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ARMY AIR FORCES
HEADQUARTERS, AIR MATERIEL COMMAND
ENGINEERING DIVISION

TSEAA-6:WFG:meo

MEMORANDUM REPORT ON

DATE: 2 September 1947

SUBJECT: The Effect of Variations in Indicator Design Upon Speed and Accuracy of Altitude Readings.

SECTION: Aero Medical Laboratory

SERIAL NO. /TSEAA-694-14

Expenditure Order No. 694-26

## A. PURPOSE.

1. This experiment was carried out in order to find improved methods of indicating altitude and similar information which requires very great scale length for sufficiently precise presentation.

## B. FACTUAL DATA.

2. A pilot interview study carried out previously by the Psychology Branch of the Aero Medical Laboratory (Memorandum Report No. TSEAA-694-12a) indicated that reading errors of 1,000 feet or more occur very frequently in reading of the conventional altimeter. Most of the reported reading errors were 1,000 feet too high, and in several instances resulted in collision with the ground.

3. Appendix I reports in detail an investigation which determined the speed and accuracy of altitude readings from nine experimental indicator designs, including the conventional altimeter. Printed test booklets presented twelve settings on each of the nine indicators. These test booklets were administered to 97 AAF pilots in the Instrument School at Barksdale Field, Louisiana and to 79 college students at Denison University, Granville, Ohio.

4. The conventional altimeter was found to be a very difficult instrument to read. Even AAF pilots who had spent several years flying by this instrument required 7.1 seconds interpretation time to read all three hands, and 11.7 percent of their readings were in error by 1,000 feet or more. Of the pilots, 70.1 percent made at least one error in reading the 12 different settings of the conventional altimeter.

5. All experimental indicators which involved a combination of pointers (or pointers and non-intermittently rotating dials) were very difficult to read.

6. The indicators which were easily read were: (a) a sensitive pointer and Veeder type counter combination; (b) a moving vertical scale and counter combination (c) a long moving vertical scale; and (d) a direct reading counter.

C. CONCLUSIONS.

7. The following conclusions are drawn from this investigation regarding design features of multi-revolution instruments in relation to speed and accuracy of readings

a. The conventional altimeter and similar multiple-pointer instruments are very difficult to read. Not only is the time for reading such instruments very long, but a considerable proportion of the readings are in error by one or more complete revolutions of the sensitive pointer.

b. The ease with which multi-revolution instruments can be read is greatly increased by the use of a Veeder type counter instead of supplementary pointers to indicate the number of revolutions of the sensitive pointer.

c. A very long vertical scale moving behind a window, or a repeating vertical scale combined with a counter, is relatively easy to read quantitatively (but may be less desirable for check-reading than a moving pointer).

d. Part of the difficulty in reading multiple-pointer (or multiple-dial and pointer) instruments results from the necessity of combining mentally several separate indications. The difficulty in reading is proportional to the number of such separate indications to be combined.

e. Additional difficulty in the reading of multiple-pointer instruments results because the non-sensitive pointers (1,000- and 10,000-foot pointers on the altimeter) must often be read not to the number toward which they are pointing but to the next lower number. Which number is to be read can be determined only by simultaneous consideration of the position of the more sensitive pointer in relation to the zero point on the scale. This difficulty can probably be overcome only by intermittent motion on the moving pointers, dials, or counters which indicate the number of revolutions of the sensitive pointer.

f. Bearing in mind the reading requirements of an altimeter for use by the pilot, the combination of a sensitive pointer and counter offers the most promise. Such an indicator should, however, have the counter displaced approximately 90 degree from the zero position on the scale to prevent its being obscured by the pointer in its most common position.

D. RECOMMENDATIONS:

8. On the basis of the findings of this experiment the following design features are recommended for altimeters and other sensitive or multi-revolution instruments:

a. A single sensitive pointer with a Veeder type counter for indicating the number of completed pointer revolutions above zero.

b. Intermittent motion of the counter during a very small angular excursion of the sensitive pointer.

c. Digits on the counter of a size adequate for legibility under all operational night lighting [illegible].

d. Location of the counter where it will not be obscured by the sensitive pointer in its most common position during flight (zero position on the altimeter).

9. It is recommended that the following actions be taken by the organizations indicated:

a. That the Instrument and Navigation Branch of the Equipment Laboratory apply the above design recommendations in future development and service testing of pressure altimeters.

b. That the Fire Control Branch of the Aircraft Radiation Laboratory apply the above design recommendations in future development and service testing of absolute or radio altimeters.

c. That the above two organizations coordinate their respective designs in order to insure adequate visual differentiation between the two types of altimeter, and thus prevent potential confusion between the two instruments.

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APPENDIX I

**The Effect of Variations in Indicator Design Upon Speed and Accuracy of Altitude Readings**

## A. Introduction.

In a study recently carried out by the Psychology Branch of the Aero Medical Laboratory and reported in Memorandum Report No. TSEAA-694-12a, AAF pilots were asked to report personal experiences in misreading of instruments during flight which resulted or might have resulted in accidents. Of the 270 cases of instrument reading errors reported in this study, there were more involving the altimeter (37 cases) than any other single instrument. In the majority of the reported cases the altimeter was read 1,000 feet too high. In the typical instance the pilot approaching an airfield at night or under instrument conditions reported suddenly seeing the ground or trees uncomfortably near, while under the impression (from reading the altimeter) that he was still 1,000 feet above the ground. In several such cases collision with the ground resulted.

The frequency with which altimeter misreadings have caused near accidents and non-fatal accidents suggests that at least some of the more serious unexplained crashes have been caused by this same type of human error. In a number of cases, notably the loss of the Pennsylvania Central Airlines DC-4 at Leesburg, Virginia, on June 13, 1947, misreading of the altimeter offers a plausible explanation. The actual occurrence of such an error can, of course, be verified only by circumstantial evidence unless the pilot survives and can recall events preceding the crash.

The greater difficulty experienced in reading the altimeter by comparison with other aircraft instruments apparently arises from the fact that the readings of three separate pointers must be combined in order to obtain the desired information. On the majority of aircraft instruments one revolution of a pointer on a circular dial (of 2 3/4 inches or smaller diameter) gives sufficient scale length to provide the needed reading precision. The altitude range in which conventional aircraft operate (roughly 0 to 40,000 feet) cannot possibly be covered in sufficiently small steps in one revolution of a pointer on a dial of conventional size. To gain sufficient scale length on the conventional altimeter the primary (or sensitive) pointer indicates altitude in hundreds of feet, and makes one revolution in 1,000 feet change of altitude. The other two pointers, which indicate altitude in thousands and ten-thousands of feet, serve primarily to indicate the number of revolutions which the primary pointer has made above zero altitude.

The altimeter is not the only sensitive or multi-revolution instrument used in aircraft. The clock is another such instrument, and an earlier investigation by the Psychology Branch of the Aero Medical Laboratory (Memorandum Report No. TSEAA-694-8) has shown that it also is subject to a considerable number of errors in reading. A number of other instruments, notably the tachometer and airspeed indicator, have been built with more than one revolution of the primary pointer and a supplementary indication (in a window) to indicate the number of the revolution in which the pointer is operating. A number of fatal accidents have been attributed to incorrect engine settings resulting from misreadings of this type of tachometer, and for this reason it is being withdrawn from use. Errors in reading the sensitive or multi-revolution airspeed indicator have also been reported.

It would seem from the foregoing evidence that an instrument on which two or more separate indications must be combined in order to obtain a single quantitative value is particularly conducive to reading difficulty and errors. Moreover, the types of reading errors reported are usually of dangerous magnitude, such as 1,000 feet of altitude, 1,000 revolutions per minute, or 100 miles per hour. For these reasons it would seem to be particularly important to find the optimum methods of displaying types of information which require greater scale length than can be displayed by one pointer revolution.

In the present investigation the readability was investigated of nine possible methods of displaying altitude data. This experiment was not only carried out to find means of reducing altimeter reading errors but also to find out which display methods, in general, are best suited for use where considerable scale length is required.

In a recent Aero Medical Laboratory Report (Memorandum Report No. TSEAA-694-8b) it was pointed out that aircraft instruments serve three types of reading functions: (1) check reading - for assurance of a null, normal, or desired indication; (2) qualitative reading or interpretation - for the meaning of a deviation from a null or normal condition; and (3) quantitative reading - for the actual numerical value of an indication. In the case of the altimeter, specifically, we can say that the pilot may (1) merely check the instrument to find whether or not the reading has changed since his last glance at the instrument; (2) observe the direction and magnitude of pointer displacement if a change has occurred; or (3) read the instrument in detail to find his exact altitude in feet. In normal flying the pilot probably uses the altimeter most frequently for the first two types of reading. During ascents and descents, particularly under instrument conditions, the third type reading for exact quantitative information must be made. The method of evaluating altitude indicator designs in this experiment is considered to provide data only for the third of the above three types of reading.

This report is concerned primarily with a comparison of the speed and accuracy with which different altimeter designs can be read. A subsequent report will present a detailed analysis of the types of error made in reading the conventional altimeter in the present experiment.

B. <u>Experimental Procedure.</u>

The nine altitude indicator designs used in this experiment are shown, along with some of the results, in figure 2. The first of these, design A, is a simulation of the altimeter almost universally used in AAF airplanes. On this instrument the longest pointer gives readings in hundreds of feet, the broad pointer is read on the same scale in thousands of feet, and the small pointer is read on the same scale in ten-thousands of feet. Altimeter design B is a slight variant of the common instrument, and also simulates an existing type. In this design the small 10,000-foot pointer is offset and indicates on a separate scale. Design C also simulates an existing but not commonly used type, in which only two pointers are used, each indicating on a separate scale. This two-pointer design indicates only up to 20,000 feet of altitude.

Altimeter design D uses a single pointer to indicate altitude in hundreds of feet. This pointer makes one revolution for each 1,000 feet change in altitude and the multiples of 1,000 feet are indicated on a Veeder counter type display. This counter has two drums, one for 1,000 foot and the other for 10,000 foot increments. It is assumed that the motion of these drums would be intermittent and that single whole numbers would always be showing.

In design E, also, only one pointer is used, but two dials rotating behind a window indicate the multiples of 1,000 feet. In this design the motion of the dials showing through the window is assumed to be continuous rather than intermittent, thus permitting more than one number (or half numbers) to appear.

Design F indicates altitude in quite a different manner from the other instruments. In this display the pointer is assumed to make only one revolution to cover the entire altitude range. The range being covered is indicated in the window as 0 - 1,000 feet, 0 - 10,000 feet, or 0 - 100,000 feet. The meaning of the numerals on the dial graduations is, therefore, determined by the range indicated in the window. This indicator is similar in principle to a radio altimeter now in use. It is obvious that the precision of indication on such an instrument decreases as the range being covered increases.

Altimeter designs G and H are similar in that they simulate a scale moving vertically behind a window. An instrument following design G could use either an endless tape or drum to present the moving scale, with a Veeder counter to indicate multiples of 1,000 feet. An instrument using design H would require a very long tape with a scale covering the desired altitude range.

The last experimental design, I, simulates a simple Veeder counter without any moving pointer or scale. For reasons pointed out later in the discussion of results, such an indicator would probably be unsatisfactory for the pilot, but might be suitable for other aircrew members such as the navigator. One of the major reasons for including it in this study was to get an approximate measure of the time required to copy a series of numbers representing an altitude reading, it being assumed that no interpretation time would be involved in reading altitude from this type of indicator

For each of the altimeter designs used in this experiment a test booklet was prepared. Pages 1 and 2 of the test booklet for design A, the conventional altimeter, are reproduced in figure 1. The cover (page 1) of each booklet presented the experimental subject with detailed instructions for reading the dial design in that booklet, and a sample dial on which to obtain practice. On the two inside pages, 2 and 3, the dial design was reproduced with 12 different settings. Under each picture was a space for writing in the reading.[1]

Special precautions were taken in the preparation of the drawings and choice of altitude settings to be used in the various test booklets to prevent biasing the results for or against any of the indicator designs. The circular dials were 2 1/4 inches in diameter. From this, other dimensions can be estimated from figure 2. All essential numerals and graduation marks were sufficiently large and distinct to be easily legible. Except for the inner dials on designs B and C all scales were alike in having numerals at all 100-foot graduations with intervening marks at 20-foot intervals. Other factors equalized were the number of settings above and below 10,000 feet, the number of sensitive pointer settings on 100-foot graduation marks, the number of sensitive pointer settings just preceding and just following the 1,000-foot graduation mark, and the number of sensitive pointer settings on the left and right halves of the dial. Precautions were also taken to be sure that no essential information was hidden by any of the hands, and that the interrelationships between pointer positions were correct. For indicator design F some of the settings were midway between graduation marks. For the remaining designs the sensitive pointer (or reference mark) was always on a graduation mark. Thus, no interpolation was required to obtain correct readings.

The altimeter reading test was taken by 97 AAF pilots in the Instrument School at Barksdale Field, Louisiana, and 79 college men (without AAF aircrew experience) at Denison University, Granville, Ohio. In administering the test, the booklets for only one altimeter design were passed out at a time, and sufficient time allowed for reading the instructions and working the sample item. At a signal all subjects opened the booklet and worked until completing all items. Each subject's completion time was recorded on his booklet. Four sequences for administering the nine test booklets were used in order to counterbalance for learning effects. An approximately equal number of subjects (in each of the two subject groups) took the test in each sequence.

The two subject groups of dissimilar experience were used in order to get some measure of the effect of experience on the ability to read the various dial designs. All of the AAF pilots can be assumed to have spent several years flying with altimeter design A, and possibly some experience with designs B and C. The college men can be assumed to have had little, if any, experience in reading altitude from any type of indicator. In general intelligence and education the two groups were very similar.

## C. Results.

The data obtained in this investigation were analyzed to determine the frequency of errors exceeding certain values. These results are shown in table I which gives the percent total errors, percent errors of 100 feet or greater, and percent errors of 1,000 feet or greater for the nine indicator designs. [illegible] of the errors included in this table [illegible] interpolation since all settings

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[1] The large number of drawings needed for the nine test booklets were produced by Miss Mary [illegible] of the [illegible] with the photographic assistance of Mr. D. M. [illegible] of the [illegible] Laboratory.

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of the sensitive pointers were on graduation marks (except for design F which had some settings midway between marks).

Speed of reading data are shown in table II for the nine indicator designs. It will be recalled that the subjects wrote their answers in the test booklets and the time for completion was recorded in each instance. The average time per reading could thus be computed from the total time and the total number of items, but this time includes the time for recording as well as for reading or interpreting the instrument. An estimate of the time for interpretation of the instrument only was obtained by subtracting from the average time for each design the average time for design I (the Veeder counter). The reading of altitude from design I involved the mere copying of the numbers shown, and hence was assumed to require no interpretation.

In table III is shown the number of subjects in each group who made one or more errors in the twelve readings of each design.

A reproduction of each of the experimental indicator designs accompanied by graphic illustrations of the more significant findings is provided in figure 2. The upper pair of bars under each indicator shows the percent of errors equal to or exceeding 1,000 feet for the two groups of subjects. The lower pair of bars gives the computed interpretation time for each of the two groups of subjects.

B. <u>Discussion of Results for Individual Indicator Designs.</u>

<u>Indicator design A</u>

The results of this investigation, as shown in figure 1 and tables I, II, and III show that this design, which simulates the conventional altimeter, is a very difficult instrument from which to obtain quantitative readings as required in this study. Even the pilots, all of whom had spent several years flying with this instrument, spent more time per reading on this indicator than on any of the other designs studied. Only one of the remaining eight indicators, design F, resulted in a higher proportion of errors. It must be concluded that it is a very difficult task to combine into a single numerical value the readings of three pointers indicating on a single scale, as required in reading the conventional altimeter.

<u>Indicator design B</u>

This indicator differs from that of design A only in having the 10,000-foot pointer located off-center and indicating on a separate scale. This difference slightly increased the speed and accuracy with which the instrument could be read, but the improvement is so slight that it is of little importance.

<u>Indicator des</u>[illegible]

The use of two [illegible]es, as in design C, resulted in a considerable [illegible] in speed and accuracy of reading by comparis[illegible] comparison with designs D, G, H, and I, however [illegible] to read.

Indicator design D

This indicator uses only one pointer, with the 1,000-foot and 10,000-foot indications provided by a counter. Such a combination proved to be very easy to read. For AAF pilots the percent of total errors was very low, 3.5 percent, and only 1.7 sec. was required for interpretation (as contrasted with 15.9 percent and 7.1 sec. for the conventional altimeter). More significant, perhaps, is the finding that only 0.7 percent of the errors equalled or exceeded 1,000 feet. Most of the errors in reading indicator design D resulted from assigning 10 feet instead of 20 feet to each of the graduation intervals between numerals. Errors from this source are of such small magnitude that they would seldom exceed errors of the instrument itself, and in any event would not be considered as potential causes of accidents.

Indicator design E'

The substitution for two of the pointers on the altimeter of two rotating dials appearing through a window appears to have no advantage. This indicator was designed so that under most circumstances only one number would appear on each of the two rotating dials. But if such dials rotate continuously (rather than intermittently) during altitude changes, as assumed in this test, it is inevitable that at certain settings two numbers will be equally visible. Such indications are very difficult to read correctly.

Indicator design F

On this indicator the range covered by the indicating pointer and scale is dependent upon range limits shown in the window. The high proportion of errors and slow reading time indicate that the required changes in interpretation of the primary scale are difficult for human beings to carry out.

Indicator design G

A vertical scale indicating up to 1,000 feet, with a counter to show the 1,000-foot and 10,000-foot multiples, as similated in design G, is read with considerable speed and a high level of accuracy when exact quantitative readings are required. The virtues of such an instrument for check reading and qualitative reading were not evaluated in this study.

Indicator design H

This instrument, which presents all indications by means of a very long vertical scale, is very similar to design G in the manner of indication and in the speed and accuracy with which it is read.

Indicator design I

This indicator, which simulates a simple Veeder counter, was read with greatest speed and accuracy of all the indicators. This would suggest that where only quantitative readings are to be provided this would be the most desirable type of instrument. It is believed that for check reading and for qualitative reading such an instrument would be quite inferior to one using a moving pointer.

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F. Analysis of Causes of Error.

A detailed analysis of the causes of error, particularly for the conventional altimeter, will be presented in a later report. However, a number of general interpretations can be offered here. From the findings of the present study some of the basic sources of error and delay in obtaining readings on an instrument such as the altimeter would seem to be:

(1) A pointer is frequently read to the nearest number, rather than lowest adjacent number. Such an error frequently occurs in reading of the 1,000-foot pointer on the conventional altimeter. This is probably the most dangerous of all possible types of error, since the actual altitude will always be 1,000 feet lower than that at which the pilot thinks he is flying. It is believed that most of the cases of altimeter misreading uncovered in the earlier interview study (Memorandum Report No. TSEAA-694-12a) resulted from this type of error. The best method of eliminating this source of error would seem to be intermittent motion of the 1,000-foot and 10,000-foot indications, as on the counters in designs D, G, and I.

(2) The necessity for reading in succession the indications of two or more pointers, and remembering the several readings until a final combination is achieved, constitutes a rather complicated mental process. The chances of error, particularly of decimal displacement of one or more digits, are very great. Indicator designs D, G, H, and I simplify the reading process in at least two ways. In the first place, the reading of a single digit directly is easier than getting the same value from a pointer indicating on a scale. In the second place, some or all of the digits are presented in their proper sequence, thus reducing the amount of combining which must be accomplished mentally on the multiple pointer indicators.

G. Application of Results to Problems of Indicating Altitude in Aircraft.

The results of this investigation show quite clearly that for providing exact quantitative readings at least four indicator designs, D, G, H, and I, can be read with much greater speed and accuracy than multiple pointer altimeters. Of these four instruments, design I (the Veeder counter) would probably be quite unsatisfactory as an altimeter for use by the pilot. To check read such an indicator would require reading several separate numerals which is more difficult and time-consuming than merely observing the angular position of a pointer. For qualitative reading, likewise, this indicator would be rather unsatisfactory since the changing numbers in the window would be rather difficult to interpret in terms of increases or decreases in altitude. On the other hand, the navigator, who uses the exact altitude in his calculations, would probably benefit from such a direct reading instrument.

Indicators G and H, with the vertical scales, would probably also be more difficult to check read than a moving pointer unless some special markings, such as heavy bars at the 500- and 1,000-foot intervals, were added to the scale. For indicating direction and approximate rate and magnitude of altitude changes this type of indicator would probably be quite satisfactory, but further research is needed on this point.

Indicator design D with a single sensitive pointer and a Veeder counter does, it is believed, retain all of the advantages of the three-pointer altimeter for ease of check and qualitative reading. The results of this study show that for quantitative reading, indicator design D is greatly superior to the conventional altimeter. For these reasons this modification of the altimeter, with a counter replacing the 1,000- and 10,000-foot pointers is considered as being the most promising of the nine designs which were investigated.

Although this study demonstrates that the principle of indication involved in design D is very good, the particular indicator shown in figure 2 is not necessarily the optimum application of the principle. A number of probable improvements can be suggested. In the first place, the counter should probably not appear directly above the pointer shaft. In this location it will be partially obscured by the pointer in its most common location, namely, straight up. It is suggested, instead, that the counter be located to the left of the pointer shaft, opposite the window used for setting in barometric pressure. Location of the counter to the side of, rather than above, the pointer shaft should also permit the use of larger counter drums. This should make possible the use of very large numerals as is important for obtaining maximum speed of reading. A second possible improvement would be the placement of the zero position at the left side rather than at the top of the dial.[2] Thus, while flying at some multiple of 1,000 feet, as is the usual procedure, the pointer would move upwards for increases over the desired altitude and downward for decreases. If this were done, however, the counter should, contrary to the previous suggestion, be located above rather than to the left of the pointer shaft.

H. <u>Conclusions</u>.

The following conclusions are drawn from this investigation regarding design features of multi-revolution instruments in relation to speed and accuracy of reading;

1. The conventional altimeter and similar multiple-pointer instruments are very difficult to read. Not only is the time for reading such instruments very long, but a considerable proportion of the readings are in error by one or more complete revolutions of the sensitive pointer.

2. The ease with which multi-revolution instruments can be read is greatly increased by the use of a Veeder type counter instead of pointers to indicate the number of revolutions of the sensitive pointer.

3. A very long vertical scale moving behind a window, or a repeating vertical scale combined with a counter are relatively easy to read quantitatively (but may be less desirable for check-reading than a moving pointer).

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[2] This suggestion was made to the author by W. Langewiesche of the Kollsman Instrument Company.

4. Part of the difficulty in reading multiple-pointer (or multiple-dial and pointer) instruments results from the necessity of combining mentally several separate indications. The difficulty in reading is proportional to the number of such separate indications to be combined.

5. Additional difficulty in the reading of multiple-pointer instruments results because the non-sensitive pointers (1,000- and 10,000-foot pointers on the altimeter) must often be read not to the number toward which they are pointing but to the next lower number. Which number is to be read can be determined only by simultaneous consideration of the position of the more sensitive pointer in relation to the zero point on the scale. This difficulty can probably be overcome only by intermittent motion on the moving pointers, dials, or counters which indicate the number of revolutions of the sensitive pointer.

6. Bearing in mind the reading requirements of an altimeter for use by the pilot, design D in this experiment offers the most promise. Such an indicator should, however, have the counter displaced approximately 90 degrees from the zero position on the scale to prevent its being obscured by the pointer in its most common location.

TABLE I

Frequency of Errors Exceeding Certain Values in the Reading of Altitude from Nine Experimental Indicators

| Altitude indicator design | AAF pilots N = 97 Percent errors Total | 100+ | 1000+ | College men N = 79 Percent errors Total | 100+ | 1000+ |
|---|---|---|---|---|---|---|
| A | 15.9 | 13.1 | 11.7 | 20.8 | 18.6 | 17.4 |
| B | 15.0 | 12.6 | 11.7 | 17.9 | 14.7 | *12.9 |
| C | *8.3 | *5.5 | *4.8 | *11.4 | *8.6 | *7.7 |
| D | *3.5 | *0.9 | *0.7 | *2.1 | *0.9 | *0.7 |
| E | 17.3 | 15.0 | 14.5 | *15.3 | *13.5 | *12.9 |
| F | 24.1 | 22.0 | 14.1 | 21.0 | 19.1 | *13.0 |
| G | *2.1 | *0.5 | *0.3 | *3.0 | *1.0 | *0.4 |
| H | *2.5 | *1.7 | *1.3 | *4.5 | *3.0 | *1.5 |
| I | *0.6 | *0.6 | *0.4 | *0.3 | *0.1 | *0.0 |

* Asterisk indicates statistical significance (at one percent level of confidence) of superiority over conventional indicator (design A).

TABLE II

Speed of Reading Altitude from Nine Experimental Indicators

| Altitude indicator design | AAF pilots N = 97 Seconds per reading: Interpret & record, Mean | AAF pilots N = 97 Seconds per reading: Interpret only **, Mean | College men N = 79 Seconds per reading: Interpret & record, Mean | College men N = 79 Seconds per reading: Interpret only **, Mean |
|---|---|---|---|---|
| A | 9.6 | 7.1 | 9.8 | 7.5 |
| B | *8.6 | *6.1 | 9.6 | 7.3 |
| C | *7.3 | *4.8 | *7.6 | *5.3 |
| D | *4.2 | *1.7 | *4.1 | *1.8 |
| E | 8.8 | 6.3 | 9.2 | 6.9 |
| F | *8.7 | *6.2 | *8.3 | *6.0 |
| G | *4.8 | *2.3 | *4.2 | *1.9 |
| H | *4.2 | *1.7 | *4.2 | *1.9 |
| I | *2.5 | *0.0 | *2.3 | *0.0 |

* Asterisk indicates statistical significance (at one percent level of confidence) of superiority over conventional indicator (design A).

** The time values in the "interpret only" column were obtained by subtracting the "interpret and record" time for design I from the total time for the other designs. This was done on the assumption that design I (a simple Veeder counter) would require no interpretation and that the average time per reading of this design would give a reasonably accurate estimate of the average time consumed by the subjects in writing down their answers.

TABLE III

Percent of Individuals Who Made One or More Errors in Reading of Twelve Settings on Each of Nine Indicator Designs

| Altitude indicator design | AAF pilots N = 97 Percent | College men N = 79 Percent |
|---|---|---|
| A | 70.1 | 81.0 |
| B | 77.3 | 73.4 |
| C | 51.5 | 55.7 |
| D | 33.0 | 20.3 |
| E | 79.4 | 77.2 |
| F | 72.2 | 67.1 |
| G | 19.6 | 27.8 |
| H | 22.7 | 38.0 |
| I | 6.2 | 3.8 |

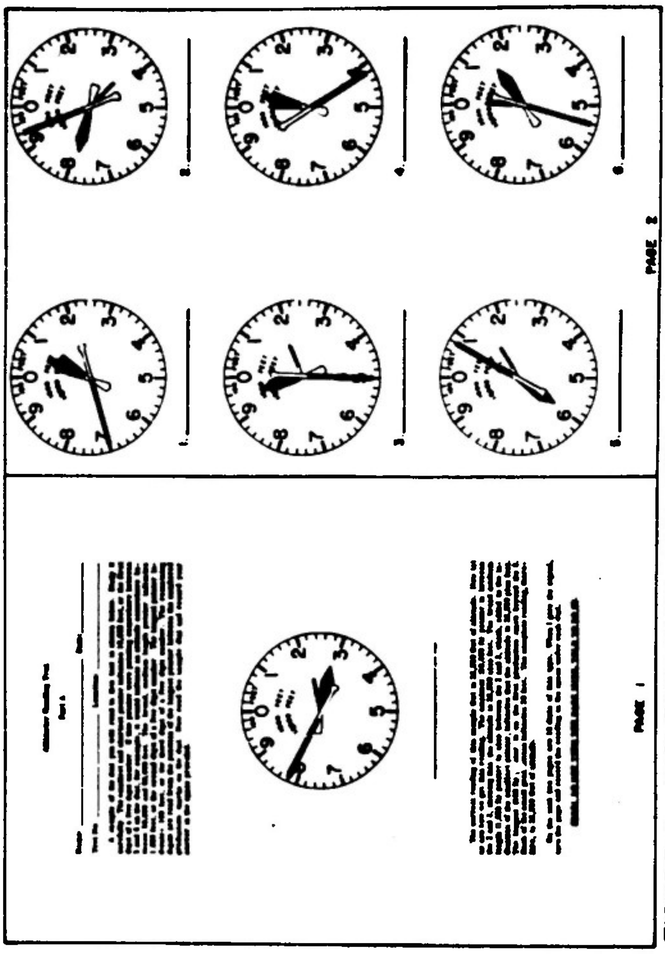


FIGURE I. INSTRUCTIONS AND ONE PAGE OF TEST ITEMS FROM EXPERIMENTAL BOOKLET FOR INDICATOR DESIGN A.

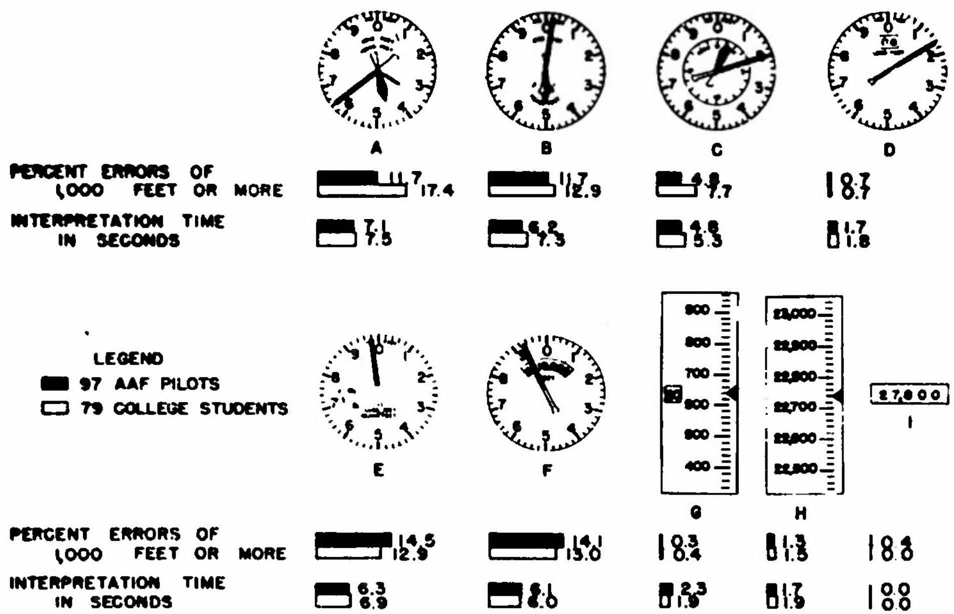


FIG. 2. SPEED AND ACCURACY IN READING ALTITUDE FROM DIFFERENT TYPES OF INSTRUMENTS.

**REFERENCES**

Memorandum Report No. TSEAA-694-12a. Analysis of Errors Made By Pilots in Reading and Interpreting Aircraft Instruments.

Memorandum Report No. TSEAA-694-8. Design of Clock Dials for Greatest Speed and Accuracy of Reading in Military (2400 hour) Time System.

Memorandum Report No. TSEAA-694-8b. Discussion of Pictorial Versus Symbolic Aircraft Instrument Displays.