A REVISED TWO-HAND COORDINATION TEST

by

Ross A. McFarland

and

Ralph C. Chamnli

A report on research conducted under grants-in-aid to the Division of Research, Graduate School of Business Administration, Harvard University, by the National Research Council Committee on Selection and Training of Aircraft Pilots from funds provided by the Civil Aeronautics Administration.

October 1944

CIVIL AERONAUTICS ADMINISTRATION
Airman Development Division
Report No. 36
Washington, D. C.

National Research Council

Committee on Selection and Training of Aircraft Pilots

Executive Subcommittee

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National Research Council

1944

LETTER OF TRANSMITTAL

NATIONAL RESEARCH COUNCIL

2101 Constitution Avenue, Washington, D. C.
Division of Anthropology and Psychology

Committee on Selection and Training of Aircraft Pilots

October 19, 1944

Dr. Dean R. Brimhall, Director
Airman Development Division
Civil Aeronautics Administration
Washington 25, D. C.

Dear Dr. Brimhall:

Attached is a report entitled A Revised Two-Hand Coordination Test, by Ross A. McFarland and Ralph C. Channell. This report is submitted by the Committee on Selection and Training of Aircraft Pilots with the recommendation that it be included in the series of Technical Reports issued by the Airman Development Division, Civil Aeronautics Administration.

This report, one of several devoted primarily to apparatus, contains a description of the original and revised forms of the Two-Hand Coordination Test, together with distributions of test scores on both forms of the equipment for subjects differing in age and flying experience. Earlier models of the Two-Hand Coordination Test have been employed in industry for selection purposes. The utilization of the revised apparatus in the present study represents an application of this device to the selection of candidates for flight training.

Cordially yours,

Morris S. Viteles, Chairman
Committee on Selection and
Training of Aircraft Pilots
National Research Council

HKB:rm

Rec'd 11-1-44

EDITORIAL FOREWORD

This report is one of a group describing the development and initial use of apparatus designed for research in the selection and training of aircraft pilots. It is, in a sense, a companion report to Technical Report No. 34, which describes the revision and modification of a Revised Serial Reaction Time Test.

Like the Revised Serial Reaction Time Test, the Two-Hand Coordination Test described in this report, is an outgrowth of the extensive investigation, called the Pensacola Study of Naval Aviators, conducted in 1940-41 through the cooperation of the United States Navy. Experience with the Farmer-Chambers Coordination Test during this study of Naval Cadets revealed certain unsatisfactory characteristics of that apparatus and led to the construction of a revised form (called the Two-Hand Coordination Apparatus) which was then used in testing groups of civilian pilots.

The report is of value by reason of the detailed description of the apparatus and because it presents test results obtained on the original and the revised forms with groups of subjects differing in age, experience, and success in flight training.

CONTENTS

SUMMARY

This report describes the development and early use of a psychomotor test requiring coordinated movements of the two hands in response to a moving target. It is essentially an adaptation of the lathe-type test first used in industrial selection programs.

The Two-Hand Coordination Test, described in this report, is a revision of the Farmer-Chambers Coordination Test, modified so as to eliminate certain defects in apparatus and scoring. By means of a constant speed electric motor a target disc is moved in a standardized irregular pattern. The subject, by revolving two crank handles (one in each hand), controls the movement of another disc in an attempt to keep the two discs together. The percent of time per trial during which the two discs are in contact is recorded by means of a microswitch and electric timer. For ease in construction and maintenance the apparatus is constructed of standard parts obtainable from commercial manufacturers.

Included in the report are descriptions of the apparatus, drawings of the component parts, and specifications as to the materials and parts needed for its construction.

Illustrative test results on both the original Farmer-Chambers model and the Revised Two-Hand Coordination Test are presented, based on score distributions obtained from 288 primary pilots in the C.P.T. Program, 141 advanced pilots in training at Northeast Airlines, 786 naval aviation cadets and 83 flight instructors at the Naval Air Station, Pensacola, Florida. The groups differed widely in age and flying experience.

Exploratory information on the relationship between test scores and success in flight training was obtained by comparing the test score distributions of Pensacola naval cadets who passed versus those who were washed out, and of those who passed without Board Appearances versus those who had Board Appearances or were washed out. Significant differences between mean scores indicated that the poorer cadets did worse on the test than did the better cadets. The Pensacola flight instructors' scores were similar to those of the better cadets.

The test also differentiated between "good" and "poor" student pilots in the C.P.T. Program, the subjects being classified on the basis of "time to solo" and "time for certification" for a private pilot license.

Intercorrelations among the six successive trials given on the Revised Two-Hand Coordination Test during test administration, in a study based on 108 C.P.T.P. primary students, ranged from .38 to .74. The mean of the six trials was found to correlate .78, .87, and .80 with Trials 4, 5, and 6, respectively.

A REVISED TWO-HAND COORDINATION TEST

INTRODUCTION

Even a casual analysis of the task of flying a plane suggests that an important requirement for successful piloting is the ability to make smoothly coordinated movements of both hands. The pilot, for example, must move the control stick in a desired pattern with one hand, while adjusting other controls, like the throttle, with the other. Attempts have thus been made to develop instruments and methods for measuring this ability with the hope that reliable and valid tests, valuable for selection of pilot trainees, would result.

This report presents a description of a two-hand coordination test, representing an outgrowth of an improvement over similar tests previously developed for research in industrial selection. The revised form is described in detail and comparative test results are presented, based on a try-out administration of the original and revised forms on groups of pilots in various stages of flight training. Preliminary data on the relationship between test scores and success in pilot training were also obtained in this exploratory study.

EARLIER FORMS OF TWO-HAND COORDINATION TESTS

As mentioned in the Introduction, tests requiring a simultaneously coordinated pattern of movement of both hands had already been devised for use as aptitude tests in industrial selection programs. The two from which the present Two-Hand Coordination Test has most directly developed are the Wisconsin Engine-Lathe Test and the Farmer-Chambers Coordination Test.

A. The Wisconsin Engine-Lathe Test

This test "attempts to duplicate that part of an engine-lathe which controls the movement of the cutting tool."[1] As shown in Figure 1, turning the cranks H and H' will result in movement of the pin P over the plate X and in a graphic record of the movement by means of a pencil stylus P' moving over a paper mounted on plate Y. The task of the subject is to move the pin P around the series of six electric contacts shown on plate X as rapidly and as directly as possible. When the pin touches a contact point the electric bell B rings to notify the subject that he may proceed to the next contact. This was designed as a "miniature test," duplicating the hand positions and movement requirements for ordinary bench lathe operations.

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[1] Hull, C. L. Aptitude testing. New York: World Book Co., 1928, p. 67.

B. The Farmer-Chambers Coordination Test[2]

The Farmer-Chambers apparatus, developed in England as part of an Industrial Health Research Board study of accident-proneness, also required coordinated rotation of two cranks by means of which the subject controls the movement of a pointer disc in an attempt to keep the pointer disc over a target disc moving in an irregular pattern. Since the present Two-Hand Coordination Test is essentially an improved revision of the Farmer-Chambers apparatus, a detailed description of the latter is presented below:

1. As shown in the simplified diagram in Figure 2 and the photograph in Figure 3 the mechanism by which the target disc is moved is as follows: a horizontal circular metal plate A (Fig. 2), mounted on a vertical axis and rotated by a gramophone motor, has a small curved slit B through which rider C projects. The rider, free to move from end to end of the slit, is kept pressed to the edge of a horizontal plate cam D of irregular outline, by means of a spring E. The rider is fitted with a wheel bearing so that it moves smoothly along the edge of the cam. This cam is fixed and does not move so that when the plate A rotates the rider C describes an irregular path, the resultant of excursions of varying lengths towards and away from the center of the plate imposed on a circular orbit. The velocity of these transverse excursions also varies, depending on the angle of the irregularities in the cam, so that the rider has also an irregular velocity pattern. The target disc which the subject is required to follow is fitted to a small brass cylinder and screwed on the rider C.

2. The part of the apparatus under the subject's control consists of a graduated metal drum, F, on a carriage bearing a short metal arm at the end of which the pointer disc G is attached. As shown in Fig., 2, the carriage slides to the right and left along a guide bar H. The bar H itself, together with the carriage and drum, slides along two guide bars, J and J'. When the handle K is turned in a clockwise direction the carriage bearing the drum is moved along the bar H towards K. Similarly, when L is turned, the bar H with the drum and carriage moves along the bars J and J' towards or away from L, depending on whether the handle is turned clockwise or anti-clockwise. Hence, when both handles are being turned at once the motion of the pointer disc is the resultant of two motions at right angles to each other, so that G can be moved over any part of the plate A by proper turning of K and L. Also, the velocity of G is the resultant of two velocities at right angles to each other, and can be controlled by the subject. (Two departures from the original description[3] should be noted here: (1) the subjects were instructed to operate the apparatus with their bodies parallel to H, rather than with their bodies at right angles to H; (2) in the original Farmer-Chambers apparatus the two screw spindles were of different pitches, while in the revised equipment used in this study the two screw spindles were of the same pitch.)

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[2]Farmer, Eric and Chambers, E. G. A study of personal qualities in accident proneness and proficiency. Industrial Health Research Board, His Majesty's Stationary Office, London, 1929, Report No. 55.

[3]Ibid.

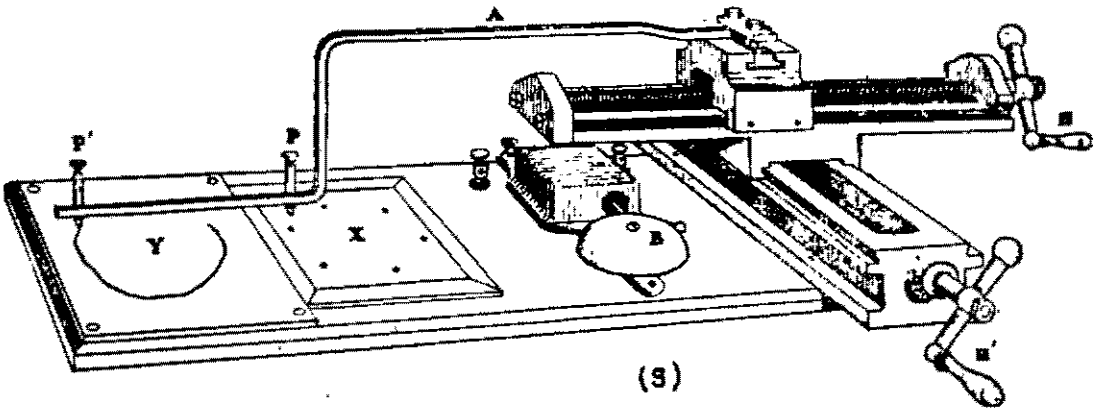


Figure 1

WISCONSIN ENGINE-LATHE TEST

Subject's position at bottom of figure (S), for operation of H by right hand and H' by left hand. Clockwise rotation of H shifts P to left, and of H' shifts P upward in the figure.

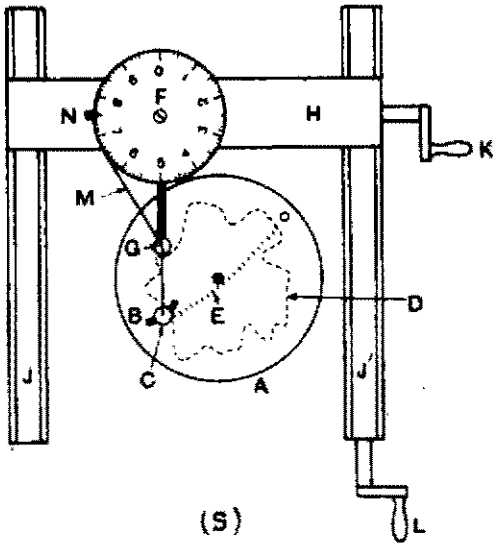


Figure 2

FARMER-CHAMBERS COORDINATION TEST

The subject's position used in this study is at the bottom of the figure (S) for the operation of K by the right hand and L by the left hand.

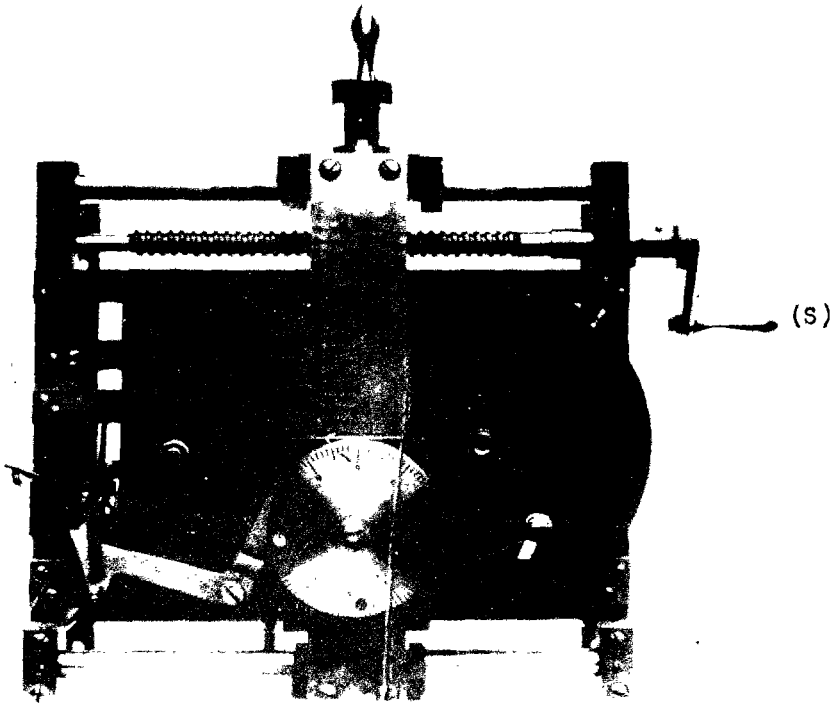


Figure 3

FARMER-CHAMBERS COORDINATION TEST

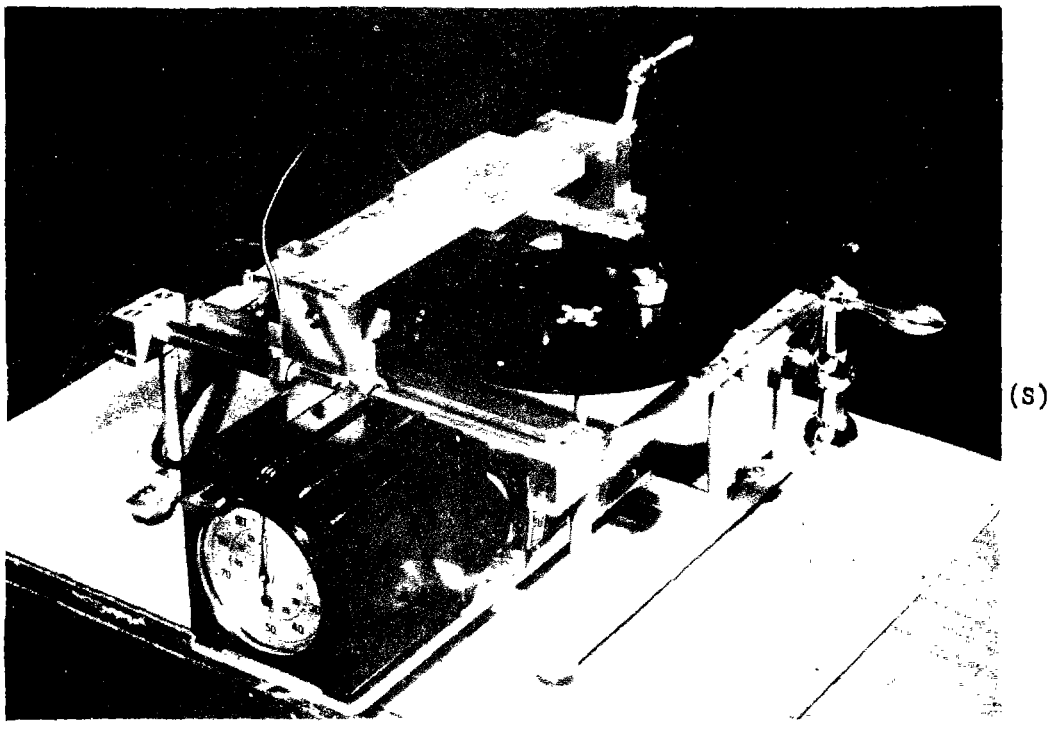


Figure 4

REVISED TWO-HAND COORDINATION TEST

In this study the subject always operated the apparatus in the position indicated at (S).

3. The subject's ability to keep the pointer disc over the target one is measured by means of the graduated drum F. This drum is in two parts, both rotatable about a vertical axis and connected together by a friction ratchet of the ball and inclined plane type. When the lower part of the drum is rotated in an anti-clockwise direction the upper part is prevented from turning by a second friction ratchet working on a fixed axis. The lower part is fitted with a watch spring so that anti-clockwise rotation is always made against the action of the spring. Round a groove at the bottom of this lower part of the drum passes a cord M, secured at one end to the drum and at the other, after passing through an eyehole in the pointer disc, to the target disc. Hence, when the pointer and target discs are moved apart the cord is pulled out and rotates the drum in an anti-clockwise direction, causing the graduations on the upper part of the drum to move past a pointer, N. When the discs come together again the spring in the drum automatically rotates the lower part in a clockwise direction, thus taking up the slack in the cord but not moving the upper part of the drum. In this way the rotation of the upper part of the drum sums the various deviations of the pointer disc from the target one. The reading on the graduations thus gives a quantitative measure of the subject's ability to keep the two discs together. The drum is set to zero for each subject by rotating the upper part by hand in an anti-clockwise direction.

4. A simple stopping device is fixed to the gramophone motor so that when the machine is started the plate A makes one revolution and then stops automatically. In this way, each subject has precisely the same task to perform and the various scores of the subjects are directly comparable. One revolution of the plate takes 100 seconds. The individual's score is given in terms of the amount of deviation registered on the drum, F. The lower scores thus indicate better performance, i.e., a small amount of deviation between the two discs, G and B, during the test.

DESCRIPTION OF THE REVISED TWO-HAND COORDINATION TEST

Experience with the Farmer-Chambers version of the two-hand coordination test revealed several defects and limitations: (1) the phonograph motor tended to vary in speed unless tightly wound at the beginning of each test, (2) the subject could make a good score by merely keeping the pointer disc G relatively near to the target disc B, and (3) the string M (see Figure 2) tended to break or to stretch, thus preventing constant calibration of the scale.

In the present revision these defects were eliminated in the following manner:

1. A constant speed electric motor was used to activate the disc to be followed by the subject.

2. Scoring of the performance was obtained in terms of the time during which the two discs were in actual contact, by use of electrical contacts activating an electric clock.

Following is presented a detailed description of the Revised Two-Hand Coordination Test, embodying these and other minor improvements.

A. The Assembled Apparatus

Figure 4 presents a photograph of the assembled apparatus with the timer in the left foreground. Drawings in Figure 5 present the top, front, and side views of the newly designed apparatus as seen by our subjects. A wiring diagram is also shown in the upper right-hand side of the figure. Special attention should be given to the timer, synchronous motor, and the small microswitch, which comprise the essential innovations of the design. These are standard parts and may be obtained from the manufacturers listed in Appendix B.

B. Detailed Plans for Construction

Figures 6, 7, and 8 show further details of the apparatus. Drawings and descriptive information are presented for each part.

1. The irregular cam, shown in Figure 6, is an important feature of the apparatus since it governs the movement of the target to be followed by the subject. Identical patterns of movement are presented on each trial. No attempt has been made to experiment with different types of cams or with varying speeds of movement.

2. Figure 7 shows the details of the frame, cross-members, vertical supports, and guide rods. The exact size of each part is indicated and has been carefully checked. It should be noted that the frame has been greatly simplified over the model shown in Figure 4.

3. In Figure 8, the various parts of the movement assembly are described in detail, and measurements given. The lead-screws (Part 4-2) shown in the figure are extremely important and should be purchased or manufactured to the exact details. These are right-hand thread lead-screws which have been standard on all models of the apparatus. It is necessary to use this type of lead-screw so as to standardize the difficulty of movement required in turning the handles of the apparatus. In addition, the direction of this movement is opposite from that in almost all other pieces of equipment such as lathes, milling machines, etc., in which clockwise motion of the hand advances the tool or the work away from or toward the left of the subject. In the Two-Hand Coordination Test apparatus clockwise motion of the subject's hand produces the opposite result, thus minimizing the effect of specialized experience with ordinary lathe equipment.

C. Important Features in Standardization of the Test

In the revised equipment the following features were incorporated so as to provide a highly standardized task and method of scoring:

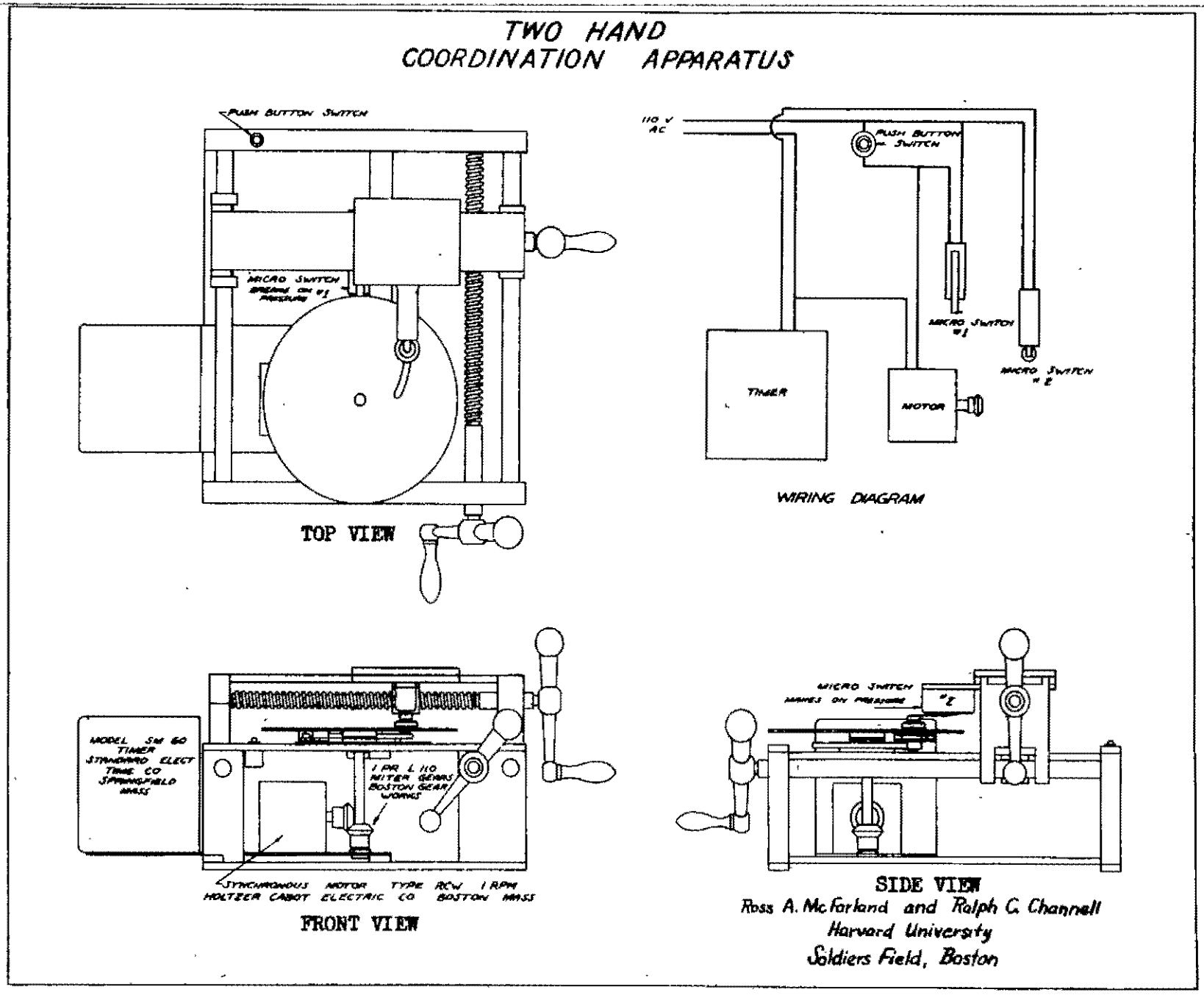
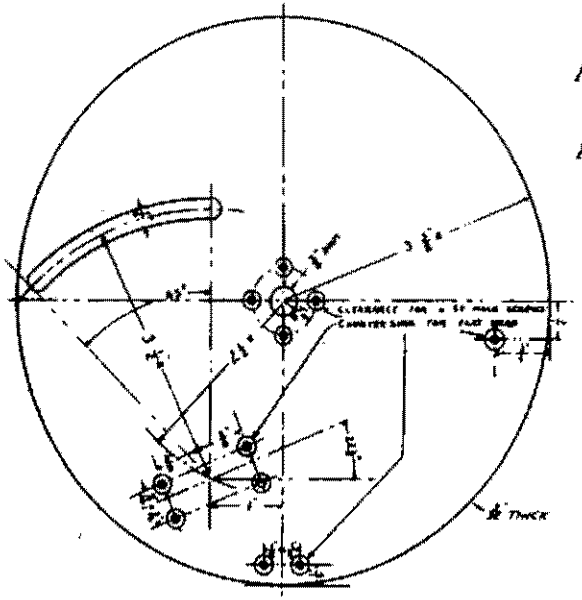
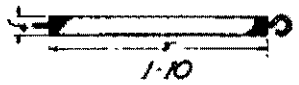

TWO HAND
COORDINATION APPARATUS
PUSH BUTTON SWITCH
MICRO SWITCH
TOP VIEW
110 V
AC
PUSH BUTTON
SWITCH
MICRO SWITCH
#1
MICRO SWITCH
#2
TIMER
MOTOR
WIRING DIAGRAM
MODEL SM 60
TIMER
STANDARD ELECT
TIME CO
SPRINGFIELD
MASS
1 PR L 110
MITER GEARS
BOSTON GEAR
WORKS
SYNCHRONOUS MOTOR TYPE RCW 1 RPM
HOLTZER CABOT ELECTRIC CO BOSTON MASS
FRONT VIEW
MICRO SWITCH
#2
SIDE VIEW
Ross A. McFarland and Ralph C. Channell
Harvard University
Soldiers Field, Boston

Figure 5

COORDINATION APPARATUS



TURNTABLE 1-1



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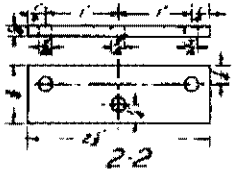

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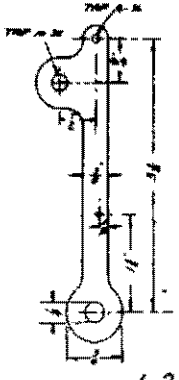

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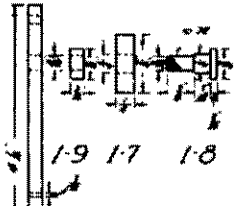

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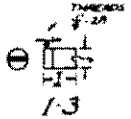

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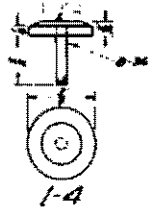

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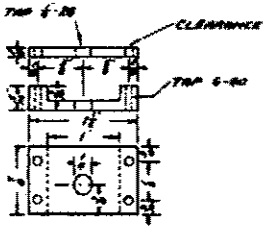
1-5



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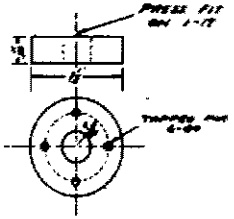
1-12



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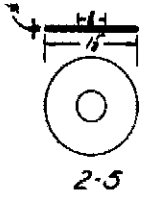

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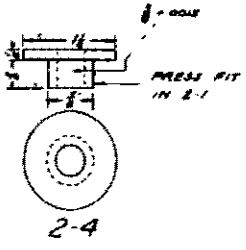

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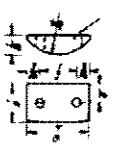

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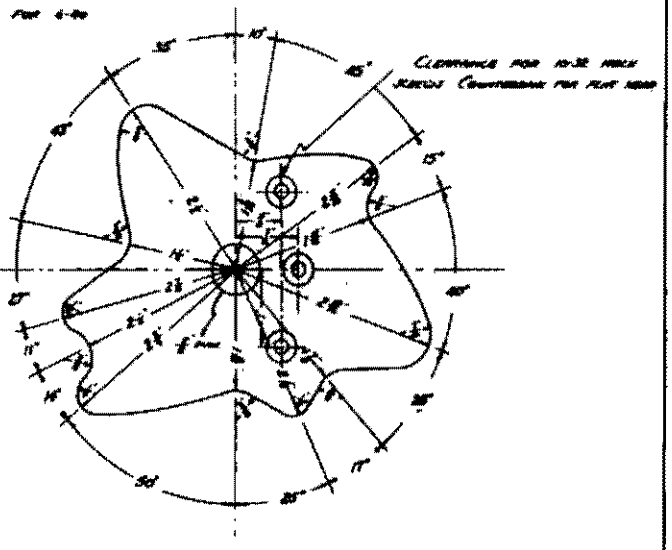
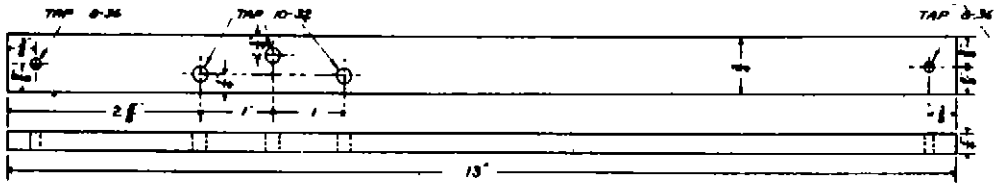


CAM 2-1

PART	DESCRIPTION	MATERIAL	NO
1	Turntable Assembly		
1-1	Turntable	Aluminum ¾" Thick	1
1-2	Lever	Mach. Steel	1
1-3	Fulcrum Pin	¼" Drill Rod	1
1-4	Lower Button	Mach. Steel	1
1-5	Upper Button	Mach. Steel	1
1-6	Lock Nut	Plain 8-32 Nut	1
1-7	Cam Follower	Stock Ball Bearing	1
1-8	Follower Screw	Mach. Steel	1
1-9	Follower Spacer	Mach. Steel	1
1-10	Spring		1
1-11	Spring Support Screw	6-40 x ⅜" Flat Head, 2 Nuts	1
1-12	Lever Support	Mach. Steel	1
1-13	Support Cover	Mach. Steel	1
1-14	Support Screws	6-40 x ⅜" Flat Head	4
1-15	Turntable Hub	Mach. Steel	1
1-16	Hub Screws	6-40 x ⅜" Flat Head	4
1-17	Turntable Shaft	Drill Rod ⅜" x 4 ⅜"	1
1-18	Stop	Mach. Steel	1
1-19	Stop Screws	6-40 x ⅜" Flat Head	2
2	Cam Assembly		
2-1	Cam	Mach. Steel ¾" Thick	1
2-2	Spacer	Mach. Steel	1
2-3	Cam Screws	10-32 x ⅜" Flat Head	3
2-4	Upper Shaft Bushing	Mach. Steel	1
2-5	Thrust Washer	Mach. Steel	1

Figure 6

COORDINATION APPARATUS



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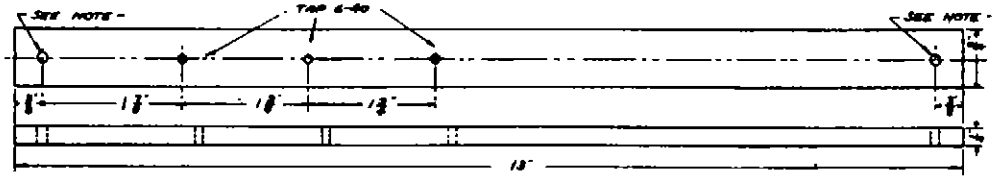
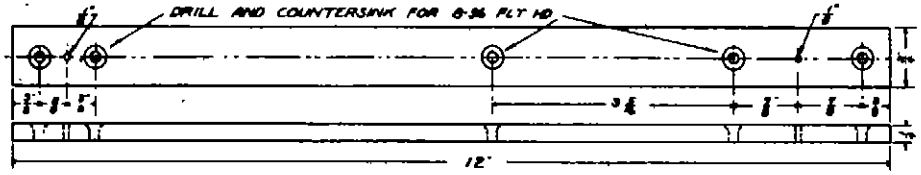


3-3

NOTE 2 BARS REQUIRED
1 WITH END HOLES TAPPED 8-36
1 WITH END HOLES CLEARANCE 8-36



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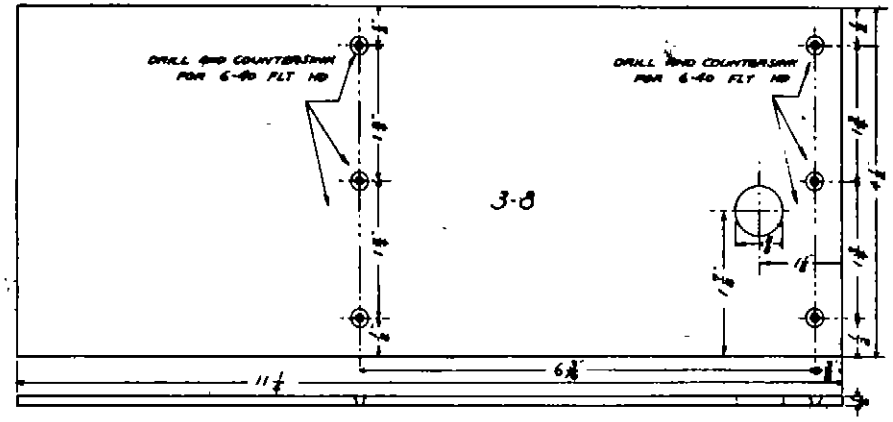

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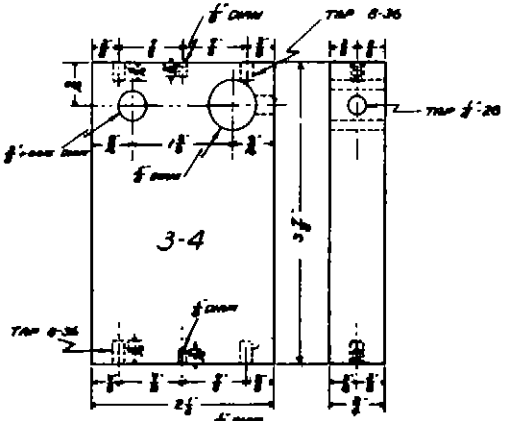
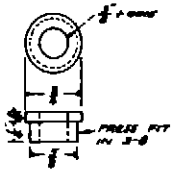


3-4



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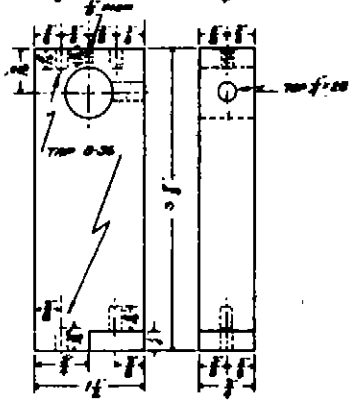
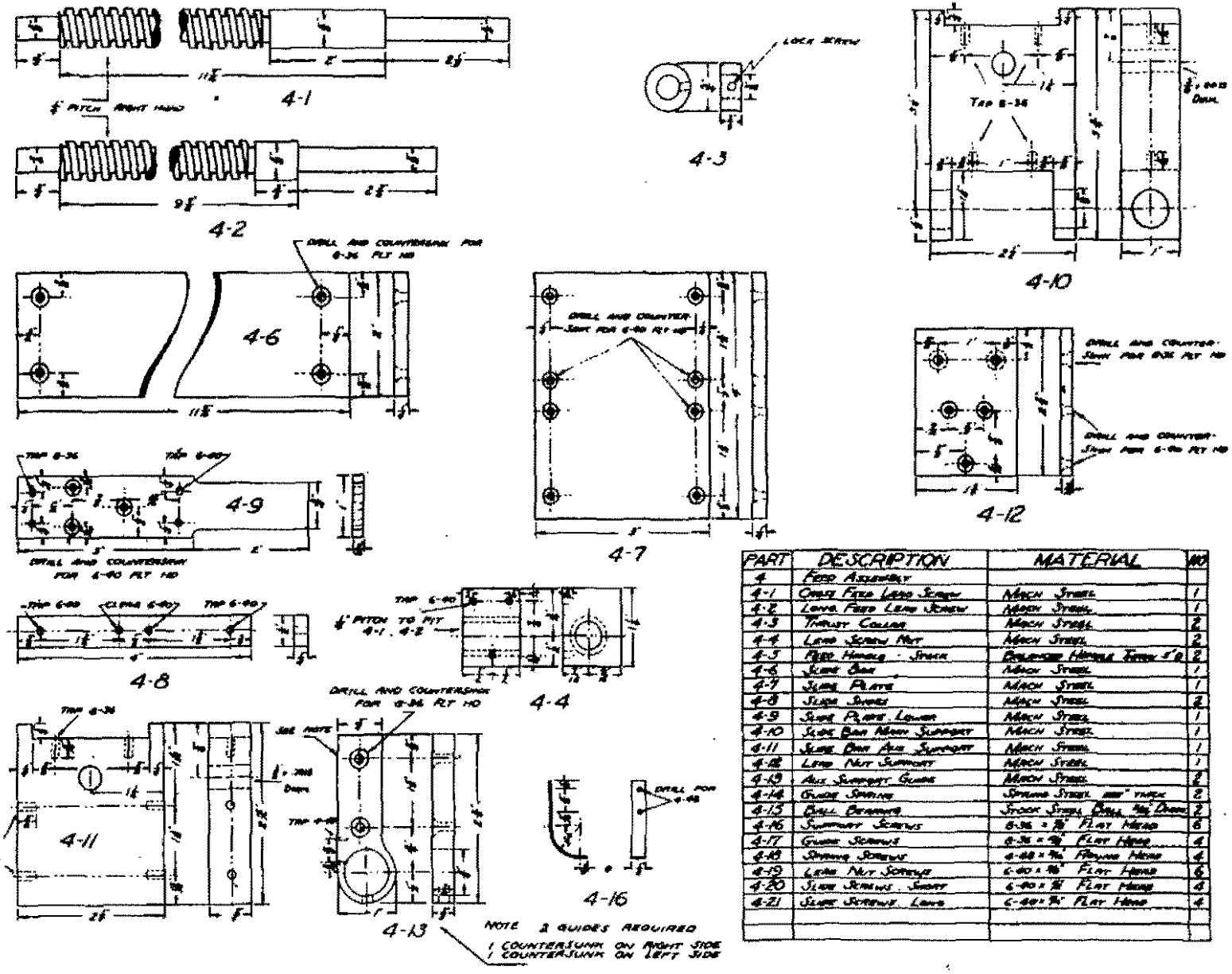


3-5

PART	DESCRIPTION	MATERIAL	NO
3	FRAME		
3-1	MAIN MEMBER	MACH STEEL	4
3-2	TOP CROSS MEMBER	MACH STEEL	1
3-3	BOTTOM CROSS MEMBER	MACH STEEL	2
3-4	LARGE VERTICAL SUPPORT	MACH STEEL	2
3-5	SMALL VERTICAL SUPPORT	MACH STEEL	2
3-6	GUIDE ROD	DRILL ROD ⅜" x 13"	2
3-7	ROD LOCK SCREW	¼-20 x ⅜" ALLEN SCREWS	2
3-8	MOTOR BASE	MACH STEEL ⅜" THICK	1
3-9	LOWER SHAFT BEARING	MACH STEEL	1
3-10	LOCATING PINS	DRILL ROD ⅜" x ⅜"	6
3-11	SHORT SCREWS	8-36 x ⅜" FLT HD	18
3-12	LONG SCREWS	8-36 x ½" FLT HD.	2
3-13	BASE SCREWS	6-40 x ⅜" FLT HD	6

Figure 7

COORDINATION APPARATUS



PART	DESCRIPTION	MATERIAL	NO
4	FEED ASSEMBLY		
4-1	COARSE FEED LEAD SCREW	MACH STEEL	1
4-2	LONG FEED LEAD SCREW	MACH STEEL	1
4-3	THRUST COLLAR	MACH STEEL	2
4-4	LEAD SCREW NUT	MACH STEEL	2
4-5	FEED HANDLE - SPIDER	DIECASTING HANDLE KNOB 5/8	2
4-6	SLIDE BASE	MACH STEEL	1
4-7	SLIDE PLATE	MACH STEEL	1
4-8	SLIDE STRIPS	MACH STEEL	2
4-9	SLIDE PLATE LOWER	MACH STEEL	1
4-10	SLIDE BAR MACH SUPPORT	MACH STEEL	1
4-11	SLIDE BAR ALT SUPPORT	MACH STEEL	1
4-12	LEAD NUT SUPPORT	MACH STEEL	1
4-13	ALT SUPPORT GUIDE	MACH STEEL	2
4-14	GUIDE SPRING	SPRING STEEL .005" THICK	2
4-15	BALL BEARING	STOCK STEEL BALL 3/16" DIAM	2
4-16	SUPPORT SCREWS	8-36 x 3/8" FLAT HEAD	6
4-17	GUIDE SCREWS	8-36 x 3/8" FLAT HEAD	4
4-18	SPRING SCREWS	6-32 x 3/8" FILLISTER HEAD	4
4-19	LEAD NUT SCREWS	C-40 x 3/8" FLAT HEAD	6
4-20	SLIDE SCREWS SHORT	C-40 x 3/8" FLAT HEAD	4
4-21	SLIDE SCREWS LONG	C-40 x 3/4" FLAT HEAD	4

Figure 8

1. The turntable, operated by a synchronous motor, makes one revolution of one minute duration at constant speed and is then automatically stopped.

2. The diameter of the target is of such a length that four revolutions of either crank handle are required to carry the pointer across the target (along the diameter of the latter) from the "make" to "break" positions of the microswitch contacts. Thus, with the target stationary and the pointer centered on it, two complete revolutions of either crank handle are required to break the contact. This tolerance may be designated as the "operational margin of safety."

3. The resistance in turning the handles is made uniform by employing a balanced handle which revolves with equal freedom at any point in the arc. The grips are fixed, but highly polished to glide easily in the operator's hands.

4. A standard clock timer calibrated in hundredths of a minute gives a score in direct percentage of time on the target. Theoretically, a perfect score would be 100% and the poorest score 0%, but in actual practice the highest score obtainable is 98% since a short period of time is involved in the starting and stopping of the turntable motor.

D. Names and Addresses of Manufacturers of Standard Parts

In Appendix B the names and descriptions of the parts, the quantity required for the construction of the apparatus, and the names of the manufacturers handling them are listed.

RESULTS OBTAINED WITH THE ORIGINAL AND THE REVISED FORMS OF THE TEST

This section of the report presents preliminary results obtained on the original and revised models of the Two-Hand Coordination Test. As pointed out, scoring on the original test was in terms of distance off the target, with a low score indicating superior performance, while in the revised form of the test the score was in terms of the amount of time during which the two discs were in contact, with a high score indicating superior performance. With the original test, the "score" was the mean of four successive trials, with the revised form the mean of six successive trials. The duration of each trial was also different for each form of the test. In the original version one revolution of the turntable takes 100 seconds; in the revised test, one revolution of the turntable takes 60 seconds, the timer, however, being calibrated in 100ths of a minute to give scores in direct percentage of time on the target. The position of the subject was the same for both forms of the apparatus, i.e., the left hand operated the cross feed, and the right hand operated the lateral feed. It is to be noted that the subject's position differs from that used by Farmer and Chambers[4] and in more recent experiments with this apparatus by the A.A.F.[5]

The subjects, ranging in age from 18 to 37 years, consisted of 288 student pilots in the Civilian Pilot Training Program, 141 advanced pilots in training at Northeast Airlines, 786 aviation cadets and 83 flight instructors at the U. S. Naval Air Station, Pensacola, Florida. With the exception of the Flight

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[4]Farmer, Eric and Chambers, E. G. Op. cit.

[5]Melton, A. W. The selection of pilots by means of psychomotor tests. J. Aviation Med. 1944, 15, 116-123. (See Fig. 4.)

TABLE 2

THE MEAN, STANDARD DEVIATION, AND RANGE IN THE TWO-HAND COORDINATION TEST FOR VARIOUS GROUPS OF PILOTS RANGING IN AGE FROM 18 TO 37 (N = 1298)

Subjects	N	Age Range	Mean Flying Hours	Mean	S.D.	Range
				Original Apparatus*		
1. Pensacola Cadets & Officers						
Classes 147-151	376	21-27	10	59.0	12.1	31-96
Classes 152-164	410	21-27	10	69.7	12.1	31-105
2. Pensacola Instructors	83	25-37	1,500	58.2	11.9	32-87
3. C.P.T.P. Student Pilots						
Primary, 1939-40	110	18-32	0	61.1	13.0	18-89
				Revised Apparatus*		
Primary, 1940-41	70	19-26	0	64.7	12.1	24-83
Primary, Fall 1941	108	18-22	0	53.3	11.3	21-79
4. Flight Officers Training School, Northeast Airlines	141	21-28	200	61.6	11.4	28-86

*On the original apparatus a low score indicates superior performance, the final score being based on the mean of four trials. On the revised apparatus a high score indicates superior performance, the final score representing the mean of six trials.

Officers in the Northeast Airlines School and the Pensacola instructors, the members of the other groups had little experience as aircraft pilots. The groups, the form of the apparatus used, and the means, standard deviations, and ranges of each distribution are given in Table 1.

A. Aviation Cadets and Instructors at Pensacola

The results obtained for the Pensacola aviation cadets on the original model of the apparatus are divided into two parts, as indicated in Tables 2, 3, and 4. Part 1 shows the frequency distributions for pilots who passed flight training (Successes), compared with pilots eliminated from flight training for poor aptitude (Washouts). Part 2 shows the frequency distributions of successful pilots who never had a Board Appearance (Good Pilots), compared with Washouts plus those pilots who, because of difficulties during their flight training, appeared before the Commandant's Advisory Board but finally passed (Board Appearances). The data in Table 2 were obtained from classes 147 to 151 and the data in Table 3 from classes 152 to 164. In Table 4 results of the entire group of Pensacola Aviation Cadets (classes 147 to 164) have been tabulated on the basis of standard scores.[6]

[6]A detailed description of the study from which these data were obtained may be found in: McFarland, R. A. and Fransen, R. The Pensacola Study of Naval Aviators. Final Summary Report. (To be issued shortly in the Technical Series Reports of the National Research Council Committee on Selection and Training of Aircraft Pilots.)

TABLE 2

THE DISTRIBUTIONS OF RAW SCORES IN THE TWO-HAND COORDINATION TEST FOR SUCCESSFUL AND UNSUCCESSFUL PENSACOLA AVIATION CADETS (Classes 147-151)

Part 1			Part 2		
Raw Score*	Successes	Washouts	Raw Score*	Good Pilots	Washouts Plus Board Appearances
26-31	4	--	26-31	4	--
32-37	12	--	32-37	9	3
38-43	19	--	38-43	19	--
44-49	46	1	44-49	38	9
50-55	71	4	50-55	68	7
56-61	67	5	56-61	63	9
62-67	55	13	62-67	48	20
68-73	34	7	68-73	28	13
74-79	14	5	74-79	12	7
80-85	9	3	80-85	9	3
86-91	4	--	86-92	3	1
92-97	2	1	92-97	2	1
N	337	39	N	303	73
Mean	58.02 ± .65	67.31 ± 1.57	Mean	57.93 ± .68	63.36 ± 1.41
Sigma	11.97 ± .47	9.76 ± 1.11	Sigma	11.86 ± .48	12.06 ± 1.00
Range	31.5 - 95.0	44.5 - 96.5	Range	31.5 - 95.0	33.0 - 96.5
Critical Ratio (Mean)		5.46	Critical Ratio (Mean)		3.48
Critical Ratio (Sigma)		1.83	Critical Ratio (Sigma)		0.18
Chi-Squared		P < .01	Chi-Squared		P < .01

*Low score indicates superior performance; data are based on the original apparatus.

It should be noted that the mean scores for Classes 147-151, on which Table 2 is based, are "better" than those of Classes 152-164, as given in Table 3. This may partially be accounted for by the fact that there were fewer officers from the Naval Academy and a larger number of enlisted men and cadets in the later classes. The officers tended to score better on all tests of the battery than did the cadets and enlisted men. Another possible cause, however, for this difference in the mean scores may have been the testing apparatus itself, since the original form, used in this study, had the defects noted above. In fact, it was due to the difficulties experienced in using the apparatus during the testing of the Pensacola groups which led to the development of the revised model of the apparatus.

TABLE 3

THE DISTRIBUTION OF RAW SCORES IN THE TWO-HAND COORDINATION TEST FOR SUCCESSFUL AND UNSUCCESSFUL PENSACOLA AVIATION CADETS (Classes 152-164)

Part 1			Part 2		
Raw Score*	Successes	Washouts	Raw Score*	Good Pilots	Washouts Plus Board Appearances
30-35	1	--	30-35	1	--
36-41	3	--	36-41	3	--
42-47	8	--	42-47	8	--
48-53	20	6	48-53	18	8
54-59	37	9	54-59	32	14
60-65	64	12	60-65	51	25
66-71	64	9	66-71	54	19
72-77	60	19	72-77	47	32
78-83	39	16	78-83	35	20
84-89	14	13	84-89	11	16
90-95	1	3	90-95	1	3
96-101	8	2	96-101	7	3
102-107	2	--	102-107	2	--
N	321	89	N	270	140
Mean	68.72 ± 0.66	73.31 ± 1.27	Mean	68.53 ± 0.74	72.00 ± 0.95
Sigma	11.88 ± 0.47	11.94 ± 0.90	Sigma	12.24 ± 0.53	11.28 ± 0.67
Range	31 - 105	50 - 98	Range	31 - 105	50 - 98
Critical Ratio (Mean)	3.21		Critical Ratio (Mean)	2.89	
Critical Ratio (Sigma)	0.06		Critical Ratio (Sigma)	1.13	
Chi-Squared	P = $<$.01		Chi-Squared	P = $<$.04	

*Low score indicates superior performance; data are based on the original apparatus.

The critical ratios between the mean scores of pilots who passed the flight training course at Pensacola (Successes) and those who failed are shown in Part 1 of each Table. In Part 2 both the Washouts and Board Appearances are combined and compared with the Good Pilots. All but one of the critical ratios between the means are above 3.00,[7] indicating that the

[7] A critical ratio of 3.00 indicates a highly significant difference between the measures of two distributions.

differences between the mean scores of the two groups were probably not due to chance fluctuations in random sampling. Likewise in all but one instance, the probability as shown by the chi-squared test, is less than 1 in 100 that the obtained differences in the two compared distributions are due to chance. In other words, there is a statistically significant displacement of the poor pilots toward the poorer scores. The critical ratios between the standard deviations (variability) in the comparisons shown in Tables 2 and 3 were not significant. In Table 4 (all classes combined) the critical ratios between the means of the successful and unsuccessful cadets are above 3.00, indicating that the probability that the difference between the means is due to chance is even less than when the data were divided into groups according to classes. The difference in variability, however, is not significant.

TABLE 4

THE DISTRIBUTION OF STANDARD SCORES IN THE TWO-HAND COORDINATION TEST FOR SUCCESSFUL AND UNSUCCESSFUL PENSACOLA AVIATION CADETS
(Classes 147-164)

Part 1			Part 2		
Standard Score	Successes	Washouts	Standard Score	Good Pilots	Washouts Plus Board Appearances
3.0	1	--	3.0	1	--
2.5	7	--	2.5	7	--
2.0	20	--	2.0	17	3
1.5	39	6	1.5	37	8
1.0	83	10	1.0	70	23
.5	135	16	.5	119	32
.0	131	14	.0	117	28
-.5	115	32	-.5	95	52
-1.0	73	23	-1.0	63	33
-1.5	28	18	-1.5	23	23
-2.0	10	6	-2.0	10	6
-2.5	12	2	-2.5	10	4
-3.0	4	1	-3.0	4	1
N	658	128	N	573	213
Mean	-.05 ± .04	-.46 ± .08	Mean	.07 ± .04	-.29 ± .07
Sigma	1.00 ± .03	.96 ± .06	Sigma	1.01 ± .03	.97 ± .05
Critical Ratio (Mean)	5.67		Critical Ratio (Mean)	4.50	
Critical Ratio (Sigma)	0.57		Critical Ratio (Sigma)	0.67	
Chi-Squared	P = <.01		Chi-Squared	P = <.01	

Table 5 shows the distribution of scores for 83 instructors at the U. S. Naval Air Station, Pensacola, Florida. The mean score for this

group is similar to that of the successful cadets in Classes 147-151. One might expect experienced instructors to make higher scores than the cadets who had only a few hours of flight training. The average age of the instructors, however, was approximately 10 years greater than that of the cadets, and it is well known that age is an important variable in tests of this nature. The advantages which the older pilots have in experience and judgment do not seem to outweigh the quickness of the younger men. The cadets were also highly motivated since they believed that their scores would contribute to their general standing at the Naval Air Station.

TABLE 5

THE DISTRIBUTIONS OF RAW SCORES IN THE TWO-HAND COORDINATION TEST OF THE PENSACOLA INSTRUCTORS

Raw Score*	
30-34	2
35-39	4
40-44	6
45-49	9
50-54	11
55-59	14
60-64	10
65-69	17
70-74	4
75-79	3
80-84	1
85-89	2
	83
Mean	58.22 ± 1.31
Sigma	11.92 ± .92
Range	32 - 87

*Low score indicates superior performance; data are based on the original apparatus.

B. Student Pilots in the Primary Course of the Civilian Pilot Training Program

Student pilots in the C.P.T. Program in the Boston area for both the academic years 1939-40 and 1940-41 were tested, the first group with the original form and the later groups with the revised apparatus. Table 1

includes the summary data on these groups. Table 6 presents distributions for "Good" and "Poor" pilots from the 1939-40 group. The criteria used in classifying the pilots as good or poor were based on a combination of time to solo and time to certification for a pilot's license. The good pilots soloed in less than 8.5 hours and the poor ones 9.5 hours or longer. The good pilots were certified in less than 36.5 hours and the poor ones obtained their certificates in 39.0 or more hours. The student pilots who fell between these two extremes are not shown in the distributions. In Table 7, the criteria for aptitude in flying were based upon instructors' ratings in flight training. The ability of each pilot was not made known to those giving the tests in the laboratory. In fact, the results obtained from the airport in regard to the flight tests and the data from the laboratory were not compared until the end of the study.

TABLE 6

THE DISTRIBUTIONS OF RAW SCORES IN THE TWO-HAND COORDINATION TEST FOR THE C.P.T. STUDENT PILOTS IN THE BOSTON AREA (1939-40)

Raw Score*	Good Pilots	Poor Pilots
15-19	1	
20-24	0	
25-29	0	
30-34	0	
35-39	2	
40-44	2	
45-49	7	1
50-54	4	0
55-59	4	2
60-64	2	6
65-69	3	3
70-74	1	6
75-79	1	3
80-84	1	2
85-89	1	
	29	23
Mean	55.09 ± 3.69	68.37 ± 1.76
Sigma	19.85 ± 2.61	8.43 ± 1.24
Range	18.0 - 89.0	48.2 - 82.5

Critical Ratio (Mean) 3.25
Critical Ratio (Sigma) 3.95
Chi-Squared P ≤ .01

*Low score indicates superior performance; data are based on original apparatus.

TABLE 7

THE DISTRIBUTIONS OF RAW SCORES IN THE TWO-HAND COORDINATION TEST FOR THE C.P.T. STUDENT PILOTS IN THE BOSTON AREA
(Spring 1941)

Raw Score	Good Pilots	Poor Pilots
80-84*	6	--
75-79	5	--
70-74	8	4
65-69	10	1
60-64	10	2
55-59	3	11
50-54	1	3
45-49	1	1
40-44	--	2
35-39	--	1
30-34	--	--
25-29	--	--
20-24	1	--
	45	25
Mean	67.95 ± 1.61	57.75 ± 1.82
Sigma	10.77 ± 1.14	9.11 ± 1.29
Range	24.0 - 82.7	38.4 - 74.2

Critical Ratio (Mean) 4.20
Critical Ratio (Sigma) 0.96

Chi-Squared P = <.01

*High score indicates superior performance; data are based on the revised apparatus.

The critical ratios of the differences between the mean scores shown in Tables 6 and 7 are 3.25 and 4.20 respectively. The chi squared test also showed that the differences in the distributions are not due to chance. In Table 6 the critical ratio between the standard deviations (variability) is significant, (3.95), but this is not true for the data presented in Table 7.

The correlations between the different trials of the test are shown in Table 8 for the Fall 1941 group of C.P.T.P. students in the Boston Area.[8]

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[8] Dr. P. S. Lawrence aided in the analysis of the data in Tables 2 to 7 inclusive, and Dr. Jack W. Dunlap in the analysis of the data in Table 8.

The reliability of the test, in terms of the correlation between trials, is not so high as might be desired for a test of this kind. This may be due to the fact that there is a considerable amount of learning involved in the test, as indicated by the gradual increase in the scores from the first trial to the sixth one. It is possible that the fairly low intercorrelations between trials might indicate that the speed of the movement of the target is too slow. Increasing the number of trials might give a higher reliability to the test as a whole.[9]

TABLE 8

INTERCORRELATIONS OF TEST SCORES OBTAINED FROM THE REVISED TWO-HAND COORDINATION TEST

C.P.T.P. Primary Students (Fall 1941)
(N = 108)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Mean 1-6	Lowest	Highest
Mean	41.3	48.7	54.3	56.3	58.0	60.8	53.3	36.4	66.6
Sigma	13.9	14.7	14.2	14.2	14.2	14.4	11.3	12.3	12.2
Trial 1		.49	.46	.38	.49	.37	.67	.79	.52
2			.55	.46	.57	.53	.77	.70	.67
3				.69	.70	.59	.84	.67	.75
4					.63	.54	.78	.65	.67
5						.74	.87	.66	.85
6							.80	.52	.88
1-6								.84	.92
Lowest									.67

[9] Editor's Note. In studies subsequent to the one described in this report test-retest correlations were obtained, using groups of C.P.T. students in the Boston area. The test-retest correlations, based on the mean of six trials, were .75 and .50, with N's of 98 and 88, respectively. Additional data on the reliability of this test will be available in the near future when the results of current research by K. W. Spence and C. E. Buxton at the State University of Iowa are presented. In this later study (1944) the Two-Hand Coordination Test (revised form) has been given for 30 successive trials in order to determine the characteristics of the learning curve and the maximum reliability of the test.

C. Flight Officers Training School Pilots (Northeast Airlines)

These subjects had completed the Primary, Secondary, Cross Country, and Instructor's Courses of the C.P.T. Program of the Civil Aeronautical Administration. They averaged 200 hours of flying time. The test was given as one of a series of aptitude tests as a basis for enrollment in the Flight Officers Training Course at the Northeast Airlines. None of the pilots had taken the test previously, and they understood that the results had some bearing on their being selected for the course. The mean score for this group on the revised apparatus was 61.6 (see Table 1). Twenty-nine pilots who applied for this course were disqualified both in flight tests and in aptitude and medical examinations. The mean score for this group was 55.3, or 6.3 points poorer than for the mean of the group in training. The critical ratio between these two means was 2.89.

SUMMARY

A brief description has been given of the development of a revised Two-Hand Coordination Test. The original Farmer-Chambers apparatus was modified by the introduction of a synchronous motor, a timer, and a microswitch in order to standardize the performance of the apparatus and to provide a more reliable scoring procedure.

The original and the revised forms were given to sample groups of subjects representative of various levels of training and experience. The means and standard deviations of these groups are presented. In comparisons where criteria of flight performance were available, statistically significant differences in test performance were exhibited by groups classified according to success in flight training programs.

Coefficients of intercorrelation among the six trials on the revised apparatus ranged from .38 to .74, and the mean score of the six trials correlated .78, .87, and .80 with the scores of Trials 4, 5, and 6, respectively.

APPENDIX A

INSTRUCTIONS FOR GIVING THE TWO-HAND COORDINATION TEST

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INSTRUCTIONS FOR GIVING THE TWO-HAND COORDINATION TEST

The following instructions and procedures should be followed very closely in order to obtain the most satisfactory results with the test. The experimenter should either memorize the instructions or read each step from a 3 x 5 inch card held in the palm of the hand. This will make certain that each candidate receives the same standard instructions.

1. A small rigid table and adjustable stool should be included as a part of the equipment for this test. Adjust the stool to the comfort of the subject as he places his hands on the handles of the machine. The subject should be seated at right angles to the table with the apparatus slightly displaced to his left so that he can manipulate the handles freely.

2. Give the following instructions: "This machine is designed to measure a subject's ability to make accurate and rapid coordinated movements with both hands simultaneously. You will notice that this machine contains two discs, an upper one and a lower one (point to them). Movements of the upper one can be controlled by turning the two handles. The right handle moves it to the right and left, and the left handle moves it to and from you, depending upon which direction the handles are turned (demonstrate for the subject). You see that by coordinating the movements of your two hands the upper disc can be located in any desired position above this circular platform. When the machine is started the lower disc will move around on the circular platform in an irregular pattern and at varying rates of speed. You are to turn the handles in such a way as to keep the top disc over the lower one as much of the time as possible. Notice the click between the contacts. This will indicate whether or not you are above the lower disc. You are scored on the percent of time that you maintain contact between the two discs. The higher the score, the better it is."

3. Allow the subject to see how the handles operate without turning on the machine. This should take about 30 seconds. Then say, "Now set the upper disc directly in the center of the lower one. Do you understand the instructions?"

4. "Are you ready?" Start the machine.

5. At the end of the first trial say: "That time you remained on the lower disc __ percent of the time. We are going to give you several trials on this test so try to better the score which you just made."

6. Give the subject six trials, telling him his score each time and briefly encouraging him to do better on succeeding trials.

APPENDIX B

TABLE OF STANDARD PARTS AND MANUFACTURERS

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TABLE OF STANDARD PARTS AND MANUFACTURERS

Name and Address of Mfr.	Name and Description of Part	Quantity Per Unit	Catalog No.
Standard Electric Time Co. Springfield, Mass.	60-sec. timer Dial-faced, calibrated in 100ths of a minute	one	S360
Holtzer-Cabot Electric Co. Boston, Mass.	Synchronous Motor	one	Type ROW1r.p.m.
Boston Gear Works Boston, Mass.	One pair miter gears	one pair	L110
Micro Switch Corporation Freeport, Illinois	Micro Switch, open	one	YZRQ1
" " "	Micro Switch, closed	one	BZRQ1