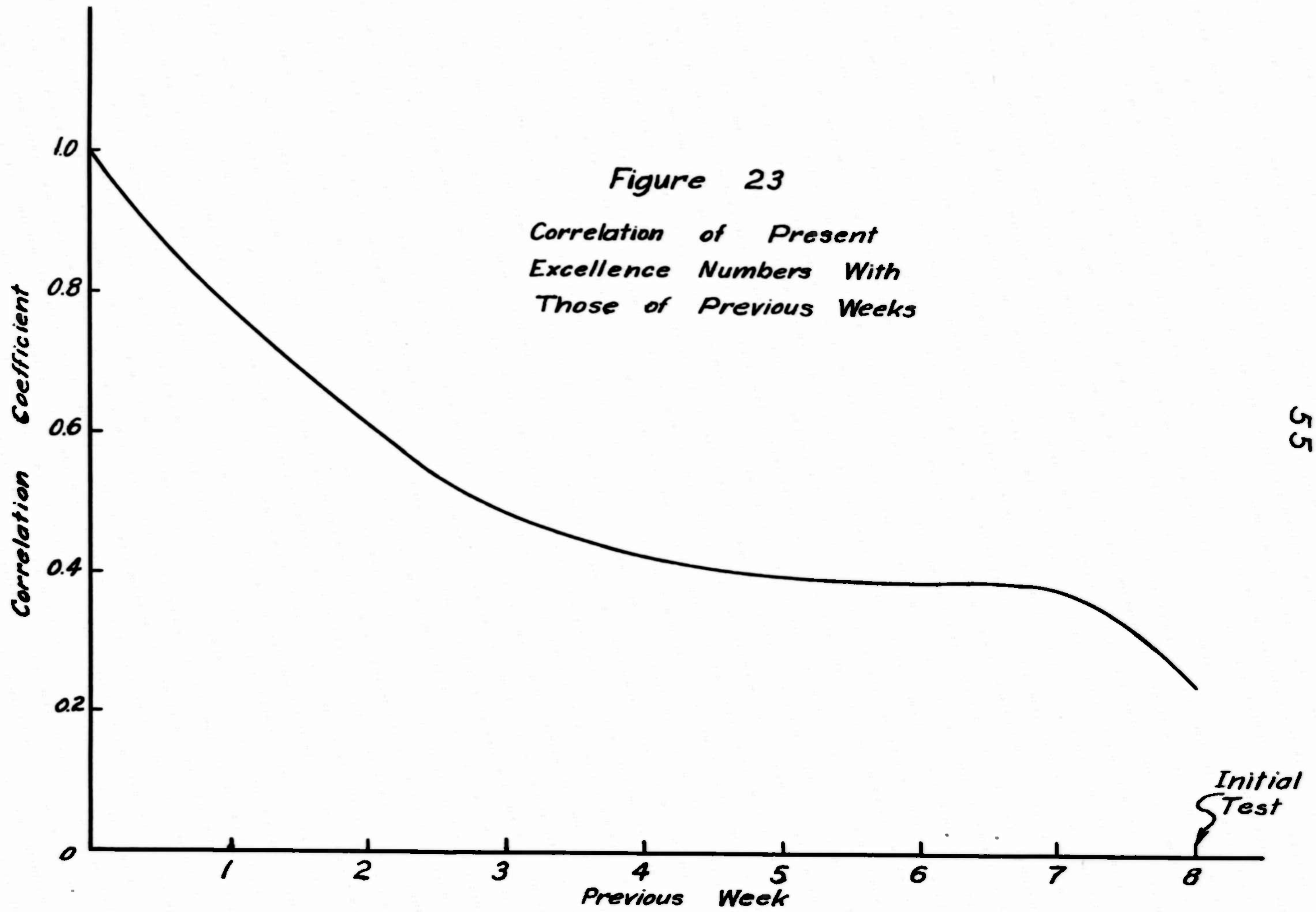


Figure 23

Correlation of Present Excellence Numbers With Those of Previous Weeks underestimates of the true magnitudes of the several relationships. Those estimates which are already available follow.

1. Coordination versus centile rank on the American Council on Education Examination.

   r = 0   p = insignificant

2. Coordination versus inventory of personal data.

   a. Coordination versus troublemaker

      r = 0   p = insignificant

   b. Coordination versus neuroticism

      r = 0   p = insignificant

   c. Coordination versus reliability*

      r = -0.575   p = .01

3. Coordination versus 9-hole steadiness test

   r = 0   p = insignificant

4. Coordination versus ambidextrality on dynamometer.**

   r = 0.48   p = .01

5. Coordination versus ambidextrality on Minnesota rate of Manipulation Test.***

   r = 0.34   p = .05

6. Coordination versus Renshaw pursuitmeter

   r = 0   p = insignificant

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* The reliability score relates to the subject's consistency in answering certain dummy items.

** This is a mean percent difference score, the subject being required to grip the dynamometer with each hand on three separate occasions.

*** This is a simple difference score. The test was administered in standard form, and the subjects took it with each hand separately.

7. It should also be observed that while the present subjects were not selected for visual efficiency, they all but one possess, corrected or uncorrected, the equivalent of 20-20 Snellen visual acuity. This would seem to indicate that the coordination test has acted to select subjects with clear and effective vision.

An evaluation and interpretation of these results will be attempted at a later date, if warranted by the evidence.

X. CONCLUSIONS

On the basis of the information supplied in this report one can draw the following conclusions:

1. Subjects should be selected after considerable practice on the apparatus in actual use or a good "job miniature." Fig. 23 may be used to indicate the point in the training period at which selection is justified but it is clear that to be most efficient the process of selection should take place at intervals with intervening training periods. A preliminary test for acuity of vision seems justified, and it may be that other tests (ambidextrality, reliability, etc.) can be employed to reduce the time and expense of selection. Such a process should yield 10% of the original number of trackers who can track with errors well under 40% of the original group average.
2. There can be little doubt that double fingerknobs of two inch diameter are distinctly better as manual controls (about 65% as much error) than the handwheels now in use. This superiority still persists with a loading resistance of 1500 gm.-cm.
3. If an aided rate follower is used the time constant seems quite independent of the angular velocity at crossover and the type of manual control used. The most advantageous value seems to be $R = .17 - .20$ seconds which is near the Kerrison value.
4. With $R = .17$ seconds the best overall results when $p = .042$ to $p = .125$ sec.$^{-1}$ are obtained with a fingerknob with a value of 3.3 mils per revolution The slower courses, however, permit corresponding lower values with no loss (or gain) of accuracy.

5. Magnification does not seem to be an important factor if sufficiently high to make the errors easily resolved. It should be remembered however that this resolution will increase in difficulty as the errors are reduced by improvements of various kinds and this may require increased magnification if the full benefit of the improvements are to be obtained.

6. Still more accurate following can be obtained by employing acceleration-velocity-direct combinations. Errors are very low and the following is very smooth but there is difficulty in "getting on" the course initially. It may be that some method can be perfected for overcoming this difficulty; whether the target can itself cause the same difficulty by changing its course is not certain but the answer is probably in the negative. The smoothness of tracking obtained with this device should be a marked advantage in prediction.

7. By the methods described above the errors can be enourmously reduced. R.M.S. errors of .14 R.M.S. mils for velocity-direct combinations and of .09 R.M.S. mils for acceleration-velocity-direct combinations have been obtained when following a course with p = .071 $sec.^{-1}$. These results are not for a selected group of operators during a lucky run but are group averages reduced to the ability of our average upper quartile operator by the use of excellence numbers and containing approximately ten runs for each of ten operators. It appears to us that even this small error is at least partly due to unavoidable fluctuations in the apparatus. These results are to be compared with errors of .50 average mils (average error equals .80 times the root-mean-squared error) on courses which are not so fast as ours according to results of tests on tracking at Fort Monroe.

REEL – C

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ABSTRACT:

A study is made of human beings in servo-roles in connection with antiaircraft fire (pointer matching). Emphasis is given to the design of associated apparatus by which the servo action is obtained. Information is given on the selection and training of personnel for operating such devices. Problems of angular tracking and tracking in azimuth are considered. Double finger knobs of two inch diameter were found to be better manual controls than handwheels now in use. If aided rate follower is used, the constant seems independent of angular velocity at crossover and type of manual control used. Magnification is not important if sufficiently high to make errors easily resolved. More accurate following can be obtained by employing acceleration-velocity-direct combinations.

DISTRIBUTION: Copies of this report obtainable from Air Documents Division; Attn: MCIDXD

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(*) TLACHING

AERIAL TARGETS