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WADC TECHNICAL REPORT 54-32

ADC034642

AN EXPERIMENTAL COMPARISON OF FIVE DIFFERENT ATTITUDE INDICATORS

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MAY 1954

WRIGHT AIR DEVELOPMENT CENTER

20050713145

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Aero Medical Laboratory

May 1954

RDO No. 694-31

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

McGregor & Werner, Inc., Dayton, Ohio
150 June, 1954

FOREWORD

The experiments included in this report were conducted by the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, under Research and Development Order No. 694-31, "Principles of Instrument Presentation," with Captain John F. Gardner as Project Engineer.

Prior to completion of the report Captain Gardner was assigned to overseas duty in 1951. The present report is largely the work of Captain Robert J. Lacey.

ABSTRACT

Two ~~studies~~ experiments were conducted in which five simulated aircraft attitude indicators, representing three different indicating principles, were compared. Two indicators were of the "earth reference" type, in which the moving element represented the horizon as on the conventional aircraft attitude indicator. Two indicators were of an "airplane reference" type, which presented aircraft rather than horizon movement. The fifth indicator provided a "stabilized sphere" type of presentation. Tests were made in a C-8 Link Trainer and records were made of (1) pilot performance for a variety of flight maneuvers, (2) control reversals following simulated rough air gusts, and (3) pilot preferences. Major interest centered around comparison of the "earth reference" and "airplane reference" principles of attitude indication, since these provide opposite directions of movement on the indicator.

For experiment #1 Each of the five indicators was flown by Air Force pilots, eight different pilots per instrument. ~~In addition,~~ two indicators representing the two opposed types, were flown by college students with no prior flight experience. The Air Force pilots used in this study were highly experienced on the earth reference type of indicator, and had not previously flown indicators using the airplane reference principle. For this reason, apparently, they made more aileron reversals on the airplane reference type indicators. In the pitch dimension, however, they made slightly, but not significantly, fewer control reversals on these indicators. Moreover, their preferences somewhat favored the unfamiliar airplane reference indicators. For the college students, both the control reversal and preference data favored the airplane reference principle.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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AN EXPERIMENTAL COMPARISON OF FIVE DIFFERENT ATTITUDE INDICATORS

I. INTRODUCTION

The need for an attitude indicator on the pilot's instrument panel has been recognized since the earliest days of flying. In the absence of the usual cues such as the pull of the earth's gravity, the sight of the earth's surface and horizon, or the pattern of surrounding clouds, the pilot needs some other source of information concerning the attitude of his aircraft with reference to the earth's surface. Although this information may be indirectly obtained by integrating the information presented by several separate instruments on the panel, this process is relatively slow and is susceptible to many different types of error. A single instrument specifically designed to provide attitude information, therefore, has become a standard requirement.

For many years the Artificial Horizon (A/H) (Figure 1-C) has been the accepted instrument for attitude indication. This instrument consists of a fixed element symbolizing the silhouette of an airplane and a movable bar behind it symbolizing the horizon. When this bar is aligned with the wings of the airplane, the aircraft is flying straight and level. If the bar appears above the airplane symbol, the

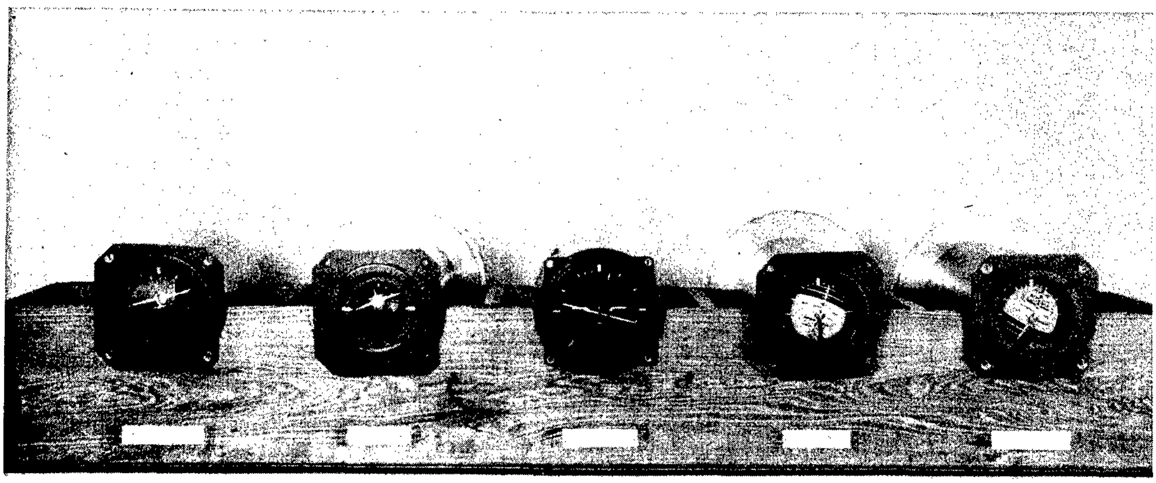

Figure 1: Five Experimental Attitude Instruments

aircraft is diving. If the bar is tilted to the left, the aircraft is in a right bank. These relationships are consistent with the appearance of the actual horizon through the wind screen of the aircraft but many additional cues, present in the visual field during contact flying, are not reproduced in the pictorial abstraction which the instrument represents. This latter fact has been suggested as one reason for the misinterpretations which often occur during training and later during moments when conditions allow only a quick glance at the instrument. This problem has been discussed at length by Grether (5) and by Fitts and Jones (3).

The basic problem of interpretation is evident in the data on reversal errors collected from field surveys (Fitts, et al., 2, 3) and laboratory studies by Brown (1), Gardner (4) and Loucks (6, 7). Pilots on occasion respond to the attitude indicator in exactly the opposite way from that in which they should respond. The explanatory hypothesis developed as a result of these data involves the relationship between control movements and indicator movements, and the significance assigned to the two elements of the indicator.

II. BACKGROUND

Attitude indicators typically consist of two basic elements; a movable element and a fixed element. Either of these elements may be designated as the external fixed reference and the other becomes the moving aircraft. If the movable element is designated as the aircraft, the indicator may be classed as the "airplane reference" type (Fitts, 3). If the movable element is designated as the horizon, the indicator is classed as an "earth reference" type. Research regarding these alternate principles is confined to two laboratory investigations.

In 1945, Browne of England and Loucks of this country both published reports which demonstrated some superiority of instruments that presented bank movements contrary to the standard A/H, (Figure 1). Both of these studies were done in simulated flight trainers with naive or partly naive students. Browne (1) compared subjects' performance in a flight trainer using the A/H indicator with their performance using an instrument that had a stationary horizon and a movable airplane that moved as the trainer moved. He found that there were significant differences in performance favoring the movable airplane display when compared on two accounts; time within a given degree of bank from the center point, and total area displacement of the trainer over a period of time. He also found that those subjects who were taught to use the moving airplane type of instrument required less instruction than those who were taught to use the standard instrument. These results support the hypothesis that it is more difficult to imagine yourself at a point in space looking out an imaginary porthole in the instrument panel at the horizon (earth reference) than it is to assume the cockpit as an environment and determine its movement by direct reference to the instruments (airplane reference). In the latter case no assumption has to be made, and the information presented is easier for the pilot to assimilate.

Loucks (7) went a little further than Browne in some respects and stopped short in others. He made five comparisons; (a) one copy of the standard A/H with another copy of the standard A/H, (b) the standard A/H with a modified A/H that had a moving scale rather than a pointer at top, (c) the standard A/H with a modified A/H that had no scale at top, (d) the standard A/H with a modified A/H that had a fixed scale at the bottom and (e) the standard A/H with a modified A/H that had the horizon bar moving in a direction opposite to the bar motion in the standard A/H. In all comparisons between the standard A/H and a modified A/H he found the standard A/H to be inferior. In comparison (e), where the bar movement of the standard instrument was reversed, he found significant differences favoring the reversed movement.

This again supports the above mentioned hypothesis. However, from the report it is not quite clear as to the degree of information each subject was given about the relationship of his instrument to the attitude of the trainer. It appears that the subject was asked to discover this relationship himself. This method, though it does uncover the movement relationship that is most readily assumed, is not a fair test of the operating differences of all instruments involved because it is quite important for one to understand the point of view he must adopt before he can do his best on the standard A/H.

One other point made by Loucks is of interest. He found that regardless of which instrument the subject used last, he preferred that instrument in most cases.

The lone exception was comparison (e), above. For the subjects of this comparison the first choice was invariably the reversed movement type instrument.

A third principle of indication utilizes the concept of a "stabilized sphere." This sphere is conceived as located either at the axial center of the aircraft or at some point in space ahead of the aircraft. The top and bottom halves of the sphere are of different colors. The plane of the dividing line between the two halves remains parallel to the earth's surface at all times. No systematic research is available concerning the interpretation problems presented by instruments using this principle.

Examples of all three indicating principles were included in the group of instruments selected for the present study. The experimentation was divided into two parts. The first part used experienced pilots and all five instruments. The second part used inexperienced college students and only two of the instruments. Where appropriate, the two parts of the experimentation will be discussed separately.

III. APPARATUS

A. General Design of Mock-up Instruments

For these experiments, five simulated instruments (Figure 1) were designed so that they would be interchangeable in a Link Trainer. Dr. Walter F. Grether suggested the designs and Link Aviation, Inc. developed the instruments. Each instrument was so constructed that it could be readily placed in the special C-8 Link Trainer (Figures 2 and 3) used for this experiment. All instruments had similar take-off mechanisms so that clock scores and graphic recordings could be made of the indications of the instrument. All the instruments were mechanically driven. Unfortunately, it was difficult in some cases to design the instrument so that adjustments for parallax could be made. However, in three of the instruments (Figure 1-C, D and E) parallax adjustments were possible. The over-all dial size of the instrument was limited by construction difficulties. Therefore, in some cases, the face design was smaller than 2 3/4 inches. All instruments were designed with the same sensitivity ratios for bank and pitch indications.

As stated above, the five instruments include examples of all three indicating principles. The "earth reference" principle is illustrated by the standard A/H (Figure 1-C) and the Reversed Pitch Stabilized Sphere (RPS/S) (Figure 1-E). The "airplane reference" principle is illustrated by the Semi-Three Dimensional Plane Type instrument (3D P/T) (Figure 1-A) and the Plane Type instrument (P/T) (Figure 1-B). The stabilized sphere principle is illustrated by the Stabilized Sphere (S/S) (Figure 1-D).

B. The Link Trainer

The Link Trainer used in this experiment was a modified C-8 (Figure 2). Modifications to this trainer were such as to enable graphic and time clock recordings of the attitude of the trainer, the indications of the various instruments and the positions of the various controls used to maintain the attitude of the trainer. These modifications were made by Link Aviation, Inc. Other slight modifications for rough air control were made at the Aero Medical Laboratory. Cords were attached to the rough air mechanism valves for bank and pitch, so that they could be manually operated to control the direction and amount of bank or pitch deviations.

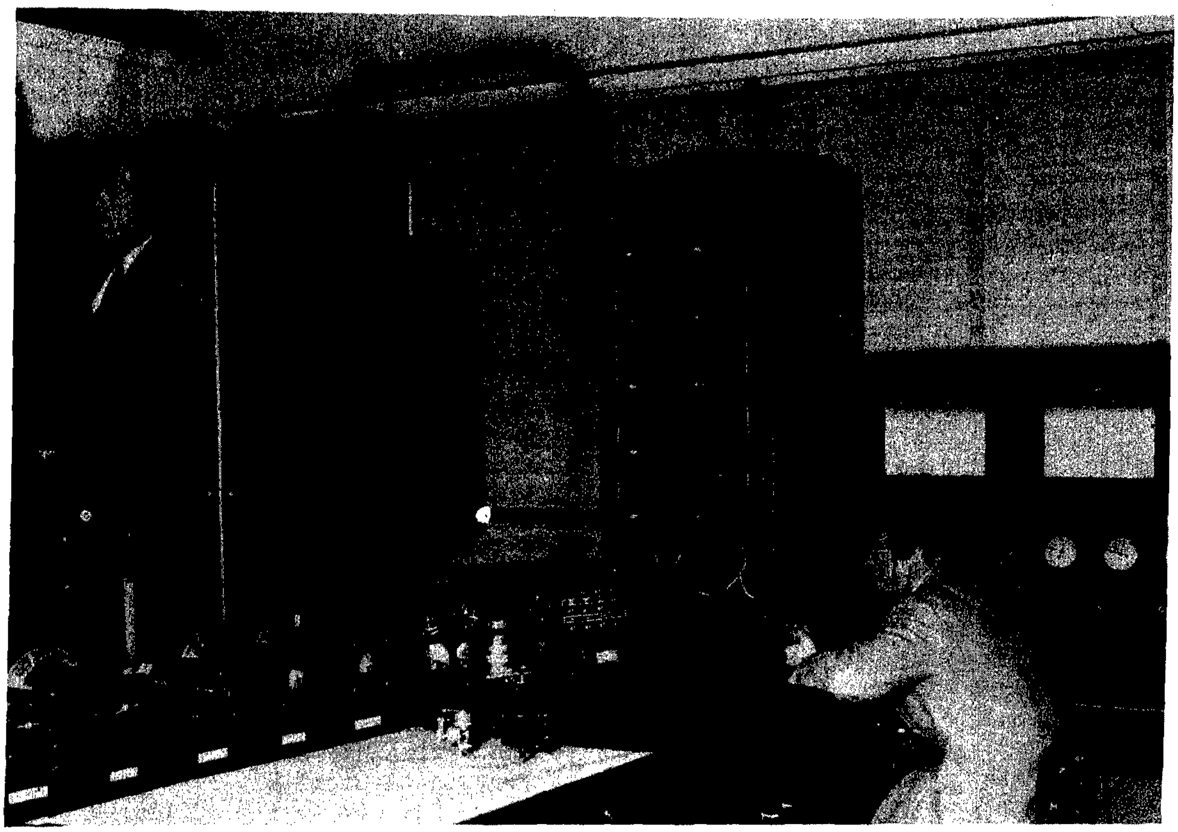

Figure 2: Special C-8 Link Trainer

C. Recording Equipment (Figure 3)

Two types of recording were available, graphic recording and time-clock scores. The graphic recording equipment which was used permitted the recording of 10 variables at any one time and a total of 14 variables. The time clocks permitted the recording of the time during which the subject maintained each of nine variables within prescribed limits or tolerances. The center value of the scoring range for each variable could be set in by means of a centering switch. The width of the scoring range could also be adjusted by means of a switch. The clocks ran only when the subject maintained his attitude, heading, airspeed, etc. within the tolerances prescribed by these settings. A master clock recorded total time of the recording period. A "simultaneous clock" could be connected in series to two or more of the variable clocks. This was accomplished by means of a separate switch for each of the single-variable clocks. The "simultaneous clock" ran only when all the clocks with which it was connected were running simultaneously.

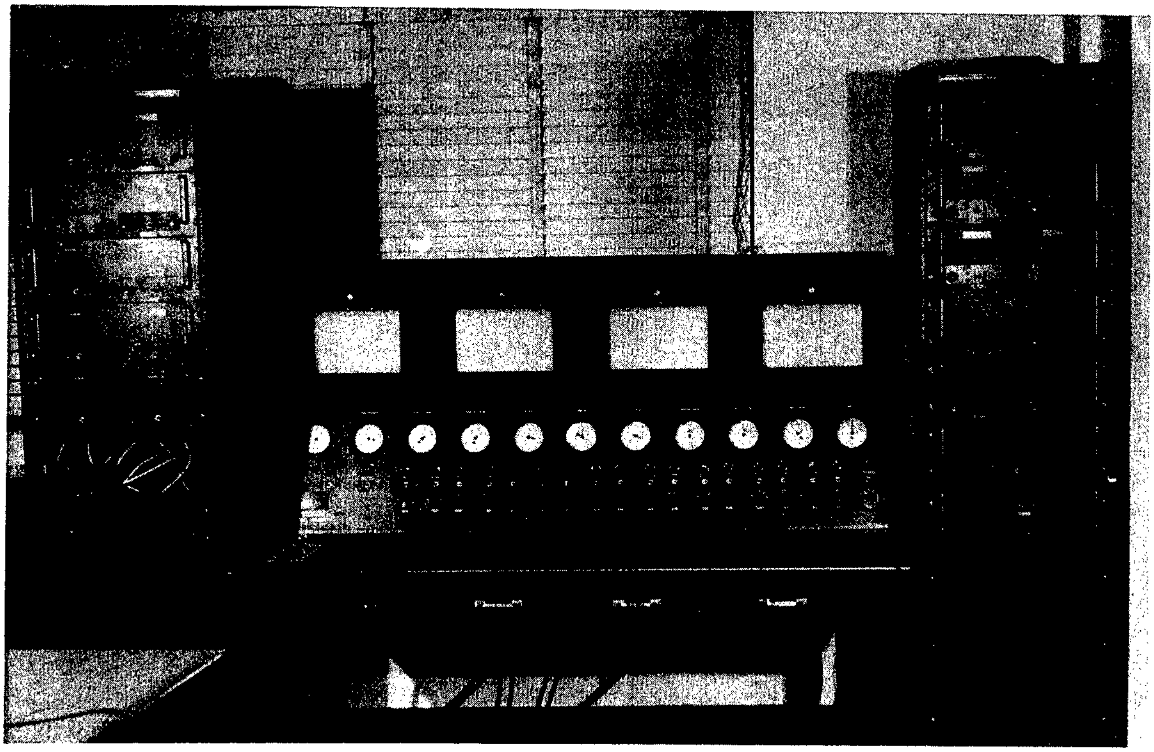

Figure 3: Scoring and Recording Console for Special C-8 Link Trainer

IV. EXPERIMENT NO. I

A. Purpose

The purpose of this experiment was to compare five attitude indicators, using experienced pilots as subjects. This comparison was effected by obtaining measurements of (a) general performance in terms of the proportion of time a prescribed attitude was maintained, (b) the number and types of reversals, and (c) pilots' preferences for the experimental instrument they used compared to the standard A/H.

B. Indicating Principles of the Mock-Up Instruments

In Figure 1 all five instruments indicate a climbing turn to the left. Reference to this figure will facilitate the understanding of the descriptions which follow.

The Semi-Three-Dimensional Plane Type Indicator (3D P/T) (Figure 1-A) is an airplane reference instrument. A cross section of a wing of an aircraft moves behind a pivoted cross section of the tail. These elements represent an aircraft seen from the rear. At the top of the dial there is a moving pointer which rotates to give the direction as well as the degree of bank. When a bank alone is made, three moving elements, the tail cross section; the wing cross section; and the pointer on top, all move in the same direction, the direction of the turn. For pitch indications, the cross section of the wing alone moves in a vertical plane. For climbs, the cross section of the wing moves up. For dives, the cross section of the wing moves down. This gives the relationship which would be apparent if the airplane were being viewed from the rear.

The Plane Type Indicator (P/T) (Figure 1-B) also uses the airplane reference principle. This instrument presents a rear view of a miniature airplane pivoted at a fixed point on a movable sphere. When the miniature airplane banks to the left it indicates the pilot's airplane is banking left. When the miniature airplane moves up with reference to fixed points on the side of the dial it indicates that the pilot's airplane is climbing. Painted on the movable sphere are the degrees of bank indications. The vertical stabilizer of the miniature airplane serves as a pointer to read the degrees of bank. Also painted on the sphere is an horizontal line aligned with the pivot point of the miniature airplane. This line is intended to facilitate pitch indications when the airplane is in a bank.

The standard Artificial Horizon (A/H) (Figure 1-C) is an earth reference instrument. The moving elements consist of a pointer at the top for degree of bank indications and a bar across the face for attitude indications. The fixed element consists of a symbol of an airplane at the center of the dial face. When the bar rotates to the right the pointer at the top also moves to the right, signaling a turn to the left. It is necessary to assume that the left wing of the fixed miniature airplane goes below the horizon bar for a turn to the left and that the pointer at top is an externally located point which moves to the right as the pilot's aircraft turns to the left, away from it. For pitch indications, the bar moves up for dives and down for climbs.

The Stabilized Sphere (S/S) (Figure 1-D) represents a sphere stabilized with reference to the earth's surface. Although its location may be considered as either at the axial center of the pilot's airplane or at a point in space ahead of the pilot's airplane, for purposes of the present experiment the latter viewpoint was used exclusively. When the midline which divides the top and bottom halves tilts to the right, the pilot's airplane is in a left bank. That is, the airplane symbol fixed at the center of the dial face must be seen as tilted to the left with reference to the midline of the sphere. When the midline of the sphere appears above the fixed airplane symbol, the pilot's airplane is in a climb - that is, it is approaching the sphere from below. It should be noted that the midline of the sphere acts in the same way for bank indications as the horizon bar in the A/H. However, for pitch indications the movement of the midline of the sphere is in exact opposition to the movement of the horizon bar in the Artificial Horizon.

The Reversed Pitch Stabilized Sphere (RP S/S) (Figure 1-E), as its name implies, is the S/S with the pitch indications reversed. This change necessitates a change in the concept of what the display represents. The midline of the sphere now represents the horizon and the concept of a sphere located at some point in space is no longer tenable. Bank and pitch indications are the same as those described for the A/H.

Bank markings are present and similar in degree on all five instruments. Only the S/S and the RP S/S, however, have scales for indicating degree of pitch.

C. Experimental Procedure and Subjects for Experiment 1

Eight subjects (S's) per instrument were used in Experiment 1. All the S's were Air Force pilots each with a minimum of 1500 hours total flying time and 150 hours instrument time. All pilots were students at the USAF Institute of Technology, Wright-Patterson Air Force Base, Ohio.

The experimental period was broken into two tests. The first test consisted of a period of straight and level flying followed by eight two-minute turns. During the entire period, the attitude of the aircraft was systematically upset at prescribed intervals. The second test was a period of straight and level flying through continuous rough air.

Before the experiment started, each S was given a clear explanation of the three different methods of presenting attitude information. Following this, explicit instructions were given concerning the instrument he was to use. No instructions were given to those S's using the A/H. After the instrument and its use were explained to S, he was permitted a five-minute trial run in the Link Trainer. During this run he was requested to make several turns and attempt to become as familiar with the instrument as possible. At the end of this period S was asked to level off at 2000 feet, 160 degree heading and 160 miles per hour. When this was accomplished, the testing procedure began.

The straight and level part of Test One lasted for 20 minutes and was broken into two ten-minute recording periods. During each recording period, 16 separate interruptions of the attitude of the Link Trainer were imposed. Graphic recordings during this straight and level period were made slightly before, during, and just after interruptions of the attitude of the Link. Altitude, bank, pitch, aileron position and elevator position were recorded. The graphic recording was intermittent in order to facilitate the isolation of the time and location of the attitude deviations (due to the rough air injections) and the responses made by the subject to these deviations. Deviations of the attitude of the Trainer were imposed approximately every 30 seconds. The Trainer was deviated by pulling cords attached to valves which vented the bellows of the Trainer. An equal number of "gusts" were distributed to the control surfaces in both directions for each S. The "gusts" were in irregular order. Time-within-limits was recorded for degree of bank, degree of pitch, heading, airspeed, vertical speed, and rate of turn. Time clocks operated continuously for 10-minute periods.

The turning part of Test One consisted of eight two-minute turns. The time clocks were run continuously for all variables except bank and rate of turn. The time clocks for bank and rate of turn were not operated during the roll into or during the roll out of the turn. Graphic records were kept only of the interruptions made during each turn. There were three interruptions of each turn: at one-half minute, at one minute and at one and one-half minutes. The turns were alternated left and right.

Test Two consisted of five minutes of continuous rough air. Graphic and time recordings were made of this entire five-minute period.

D. Results of Experiment 1

Periodic Graphic Records. The graphic records of aileron position and elevator position in this experiment were analyzed in terms of control reversals following sudden "gusts of rough air" (Test One) and in terms of deviation from prescribed values during "flight through continuous rough air" (Test Two). The systematic upset of the Trainer in Test One established a prescribed attitude deviation and thus required a corrective response in each instance. Control action in a direction opposite to the required response was labeled a reversal. The records were analyzed independently by two persons. The results of this analysis are presented in Table 1.

TABLE 1

Mean Number of Control Reversals Following Periodic Gusts* during Straight and Level Flight and 21 degree Turns in Smooth Air (Experiment I, Test One)

(n = 8 Ss per group)

Straight & Level Flight	Aileron	Elevator	21 degree Turns	Aileron	Elevator
A/H	2.00	1.12	A/H	2.12	0.90
RP S/S	2.62	1.00	RP S/S	1.57	0.75
S/S	3.25	2.50	S/S	2.25	1.00
P/T	6.00**	0.75	P/T	3.88	0.50
3D P/T	6.25**	1.25	3D P/T	2.68	0.50

* Total number of rough air injections:

a. Straight & Level Flight - Aileron 24, Elevator 24.
b. 21 degree Turns - Aileron 18, Elevator 18.

** Mean differences from A/H - 5% level of confidence.

It should be noted that the frequency of aileron reversals when using the A/H is smaller than when using the P/T or the 3D P/T under conditions of periodic gusts occurring during straight and level flight in smooth air. These are the only differences which are statistically significant in Table 1.

Continuous Graphic Records. The graphic records obtained under conditions of continuous rough air (Test Two) were analyzed by means of an analysis of variance performed on each of the following variables:

1. Average deviation of pitch.

2. Average deviation of bank.

3. Number of times bank exceeded 24 degrees.

4. Number of times bank crossed center position.

5. Number of times aileron crossed center position.

6. Number of times elevator crossed center position.

7. Average deviation of aileron position.

8. Average deviation of elevator position.

The only significant F-ratio was that for average deviation of pitch. A summary of the analysis is presented in Table 2A. Table 2B presents the results of significance tests between the instruments. It will be noted that the significant variance lies in the inferiority of the S/S results.

TABLE 2A

Analysis of Variance for Average Deviation in Pitch (Test Two)

Source	Sum of Squares	df	Variance Estimate	F
Within Groups	14.21	35	.41	
Between Groups	8.77	4	2.19	5.34**
Total	22.98	39	.59	

** Significant at the .01% level.

TABLE 2B

Means & Significance of Mean Differences for Average Deviation in Pitch (Test Two)

Means (in degrees)			Significance (P)*			
			P/T	A/H	3D P/T	S/S
PR S/S	2.50					
P/T	2.70	RP S/S	-	-	-	.01
A/H	2.89	P/T		-	-	.01
3D P/T	2.96	A/H			-	.01
S/S	3.86	3D P/T				.05

* Values shown here indicate the probability that these differences (between instruments) are due only to chance; thus, .01 = would happen by chance but once in 100 times; .05 = five times in a hundred times). The lower the value, therefore, the greater is the confidence that the differences did not occur by chance.

Clock Scores. The combined mean clock scores and the significance of the difference between these means are presented in Table 3. No significant difference between means was found under conditions of periodic gusts in smooth air. However, under rough air conditions, the mean clock score obtained with the S/S was significantly inferior to those obtained with the 3D P/T, the A/H, and the RP S/S. Also, the mean clock score obtained with the P/T was significantly inferior to that obtained with the RP S/S.

Opinion Questionnaires. As each S completed his portion of the experiment he was asked if he would prefer to use, under actual instrument conditions, the

TABLE 3

Mean Combined Clock Scores and the Significance of Mean Differences Obtained with Five Different Attitude Indicators under Three Conditions of Flight

(Time expressed in minutes)

Mean Combined Clock Scores

	Straight & Level Flight in Smooth Air with Periodic Gusts.	21 degree Turns in Smooth Air with Periodic Gusts.	Straight & Level Flight in Continuous Rough Air.
RP S/S	15.168	13.834	2.903
A/H	15.501	13.254	2.692
3D P/T	14.947	12.897	2.692
P/T	15.201	13.494	2.623
S/S	15.091	12.874	2.420
Maximum Possible	20.000	19.000	5.000

Significance of Mean Differences*

(Straight and Level Flight in Continuous Rough Air)**

	A/H	3D P/T	P/T	S/S
RP S/S	-	-	.05	.01
A/H		-	-	.05
3D P/T			-	.05
P/T				-

* Values shown here indicate the probability that these differences (between instruments) are due only to chance: thus, .01 = would happen by chance but once in 100 times; .05 = five times in a hundred times). The lower the value, therefore, the greater is the confidence that the differences did not occur by chance.

** None of the mean differences under conditions of smooth air with periodic gusts are significant.

experimental instrument with which he had just flown or the standard A/H. A tabulation of the answers is presented in Table 4.

TABLE 4

Pilot's Preference for the Various Instrument Types

Subject's Preference under Actual Instrument Conditions	Experimental Instrument Used				
	3D P/T	P/T	S/S	RP S/S	Total
Experimental Instrument	6	5	2	4	17
Standard Artificial Horizon	2	3	6	4	15

E. Discussion of Results -- Experiment 1

The results of this experiment seem to be interpreted most plausibly in terms of habit interference. All pilots who served as subjects had had extensive experience with the A/H. It is important, then, to note the differences between the movement relationships on the experimental instruments and movement relationships on the A/H. On the RP S/S there is no change in the relationships. The pilot simply needs to consider the dividing line between the upper and lower halves of the sphere as the same as the horizon bar on the A/H. However, on the S/S this is not true. Any tendency of the pilot to interpret the dividing line on the sphere as the horizon would cause him to misinterpret the true attitude of the airplane. Although the bank relationships are the same as on the A/H, the pitch relationships are just the reverse.

In the case of the airplane reference instruments (P/T and 3D P/T) a complete change of set is required. The relationships in both bank and pitch are reversed from those on the A/H. However, they are consistent with an "horizon-aircraft" concept. As displays, they appear quite different from the A/H and to that extent should cause less habit interference than if more similarities were present.

From the body of knowledge concerning habit interference, then, one would expect the A/H and the RP S/S to produce the best performance and the S/S to produce the poorest. Although the results are not as clear cut as would be desired, the differences which were found are consistent with the above expectation. The significant differences in the graphic records of Test One involve the superiority of the A/H (Table 1). The significant differences in the graphic records of Test Two involve the inferiority of the S/S (Tables 2A and 2B). The significant differences in the clock scores of Test Two again involve the inferiority of the S/S (Table 3). Performance on the RP S/S consistently compares favorably with that on the A/H.

These results suggest that the performance differences attributable to display differences existing between instruments must be obtained with naive S's; that the training which experienced pilots have received on a standard instrument masks the effects of display differences between experimental instruments when such pilots are used as S's. Experiment 2 compares the A/H with the P/T using naive S's.

V. EXPERIMENT NO. 2

A. Purpose

The purpose of this experiment was to compare performance on an airplane reference type attitude indicator with performance on an earth reference type. In order to avoid the masking effects of previous training, college students with no experience with flight attitude indicators were chosen as S's. An added purpose was the investigation of interference effects attendant upon a change of indicator types during training.

B. Indicating Principles of the Mock-Up Instruments

The two instruments used in Experiment 2 are those shown in Figures 1-B and 1-C. These instruments are, respectively, the P/T and the A/H described in Section III-B.

C. Experimental Procedure and Subjects for Experiment 2

The 20 S's used for this experiment were male college students at Antioch College, Yellow Springs, Ohio. All S's were naive in the sense that they had had no pilot experience and were unfamiliar with the instruments. Except for the above restrictions they were selected randomly from the college population. S's were reimbursed for the time spent participating in the experiment. Motivation in all cases appeared very high. Each S reported to the Aero Medical Laboratory on three different afternoons. The first day S was given preliminary instructions about the Link Trainer. This instruction period consisted of approximately 1 1/2 hours. The student was informed about the general principles of contact flying, given some theory of flight, and told how the Link Trainer was used as an instrument training mechanism. He was then allowed to use the Link Trainer with the hood removed so that he could maintain his attitude by reference to the room. During this preliminary period S was shown the correct way to make turns, the correct way to climb, to fly straight and level and to descend. He was shown how to roll into and out of turns. He was shown how to level off at a given altitude from either a descent or an ascent. During this period S was asked to pay particular attention to the appearance of the room, using his instruments as little as possible. The only instruments available to S during this period were the altimeter, air-speed indicator, and auxiliary engine instruments. S practiced the maneuvers in smooth and rough air. Each S received considerable individual attention so that his understanding of the way the Link Trainer should be flown was considered adequate. Questions were allowed and encouraged for all phases of the flying training.

Emphasis during this training period was placed upon maintenance of constant attitudes in relation to the room. S was taught to maintain a given altitude during level turns and during straight and level flight. To insure that the student had a proper understanding of the rate of turn and rate of climb and to facilitate the student's understanding of the use of the controls, he was asked to make timed maneuvers, i.e., standard rate turns, climbs, and descents. He was given ample instructions on procedures for making these various rate maneuvers and supervised closely to insure that he understood the instructions.

On the second afternoon, which usually followed the first by two days, the student was again given 1 1/2 hours preliminary training in the Link Trainer. The training during this period was very similar to the first day's training. However, more emphasis was put on precision of maneuver and use of the controls for maintaining exact attitudes. During this second training period, more emphasis was placed upon coordination of rudder, ailerons, and elevators and more emphasis was also placed upon acquiring a feel for the controls rather than being merely mechanical. Some of the phenomena of stability and torque characteristics were explained to the student so that as he acquired feel for the Link Trainer he would understand why certain control movements caused deviations in attitude. At the end of this second 1 1/2 hours of training S was readied for Test One of Experiment 2. He was given a thorough explanation of the attitude instruments he would be using. He was allowed to climb from 0 to 2000 feet using the attitude instrument, then allowed to make one 360 degree turn. During the climb and turn, the relationship of the instrument to actual environment was stressed. He was then instructed to level off at a given altitude. As soon as this had been accomplished the hood of the trainer was slid forward and the testing procedure began.

The main interest during Test One was in general flying proficiency with a given type of instrument. For this part of the experiment, the rough air was turned on a specified amount and S was told to maintain his attitude at a given altitude. His performance on this task was recorded, as in Experiment 1, both graphically and in terms of clock scores.

Test One was divided into five phases. These consisted of two five-minute straight and level periods and three two-minute turn periods. During all periods indicated pitch, indicated bank, indicated altitude, aileron movement, and elevator movement were graphically recorded. The time-within-limits for bank, pitch, vertical speed, rate of turn and altitude were recorded on the time clocks. The clock scores also indicated the time during which these variables were simultaneously maintained within limits.

After completing Test One, S was given a five-minute rest, although he remained in the Link Trainer. At the end of the five-minute rest period Test Two was begun. S was instructed to realign the airplane in a straight and level attitude at 2000 feet. He was then informed that the testing period to follow would consist of operating the Link in relatively smooth air but occasionally the experimenter was going to arbitrarily upset the attitude of the Trainer with an induced gust of rough air. At such times he was to right the airplane as rapidly as possible and continue with the assigned maneuver.

Test Two of Experiment 2 consisted of six phases. These were two five-minute straight and level periods and four two-minute turns. The variables recorded in Test Two were the same as those recorded in Test One. During Test Two, however, graphic recording was performed only just before, during, and just after the upsets of the Trainer, with the exception of altitude which was recorded continuously. At the completion of Test Two S was dismissed for that day.

On the third day, which usually followed the second day by one week, S was asked to participate in two more tests, called Tests Three and Four. Test Three was the same as Test Two, and Test Four was the same as Test One. However, S's using one type of instrument during the first pair of tests used the alternate type of instrument during the second pair of tests. Again, preceding the tests, S was given a thorough explanation of the instrument he would be using.

Assignment of the initial instrument which each S used was done in a random fashion. S's using the P/T first were designated Group I. S's using the A/H first were designated as Group II. Ten S's served in each group.

Following the completion of all four tests in Experiment 2 each S was asked to state which of the instruments he preferred and which of the instruments was more "natural".

D. Results of Experiment 2

Continuous Graphic Records. The results of analysis of continuous graphic records of altitude, bank, aileron position and elevator position taken during Test One and the continuous record of altitude during Test Two are presented in Table 5.

Table 5

Means and Significance of the Mean Differences for Measures of the Continuous Graphic Records

Measure	Mean PT_1	Mean AH_1	diff.	t	Measure	Mean PT_2	Mean AH_2	diff.	t
				Straight and Level Flight in Rough Air N=20 (n=10 Ss Per Group)					
C_1	65.40	101.10	32.047	1.114	C_1	39.00	54.00	18.900	.794
C_2	6.52	6.11	.984	.470	C_2	6.47	5.83	.897	.713
C_3	3.30	5.20	1.522	1.248	C_3	2.60	2.90	1.282	.234
C_4	137.50	131.50	20.001	.291	C_4	139.50	148.90	16.742	.561
C_5	107.70	126.50	16.697	1.126	C_5	106.90	105.90	12.629	.079
C_6	54.50	55.50	15.057	.060	C_6	52.20	55.50	9.870	.334
C_7	4.52	5.11	.396	1.490	C_7	4.29	5.41	.728	1.538
C_8	1.79	1.29	.177	2.825*	C_8	1.71	1.75	.250	.160
		df = 18					df = 18		
				21 degree Turns in Rough Air					
C_1	78.40	176.60	33.645	2.919**	C_1	87.30	61.00	31.512	.835
C_2	7.65	9.62	1.230	1.599	C_2	6.19	5.74	.941	.475
C_3	--	--	--	--	C_3	--	--	--	--
C_4	1.80	4.50	.943	2.863*	C_4	1.20	2.50	.945	1.376
C_5	43.80	46.80	6.503	.461	C_5	39.70	43.30	3.986	.903
C_6	25.70	18.00	4.361	1.766	C_6	18.40	22.50	3.776	1.086
C_7	5.13	5.77	.389	1.645	C_7	4.72	5.42	.457	1.532
C_8	1.42	1.12	.178	1.685	C_8	1.33	1.77	.337	1.306
		df = 18					df = 17		
				Straight and Level Flight in Smooth Air					
C_1	32.20	52.40	15.300	1.320	C_1	34.80	33.00	8.600	.209
		df = 18					df = 18		
				21 degree Turns in Smooth Air					
C_1	47.60	97.50	20.40	2.446*	C_1	41.40	45.10	11.70	.316
		df = 18					df = 18		

* Significant beyond the 5% level.
** Significant beyond the 1% level.

Analytical measures used:

- C_1 - Average deviation of pitch.
- C_2 - Average deviation of bank.
- C_3 - Number of times bank exceeds 24 degrees while flying straight and level.
- C_4 - Number of times the bank indicator crossed the zero position.
- C_5 - Number of times the aileron control crossed the center null position.
- C_6 - Number of times the elevator control crossed the center null position.
- C_7 - Average deviation of the aileron position.
- C_8 - Average deviation of the elevator control position.

The measures used in the analysis are essentially the same as those used in Experiment 1 and are listed at the bottom of Table 5. In this table and the tables to follow, the mean values are distinguished by a label indicating the instrument and a subscript indicating whether the instrument was used first or second. Thus, AH_2 indicates that the data were gathered from S's using the A/H and that the A/H was the second instrument they used. Records taken during straight and level flight are treated separately from records taken during 21 degree turns.

It will be noted that only one analytical measure (average deviation of elevator position) produced a significant difference in the straight and level flight records. This difference occurred between performances of the two groups on the first instrument used and showed a smaller average deviation in elevator position for the group using the A/H.

The only significant differences in the 21 degree turns data also occurred between performances on the initial instrument assigned. Average deviation of altitude during 21 degree turns showed a significant difference both during continuous rough air and during smooth air with periodic "gusts". In both cases the average deviation in altitude is smaller for the group using the P/T. In addition, the mean number of times the bank indicator crossed the zero position during 21 degree turns in continuous rough air was significantly smaller for the group using the P/T.

Clock Scores. Table 6 presents the mean clock scores for five variables obtained by the two groups under four conditions of flight. As may be seen from the table, the mean differences were not large and did not consistently favor either instrument. The following analyses of variance were performed for each of the four flight conditions:

1. P/T vs A/H for Group I.
2. P/T vs A/H for Group II.
3. First instrument for Group I vs first instrument for Group II.
4. Second instrument for Group I vs second instrument for Group II.
5. P/T vs A/H for both groups combined.

No significant differences were found.

Periodic Graphic Records. The periodic graphic records taken during Test Two allowed an analysis of performance in terms of control reversals. That is, the effect of Trainer attitude of each systematic "gust" was known and therefore the correct response was known. The same procedure for detecting reversals was used in Experiment 2 as was described in Section III for Experiment 1. Only aileron control reversals were analyzed. The results of this analysis are presented in Table 7.

Opinion Questionnaires. The results of the questionnaire completed by each S after all phases of the experiment had been conducted are presented in Table 8. It is noted that 18 of the S's indicated that they preferred the Plane Type instrument and 19 S's thought that the Plane Type instrument had the most natural indication. The two S's in Group II who preferred the standard instrument but thought that the Plane Type instrument was more natural explained their preference in terms of the

Table 6

Mean Clock Scores (in minutes) for Five Variables Using the P/T and the A/H under Four Conditions of Flight*

Straight and Level Flight
(Maximum score possible = 5.000)

Variable	Continuous Rough Air				Periodic Gusts in Smooth Air			
	PT_1	AH_1	PT_2	AH_2	PT_1	AH_1	PT_2	AH_2
Bank	1.311	1.333	1.521	1.523	2.873	3.225	2.874	3.299
Pitch	1.510	1.549	1.827	1.868	1.945	2.416	2.581	2.165
Altitude	3.153	2.484	3.465	3.546	4.226	3.653	3.917	4.065
Vertical Speed	1.136	.979	1.199	1.223	1.441	1.367	1.442	1.428
Rate of Turn	2.974	3.007	3.198	3.215	4.295	4.442	4.289	4.422

21 degree Turns

(Maximum score possible = 2.000)

Variable	Continuous Rough Air				Periodic Gusts in Smooth Air			
	PT_1	AH_1	PT_2	AH_2	PT_1	AH_1	PT_2	AH_2
Bank	.480	.445	.545	.674	.921	1.049	.901	.980
Pitch	.672	.514	.689	.640	.800	.932	.929	.874
Altitude	.947	.374	1.229	1.257	1.412	.982	1.345	1.458
Vertical Speed	.442	.321	.477	.408	.594	.574	.562	.607
Rate of Turn	.450	.324	.614	.510	.670	.720	.835	.601

* Group I used P/T first (PT_1) and A/H second (AH_2)
Group II used A/H first (AH_1) and P/T second (PT_2)

relative size of the two instruments. The Plane Type instrument used in this experiment is somewhat smaller than the standard instrument. It is interesting to note that the type of instrument used first did not affect the S's preference.

TABLE 7

Mean Number of Aileron Reversal Errors and Significance of Mean Differences Obtained under Conditions of Periodic Gusts in Smooth Air*

	Straight and Level Flight					21 degree Turns				
	Mean PT	Mean AH	t	df	P	Mean PT	Mean AH	t	df	P
Group I	1.5	3.8	2.447	9	.05	1.7	5.1	4.146	9	.01
Group II	3.5	4.5	1.299	9	---	1.9	2.2	0.577	9	---
First Instrument Used	1.5	4.5	3.448	18	.01	1.7	2.2	0.649	18	---
Second Instrument Used	3.5	3.8	0.263	18	---	1.9	5.1	3.556	18	.01
Groups I and II Combined	2.5	4.1	2.787	19	.05	3.6	7.3	3.051	19	.01

* Group I used P/T first and A/H second.
Group II used A/H first and P/T second.

TABLE 8

Preference of Naive S's for P/T and A/H

	Group I	Group II	Total
S's preferring Plane Type	10	8	18
S's preferring standard Artificial Horizon	0	2	2
S's who considered Plane Type more natural	9	10	19
S's who considered standard Artificial Horizon more natural	1	0	1

E. Discussion of Results - Experiment 2

There is little more consistency in the results of Experiment 2 than was found in the results of Experiment 1. The continuous graphic records and the clock scores provide no basis for a sound differentiation between the two instruments. However, the periodic graphic records which were analyzed for aileron control reversals show results which are consistent with an explanation based on the interaction of two independent effects. This explanation involves two assumptions: (1) the P/T is a better instrument to use in this task and (2) practice in this task reduces the number of reversals. In the case of straight and level flight the performance during the first practice period shows a significant difference in favor of the P/T. The combined results of the two groups also show a significant difference in favor of the P/T. These results support the first assumption. Use of the second assumption explains the lack of a significant difference between performances during the second practice period. The improvement which practice whould have made for Group I is cancelled by the detrimental effect of using the A/H. For Group II the effects of practice and using the P/T are in the same direction and result in improvement.

In the case of the 21-degree turns the results are similar and the same explanation may be utilized. It should be noted that the performance of the two groups shows no significant difference during the first practice period. However, during the second practice period the detrimental effect of using the A/H counteracts any improvement from practice for Group I, whereas for Group II the effects of practice and of suing the P/T supplement each other. A significant difference favoring Group II therefore develops.

The results of the questionnaire show a clear cut preference for the Plane Type instrument.

VI. DISCUSSION OF METHODS OF RECORDING PILOT PERFORMANCE

The recording methods used in this study were generally disappointing in the degree to which they discriminated between pilot performance using the different types of attitude indicators. Both the clock recordings (of time within tolerance) and detailed analysis of the graphic records showed surprisingly little effect from changes in method of attitude indication. The most reasonable explanation for this appears to be that this indicator was only one of the total group of instruments used in flying the Link Trainer. Considering the total task of flying the trainer, a change in only one instrument in the total complex apparently had little effect on over-all performance. In contrast, the control reversals appeared to be more discriminative, probably because they were more closely related to misreading of the attitude indicator. If this analysis is correct, it suggests that for instrument studies of this type recording of over-all performance is not likely to be as useful as more selective recording of those aspects of performance directly related to the instrument under study.

The experimenter, Captain Cardner, noted an additional difficulty in the clock recording of the time that variables were held within selected tolerances. In order to avoid very nearly 100% time within tolerance, it was necessary to use very narrow tolerance ranges. This made it possible for the pilot to be just outside the tolerance range for some measure while otherwise performing very well. As a result he might obtain a lower score than a less skillful pilot who oscillated through the tolerance range. For this reason, it was believed that the clock scores did not give a valid indication of the quality of flight performance. It would appear that further research is needed to develop better methodology for this type of study.

VII. CONCLUSIONS

The results of Experiment 1 and 2 are generally in agreement with prior studies by Browne (1) and Loucks (7) which demonstrated superiority of the airplane reference instrument over the standard A/H. Although the results and the statistical differences are not conclusive, there is a definite tendency toward superior performance using an airplane reference instrument.

Results of a questionnaire completed by each subject show that a majority of pilots and non-pilots participating in the experiments preferred the airplane reference method of attitude presentation and considered this more natural than the conventional earth reference method of indication.

BIBLIOGRAPHY

1. Browne, R. C. Trial of two attitude indicators. FPRC 611 and 611A, 1945.

2. Fitts, P. M. & Jones, R. E. Analysis of factors contributing to 460 "pilot error" experiences in operating aircraft controls. USAF Air Materiel Command Memorandum Report No. TSEAA-694-12, 1 July 1947.

3. Fitts, P. M. & Jones, R. E. Psychological aspects of instrument display. I: Analysis of 270 "pilot error" experiences in reading and interpreting aircraft instruments. USAF Air Materiel Command Memorandum Report No. TSEAA-694-12A, 1 October 1947.

4. Gardner, J. F. Direction of pointer motion in relation to movement of flight controls. Cross pointer type instrument. USAF Air Materiel Command Technical Report No. 6016, June 1950.

5. Grether, W. F. Discussion of pictorial vs symbolic aircraft instrument displays. USAF Air Materiel Command Memorandum Report No. TSEAA-694-8B, 4 August 1947.

6. Loucks, R. B. An experimental study of the effectiveness with which novices can interpret a localizer-glidepath approach indicator. USAF Air Materiel Command Technical Report No. 5959, October 1949.

7. Loucks, R. B. Evaluation of aircraft indicators on the basis of Link Instrument Ground Trainer performance. 27th Air Force Base Unit, Randolph Field, Texas, Project No. 341.